AMATEUR RADIO AND INNOVATION IN TELECOMMUNICATIONS TECHNOLOGY

by

Kevin William Lloyd McQuiggin

B.Sc., Simon Fraser University, 1983

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

in the

School of Communication

SIMON FRASER UNIVERSITY

November, 2001

Approval

Name: Kevin William Lloyd McQuiggin

Degree: Master of Arts

Title of thesis: Amateur Radio and Innovation in Telecommunications Technology

Examining Committee:

Chair: Adjunct Professor Adam Holbrook,
School of Communication
Committee Chair

____
Associate Professor Peter Anderson
Senior Supervisor
School of Communication

____
Dr. Richard Smith
Assistant Professor
School of Communication

____
Mr. Nigel Bell
External Examiner
Industry Canada,
Surrey, British Columbia

Abstract

Throughout its history, amateur radio has made significant contributions to science, industry, and the social services. The economic and social benefit derived from amateur radio research has founded new industries, built economies, empowered nations, and saved lives.

Amateur radio represents a unique research and development (R&D) environment that cannot be duplicated in the labs or research parks of either industry or the government. Existing at the intersection of the social, economic, cultural and scientific spheres, amateur radio leverages this position to invent and innovate from a unique perspective. Many now-commonplace communication technologies have their genesis in amateur radio.

However, the amateur radio service, or more specifically, the portion of the electromagnetic spectrum allocated to the activity, is under extreme pressure from the telecommunications industry. Recent exponential growth in commercial wireless communication systems has taxed existing commercial spectrum allocations, and industry is eager for expansion. Amateur radio spectrum is threatened. Ironically, many of the communication technologies used by these firms were initially developed within the field of amateur radio.

To justify their quest for additional spectrum, industry lobbyists portray amateur radio as an anachronism, and characterize amateur bands, particularly in the UHF and microwave region, as underutilized. On the contrary, innovative communications research within the hobby is alive and well, and many of these new amateur projects utilize the higher-frequency bands sought after by industry. There

is commercial interest in some of the new technologies currently under development within amateur radio, and amateur radio continues to contribute to the state of the radio art.

Therefore, amateur radio must be supported by government and the telecommunications industry it helped create, so that it may continue to innovate and serve as a source of creativity for both technological and social change as we move forward into the twenty-first century.

Dedication

To My Wife,

Laura Purcell-McQuiggin

Acknowledgments

I would like to acknowledge the assistance of the following individuals in my research and in the preparation of this thesis. Without their participation I would have had considerably more difficulty in completing my research.

First, I would like to thank my supervisors Peter Anderson (VE7PSA[1]) and Richard Smith of the School of Communication at SFU for their ongoing support and valued commentary.

I'd also like to acknowledge the assistance of the following individuals:

- Don Boekenkruger (VE7CBT), Robert Wiejak (VE7HBG), and the members of the BC Amateur Television Group;
- My colleague Jim Chu of the Vancouver Police Department, for his support of my graduate work within VPD;
- Tony Craig (VE7XQ) of Langley, BC, for his support of my amateur activities beginning in the 1970s, and his insight into early amateur radio in the Vancouver region;
- Bob Gehl of the Victoria Police Department, for some background research into sociologist Raymond Bowers;
- Fellow graduate student Gordon Gow, for extensive discussion and insight into new technologies;
- Dennis Livesey (VE7DK) of the Radio Amateurs of Canada, for statistical data on amateur radio in Canada;
- Doug Lockhart (VE7APU), packet radio pioneer, for his perspective on the beginning of this new technology;
- Jim Maxwell (W6CF) and David Sumner (K1ZZ) of the American Radio Relay League, for historical information on amateur radio;
- Peter Martinez (G3PLX), for an interesting email exchange on the future of digital communications within amateur radio;
- Keith Montgomery (VA7KWM) of E-Comm;
- Debbie Norman (VA3RGM) of the Radio Amateurs of Canada;

---

[1] Amateur radio callsigns are included for those who are licensed amateurs.

- Bruce Prior (VE7HR and N7RR) of Blaine, Washington, for his support during my early days in amateur radio in the 1970s and recent discussion on my research topic;
- Dennis Rosenauer (VE7BPE and AC7FT) of AT&T, for training on UNIX and information on the 56K packet radio network; and
- Ron Vanderhelm (VE7COR) and Dr. Norman Toms of Sierra Wireless, Incorporated, for input on the role of amateur radio in the commercial wireless industry.

Author Contact Information

Should this thesis prove of interest to future readers, and they would like to contact me, I may be reached by any of the methods below. Contact information is current as of December 2001.

Electronic mail	mcquiggi@sfu.ca
Home address	Kevin McQuiggin 5415 Smith Avenue, Burnaby, British Columbia Canada V5H 2K5
Work address	Inspector Kevin McQuiggin Vancouver Police Department 312 Main Street, Vancouver, British Columbia Canada V6A 2T2
Amateur radio callsign	VE7ZD (Try the offices of Industry Canada or the Canadian national amateur radio association "RAC", the Radio Amateurs of Canada)

Table of Contents

Glossary

The following technical terms are used in this thesis. This section serves to define these terms for the non-technical reader. Three online dictionaries[2] were employed for some of the basic definitions. Additional references are indicated.

56K
Abbreviation for 56,000 bits per second

ADSL
Acronym for "Asynchronous Digital Subscriber Line", a technology that provides high-speed Internet service to customers via the existing telephone network. ADSL provides higher speed on the incoming connection than on the outgoing

Amateur Satellites
See "OSCAR"

Amateur Television
Amateur radio hobbyists have been involved in experimentation with television since the early 1920s. Amateur television today employs standard television transmitters and receivers and the NTSC specifications, although on amateur radio frequencies. Due to bandwidth requirements for video signals, amateur television is restricted to the amateur bands above 220 MHz

Amplitude Modulation
The encoding of a carrier wave by variation of its amplitude in accordance with an input signal

---

[2] http://www.m-w.com/cgi-bin/dictionary, http://www.dictionary.com, http://www.webopedia.com

AMTOR
An HF Digital communications mode that exhibits good performance under marginal conditions of propagation. AMTOR utilizes forward error correction. See (Henry 1992 #105)

Analog
Of, relating to, or being a mechanism in which data is represented by continuously variable physical quantities

Apache
A popular world-wide web (WWW) server software package that is available at no charge. The majority of global web servers run this package

APRS
Acronym for "Automatic Packet Reporting System". An application of amateur packet radio that allows tracking of real-time events. APRS concentrates on the graphic display of station and object locations and movements. With a GPS receiver, APRS can track the location of an amateur radio station in real time. Internet gateways allow amateurs equipped with APRS throughout the world to be tracked in real time (Technical Information Service 2001 #231)

Arpanet
A pioneering long haul wide area network funded by the Advance Research Projects Agency in the United States. It became operational in 1968 and served as the basis for early networking research

ARRL
The American Radio Relay League, a national amateur radio body in the United States

Autopatch
Typically found on VHF and UHF repeaters in urban areas, an autopatch links incoming amateur signals to the telephone system, and allows these users to make telephone calls from their amateur radio equipment. The amateur repeater must have a pre-existing connection to the telephone network. Amateurs typically use the DTMF keypads on their radios to activate the autopatch and "dial" the digits of the telephone number. Circuitry within the repeater then dials the telephone number and links the amateur to the call. The call is terminated when the amateur enters a pre-arranged "hang up" sequence into his DTMF keypad. The repeater interprets this sequence of digits as a command, and terminates the telephone call. Costs of

autopatch-equipped repeaters are commonly borne by amateur radio societies formed for this purpose

AX.25

A packet radio communications protocol, currently the most popular in amateur radio. Abbreviation for "Amateur X.25". X.25 is a commercial data communications standard. This standard was modified for amateur radio use, hence the term "AX.25"

Backbone

A main support or major sustaining factor, in terms of communications networks, the conduit over which most communications or data packets must travel

Bands

Segments of the electromagnetic spectrum allocated to amateur radio. Bands are colloquially identified by their approximate wavelength, for example the amateur band from 14.000 to 14.350 MHz is referred to as "the 20-metre band"

Bandwidth

a range within a band of wavelengths, frequencies, or energies; a range of radio frequencies which is occupied by a modulated carrier wave, which is assigned to a service, or over which a device can operate; the capacity for data transfer of an electronic communications system

BBS

Acronym for "Bulletin Board System", a computer that has been configured as a repository of messages, files, and other data that can be shared amongst all users of the system

Bits per Second or BPS

A measure of the number of data bits that may be transferred per second over a computer communications channel

BPS

See "Bits per Second"

BPSK
Acronym for “Binary Phase Shift keying”, a method of transmitting information (bits) in which a change in state of the transmitted carrier signal represents a “1”, while no change represents a “0”

Byte
A group of eight binary digits processed as a unit by a computer and used especially to represent an alphanumeric character

Cable Modem
A technology that provides high-speed Internet service to customers via the existing cable television network. A cable modem provides higher speed on the incoming connection than on the outgoing. Since many customers share a single cable television segment, performance can degrade significantly as the number of subscribers increases

Carrier
An electromagnetic wave or alternating current whose modulations are used as signals in radio, telephonic, or telegraphic transmission

CB
See “Citizen’s Band”

CD22204E
An integrated circuit that converts DTMF tones to the equivalent binary number

CDPD
Acronym for “Cellular Digital Packet Data”, a data transmission technology developed for use on cellular phone frequencies. CDPD uses unused cellular channels (in the 800- to 900-MHz range) to transmit data in packets. This technology offers data transfer rates of up to 19.2 Kbps, quicker call set up, and better error correction than using modems on an analog cellular channel

Channels
Specific frequencies that are assigned to a particular radio service. Amateur radio differs from other telecommunication services in that amateurs are not assigned channels, but rather ranges of frequencies (“bands”) in which they may operate. Amateur radio is unique in that the hobbyist may change frequency at will

Circuit
A configuration of electrically or electromagnetically connected components or devices

Citizen's Band or CB
A radio-frequency band officially allocated for unlicensed private radio communications

Class C Network
A globally-recognized allocation of Internet addresses numbering up to 254 separate computers

CLOVER
An HF digital mode invented in 1993 by amateur Raymond Petit (Bixby and Horzepa 1999 #39). CLOVER incorporates error detection and correction and offers exceptional performance in the face of variable propagation on the HF amateur bands (Ford 2001 #91). It has found application in commercial as well as amateur communications (Bixby and Horzepa 1999 #39)

Computer-mediated Communication
Human communication in which a computer system plays an integral role in mediating or transmitting/receiving the information which is exchanged. Without the computer, the communication could not take place

Connectionless Communication
Communication between two individuals or amateur radio operators in which no formal protocol exists to set up or initialize the communication before it begins

CQ
General call from an amateur radio station calling any other amateur

Current
A flow of electric charge. Movement of electrons across a particular point

CW
Acronym for "Continuous Waves", in the vernacular, amateur communication using the international Morse code

Cycles per Second
The unit of frequency; one Hertz has a periodic interval of one second

Data Rate
In computer-mediated communication, the number of bits per second which are transferred between the sender and the receiver. A higher data rate implies a higher bandwidth connection between the users

Dayton Hamvention
An important amateur radio convention held annually in Dayton, Ohio. New technologies are often introduced at this gathering, and presentation of research papers at the convention serves to extend the state of the art

DBS
Acronym for “Direct Broadcast Satellite”, a relatively new direct-to-home satellite broadcasting service that includes television and music channels

Demodulation
To extract the intelligence from (a modulated signal)

Digipeater
See “Repeater”. A repeater station that receives and retransmits digital data, such as packet radio transmissions

Digital
Of or relating to a device that can read, write, or store information that is represented in numerical form

Digital Signal Processing or DSP
Computer manipulation of analog signals (commonly sound or image) which have been converted to digital form

DOS
Acronym for "Disk Operating System", an early operating system for the personal computer[3]

DSP
See "Digital Signal Processing"

DTMF
Acronym for "Dual Tone Multi Frequency". An internationally accepted standard that uses particular combinations of audible tones to represent the numbers from zero through fifteen. Eight separate audible tones are combined two at a time to represent sixteen distinct values

Dumb Terminal
A terminal that has no internal microprocessor and thus no processing power independent of its host computer

DX
Colloquialism for "distant communication". Amateurs commonly will wish one another "good DX". "DXing" is an activity within the hobby in which enthusiasts try to work as many foreign countries and distant regions as possible. The "DXCC" award ("DX Century Club") is granted by the ARRL to amateurs who submit proof of contact with amateurs in one hundred countries around the globe

Dynamic routing
A characteristic of the Internet protocol TCP/IP, whereby data packets are transmitted from the sender to the receiver in the most expedient fashion. Different packets may take different routes, i.e. travel through different intermediate computers, en route to delivery. Standard amateur packet radio, using the AX.25 protocol, does not incorporate dynamic routing, rather, the sender must explicitly state the route from sender to receiver, and identify all of the intermediate stations. Should one of the intermediate stations be unavailable, the packet will be lost

---

[3] While "DOS" in popular culture will be forever linked with the IBM personal computer, many earlier mini- and mainframe computers from IBM and other manufacturers had disk operating systems, which were invariably referred to as "DOS".

Electromagnetic Spectrum

The entire range of radio frequencies, from very low to extremely high. What we understand as “radio waves” form only a tiny percentage of the available electromagnetic spectrum. Electromagnetic signals such as radio waves travel at the speed of light, or rather, at the same speed as light travels, because visible light is simply another small slice of the electromagnetic spectrum

Email

Electronic mail, transmitted by amateur radio or over the Internet

EME or Moonbounce

Acronym for “Earth-Moon-Earth”. Vernacular for amateur radio “moonbounce” communication. Amateurs communicate with one another through intentional reflection of their signals off of the surface of the moon. This is a very specialized amateur radio activity, accessible only to the best-equipped stations

Error Detection and Correction

Mathematical manipulations of transmitted digital data allow for detection and correction of errors in the data stream. Redundancy is added to the transmitted data in a clever manner that allows bits received with the incorrect values to be corrected at the receiver

Facsimile or FAX

A system of transmitting and reproducing graphic matter (as printing or still pictures) by means of signals sent over telephone lines. Amateurs adopted facsimile for use via radio in the 1930s

Family Radio Service or FRS

An unlicensed radio communications service legislated in Canada and the United States. FRS is a low power, channelized service which allows informal, non-commercial radio communication by the general public.

Fast Scan Television

An amateur communications mode which is equivalent to “regular” television format in terms of its technical specifications. Television pictures and audio are transmitted at the standard rate of approximately 30 frames per second. This high data rate implies wide bandwidth (approximately 6 MHz), therefore amateur fast scan television operation is restricted to the larger amateur bands, those above 420 MHz

Firewall
A computer or computer software that prevents unauthorized access to private data (as on a company's local area network or intranet) by outside computer users (as of the Internet)

Firmware
Computer programs contained permanently in a hardware device (as a read-only memory)

Forward Error Correction or FEC
A method employed in digital communications whereby errors in transmitted data bits can be detected and corrected by the receiver, without the need for re-transmission of the corrupt bits by the transmitter. This is achieved by clever mathematical coding of the transmitted data bits. FEC adds overhead to digital communications

Free Software or Open Source
A concept of software development and distribution where computer programs are developed and shared at no charge to the user community. Typically the source code (the "recipe") is included with the software package so that anybody may alter it to suit his or her needs. Open source software packages typically try to restrict the user from selling the program or any derivatives of it

FreeBSD
An open source version of the UNIX operating system, widely used on the Internet and by several large corporations and governments around the world

Frequency
The number of complete oscillations per second of energy (as sound or electromagnetic radiation) in the form of waves

Frequency Modulation
Modulation of the frequency of the carrier wave in accordance with speech or a signal

Frequency Shift Keying
A type of modulation where the frequency of a carrier wave is shifted higher and lower in frequency in direct correlation with the information which is to be

transmitted. At the receiver, the frequency of the carrier is tracked and used to recover (or “demodulate”) the original information from the radio signal

Frequency-Division Multiplexing
A method of sharing the electromagnetic spectrum in which each radio signal, or radio or television station, is assigned a specific frequency or channel on which to operate. AM and FM radio are common examples of frequency division multiplexing: each station remains at a unique and legally-assigned spot on the dial

FRS
See “Family Radio Service”

GHz
Gigahertz. A unit of frequency equal to one billion (10^9) hertz. Historically called a “Gigacycle”

GPS
Global Positioning System. A system of satellites, computers, and receivers that is able to determine the latitude and longitude of a receiver on Earth by calculating the time difference for signals from different satellites to reach the receiver

GUI
Graphical User Interface. An interface for issuing commands to a computer utilizing a pointing device, such as a mouse, that manipulates and activates graphical images on a monitor

Ham
A licensed amateur radio operator

Ham Shack
Colloquialism. The location from which the amateur radio enthusiast operates her equipment.

Hertz
unit of frequency equal to one cycle per second -- abbreviation Hz

Home-Brew

An amateur colloquialism for homemade radio equipment: transmitters, receivers, antennas, and station accessories. Amateur radio was founded on an experimentalist, tinkering tradition. Home-brew equipment is still encountered in amateur radio today, but has become less popular over the past quarter-century, due to relaxation of licensing requirements and the increased complexity and lower cost of commercial radio gear

Hybrid Technology
A communications technology that combines, or exhibits aspects of, both analog and digital communications

Internet
An electronic communications network that connects computer networks and organizational computer facilities around the world

Interoperability
Ability of a system to use the parts or equipment of another system

Intranet
A network operating like the World Wide Web but having access restricted to a limited group of authorized users (as employees of a company)

Ionization
To convert wholly or partly into ions

Ionosphere
The part of the earth's atmosphere in which ionization of atmospheric gases affects the propagation of radio waves, which extends from about 30 miles (50 kilometers) to the exosphere, which is divided into regions of one or more layers whose altitudes and degrees of ionization vary with time of day, season, and solar cycle, and which is contiguous with the upper portion of the mesosphere and the thermosphere; also : a comparable region of charged particles surrounding another celestial body (as Venus)

IP Address
An address that uniquely identifies a node on a computer network. “IP” stands for “Internet Protocol”

ITU
Acronym representing “International Telecommunication Union”

K
Symbol from electronics representing the number 1000. 56K represents the number 56,000. In computer science the term K represents 1024 rather than 1000, as 1024 is a power of two (2^{10}) and is therefore easily represented in binary notation

Keyboard-based Communication
Digital amateur communications employing the keyboard rather than the microphone or other device for interaction between the parties. Examples are radioteletype (RTTY) or packet radio

Keyboarding
Vernacular for the activity of typing back and forth, using keyboard-based communication, between two or more amateur stations

LAN
Acronym for “Local Area Network”. A system that links together electronic office equipment, such as computers and word processors, and forms a network within an office or building

LEO Satellite
An orbital satellite that circles within a few hundred kilometres of the earth’s surface. Distinct from geostationary satellites, which orbit about 35,000 km above the earth, or Molniya satellites, which orbit in an elliptical fashion, varying in height between a few hundred and several thousand kilometres above the surface of the earth

Linux
A trademark for an open-source version of the UNIX operating system.

Mail Server
A repository, typically a computer system, that stores electronic mail for users, who are required to login to retrieve their messages. Typical forms in amateur radio include BBSes and packet radio mailboxes. Advanced projects such as the 56K packet network employ UNIX-based mail servers that run software and protocols equivalent to those used on the Internet

Mbone

Virtual Internet Backbone for Multicast IP. IP Multicast-based routing allows distributed applications to achieve real-time communication over IP wide area networks through a lightweight, highly threaded model of communication

Meteor Scatter

A specialized mode of amateur communication where the ionized trails of meteors that enter the Earth's atmosphere are used to propagate (reflect) radio signals

MF

Acronym for "Medium Frequency". Typically used to refer to the amateur bands up to and including 4.0 MHz in the electromagnetic spectrum

MHz

Megahertz. One million cycles per second. Used especially as a radio-frequency unit. Historically called a "Megacycle"

Microsat

A series of inexpensive amateur satellites developed and launched in the 1980s. Derided as "impossible" by the mainstream aerospace community, almost ten Microsats were built and launched for a fraction of the cost of commercial satellites. Several remain in orbit and operational almost fifteen years later. Most Microsats outlived the commercial satellites they were launched alongside of

Microwave

A comparatively short electromagnetic wave; especially one between about 1 millimetre and 1 metre in wavelength

Millimetre Wave

Electromagnetic waves having a wavelength less than 1 cm

MMIC

Monolithic Microwave Integrated Circuit. A small IC that typically acts as an amplifier for signals in the microwave region of the electromagnetic spectrum

Mode

A particular form, variety, or manner of radio communication. Examples are AM, FM, and Morse code amateur radio operation

Modem
A device that converts signals produced by one type of device (as a computer) to a form compatible with another (as a telephone)

Modulation
The process of modulating a carrier or signal (as in radio); also : the result of this process

Moonbounce
See "EME"

Morse code
Either of two codes used for transmitting messages in which letters of the alphabet and numbers are represented by various sequences of dots and dashes or short and long signals

Multicast Backbone
See "Mbone"

Multiplexing
To combine multiple signals (analog or digital) for transmission over a single line or media. A common type of multiplexing combines several low-speed signals for transmission over a single high-speed connection

MURS
Acronym for "Multi-Use Radio Service", a recently created, unlicensed radio service that may be used commercially. Low power levels and a small number of channels (frequencies) limit the utility of this service

Napster
A free music sharing system on the Internet. Napster brought copyright and intellectual property issues on the Internet to the forefront

News Reader
A computer program used to review messages posted to the "UseNet" electronic news service on the Internet

NTSC

National Television Standards Committee. The body defining the television video signal format used in the USA. NTSC signals are receivable on any television set

ODFM
Acronym for “Orthogonal Frequency Division Multiplexing”. A method of sharing a portion of the electromagnetic spectrum so that multiple users may communicate simultaneously while not interfering with one another.

Open Source
See “Free Software”

Open Standards
A computing or communication standard that is non-proprietary, the specification being made freely available to any interested party. An example of an open standard for computer networking is TCP/IP

Operating System
Software designed to control the hardware of a specific data-processing system in order to allow users and application programs to make use of it

OSCAR
Acronym for “Orbital Satellite Carrying Amateur Radio”. The amateur satellite program began in the early 1960s, and amateur satellites have been in service continuously since that time

Packet Radio
Computer-mediated wireless data communications. A computer or microprocessor on each end of a wireless communications link ensures that the digital data transferred via radio arrives intact (without error) and in the correct order

Parabolic Antenna
A popular antenna using a dish-shaped reflector to gather electromagnetic signals and focus them onto a small point that serves as input to a radio receiver. Conversely, signals transmitted from this small point are amplified and reflected in a single direction by the dish-shaped reflector. A popular example is the satellite “dish”

Parametric Amplifier
A very sensitive amplifier of electromagnetic waves. Amateurs made important contributions to reducing the complexity and the cost of these devices through their experimentation with “moonbounce” communications in the 1950s

Patch Antenna

An efficient antenna of relatively small size that was initially developed for use in aerospace but has recently been adopted by consumer electronics manufacturers

PCS

Acronym for “Personal Communications Service”, a term used to describe a set of digital cellular telephone technologies

pdp-11

A popular mini-computer of the 1970s through the mid-1980s. Manufactured by Digital Equipment Corporation. Popular with collectors of formative computing technology

Phase Shift Keying or PSK

A type of modulation where the phase[4] of a carrier wave is shifted in direct correlation with the information which is to be transmitted. At the receiver, the phase of the carrier is tracked and used to recover (or “demodulate”) the original information from the radio signal

Point to Point

Radio communication from one amateur station to another, without any intermediate relay points

Power

A source or means of supplying energy. In electronic work, power is generally measured in Watts

Propagation

The spreading of something (such as radio signals) abroad or into new regions

Protocol

---

[4] Phase relates to the state of the electromagnetic wave, in physical terms, the position or the timing of the wave as it is emitted from the transmitter. In practice phase modulation and frequency modulation are closely related.

A set of conventions governing the treatment and especially the formatting of data in an electronic communications system

Proxy Server
This term is used particularly for a World-Wide Web server which accepts URLs with a special prefix. When it receives a request for such a URL, it strips off the prefix and looks for the resulting URL in its local cache. If found, it returns the document immediately, otherwise it fetches it from the remote server, saves a copy in the cache and returns it to the requester. The cache will usually have an expiry algorithm which flushes documents according to their age, size, and access history

PSK
See "Phase Shift Keying"

PSK31
A new amateur mode that embodies aspects of both analog and digital communication

"Q" Signals
An internationally-recognized standard. Three-character codes are used to represent common questions, answers, and requests. These codes have been used effectively by amateurs for nearly one-hundred years to bridge language barriers. "Q" signals are used almost exclusively on the HF amateur bands. For example, "QTH" means "my location is", while "QTH?" means "what is your location?"

QPSK
Acronym for "Quadrature Phase Shift keying". Similar to BPSK, but in this mode each signal element, or transmitted element, represents two data bits

QST
Journal of the ARRL, the definitive publication for global amateur radio since 1914

RAC
Acronym for "Radio Amateurs of Canada", a Canadian amateur radio organization

Radio Contests

On-air operating events in which amateur operators contact one another and exchange signal reports or other specific information, generally with the goal of contacting as many other operators as possible in a given time period

Radiotelegraph
Telegraphy carried on by radio waves and without connecting wires -- called also wireless telegraph

Radiotelephone
An apparatus for carrying on wireless telephony by radio waves

Radioteletype
A mode in which typewritten or textual information is exchanged between stations or operators. Also a device which translates keystrokes into a form suitable for transmission by radio

Ragchewing
Amateur vernacular for informal, and often long-winded, communication

Real Time
The actual time in which a physical process under computer study or control occurs

Receiver
A device for converting signals (as electromagnetic waves) into audio or visual form: as (1) : a device in a telephone for converting electric impulses or varying current into sound (2) : a radio receiver with a tuner and amplifier on one chassis

Repeater
A device for receiving electronic communication signals and delivering corresponding amplified ones

Roundtable
A conference for discussion or deliberation by several participants

Router
Computing terminology. A computer or specialized device which receives data, generally in the form of packets, from one network, and transfers or routes those packets onto another network, and vice versa

RTTY
See “Radioteletype”

Schematic Diagram
A diagrammatic presentation of an electronic circuit; broadly: a structured framework or plan

SDR
See "Software-Defined Radio"

Selectivity
Highly specific in activity or effect. In radio, the ability of a radio receiver to separate distinct signals from one another, to separate closely adjacent signals so that each can be received without interference from the others

Sensitivity
The degree to which a radio receiving set responds to incoming waves

Serial Card
An interface module for a computing device that is capable of sending and receiving data bits in a serial (bit by bit) fashion

SHF
Acronym for "super-high frequency". Radio signals between 3 GHz and 30 GHz in frequency

Single-sideband or SSB
An advanced form of amplitude modulation ("AM") where redundant parts of the AM signal have been eliminated. This redundant information is added back into the signal by the SSB receiver. SSB has twice the spectral efficiency of AM – double the number of signals can be accommodated in the same bandwidth. Amateur radio played a key role in the adoption of SSB by the military and commercial services following World War II

Slow-scan Television or SSTV
A form of television that transmits still pictures on the shortwave bands at a rate of two to three frames per second. A product of amateur radio research in the 1950s

Software-Defined Radio or SDR

A new approach to the design of radio receivers and transmitters that allows them to be modeled mathematically rather than as sets of discrete components on circuit boards. Heavily dependent on digital signal processing, SDRs will likely revolutionize amateur radio and other modes of electromagnetic communication

Solid State

Based on or consisting chiefly or exclusively of semiconducting materials, components, and related devices

Source routing

A method of sending packets between a sending and receiving station in which all intermediate or relay stations must be specified by the sending station. This is inefficient: should one of the intermediate stations be unavailable, transmitted data packets will be unable to proceed, and will fail to reach their destination. AX.25 is an example of a source routed communication protocol. TCP/IP, on the other hand, uses dynamic routing. Packets may take any of several possible routes to their destination and relaying stations or intermediate nodes need not be specified by the sender

Spark-gap

A very early method of generating radio signals, via the discharge of a high voltage spark across a narrow gap between two electrodes. By changing the characteristics of the spark very rough changes to the resulting radio frequency signal was possible. Spark gap transmitters were amazingly inefficient, lacked selectivity, and caused much interference to other users. Spark gap transmission was superseded by “continuous wave” or “CW” signal generation by the early 1920s

Speed of Light

Light is a form of electromagnetic radiation, and travels at a rate of 186,282 miles (or about 300,000 km) per second in a vacuum

Spread Spectrum

A modulation technique whereby the information to be transmitted is widely distributed amongst a range of radio frequencies, rather than being centred on a single frequency, as is the case with AM or FM modulation. Spread spectrum is key to several modern communications devices such as PCS cellular telephones. Interesting, the concept was co-invented by the well-known actress Hedy Lamarr in August, 1942 (Markey and Antheil 1942 #156)

SSB

See “Single-sideband”

SSTV

See “Slow-scan Television”

Store-and-forward Messaging

A method for the exchange of electronic or other forms of communication, where messages are held for delivery to a specific user until that user accesses the system and requests their delivery. Electronic mail is a good example of a store-and-forward messaging system

Streaming Video

Visual information delivered via a networked computing device. The delivery of video requires a relatively high amount of bandwidth

Sub-network

Term for a group of computers that form part of a larger network of machines. Machines on a sub-network (or sub-net) generally have similar network addresses, in fact it is the closeness of their addresses that makes the computers part of the same sub-net in the first place

Sun Workstation

A popular high-powered personal computer, widely used in engineering and the academic computing communities

Sunspot Cycle

From NASA:

> “Every 11 years the sun undergoes a period of activity called the "solar maximum", followed by a period of quiet called the "solar minimum". During the solar maximum there are many sunspots, solar flares, and coronal mass ejections, all of which can affect communications and weather here on Earth” (NASA 2001 #187)

Super-heterodyne

Used in or being a radio receiver in which an incoming signal is mixed with a locally generated frequency to produce an ultrasonic signal at a fixed frequency that is then rectified, amplified, and rectified again to reproduce the sound. Technique invented by Edwin Armstrong, an amateur radio operator

TCP/IP
A protocol for communication between computers, used as a standard for transmitting data over networks and as the basis for standard Internet protocols

Telemetry
The science and technology of automatic measurement and transmission of data by wire, radio, or other means from remote sources, as from space vehicles, to receiving stations for recording and analysis

Teletypewriter
A printing device resembling a typewriter that is used to send and receive telephonic signals

Terminal Node Controller or TNC
A computing device used in packet radio that ensures accurate transmission and reception of digital data via a radio link

The Ether
An all-pervading, infinitely elastic, massless medium formerly postulated as the medium of propagation of electromagnetic waves

Time-Division Multiplexing
A method of sharing the electromagnetic spectrum in which each radio signal, or radio or television station, is assigned a specific time slot in which the station may operate. Many users may share the same frequency, but only one user may use the frequency at any one time

TNC
See "Terminal Node Controller"

Traffic handling (inter-station messaging)
Vernacular for an activity in amateur radio centred on the relay of personal messages via the amateur bands. Traffic handling was the impetus for the formation of many of the early amateur radio societies, including the American Radio Relay League (ARRL). Traffic handling activity has waned in popularity with the growth of packet radio and the Internet, but there are still hundreds of active participants throughout North America (Ewald 2000 #82)

Transceiver

A radio communications device that combines the functions of both a transmitter and a receiver into a single unit. A radio transmitter-receiver that uses many of the same components for both transmission and reception

Transducer
A device that is actuated by power from one system and supplies power usually in another form to a second system. For example, a loudspeaker is a transducer that transforms electrical signals into sound energy

Transmitter
An apparatus for transmitting radio or television signals

Turn-key
Refers to a system or software package that has been built, installed or supplied by the manufacturer complete and ready to operate. In the computer industry, the term is used to promote a system that can be easily set up and operated "right out of the box."

UHF
An acronym for "Ultra High Frequency", a term used to refer to radio frequencies between 300 and 3000 megahertz (3 GHz)

UNIX
A freely-available computer operating system that runs on several different hardware platforms. UNIX offers preemptive multitasking and supports many simultaneous users. Embodied in the personal computer world by Linux, FreeBSD, and NetBSD, UNIX offers many advantages over commercial operating systems such as Microsoft Windows

Unpopulated Circuit Board
An electronic circuit board that has appropriate connections and holes for components (such as resistors, capacitors and integrated circuits) but has not had those components mounted on it yet. Components are generally mounted on the circuit board by soldering

V1, V2, V3
Packet radio protocols (communication standards) developed by the VADCG (Vancouver Amateur Digital Communications Group), the pre-eminent organization in the early development of amateur packet radio. These protocols had several

advantages over the US standard that was popularized and eventually formally adopted by the ARRL, “AX.25”

Vacuum Tube
An electron tube from which all or most of the gas has been removed, permitting electrons to move with low interaction with any remaining gas molecules

VAX
A popular minicomputer of the 1980s through 1990s. VAXes were used in many corporate and academic computing environments. VAX is an acronym standing for "Virtual Address Extension"

VHF
An acronym for "Very High Frequency", a term used to refer to radio frequencies between 30 and 300 megahertz. Frequencies above 300 MHz are generally referred to as "UHF" or "Ultra High Frequencies"

Virtual Private Network or VPN
The use of encryption in the lower protocol layers to provide a secure connection through an otherwise insecure network, typically the Internet. VPNs are generally cheaper than real private networks using private lines but rely on having the same encryption system at both ends. The encryption may be performed by firewall software or possibly by routers

Voltage
Electric potential or potential difference expressed in volts

VPN
See "Virtual Private Network"

Waterfall Display
A graphical display of signals received in which each frequency is represented by a unique vertical position in the display. Signals of constant frequency are displayed as vertical lines. Adjacent signals produce parallel vertical lines. From (Ford 1999 #89):

> "This display is analogous to an audio spectrum analyzer, continuously sweeping through a range of audio frequencies. Detected signals appear as white traces against the dark background, moving from top to bottom like water cascading over a fall"

Watt
The absolute meter-kilogram-second unit of power equal to the work done at the rate of one joule per second or to the power produced by a current of one ampere across a potential difference of one volt : 1/746 horsepower

Wavelength
The distance in the line of advance of a wave from any one point to the next point of corresponding phase

Weak signal operations (terrestrial and EME)
Amateur activity in which the focus is on building very sensitive radio receivers, that have the capability of receiving or "hearing" signals far too weak to be detected by average equipment. Software-defined radios (SDRs) are at the forefront of weak signal work and have demonstrated tremendous potential in the recovery of weak signals from background noise

Wide-band Communications
Radio communications using higher than normal bandwidth. Legally permissible only on the UHF and higher amateur bands. In digital modes, wide-band signals exhibit very high data transfer rates

XML
Extensible Markup Language. A metalanguage that allows one to design a markup language, used to allow for the easy interchange of documents and data on the World Wide Web

Chapter I

Introduction

Amateur radio has been a rich source of innovation to the telecommunications industry and society throughout the activity's history. Over the past century amateur radio operators have contributed to our understanding of radio communications, devised entirely new radio communication technologies, combined pre-existing technologies in innovative new ways, and developed operational procedures that have largely defined the way in which communication by radio is carried out. Amateur radio has played a fundamental role in the development of radio and telecommunications technology, and it continues to do so today.

The purpose of this thesis is to contribute to the academic body of knowledge concerning amateur radio, and to present a case for the preservation of amateur radio and the unique innovative environment in which it exists. Most research on innovation studies the process within industry. Little research has been done on technological innovation in informal, non-commercial environments such as that of amateur radio. Herein I hope to fill some of these gaps, and present amateur radio and its role in innovative activities in a balanced and reasoned format that will be of assistance to government, industry, and amateur radio bodies in supporting this unique activity.

At the beginning of the twenty-first century, the amateur radio service finds itself under intense pressure from both regulatory authorities, and the very industry that it helped to create (American Radio Relay League 2000 #8; Maxwell 2001 #167). Over the past fifteen years, the explosive market growth in consumer wireless devices such as pagers, cellular telephones, and most recently wireless data devices has placed great pressure on the electromagnetic spectrum, and therefore on amateur radio as a user of this natural resource (American Radio Relay League 2000 #8). This situation is not new: in 1912, pressures from government and the Marconi Company forced amateurs to an unexplored region of the spectrum thought to be useless for long distance communication (DeSoto 1936 #70). Amateurs persevered and discovered that this region was far more capable of supporting global communication than the frequencies they had left behind. In the present day, amateur research into digital communications (Ford 2001 #91), software-defined radios (Larkin 1999 #138) and spread spectrum techniques (Bible 2001 #37) will likely result in similar discoveries. I will have more to say on this later.

Between 1982 and 1988, spectrum available to amateur radio decreased by 107 MHz in the United States (Maxwell 2001 #167), a figure of about six percent. Over the past five years, some amateur spectrum in the VHF and UHF regions has been lost to commercial interests in the United States, Europe, and Australia; many other amateur allocations are under pressure[1] (American Radio Relay League 2000 #8). Changes in spectrum management policy by the Federal Communications Commission in the United States are reconstructing spectrum as property rather than as a shared renewable resource (De Vany 1998 #68). Industry Canada is

---

[1] 2402 - 2448 MHz for airborne law enforcement video (resolved in amateurs' favour, February 2001 (American Radio Relay League 2001 #17; Federal Communications Commission 2001 #85)); 216 - 220 MHz, 2300 - 2305 MHz, 2400 – 2402 MHz and 2417 - 2450 MHz for "commercial wireless"; 3400-3700 MHz in Canada for "fixed wireless" devices; 440 - 450 MHz and 10.15 - 10.3 GHz for "fixed wireless"; 5650 - 5925 MHz for "radio LANs" and "dedicated short range communications systems"; 430 – 450 MHz again for radar; 2300 - 2400 MHz again for third-generation cellular telephones; the amateur band between 3500-4000 kHz is under consideration by the ITU for the expansion of international shortwave broadcasting; 1240 - 1260 MHz for GPS and radio navigation system satellites (American Radio Relay League 2000 #8).

balancing commercial requests against the needs of other services, including amateur radio, but nonetheless has also adopted the auction as one of the primary methods of spectrum allocation (Melnyk 1997 #178; Industry Canada 1998 #114). Although a process of comparative analysis vets proposed usage, access to spectrum in Canada is now awarded to the highest bidder. Similar spectrum auction programs are in place in Australia (Australian Communications Authority 2001 #30) and the United Kingdom (United Kingdom Radio Communications Agency 2001 #248). A single bid for access to spectrum for third generation cellular service in the UK totaled $35 *billion* (Hatfield 2000 #101). While Industry Canada effectively oversees this process in Canada, and has given amateur radio strong support, this recent reconstruction of the electromagnetic spectrum towards "property" remains a tacit threat to non-commercial users of the resource, such as amateur radio hobbyists.

Amateur radio is a hobby: it is

> "a pursuit outside one's regular occupation engaged in especially for relaxation" (Merriam-Webster Inc. 2000 #180).

I will argue that while amateur radio is a hobby, and a leisure activity, that it must not be marginalized as a source of technological innovation. Indeed, it is the "unprofessional" characteristics of the activity which help to give amateur radio its unique perspective, its innovative strengths, and make it more relevant than ever today.

It is a fact that the amateur radio service has not made best use of the spectrum allocations, especially those in the UHF and microwave bands[2]. Many of these amateur bands remain, for the most part, unoccupied. Those amateurs making use of this spectrum, however, are doing so innovatively with new techniques such as spread spectrum, digital signal processing, amateur television and high speed packet radio systems, which will be described below.

Deregulation of amateur radio has lowered the level of technical expertise required to engage in the hobby in Canada and the United States[3]. Decried by some senior hobbyists, multiple-choice examinations replaced more traditional handwritten, oral, and practical examinations in Canada in the early 1980s (Department of Communications 1985 #69). Question pools, with answers, are available from many sources including the Internet (Industry Canada 2001 #124). Pass rates for entry-level amateur exams are up an average of 11 percent following the latest round of amateur radio restructuring in the United States (Lindquist 2000 #144; Lindquist 2001 #145). These changes have had dual effect; while the ranks of amateur radio hobbyists have arguably become de-skilled, the population size has increased. There were 51,228 active amateur licences in Canada in November 2000 compared to about 15,000 in 1973, and 23,000 in 1980 (Frame 2000 #93; Livesey 2000 #146). The number of licensees in the United States increased by 6,600 to 684,359 (Lindquist 2001 #145) between 1999 and 2000. More

---

[2] Canadian amateur allocations are described in (Industry Canada 2001 #123). See (American Radio Relay League 2001 #11), page 30.32 for current US amateur radio spectrum allocations.

[3] Many prospective amateurs now study the question pool rather than learning the required fundamentals. As an amateur radio instructor I have observed this licensing strategy in several recent students.

participants imply increased pressure on amateur spectrum allocations, but new people also bring diversity and innovative potential to the hobby.

Innovation has always been evident within amateur radio. The hobby remains viable today, and a significant amount of creative activity is evident within amateur ranks. Novel applications of existing technologies are allowing amateurs to communicate in creative new ways. New technologies and operating techniques are under development; three examples will be described in detail in this paper. Other operating modes such as meteor-scatter communications, largely discarded by industry in the late 1950s as unreliable, are being refined by amateur radio operators (McMasters 1998 #172). Amateur groups are undertaking digital communications research (Larkin 1999 #138), and government acknowledges the important role of amateur radio in this development (Hatfield 2000 #101). If history is borne out, these new techniques will be adopted by industry after incubation within the amateur radio service, and serve as the basis of future commercial products (Brussaard 1999 #50).

On these bases, I will argue in support of amateur radio, and theorize that the hobby occupies a unique location in the fields of innovation and creativity. Innovations developed by hobbyists in a non-commercial environment are often distinct from those that may emerge from corporate research and development labs[4]. Such innovation may engender industrial support, be further developed, and brought to

[4] An example is the Linux operating system, developed by computer hobbyists in a free-wheeling, non-commercial environment, with subsequent unexpected value to industry.

market with consequent commercial benefit[5]. Alternatively, amateur experience may be used by industry to identify and eliminate unproductive avenues of research. Either way, amateur radio makes a significant contribution.

Although research that leads to innovations such as those described may not be commercially viable, or rather may not initially appear to be so, we cannot rely solely on corporate research and development (R&D) shops to advance the state of the art. The narrow focus and vertical nature of modern industrial R&D leaves many unusual or unfashionable ideas unexplored. Industrial investment in applied research (that intended to lead to commercial products in the shorter term) increased by twenty-two percent in the United States between 1994 and 1997, while basic research investment increased by only four percent (Pollak and Jankowski 1999 #194). Amateur radio research tends to be horizontal, with a much wider focus, and as such many of these "unusual" ideas, considered to be of no value by industry, may be fruitfully explored by "unqualified" hobbyists.

Amateur radio innovators hail from both technical and non-technical backgrounds. They investigate, experiment, and invent in a free-wheeling, broad-based, and unstructured manner. The unconstrained creative environment in which amateur radio operates fosters the development of new technologies and operating techniques. Frequency modulation, television, facsimile, single-sideband, meteor scatter, and packet radio are just some of the communication technologies that underwent initial development within the amateur radio community, and were later

[5] Several commercial products, such as the digital television recording device "TiVo", employ Linux as their base operating system (TiVo Incorporated 2001 #243).

adopted by industry. As "non-professionals", amateurs bring a breadth of experience, and a unique non-industrial perspective to bear on communication issues.

Ironically, the amateur's ignorance of electronic theory is his strength: he "doesn't know what he doesn't know". As one editor for amateur journal *QST* put it in May 1950:

> "…recall that most of the accomplishments we have made have come about because someone didn't know any better – and went ahead and did the impossible. …hams[6] jumped in and tried to do things that more learned individuals might have written off as futile" (Tilton 1950 #239).

The amateur is not afraid to conduct research in areas that, by their nature, the corporate environment cannot. Amateur radio, then, serves as a catalyst, or as a nursery of innovation, for industry. In this thesis I will demonstrate that this is certainly the case historically, and that current amateur radio research activities have similar potential, through a detailed examination of three ongoing amateur radio projects. As I will describe below, both industry and society have reaped the benefits of amateur radio research.

---

[6] The origin of the term "ham" in reference to amateur radio is uncertain, but appears to be related to the term used for an unprofessional or uncooperative operator on the wire-based telegraph system (Simpson and Weiner 1989 #221; Standage 1998 #224). A "ham" was an amateur telegraphist, or a student telegraph operator in 1919 (Simpson and Weiner 1989 #221). See (American Radio Relay League 2000 #9) for more information. Merriam-Webster's dictionary indicates the etymology of the word as "[short for *hamfatter,* from "The *Ham-fat* Man," minstrel song]**:** a showy performer; *especially* an actor performing in an exaggerated theatrical style" (Merriam-Webster Inc. 2000 #180).

Methodology

In preparing this thesis I conducted an extensive literature search on the subject of innovation and amateur radio. Technological innovation has an extensive literature base, but material on the subject of innovation arising from non-industrial research, such as that arising from hobbies and other leisure activities like amateur radio, is sparse. There is opportunity here for further research, particularly in the area of the social construction of technology.

As an amateur radio operator, I have almost twenty-five years experience in the activity, its innovative characteristics, and its place in Canadian society. I have personal experience with the following aspects of amateur radio communication:

- Morse code
- Voice (AM, FM, Single-sideband)
- Radioteletype
- Packet radio
- Amateur satellite operations
- Amateur television
- VHF/UHF/microwave technologies
- Antenna design and construction
- Traffic handling (inter-station messaging)
- Radio contests
- Emergency operations
- Disaster response
- Liaison with public service agencies (police, fire, ambulance)
- Net control
- Satellite ground station setup and administration
- Weak signal operations (terrestrial and EME[7])

---

[7] EME or "moonbounce" operation involves communication with another amateur station using the moon as a passive reflector. Both stations point their antennas at the moon and listen for the echoes of the other station. This is an extremely challenging activity. EME was developed by a group of amateur radio operators under contract to the US armed services in January, 1946 (Kauffman 1946 #130; Laport, Tilton et al. 1981 #137).

- Design and construction of transmitters, receivers, data communications devices
- Instruction of amateur radio classes
- Organizational and administrative activities (radio clubs)

I augmented this practical experience by building a solid foundation on the subject of the development of radio. I did extensive reading of technical journals, textbooks on communication technologies and on the history of radio and the electronics industry.

I consulted sociological and economic references on innovation and the diffusion of innovation, and relied heavily on the extensive body of amateur radio literature itself, in the form of books, periodicals, and online resources. Popular amateur journals were reviewed back to 1915. Much of amateur radio literature emphasizes technological innovation and the application of amateur radio to communication issues in creative ways. Such sources, however, are biased towards the operative aspects of the hobby and lack the analytical basis required for this study.

Reference sources consulted included dozens of major academic and specialized libraries, including the National Library of Canada, the National Archives, and the American Library of Congress. I visited both the National Archives and the National Library in Ottawa, and spent several days locating relevant reference material. I visited the headquarters of the Radio Amateurs of Canada in Ottawa, consulted online resources at Statistics Canada and made extensive use of Industry Canada's "Strategis" web site[8].

---

[8] "Canada's Business and Consumer Site", http://strategis.gc.ca is managed by Industry Canada, the ministry responsible for telecommunications in Canada.

The inter-library loan system provided me with copies of three relevant dissertations on social aspects of amateur radio. Several European sources were also consulted. I conducted reviews of online content at the national amateur radio societies' Internet sites in Canada, the United States, Great Britain, Germany, Australia, and New Zealand.

I met or corresponded directly with administrative and elected staff of national amateur radio bodies in Canada and the United States, who were able to provide me with pointers to additional sources of information. I also corresponded and conducted interviews with well known amateur radio innovators, senior amateurs, amateur radio historians, a scientist at the National Research Council who has conducted decades of research into the history of radio in Canada, and a manager at Industry Canada responsible for amateur radio archival material.

Summary

This thesis provides a short history of amateur radio, and identifies significant innovations from within the hobby or from amateur radio hobbyists that have been widely diffused to industry and to society. It is intended to provide an analytical framework within which to compare the characteristics of amateur innovation with that undertaken by industry.

Chapter II begins with a description of amateur radio and moves to a short discussion of terminology and the essential elements of radio technology. Spectrum allocation issues are also examined. *Chapter III* provides a short history of amateur radio in Canada and around the world, with emphasis on amateur innovation and the contribution of the hobby to society. In *chapter IV*, innovation in industry is compared to that undertaken in amateur radio. This analysis is used to develop a framework or set of criteria on comparative innovation, contrasting amateur radio and the telecommunications industry.

In *chapter V*, three case studies of current innovative activities within amateur radio test these criteria:

- *The 56K Packet Radio Project* is being coordinated by Simon Fraser University, and studies the technical and social issues surrounding the concept of low cost, moderate data rate, digital wireless networking based on open standards. This project has elicited interest from government and industry.

- *The British Columbia Amateur Television Group* is based in Burnaby, BC. The group is working to deploy an interoperable television network based on low cost analog equipment.

- *The PSK31 Project* is the most recent invention of an amateur radio operator in Britain. In this project personal computer technology is leveraged to achieve unprecedented spectral efficiency in wireless digital communications. In the three years since its introduction, use of PSK31 has spread to the global amateur radio community. A hybrid technology due to aspects of its implementation[9], PSK31 has also already elicited the interest of industry seeking to commercialize the technology.

The thesis concludes with a summary of my findings, some recommendations to government and radio amateur groups in support of the hobby, and a short discussion of amateur radio's relationship to the Internet that may form the basis of further research.

---

[9] PSK31 combines digital and analog approaches, the human brain providing error detection and correction. It is a low-speed digital mode that relies on human interpolation of its digital outputs to provide meaningful communication.

Chapter II

What is Amateur Radio?

The Canadian radiocommunication regulations describe the amateur radio service as being a:

> "…radiocommunication service in which radio apparatus are used for the purpose of self-training, intercommunication or technical investigation by individuals who are interested in radio technique solely with a personal aim and without pecuniary interest" (Industry Canada 2000 #120).

The International Telecommunications Union defines the amateur radio service in a similar fashion, in Section III Article S1.56 of the international radio regulations:

> "Amateur service: A radiocommunication service for the purpose of self-training, intercommunication and technical investigations carried out by amateurs, that is, by duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest" (International Telecommunication Union 1998 #126).

The Federal Communications Commission defines amateur radio in Title 97 of the US Code of Federal Regulations, and specifically identifies the innovative basis of the activity in Parts 97.1(b) and 97.1(c):

> "97.1 Basis and purpose.
>
>> The rules and regulations in this Part are designed to provide an amateur radio service having a fundamental purpose as expressed in the following principles:
>> …
>> 97.1(b) Continuation and extension of the amateur's proven ability to contribute to the advancement of the radio art

> 97.1(c) Encouragement and improvement of the Amateur Radio Service through rules which provide for advancing skills in both the communication and technical phases of the art" (American Radio Relay League 2001 #11; American Radio Relay League 2001 #20)

Other nations, such as Australia, the United Kingdom, and other members of the European Union, define amateur radio similarly (United Kingdom Radio Communications Agency 2000 #247; Australian Communications Authority 2001 #29).

In lay terms, the amateur radio service allows qualified individuals within Canada and around the world to experiment with radio communication for non-commercial, educational, and public service purposes. Amateur experimenters, or "hams" can choose from a range of available frequencies, from below the AM broadcast band up through the microwave region, and communicate with one another via any one of several approved methods or modes.

Amateur radio is a leisure activity. Experimental or public service activities with radio are predicated on the availability of free time and the ability to make a financial investment in equipment. Theoretically significant is the dependence of the activity upon labour; it is an applied technological activity based on building and testing physical devices. The amateur who only theorizes will never get on the air. Radio amateurs are, for the most part, pragmatic individuals with an applied outlook on the hobby and on life (DeSoto 1936 #70; Douglas 1999 #76; Maxwell 2000 #166).

The radio amateur, through his/her experimentation and tinkering, provides feedback to industry and government on technology and radio regulation. This critical commentary, which has been evident since the earliest days of radio, helps improve wireless technology and administrative practice. While the amateur has often been at odds with both industry and government, his/her contribution has been significant, as will be described below (Laport, Tilton et al. 1981 #137; Coffee 1999 #59). The amateur service also forms a reserve of trained wireless communicators for government in time of crisis (Laport, Tilton et al. 1981 #137; Davis 1995 #67; Henderson 1997 #103).

The use of amateur radio technology democratizes the participant. On radio, much as on newer modes such as electronic mail, *content* eclipses age, sex, occupation, race, geographical location, and other factors. In this way amateur radio is not unlike the Internet; I will explore this further below.

The popular image of amateur radio presents the activity as either "a colonial Williamsburg of quaint old men with soldering irons and telegraph keys" (Coffee 1999 #59), or an unusual hobby of precocious children[10]. While this demographic may have been marginally correct at one time, the nature and application of the hobby were, and are even more so today, far removed from this type of scenario. The reality of the hobby is changing (Radio Amateurs of Canada 2001 #205).

Amateur radio is a hobby of curiousity, experimentation, and growth (American Radio Relay League 2001 #11; American Radio Relay League 2001 #22). Hams today are active on dozens of communication modes. Morse code is no longer a

---

[10] Books such as "The Radio Boys" series (1922-1931) (Rowland 1999 #216), motion pictures such as "Contact" (1997); "Radio Hams" (1939); "Patrolling the Ether" (1944), "Frequency" (2000) stereotype amateur radio and present an inaccurate picture of the hobby.

licensing requirement for new hobbyists in Canada (Industry Canada 2000 #120). Over two dozen nations have recently amended their amateur regulations to reduce the required Morse code speed for licensing to five words per minute (Wireless Institute of Australia 2001 #263). The Morse code requirement will likely be eliminated completely at the next world radio conference in 2003 (Wireless Institute of Australia 2001 #262), and such an amendment to international regulations is supported by the International Amateur Radio Union (IARU) (American Radio Relay League 2001 #19). While Morse code survives and is enjoyed by millions of amateurs worldwide, voice and data traffic have overtaken other modes and augment television, microwave, satellite, and other techniques that allow hams to communicate globally, twenty-four hours a day (American Radio Relay League 2001 #11).

The applications of amateur radio emphasize research, public service and emergency preparedness, and thousands of radio clubs participate in contests and emergency exercises that simulate disaster response conditions (American Radio Relay League 2000 #5). Table 1 lists some of the popular activities within the hobby.

Activity	Users[11]	Explanation
"CW"[12]	Millions	Communicating using international Morse code
Voice	Millions	Voice communication
Radioteletype	100,000+	Keyboard-based communication
Television	10,000+	Amateur TV
Packet radio	Millions	Computer – computer data transfer, email
Satellite	10,000+	All mode communication through one of approximately twenty amateur-built satellites
Microwave	10,000+	Experimentation at frequencies > 1 GHz
Public service communication	Millions	Participation in community service, emergency communications, third party message relay
Contesting	100,000+	Contacting as many other stations as possible in a specified time frame

Table 1 – Popular Operating Activities in Amateur Radio (American Radio Relay League 2000 #5)

Recent changes to licensing requirements in Canada and most other nations have realigned amateur radio with current technologies, and brought many thousands of new people into the hobby (Livesey 2000 #146; Lindquist 2001 #145). This influx of new operators has redefined the demographic. The increase is also being used by industry to postulate a healthy amateur service that can continue to thrive despite recent reductions in spectrum allocation. This is one of the issues that will be discussed in this thesis.

Table 2 shows the growth in amateur radio operators and stations for the period 1995 through 2000. The table is divided into three parts, for each of the three administrative regions established by the International Amateur Radio Union, the

---

[11] Estimate, exact figures not available.

[12] "CW" is an acronym for "continuous wave", a term describing the radio signals used to carry Morse code transmissions (Cleveland-Iliffe and Smith 1999 #58).

IARU (see Figure 1). The IARU represents amateur radio in the International Telecommunication Union (International Amateur Radio Union 2000 #125).

	Year	Total Stations	Total Operators	Society Members
Region 3 (Asia Pacific)				
	99	1491000	1703000	198000
	98	1349000	1464000	204000
	97	1463000	1517000	221000
	96	1459000	1514000	222000
	95	1434000	1434000	303000
Region 2 (Americas)				
	99	842724	833278	187000
	98	847000	838000	191000
	97	842000	840000	204000
	96	837000	835000	219000
	95	807000	807000	217000
Region 1 (Europe, Africa)				
	99	451000	441000	215000
	98	436000	441000	224000
	97	416000	420000	233000
	96	410000	414000	241000
	95	390000	406000	245000

Table 2 – World Amateur Radio Population (adapted from (Sumner 1999 #228))

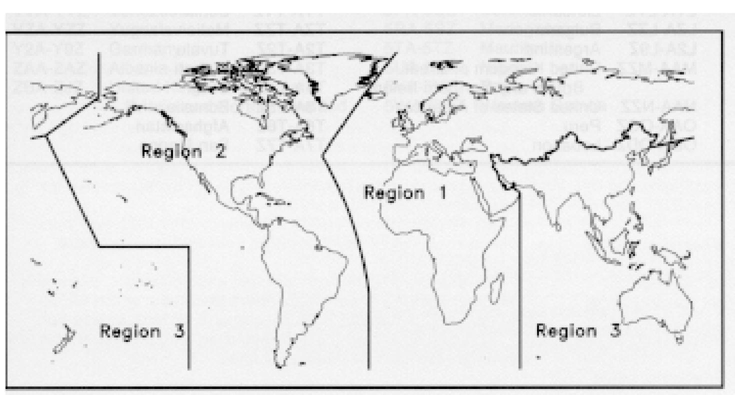


Figure 1 – IARU Amateur Radio Regions (American Radio Relay League 2001 #11)

Generally, only twenty to fifty percent of licensees are members of their national amateur radio society.

As the table indicates, the amateur population is on the increase. This trend is confirmed by Figure 2, which illustrates the growth of amateur radio since 1960. Global figures prior to 1960 are unavailable, but based on several references to the American amateur population, such as (DeSoto 1936 #70), (American Radio Relay League 1965 #2), (Kostenbauder 1976 #131), and (Smith 1975 #223), may be reasonably assumed to be under the 1960 figure.

Definitive figures for amateur radio in Canada are sporadic. In my research I was unable to obtain any historical statistical data at all from Industry Canada. Records of the federal Department of Communications, created to oversee telecommunications issues in 1969 (Treasury Board of Canada 2001 #244), were lost when the responsibility for radio issues was transferred to Industry Canada in 1995 (Government of Canada 1995 #97). In June 1931 the Minister responsible for the Radiotelegraph Act and Regulations reported 700 amateur radio stations in the nation (Bird 1988 #38, "In the Matter of a Reference as to the Jurisdiction of Parliament to Regulate and Control Radio Communication", Supreme Court of Canada 30 June 1931). The amateur journal *QST* reported 15,000 amateurs in Canada in January of 1975 (QST Editors 1975 #201). Figures provided by the BC Director of the Radio Amateurs of Canada indicate that there were approximately 15,000 amateurs in Canada in 1973, and that this number has risen to over 50,000 at present (Livesey 2000 #146).

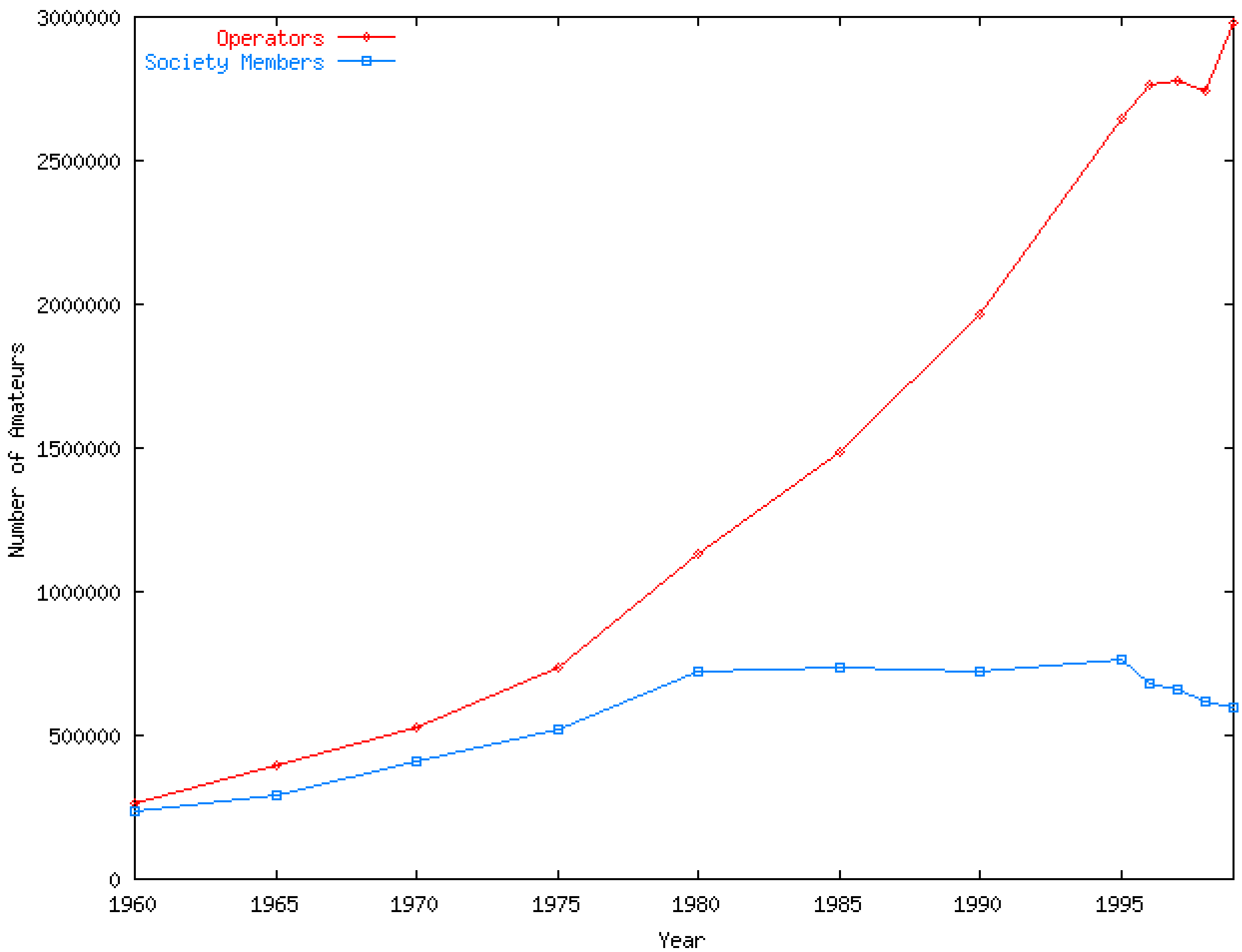


Figure 2 – Worldwide Amateur Radio Population 1960 – 1999 (Sumner 1999 #228)

Why Amateur Radio?

Why do people become involved in amateur radio? They are drawn to the hobby out of a desire to communicate, to learn, and to contribute to the betterment of society (American Radio Relay League 1976 #3). Amateur radio is a creative activity: many new communications technologies were developed by amateur experimenters and spun off to industry. Several of these technologies are commonplace today. Over the past one hundred years the hobby has made major contributions both to industry, in the form of new communication technologies, and to the efficiency of radio communications through the definition and standardization of operating methods and protocols. The Radiocommunications Agency of the United Kingdom acknowledges the important role of amateur radio in telecommunications:

> "For more than a hundred years radio amateurs have been at the forefront of developments in telecommunication. In the current information and communication technology expansion, the Radiocommunications Agency and the Radio Society of Great Britain (RSGB) have agreed that it is in the national interest that access to amateur radio be improved so that radio amateurs can continue to play a key role in these technologies." (United Kingdom Radiocommunications Agency 2001 #249).

The Electromagnetic Spectrum: A Finite Resource

Electromagnetic waves carry energy and travel at the speed of light. These waves form the basis of all wireless communication. Information can be imparted on the waves; this is termed "modulation". Radio, television, microwave ovens, even visible light, are some examples of electromagnetic radiation (Cleveland-Iliffe and Smith 1999 #58). Electromagnetic waves may be produced at many frequencies. Low frequency waves display different characteristics than those of higher frequency. This range of frequencies at which electromagnetic waves can be produced is called the electromagnetic spectrum. The spectrum is often called a natural resource because it exists everywhere, cannot be "owned"[13], and can be

[13] Spectrum cannot be owned any more than an individual or corporation could, for example, "own" the number 5 and regulate (and likely charge for, given the current economic bias) its use throughout the entire universe.

occupied by several types of radiation simultaneously (American Radio Relay League 2001 #11). It is also a limited, or finite, resource in that more spectrum cannot be generated or manufactured.

Figure 3 depicts the electromagnetic spectrum, the nature of radiation in the various portions of the spectrum, and the common terminology for some segments of this natural resource. Also indicated is the “wavelength” of the signals, in metres. Radio signals are measured in cycles per second, or Hertz (abbreviated Hz). The higher a radio signal’s frequency, the shorter its wavelength. Signals are generated by natural or human-made sources and range in frequency from the very low (a small number of cycles per second) to the very high.

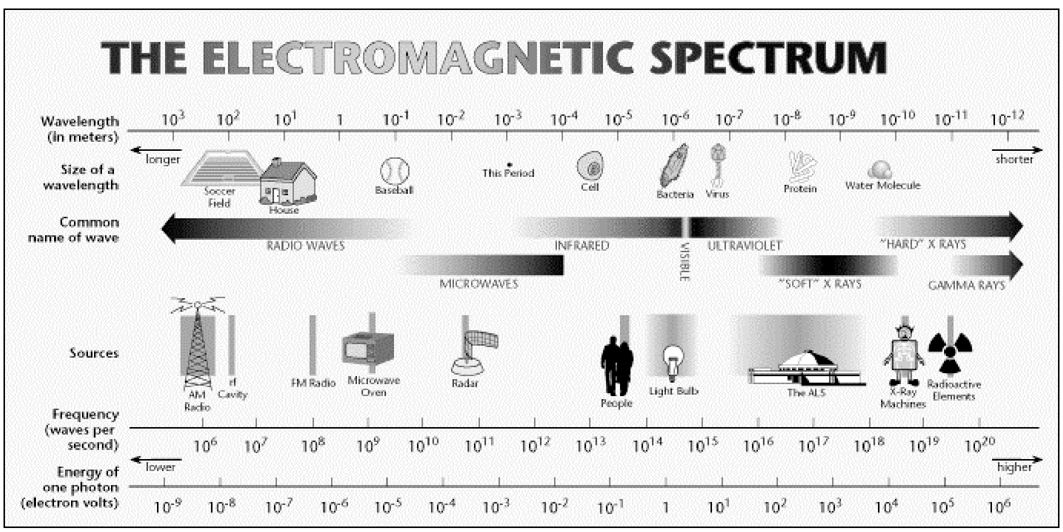


Figure 3 – The Electromagnetic Spectrum[14]

---

[14] From http://www.lbl.gov/MicroWorlds/ALSTool/EMSpec/EMSpec2.html. Used with permission, courtesy of the Advanced Light Source, Berkeley Lab.

The electromagnetic spectrum is the basis for all radio communications. The spectrum is a limited, but renewable resource. This means that while there is only one range of frequencies, these may be reused indefinitely. Interference will take place if more than one user attempts to use the same frequency at the same time. Radio frequencies must be shared between all users in such a way to minimize interference: this is the basis for international radio regulation.

Electromagnetic signals have different characteristics based on their power level and frequency. Higher power signals will travel further than lower powered ones[15]. Signals at certain frequencies will not propagate out of the local area, while those at other frequencies may be reflected off of the ionosphere and travel around the world. Signals of quite high frequency easily escape the Earth and propagate into space (Cleveland-Iliffe and Smith 1999 #58). The study of radio propagation, pioneered by amateur radio operators in June 1920 (American Radio Relay League 1965 #2), theorizes the mechanisms behind these various actions and influences spectrum allocation regulations, which balance communication needs with minimization of interference.

Radio services of all types are designed to operate at specific frequencies, or in particular frequency ranges, at specific power levels. These criteria are specified in the station's radio licence (Industry Canada 1995 #112).

---

[15] Power levels for electromagnetic signals are measured in Watts.

A radio transmitter generates a base signal called a carrier. Modulation[16] is applied to the carrier, and the resultant electromagnetic wave propagates through space. The received signal must then be demodulated to recover the transmitted information.

Transmitters and receivers must agree on certain fundamental parameters to allow radio communication to take place: the receiver must "listen" on the correct frequency, at the correct time, and signals received must be demodulated correctly in order to properly recover the transmitted information.

Spectrum, Communications, and the Wireless Industry

In Canada and around the world, wireless communications is growing at an incredible rate. Cellular telephones are the fastest growing consumer products in history (Canadian Wireless Telecommunications Association 2001 #53). In December 1998, there were almost 300 million mobile telephony subscribers worldwide. The telecommunications supplier Ericsson forecasts the world's cellular subscribers to number 1.1 billion by year-end 2004 (Canadian Wireless Telecommunications Association 2001 #53). Many developing regions are bypassing traditional wired communications systems in favour of wireless local access (Zysman 1995 #265). Wireless systems obviate complex wired telecommunications infrastructure but require radio spectrum in which to operate. A recent study forecasts 200 million wireless local access subscribers worldwide by 2005. Although half of the world's population has never made a phone call, by 2005

[16] The particular method of impressing information on the radio signal.

it is estimated that fifty percent of all telephone calls will be wireless (Canadian Wireless Telecommunications Association 2001 #53).

The wireless industry generates $5 billion annually in Canada. Over $9 billion has been invested in mobile phone communications infrastructure since 1987, and over $1 billion was invested in wireless infrastructure in Canada in 1998 alone. 1998 wireless industry revenues totaled $3.9 billion, an increase of eleven percent over the previous year (Canadian Wireless Telecommunications Association 2001 #53).

The number of wireless phones in Canada is predicted to increase between twenty to thirty percent over the next twelve months. Approximately ten million wireless devices are currently used by Canadians on a daily basis, including seven million wireless phones, more than 1.8 million pagers, 1 million mobile radios and 10,000 mobile satellite phones. Forty-one per cent of Canadian households owned or had access to a wireless phone in 1999, compared to 37 per cent in 1998. A recent report by International Data Corp. (Canada) Ltd., a Toronto-based technology research firm, states that the mobile phone market in Canada is expected to grow between 20 and 30 per cent a year, to reach 16.6 million subscribers in 2003 (Canadian Wireless Telecommunications Association 2001 #53).

Wireless Internet access is also growing at a fast pace. A survey performed by Ernst & Young indicates that only four per cent of Canadians currently use wireless Internet services, but that 24 per cent say they are likely to purchase this service in the next year (Canadian Wireless Telecommunications Association 2001 #53).

How are these facts relevant to amateur radio? All of these new wireless systems and technologies require electromagnetic spectrum in which to operate. The amateur radio allocations in the UHF and microwave regions[17] would provide suitable spectrum for these new technologies; hence these allocations are under pressure from billion-dollar industrial giants, from consumers eager for the convenience of the new technology, and ironically, from governments eager to generate huge revenue through spectrum auctions (American Radio Relay League 1997 #4; Melnyk 1997 #178; De Vany 1998 #68; American Radio Relay League 2000 #8; Maxwell 2001 #167).

Spectrum Allocation in Canada and Abroad

The electromagnetic spectrum is regulated internationally, but administered on a national basis. The International Telecommunication Union[18] (ITU), headquartered in Geneva, Switzerland is an international organization within which governments and the private sector coordinate global telecommunication networks and services (International Telecommunication Union 2000 #127). Radio communication standards, as a subset of general telecommunication issues, represent a significant percentage of the ITU's work. Federal governments are responsible for management of the electromagnetic spectrum within their borders, but recommendations on technical and operating standards from the ITU serve as the basis of radio regulations in 189 member states (International Telecommunication Union 2000 #128). Amateur radio has been recognized by the ITU as a legitimate radio service since 1927, and is represented within the organization by the

---

17 See Table 3

18 See http://www.itu.org.

International Amateur Radio Union (IARU), a society representing national amateur radio associations throughout the world (International Amateur Radio Union 2000 #125).

In Canada, spectrum allocation is managed by Industry Canada (Industry Canada 2001 #121). In the United States, the Federal Communications Commission regulates private spectrum usage (Federal Communications Commission 2001 #86), while the National Telecommunications and Information Administration has spectrum management responsibility for federal government agencies (National Telecommunications and Information Administration 2001 #189; Rinaldo 2001 #209). Significant differences exist, however, in the way Canada and the United States resolve competing interests for access to spectrum. An examination of the differences between the Canadian and American approaches to spectrum management will help shed light on the current situation for amateur radio.

In the United States the FCC favours a competitive model based on auction of spectrum to the highest bidder (Federal Communications Commission 1999 #83). While Canada has implemented a generally similar model of spectrum auctioning, Industry Canada moderates this strictly economic approach with a process of comparative analysis (Industry Canada 1998 #114). Competing interests for spectrum, commercial or otherwise, are evaluated by Industry Canada relative to criteria which balance social and economic benefits (Industry Canada 1998 #114). In this way, Canada, to a much greater extent than the United States, has recognized and is reinforcing the duty of government to manage the airwaves as a renewable natural resource on behalf of all citizens.

A report from the Public Interest Advocacy Centre in Ottawa published in 1997 identified serious problems with the American spectrum auctioning process, and recommended a participative role for government in spectrum allocation (Melnyk 1997 #178). Fortunately, most of the concerns raised in the report were addressed by Industry Canada in the regulations governing spectrum auctions, and amateur radio, for now, has the support and protection of the Ministry (Industry Canada 1998 #114). The Canadian Amateur Radio Advisory Board was created by Industry Canada and the national amateur radio society in 1993. The advisory board:

> "… is a non profit consultative group consisting of members of the Radio Amateurs of Canada (RAC) and the Radio Regulatory Branch of Industry Canada (IC). Its function is to provide a consultative forum between Canadian radio amateurs and the regulator. " (Radio Amateurs of Canada 2000 #203)

The Board serves to assist Industry Canada in spectrum management issues and gives Canadian amateurs a forum for input into the spectrum allocation process.

In the United States, however, the legal-economic research community has proposed changes in the definition of radio spectrum to interpret it as "property", rather than as a renewable natural resource (De Vany 1998 #68). In this literature the auction of spectrum to the highest bidder is presented as supportive of democracy and of the principle of non-governmental interference in the free market.

Auction revenue for the US Federal Communications Commission totaled $24.7 billion between July 1994 and July 2000 (Federal Communications Commission

2000 #84). In practice, unmediated spectrum auctions deny democracy[19], relieve the government of its responsibility to the individual, promote concentration of "ownership" and favour monopolization of wireless services (Melnyk 1997 #178).

The New York Times of October 14th, 2000 reported that:

> "… President Clinton, responding to growing airwaves congestion that threatens development of new generation of wireless devices, has ordered an extraordinary federal government review and auction of wide swaths of spectrum now controlled by government agencies and private companies. This review is expected to lead to basic reshuffling of how spectrum is used, and result in a huge 2002 auction to award new licenses *(sic)* for services like wireless phones offering high-speed Internet links. The auction could yield billions of dollars and require government to make huge payments to companies and agencies to shift their existing radio, phone and communications systems to new frequencies not considered useful for newer hand-held devices. " (Labaton 2000 #134)

Will the amateur radio service survive in this environment? Individual amateurs, even amateur organizations, if forced to bid for access to the electromagnetic spectrum, cannot hope to compete with commercial interests. In November 1999, the twelve winners of Canada's first spectrum auction bid a total of $171 million for licences in the 24 and 38 GHz bands (Industry Canada 1999 #117). The spectrum will be used to provide high-speed Internet and electronic commerce services to the public in major cities throughout Canada.

---

[19] Entry-level bidding is at the level of millions or tens of millions of dollars. In the first spectrum auction for narrow-band PCS (cellular) service, conducted by the FCC in July 1994, the average bid was $2.9 million. The individual radio amateur, the amateur radio club, even the national amateur associations cannot hope to compete in such a "democratic" process.

Spectrum Allocation: A Technical Challenge

The electromagnetic spectrum must be managed to maximize use of the resource. Uncooperative (or unregulated) users can cause interference to other users by inappropriate choice of operating frequency. Amateur radio interference with United States naval vessels, and the Titanic sinking of April 1912, with wireless playing a significant role in the disaster, consolidated political forces within the US and resulted in the first Radio Act in that nation in 1912. Amateur radio was first defined in Canada in 1905 (Bird 1988 #38), but additional duties and responsibilities were imposed on amateur operations in Canada with the creation of the Radiotelegraph Act in 1913 (Department of Communications 1985 #69; Bird 1988 #38). The issue of interference remains the basis for the extremely fine-grained level of spectrum regulation today.

Spectrum allocation may be described as a complex, multi-dimensional problem in which competing and often contradictory criteria must be balanced to reach a “best-fit” solution. The end result is rarely optimal; tradeoffs must be performed to reach a workable compromise and allow the new service to co-exist with earlier services.

The technical characteristics of a proposed service (bandwidth or data rate, topology, and content type) and federal and international regulations may restrict the choice of possible frequencies. Proposed services must be examined to determine whether they may co-exist, i.e. share spectrum allocation, with other existing wireless services. Some technologies such as spread-spectrum communications can share spectrum with other existing services: their design allows them to co-exist and cause minimal interference to other services operating in the same segment of spectrum. Other services such as broadcasting require dedicated spectrum.

A simplistic method of spectrum allocation assigns each service a separate frequency. This is called frequency-division multiplexing. These frequencies may be used concurrently, because spectrum allocations do not overlap. The problem with this method of spectrum allocation, however, is that there is not enough spectrum to meet all users' needs. A good example is the assignment of frequencies to AM broadcast stations.

Alternatively, a radio frequency may be assigned cooperatively. A service may be assigned to a particular frequency, but only for a certain period of time. This is called time-division multiplexing. While several services can share spectrum without interference, the drawback with this method is that each service is not available on a twenty-four hour basis. A good example of time-division multiplexing is international shortwave broadcasting[20]. A particular popular shortwave frequency is shared by several nations' international services throughout the day.

Services may also be given access to spectrum on a primary, secondary, or tertiary basis. Secondary and other lower-priority users may use assigned spectrum on a "non-interference, non-protected" basis: they must not interfere with communications between primary users of the same spectrum; furthermore, they must accept without recourse any interference to their own communications caused by higher-priority users. Amateur radio allocations above 220 MHz are routinely shared, on a secondary basis, with other services.

---

[20] In a non-radio frame of reference, a "party line" is a good example of time-division multiplexed telephone service.

Spectrum may also be assigned to different users in different geographical regions. Regional assignment of spectrum is based on the propagation characteristics at the given frequency. Spectrum may be re-used in different geographical areas as long as the coverage areas do not overlap.

Amateur Radio Spectrum Allocation

Amateur radio occupies a privileged international position in regard to spectrum allocation. Other than the various military agencies, amateur radio is the only service with internationally allocated ranges of frequencies throughout the electromagnetic spectrum (Moseson 2001 #185). Table 3 indicates the frequencies allocated to amateur radio operation in Canada and much of the world.

Band Limits	Units	Size of Amateur Allocation (MHz)
1.800 to 2.000	MHz	0.2
3.500 to 4.000	MHz	0.5
7.000 to 7.300	MHz	0.3
10.100 to 10.150	MHz	0.05
14.000 to 14.350	MHz	0.35
18.068 to 18.168	MHz	0.1
21.000 to 21.450	MHz	0.45
24.890 to 24.990	MHz	0.1
28.000 to 29.700	MHz	1.7
50.000 to 54.000	MHz	4
144.000 to 148.000	MHz	4
220.000 to 225.000	MHz	5
430.000 to 450.000	MHz	20
902.000 to 928.000	MHz	26
1.240 to 1.300	GHz	60
2.300 to 2.450	GHz	150
3.300 to 3.500	GHz	200
5.650 to 5.925	GHz	275
10.000 to 10.500	GHz	500
24.000 to 24.050	GHz	50
24.050 to 24.250	GHz	200
47.000 to 47.200	GHz	200
75.500 to 76.000	GHz	500

76.000 to 81.000	GHz	5000
142.000 to 144.000	GHz	2000
144.000 to 149.000	GHz	5000
241.000 to 248.000	GHz	7000
248.000 to 250.000	GHz	2000
Total Amateur Allocation:		**23,197.75 MHz**

Table 3 - Frequency Bands and Bandwidths for Use by Amateur Stations Operating in Canada and in IARU Region 2 (Industry Canada 2001 #123)

Columns one and two indicate the frequency range of the amateur band, and column three indicates the size of the allocation. Larger allocations can either support more simultaneous communications, or higher data rates. Modes such as television require a high data rate and are therefore best suited for the higher frequency amateur bands, which have greater size allocations.

What is so special about this set of amateur frequency allocations? Amateur radio includes spectrum assignments from the low (1.8 MHz) to the extremely-high (248 GHz) frequencies, broken up in such a way as to give amateurs access to all major sections of the spectrum. Almost 24 GHz (24,000 MHz) of spectrum is allocated to the amateur service on either a primary or secondary basis.

Furthermore, each amateur band is in a different segment of the electromagnetic spectrum. Each segment exhibits different, and in some cases unique, propagation effects. Some bands may be used to communicate locally, others globally, depending upon time of day, season, and other factors. Still other amateur bands are well suited to satellite communications (Cleveland-Iliffe and Smith 1999 #58). The size of the amateur allocations in the UHF and microwave regions of the spectrum is comparable to that assigned to commercial carriers. The amateur radio service holds “prime real estate” in every “neighbourhood” in town!

Most of the amateur allocations above 220 MHz are assigned to the service on a secondary basis[21]. This means that amateur operations on these frequencies shall not interfere with those of the primary users, and that amateurs must simply accept any interference caused by coexisting services. With the deployment of new, and largely unlicensed, consumer devices which operate in these bands (Maxwell 2001 #167), amateur operations and the opportunity for unfettered amateur research may be severely restricted, as described below.

Many amateur radio bands are under scrutiny by industry, which is lobbying for their reallocation to commercial wireless services. Should appropriate governmental support such as that which currently exists within Canada be lost, the amateur radio service may not survive.

The importance of the amateur service to telecommunications development is recognized by the United States and Great Britain (Hatfield 2000 #101; United Kingdom Radiocommunications Agency 2001 #249). For the time being, the Canadian process of spectrum auction moderated by comparative evaluation keeps the government in the loop, and allows Canadian amateurs a voice in spectrum allocation issues within our nation.

---

[21] See table 3 and (Industry Canada 2001 #123).

Amateur Activities at VHF and Higher Frequencies

A significant amount of amateur radio operation takes place at frequencies above 30 MHz. Ninety-four percent of amateurs responding to a recent survey in the amateur journal *"CQ Amateur Radio"* reported frequent operation on frequencies above 144 MHz (CQ Communications (Editors) 2001 #62). Table 4 lists some typical amateur activities on these bands. These higher amateur frequencies include several bands that are in great demand for reallocation by commercial services.

The 2.4 GHz band is particularly popular, as commercial devices in this region do not have to be individually licensed (Maxwell 2001 #167). Federal approval of a device that transmits in this band permits the device to be sold in unlimited numbers. Examples of such devices include microwave ovens, cordless telephones, baby monitors, television repeaters intended for in-home use, "Bluetooth" devices[22], residential Internet services, and several types of wireless local area networking components.

Usage	Mode	Path
Personal Communications	Morse Code	Local Line-of-Sight
Public Service Nets	Voice	Terrestrial Repeater
Search & Rescue	Data/Packet	Spacecraft Repeater
DX/Contests/Awards	Image	Reflectors/EME
Experiments	Unmodulated Carrier	Ionospheric Ref & Scatter
Education	Pulse	Tropospheric Ref & Scatter
Training	Spread Spectrum	Meteor Scatter
Remote Control		Hybrid (e.g. RF-Internet)
Telemetry		Fixed
Information Bulletins		Mobile
Propagation Beacons		

[22] See http://www.bluetooth.com for a description of this short-range wireless communication technology, targeted at mobile and hand-held computing devices.

Radio Direction Finding Position Reporting Internet Gateway		

Table 4 - Amateur Radio Usage of Frequency Bands Above 30 MHz. From (Maxwell 2001 #167). Used with permission.

All of these devices have the potential of interfering with amateur radio communications. In Canada,

> "The deployment of licence-exempt low power applications in this range will be permitted as a secondary service that is, on a non-interference basis without protection from interference from licensed users." (Industry Canada 1995 #113)

In the United States regulations concerning such consumer equipment are similarly defined under "Part 15" of the radio regulations (American Radio Relay League 2001 #18). Legally, the devices may not interfere with amateur radio operation. In practice however, the proliferation of these devices has made enforcement impracticable. In metropolitan areas much of the 2.4 GHz band has become unusable (Maxwell 2001 #167). As much of current amateur radio research is taking place in this microwave region of the spectrum, the impact of these unlicensed devices on the amateur's ability to experiment and innovate is proving significant. Two of the three amateur innovative research projects described in chapter IV (the BC Amateur Television Group amateur television project, and the 56K packet project) have already been negatively affected by unlicensed-device interference in the 2.4 GHz band.

Alternatives: Citizen's Band Radio, the "Family Radio Service", and the "Multi-Use Radio Service"

Those unfamiliar with amateur radio may not understand the important role played by the activity in communications research. Amateur radio is often compared to both citizen's band ("CB" radio) and the Family Radio Service ("FRS"), a new radio service approved by Industry Canada on April 3, 2000 (Industry Canada 2000 #118). The Multi-Use Radio Service ("MURS") is a newly created commercial data service in the United States (American Radio Relay League 2000 #7). Each of these services offers radio communications to the public.

CB is based on amplitude modulation in a small segment of the spectrum near 27 MHz. The new family radio service offers a similar channelized service to the public, using frequency modulation in two sub-bands near 462 and 467 MHz in the UHF portion of the spectrum (Industry Canada 2000 #119).

MURS permits unlicensed operation on five non-amateur frequencies in the VHF portion of the spectrum. The intent of this service, which has a power limit of 2 watts, is to support voice, data, and image communications between commercial users in the same locality (American Radio Relay League 2000 #7). MURS is a CB-type of service in the VHF portion of the spectrum.

All of these services differ significantly from that of amateur radio. While the obvious difference is that of the licensing requirement, there is more to it than that. Amateur radio is a scientific hobby, and may be characterized as a communicative activity with a strong underlying fabric of technical know-how. To use an analogy, amateur radio hobbyists focus on the *journey*, while users of these other services simply want to reach the *destination*. The freedom amateur radio operators enjoy, in terms of their several allocations of radio spectrum, from long wave through millimetre wave, their choices of operating modes, modulation techniques, and legislated privileges to experiment and innovate, is a consequence of licensing and their willingness to learn about radio and associated subjects.

Amateur radio is a licensed activity[23]: operators must be qualified and have significant knowledge of radio regulations, spectrum allocation, radio theory, and communications technologies. No qualifications are required for MURS, CB or FRS, and participants typically have no understanding of, nor, significantly, any interest in the communication technologies themselves.

MURS, CB and FRS users are restricted to a small number of channels, low power levels, and a limited selection of commercially manufactured equipment. They have none of the freedom the amateur radio enthusiast enjoys, to choose frequency, antenna, mode, to build and modify equipment, or to experiment with new communication technologies or new applications of existing devices.

Thus constrained, these radio services differ significantly from amateur radio. The historically embedded, legislated flexibility of the amateur radio service supports discovery, invention and innovative activities. These other services are neither sources of invention or innovation, nor bellwethers to industry of new horizons. Users of FRS, CB, or MURS have not discovered any significant new

---

[23] In 2000 Industry Canada ceased “licensing” of radio amateurs in favour of an Amateur Radio Operator Certificate that is valid for life (Industry Canada 1999 #115). Annual licence fees are no longer required for amateur radio stations.

communication technologies. Most users of these services lack the curiousity and experimental bent so common among amateur radio hobbyists. These services cannot replace amateur radio.

What Sets the Amateur Radio Service Apart

Amateur radio is different from any other commercial or citizen-oriented radio service. Key to the amateur radio service:

- *The experimental nature of the activity*

  Amateur radio is an experimental service, a legally sanctioned, international program that allows individuals or groups to experiment with radio communication of all types. Individuals frequently get involved with the hobby in order to experiment with radio communications technologies, rather than simply to communicate. Amateur radio stresses the technology over its application, form over function.

- *The amateur radio operator may choose which frequency to operate on, and the power level to be employed*

  Other services are licensed for particular frequencies or channels at predetermined power levels. Deviation from these terms of licence is not permitted without a complicated review process. Amateur radio operators may freely operate on any amateur band using a flexible range of power levels.

- *The amateur may choose the "mode", or type of modulation to be employed, on any particular frequency*

  Radio amateurs may employ any one of dozens of modes (for example, AM, FM, television, radioteletype, Morse code), at their discretion, on the chosen frequency, subject to general regulations. Commercial services (for example, shortwave broadcasters or television stations) and other licensed entities are usually limited to a single mode as stipulated in their licence.

Challenges to Amateur Frequency Allocations

There is not enough radio spectrum to meet the demand of commercial interests. This presents a serious problem for amateur radio. The recent increase in demand for spectrum by commercial wireless services, such as paging and cellular telephone, is putting pressure on amateur radio frequency allocations (American Radio Relay League 2000 #8). New and existing companies want access to amateur radio spectrum so that they can offer additional commercial services, such as wireless email and Internet browsing. Pressures on the VHF, UHF and microwave regions are significant (Maxwell 2001 #167). Loss of these amateur bands would represent a significant reduction in research and public service capabilities of the amateur radio service.

Amateur radio faces challenges from commercial service providers in all regions of the electromagnetic spectrum. Commercial services proposed for these bands include broadcasting expansion, new satellite services, commercial radar, navigational aids, third generation cellular telephones, and fixed wireless networking (American Radio Relay League 1997 #4; American Radio Relay League 2000 #8).

Non-commercial services such as education and amateur radio are at particular risk (Brewin 2001 #47). Table 5 summarizes current challenges to amateur radio frequencies.

The International Telecommunication Union (ITU) holds world radio conferences (WRCs) at periodic intervals. The purpose of these meetings is to review and revise international radio regulations (Price, Sumner et al. 2000 #198). As recently as the 1979, this conference was on a twenty-five year cycle. The increased demand for electromagnetic spectrum has pushed these meetings also to a higher frequency: the 1979 conference was followed by a conference in 1992 (Sumner 2000 #229), and the most recent meeting was held in Istanbul, Turkey, in May 2000. The next meeting is scheduled for 2003 (Price, Sumner et al. 2000 #198).

The results of the 2000 conference luckily did not have significant negative impact upon amateur radio (Radio Amateurs of Canada 2000 #204). Amateur organizations credit these results to their level of preparation. Threats to amateur spectrum at 2.4 GHz are particularly acute[24], and as this thesis nears completion the Federal Communications Commission has made two separate proposals for reallocation of amateur spectrum in the 420 MHz and 2.4 GHz bands for unlicensed commercial products (American Radio Relay League 2000 #8).

[24] See "3G Bullet Dodged" in (Price, Sumner et al. 2000 #198).

Amateur Band	**Proposed Reallocation**	**Initiated By**
3.5 – 4.0 MHz	Expanded shortwave broadcasting	World Radio Conference, 2000
146 – 148 MHz, 219 – 225 MHz, 430 – 450 MHz	LEO position location, data messaging satellites	OrbComm, GE, others
400 – 500 MHz	Synthetic aperture radar (earth exploration satellites)	Netherlands, others
440 – 450 MHz, 3.4 – 3.8 GHz. 10.15 – 10.3 GHz	Fixed wireless service (wireless telephones)	Inter-American Telecommunication Commission (CITEL), led by Canada
216 – 220 MHz, 2.3 – 2.305 GHz, 2.390 – 2.4 GHz 2.4 – 2.402 GHz, 2.417 – 2.450 GHz	Third generation cellular telephone, mobile and fixed wireless services	FCC (American Radio Relay League 2001 #16), cellular service providers, AeroAstro (American Radio Relay League 2001 #14). See also (American Radio Relay League 2001 #13).
2.402 – 2.448 GHz	Helicopter video downlink	Los Angeles County, area only
1.260 – 1.300 GHz	Galileo global positioning system	France, Germany
5.0 – 6.0 GHz	Wireless LAN, short range point-to-point data link	Various, FCC

Table 5 – Amateur Spectrum Under Consideration for Reallocation to Commercial Service (from (American Radio Relay League 2000 #8), (American Radio Relay League 1997 #4))

Increased demand for electromagnetic spectrum by industry is putting amateur allocations in the VHF, UHF, and microwave bands under pressure. Commercial service providers need spectrum to support new customers. Amateur spectrum in this region is underutilized when examined in strict statistical terms: while there is plenty of amateur operation in these bands (Maxwell 2001 #167), amateurs do not utilize all of their spectrum twenty-four hours per day like many commercial service providers. Such amateur usage that does exist, however, includes leading-edge experimentation with new modes and new techniques, such as digital signal processing and spread-spectrum communications. A large amount of research activity is taking place on these higher frequency bands.

The amateur population is growing (Lindquist 2001 #145), and most new hobbyists use the VHF and UHF amateur bands as their entry point into the activity. Industry postulates a healthy amateur service based on these growth figures, and proposes a reduction in amateur spectrum allocation on the basis that most of these new amateurs operate on only a small number of amateur bands, typically 144, 220, and 430 MHz. In industry's view, a growing service cannot be at risk, and the fact that new amateurs do not populate the higher frequency microwave bands makes them ripe for reallocation. This is myopic.

What is really at risk is the value of amateur radio as a source of innovation. Amateur access to radio spectrum must be assured to support innovative activities, enable continued creativity, and allow the hobby to continue to contribute to industry and society. Industry in particular has lost sight of this fact, and in the name of profit and market share would kill off the service that, ironically, gave birth to it (and its products) in the early part of the last century.

The fact that amateur numbers are increasing is orthogonal to the ability of the amateur service to innovate. An examination of innovative activities within amateur radio reflects that in other segments of society. I base these observations on my broad personal experience in the hobby, its clubs and associations, and study of amateur radio literature and periodicals. The greater percentage of amateurs does not significantly innovate. They use amateur spectrum and communications technologies as they exist; some are early adopters, some laggards, but the majority falls into an intermediate category. Perhaps five percent of amateurs are innovators: those responsible for the majority of invention and creativity within the hobby. Such a figure is consistent with that of other activities and with industrial innovation (Rogers 1962 #211). To reduce amateur spectrum allocations in favour of industry limits the scope of amateur experimentation, and its ability to further contribute to the field.

Chapter III

A Short History of Radio and Amateur Radio Activities

Research into wireless electromagnetic communication came to fruition in the latter part of the 19^{th} century (McElroy 1994 #168). Professor Heinrich Hertz of the University of Bonn was able to demonstrate the efficacy of electromagnetic communication in 1887. Hertz succeeded in transferring information short distances between two sets of apparatus without wires, through the use of a spark-gap transmitter and simple receiver (Dalton 1975 #64). The information was postulated to be carried on "radio waves". The Barnhart Dictionary of Etymology defines the term "radio" as a "combining form of 'radiant energy'" (Barnhart 1988 #32), and the Oxford English Dictionary mentions the term as being first used in conjunction with Hertz's study of electromagnetic radiation in 1886 (Simpson and Weiner 1989 #221).

These experiments built upon theoretical work performed by British scientist James Clerk Maxwell into the nature of magnetism and electricity (Campbell and Garnett 1882 #51), and were in fact the first applications of his theory to the development of a practical communications system. As a mathematician, Maxwell had had little interest in the application of his equations, and it fell to Hertz and others such as the Yugoslavian inventor Nikola Tesla to apply Maxwell's theory after his death in 1879, and develop actual wireless transmitters and receivers (Dalton 1975 #64; Cheney 1981 #56).

Few others appreciated the import of Hertz's work. Sir William Crookes, the noted British chemist and physicist, wrote of "a new and astonishing world" arising out of the fact that radio waves would pass through buildings and solid objects, and envisioned “the bewildering possibility of telegraph without wires” (Rowland 1999 #216).

Arguably, these experimental activities, which were based on minimal theoretical understanding and relied largely on trial and error to generate improvements in “wireless” communication, constitute the beginning of amateur radio (Dalton 1975 #65; Lewis 1993 #141). Experimenters observed phenomena that had been “proven” impossible by mainstream scientists (DeSoto 1936 #70). In an era before regulation, without theoretical basis for their observations, <u>everyone</u> was an amateur.

In 1894 the Italian/English inventor Guglielmo Marconi, then just seventeen years of age, read of Hertz’s and others experiments in this new field, dubbed “wireless telegraphy”, and determined to repeat these experiments to see if he could improve upon their results. Marconi’s research led to significant improvements in the range of wireless equipment, and encouraged him to form a company to provide wireless equipment to the British government. In December 1901 Marconi bridged the Atlantic ocean with wireless[1], an achievement that brought great publicity and fame to him and his company (Dalton 1975 #64; Lewis 1993 #141). “Wireless” had captured the public imagination.

---

[1] Questions have arisen as to whether Marconi was in fact successful in these tests. See (Belrose 2000 #34).

While never licensed, Marconi considered himself an amateur radio operator, and was a frequent collaborator with leading amateur experimenters in radio through the early part of the 20th century (Dalton 1975 #65; Lewis 1993 #141).

Those with leisure time, curiousity, and an inclination for experimentation became enthralled with the new "wireless". A modest investment in equipment could produce demonstrable results. These individuals, many in their teenaged years, sought to duplicate Marconi's experiments, for much the same reasons as they had been building their own local telegraph and telephone systems: not for profit, but simply to satisfy their own curiosity, and to experience the "magic" of a new technology firsthand (DeSoto 1936 #70; Archer 1971 #27).

Early wireless equipment was simplistic and inefficient, because the mechanisms of radio were not well understood. Construction details were hard to find. When an article on wireless, complete with circuit diagrams, was published in the magazine *American Electrician* in July 1899, the era of amateur wireless communication began (DeSoto 1936 #70). Soon a complete station (transmitter and receiver) could be assembled with minimal cost, from parts readily available around the house and a visit to the local hardware store (Archer 1971 #27; Douglas 1986 #75). The Electro-Importing Company in New York became the first store to specialize in wireless apparatus, in 1906 (McElroy 1995 #169).

In this early period, North America was the centre of most leading-edge radio research, and the home of the most active amateur experimental community. Europe, and especially Great Britain, lagged other regions. Some have argued that this was due to the strict regulation of radio in these regions. Dalton describes early amateur licensing restrictions in Great Britain by the British government's desire to preserve the existing monopolies of the print media over news, and that of the telegraph and wireless companies over messaging (Dalton 1975 #65). Then as now, with the resistance to open source software by government and industry (Raymond 2001 #207), political economy played a role in the social construction of new technology.

Radio Regulation

In November 1906, the International Wireless Telegraph Convention was signed by twenty-seven nations in Berlin (DeSoto 1936 #70). This set of protocols addressed commercial and ship-to-shore wireless communications and formed the basis of future radio regulation[2]. Interference between wireless stations was a significant problem. Commercial, military, and amateur services shared the electromagnetic spectrum, and frequently interfered with one another. In the United States the problem of interference was particularly severe (Archer 1971 #27). Amateurs interfered with military (primarily naval) wireless stations, the Marconi Company, which handled commercial messaging, and one another. Attempts to legislate radio communication began from 1906. Several bills were introduced but none were passed into law. Thirteen bills were introduced in 1912 alone. Amateur radio hobbyists were cast in a negative light and blamed for most of this interference (DeSoto 1936 #70).

---

[2] The 1906 agreement did not specifically mention amateur radio. It's greatest legacy may be the adoption of the term “radio” for wireless communications (DeSoto 1936 #70; Simpson and Weiner 1989 #221).

In 1912, the first Radio Act in the United States "banished" amateur operators to the "useless" frequencies "below two hundred metres in wavelength"[3] (DeSoto 1936 #70). Propagation theory, then in primitive form, held that frequencies above 1.5 MHz would not allow communication over any significant distance (DeSoto 1936 #70). As DeSoto described it,

> "… the general belief was that wavelengths below 250 meters were essentially worthless for anything but the most limited work. So, said the lawmakers, we will give amateurs this useless wavelength of 200 meters. That will reduce the amateur to oblivion as surely as another way, quoth they; for who will work long in worthless territory?" (DeSoto 1936 #70)

This muzzling of the hobbyists served industry in two ways: radio amateurs regulated to these frequencies would not cause further interference to commercial services (which had no interest in this region of the spectrum); and the popularity of the hobby, limited to a "useless" region of the electromagnetic spectrum, would plummet (Barnouw 1966 #33; MacLaurin 1971 #152). In time, amateur radio would cease to exist (DeSoto 1936 #70; Laport, Tilton et al. 1981 #137; Maxwell 2000 #166).

Radio regulation was also intended to prevent amateurs from handling commercial traffic. Some amateur groups had been relaying messages faster and with more accuracy than the commercial carriers (Barnouw 1966 #33). Interference between amateur and commercial operators had indeed been a problem, but interestingly, the main reason for this was the outdated equipment being employed by the

---

[3] Early radio terminology was based on wavelength rather than frequency. "Below 200 metres" meant wavelengths ***less than*** 200 metres. This corresponds to frequencies ***above*** approximately 1.5 MHz.

commercial operators. Low sensitivity, poor selectivity, and susceptibility to interference were characteristic of commercial radio gear of the time (DeSoto 1936 #70). The science of electronics was new, and the pace of technical advancement within the field put commercial operations at a disadvantage. Commercial wireless services could not upgrade their infrastructure quickly enough to keep pace with the rapid refinement of radio technology. The Marconi Company had a virtual monopoly on commercial wireless services. Radio equipment was leased, rather than sold (Rowland 1999 #216); upgrade of commercial wireless sets was not under the control of the end user (Lewis 1993 #141).

Amateurs, in contrast, were much more flexible and adaptive in the face of technological advances. In fact, amateurs were responsible for several of these new developments (Laport, Tilton et al. 1981 #137; Maxwell 2000 #166). Consequently, it was not unusual for amateur stations to be better equipped, and more professionally operated than those of the commercial wireless stations (DeSoto 1936 #70; Archer 1971 #27; Douglas 1986 #75). Amateurs were involved in wireless out of personal interest, and enthusiasm for the field, rather than as employees of large companies.

The agility of the small software company versus the sluggishness of large software firms is presenting an equal challenge to industry today. Significant new and creative technologies are emerging from startup companies, basements, and “amateur” programmers[4]. Amateur software leads in creativity and is sometimes more responsive to users’ needs. Industry is threatened and seeks remedies in

---

[4] Examples: “Linux”, “Apache”, “Napster”.

legislation, the courts, and commercialization of free technologies through purchase of them. The many parallels between early amateur radio and the recent "open source" software movement warrant further research, and have been noted by other authors such as Andrew Ross, Carolyn Marvin, Dennis Hayes, and Susan Douglas (Ross 1991 #215).

The amateurs' move to the "useless" region of the spectrum below two hundred metres in fact heralded a new era of discovery and research, in which amateur radio played a leading role. The American Radio Relay League (the ARRL), founded in 1914, was to coordinate this research and represent amateur radio's interests in Washington DC, and later internationally through the International Amateur Radio Union (IARU) (American Radio Relay League 1965 #2).

The move to these shorter wavelengths[5] by amateur radio led to important discoveries about the nature of radio propagation. As amateurs moved their equipment to shorter and shorter wavelengths, their ability to communicate with ever more distant stations improved. This contradicted accepted radio theory of the day. Higher frequencies, well into the "useless" region, proved to be able to support first intercontinental, then transoceanic, and finally global radio communications, twenty-four hours a day (DeSoto 1936 #70; American Radio Relay League 1965 #2; Maxwell 2000 #166).

---

[5] Shorter wavelength implies higher frequency. A wavelength of 200 metres corresponds to a frequency of about 1.5 MHz, therefore amateur operation was restricted to frequencies above 1.5 MHz. The AM broadcast band today occupies .525 through 1.705 MHz in Canada (Industry Canada 1995 #112). Wavelength was commonly used as a method of identifying a region of the electromagnetic spectrum in the early 1900s. As wireless equipment became more sophisticated, the nomenclature shifted to using frequency rather than wavelength as a standard of measurement. Today, wavelength is generally used to refer to a range of frequencies, for example, the "20 metre amateur band" is vernacular for the frequency range of 14.000 through 14.350 MHz.

Needless to say, as the "expert" assessment of the utility of these amateur frequencies was proven incorrect, commercial wireless service providers changed their approach, eyed the amateur operations below 200 metres (i.e. frequencies above approximately 1.5 MHz), and sought exclusive rights to this part of the spectrum. Industry lobbied government for regulatory changes, and in October 1924, amateur radio operators in the United States found themselves restricted to small segments of the spectrum below 200 metres (DeSoto 1936 #70).

Amateur Radio in Canada

Amateur radio in Canada began in the early 1900s. The activity was formally addressed by the federal (then Dominion) government in subsection 6 of the Wireless Telegraphy Act of 1905:

> "Where the applicant for a licence proves to the satisfaction of the Minister that the sole object of obtaining the licence is to enable him to conduct experiments in wireless telegraphy, a licence for that purpose shall be granted, subject to such special terms, condition, and restrictions as the Minister thinks proper" (Bird 1988 #38, "The Wireless Telegraph Act").

Regulations governing amateur licensing were first stipulated in the Radiotelegraph Act of 1913[6] (Bird 1988 #38, "The Radiotelegraph Act"). The qualifying examination for amateur radio operators at this time consisted of an inspection of the applicant's station, and a test of his/her ability to send and receive Morse code

---

[6] An alternate reference, (Department of Communications 1985 #69) states that amateur radio was first regulated in Canada in 1914.

at the relatively slow rate of five words per minute. A written examination was introduced in the early 1920s that tested the applicant's technical knowledge of radio. In the 1930s, as the body of knowledge on radio technology grew, prospective amateurs were also required to draw, from memory, schematic diagrams of transmitters and receivers. The Morse code standard was increased at this time to ten words per minute (Department of Communications 1985 #69).

With the advent of amateur radiotelephone operation, an endorsement was offered to amateurs who could copy Morse code at fifteen words per minute that would permit voice communications on some amateur bands. From 1955, this endorsement was formalized as an "advanced amateur" operator's certificate (Department of Communications 1985 #69).

The Department of Communications introduced a multiple-choice written examination to the Canadian amateur service in January 1975 (QST Editors 1975 #201). Canada led the world in the recognition of the importance of digital communications with the introduction of the Amateur Digital Radio Operator's Certificate on September 15, 1978 (Hesler 1978 #107; Department of Communications 1985 #69). Digital transmission had been pioneered by three amateur groups in Canada (Borden and Rinaldo 1981 #43; Ball 1989 #31; Lockhart 2000 #147), and was to develop into a global packet radio network over the next decade (Lockhart 2000 #147). Further changes to the regulations in Canada in 1990 (Hennessee 1990 #104), and again in 1999 and 2000 modified amateur licensing to reflect newer technologies, some changes in amateur spectrum allocation, and operating requirements. In May, 2001, the Morse code requirement for full amateur operation on the short wave amateur bands was reduced from twelve to five words per minute (Charron 2001 #55; Industry Canada 2001 #123).

Four Eras of Amateur Radio Development

Figure 4 depicts the development of the amateur radio, identifies key points of innovation, and fixes important events in its development.

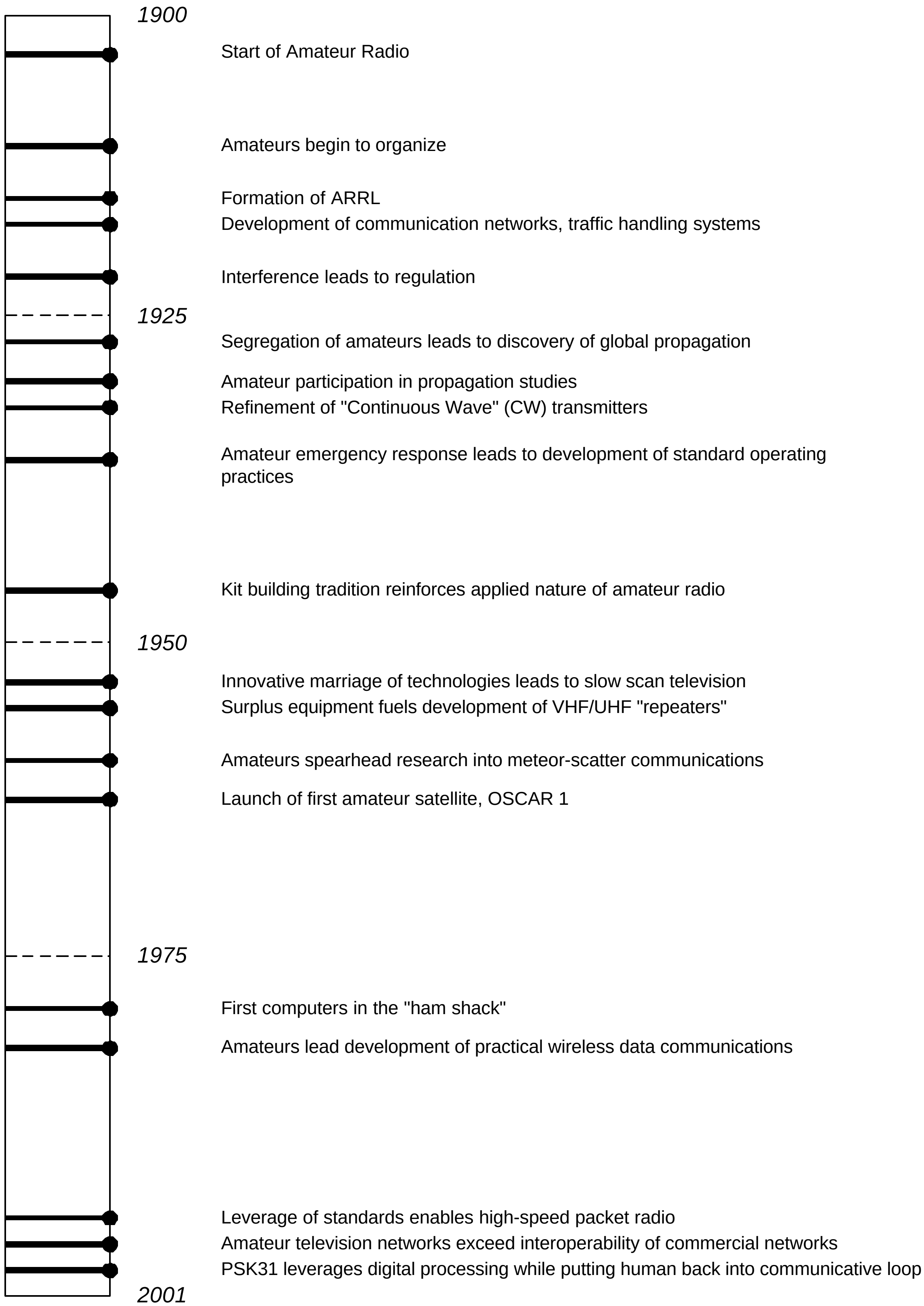


Figure 4 – Innovative Timeline of Amateur Radio

For analytical purposes, I have divided the development of amateur radio into four time periods:

- Amateur radio through 1929;
- Between 1930 and 1945;
- Between 1946 to 1975; and
- From 1976 to the present day.

The dates ending each of these periods are significant. The market crash of 1929 had important impact on amateur radio; 1945 marked the end of the Second World War and the beginning of a period of enthusiastic growth for the hobby; and 1975 saw the introduction of the personal computer, a device which has had profound effect upon everyday amateur operation and has arguably redefined amateur radio itself.

In each of these eras, amateur radio displays creativity and innovative spirit in not only the fundamental technologies encompassing radio, but also in the social application of the technology. Each period is summarized below.

Amateur Radio Through 1929

The period from about 1901 through 1929 was one of significant technical development for both the new science of electronics, and for amateur radio. Indeed, the electronics “industry” did not even exist prior to 1901. Most of the scientists active in the field were also amateur radio operators, and many had received their introduction to radio and electronics through amateur wireless activities. Arguably, especially early in the century, there was little if no difference between them (Dalton 1975 #65)[7].

This period saw the discovery and refinement of spark gap transmission techniques, the development of continuous wave ("CW") transmission as a superior technology to "spark" that made more efficient use of radio spectrum, and the replacement, by about 1925, of "spark" with CW (DeSoto 1936 #70; Hyder 1992 #111).

Amateur interference with commercial and military radio operations led to demands for regulation[8]. In 1910, no less than six bills to "clean up the airwaves" were before the American congress (McElroy 1995 #169). This number grew to thirteen by 1912 (DeSoto 1936 #70). Wireless technology was improving quickly, with amateurs at the forefront. Commercial wireless stations did not have the sensitivity, and especially the selectivity, of amateur equipment. Consequently, the commercial installations were plagued by "interference" from amateurs, although arguably it was the poor quality of their own equipment that was responsible (Rowland 1999 #216). Interference with wireless communications during the rescue/recovery operations following the RMS Titanic disaster in April, 1912 brought the issue to a head (Barnouw 1966 #33), and resulted in the creation of the Radio Act of 1912 in the United States, and, shortly thereafter, the Radiotelegraph Act of 1913 in Canada.

---

[7] Figure 4, *"Start of amateur radio".*

[8] Figure 4, "*Interference leads to regulation".*

The inclusion of provisions in this legislation which regulate the *content* of amateur communications (still in force today, see (Industry Canada 2000 #120) and (International Telecommunication Union 1998 #126)) is an interesting point that is worthy of further research.

Amateurs transmitting “important” messages could be prosecuted. “Important” messages contained information of more than a trivial nature, information that could be considered by a judge as worthy of transmission by a commercial service. In this way the commercial wireless firms, led by the Marconi Company, preserved their monopoly by limiting the ability of newcomers to compete. Enforcement sections within the legislation allowed for revocation of licences, seizure of amateur equipment, fines, and even imprisonment for violators (Dalton 1975 #65; Stevenson 1996 #227).

Like the evidence of lobbying by the print media to restrict wireless communications in Britain (Dalton 1975 #65), this aspect of the Radio Act may have been intended to prevent competition between the established wireless firms, notably the Marconi Company, and amateurs. As noted above, amateur stations possessed superior technology, and left unchecked, amateur messaging could have surpassed commercial services in accuracy and speed of delivery.

In the period 1905 to 1914, wireless clubs became popular venues for amateur radio enthusiasts to share information and collaborate[9]. The Wireless Association of America was founded by amateur radio enthusiast, entrepreneur, and eventual

[9] Figure 4, *“Amateurs begin to organize”*

science fiction luminary Hugo Gernsback in New York in 1909 (Ross 1991 #215). Within the year the association boasted over 10,000 members (McElroy 1995 #169). Radio clubs served as the front line of resistance to government (specifically the Navy Department) and commercial desire for monopoly over the electromagnetic spectrum. As Andrew Ross put it:

> "This fiercely networking community of boy ham operators played a significant role in contesting corporate and military attempts to establish monopoly control over the ether in the years before and after the first world war" (Ross 1991 #215).

In March 1914, a transcontinental network of amateur radio stations in the United States and Canada, to be named the "American Radio Relay League", was established by American amateurs Hiram Percy Maxim and Clarence Tuska of Hartford, Connecticut[10] (DeSoto 1936 #70). The purpose of the organization was to assist passing of messages[11] among amateur operators throughout North America (DeSoto 1936 #70; ARRL Technical Information Service and DeSoto 2001 #28).

Direct contact between distant stations was not possible at this time, as the important discoveries concerning radio propagation at higher frequencies were still in the future. Messages destined for delivery to stations beyond a range of fifty to one hundred miles had to be relayed by intermediate stations.

---

[10] Figure 4, *"Formation of ARRL".*

[11] "Traffic handling"

A “traffic handling” network first proposed by Maxim in the pages of the organization’s journal, <u>*QST*</u>[12] in February 1916 (reproduced as Figure 5) allowed messages to be passed from the east to west coast in minutes[13]. The topology of the ARRL network in 1914 is surprisingly similar to that of the early Internet, shown in Figure 6 (The Computer Museum History Centre 2001 #235).

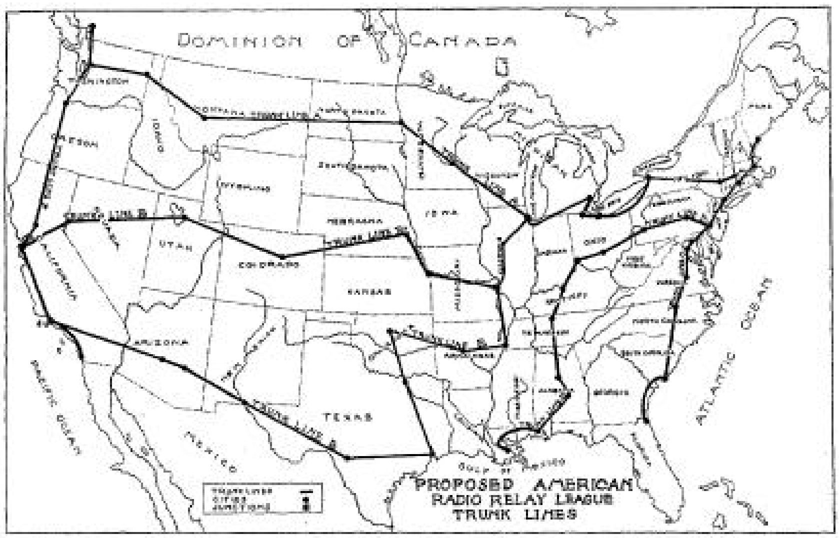


Figure 5 – Amateur Radio Message Handling Network, 1914 (Maxim 1916 #164)

---

[12] “QST” was a code, or shorthand term, standing for “calling all radio amateurs”. A series of codes for common questions and answers, called the “Q Code”, originated in commercial wireless in 1912, but was popularized by amateur radio operators (American Radio Relay League 2001 #21). It remains universally understood today.

[13] Figure 4, *“Development of communication networks and message handling systems”.*

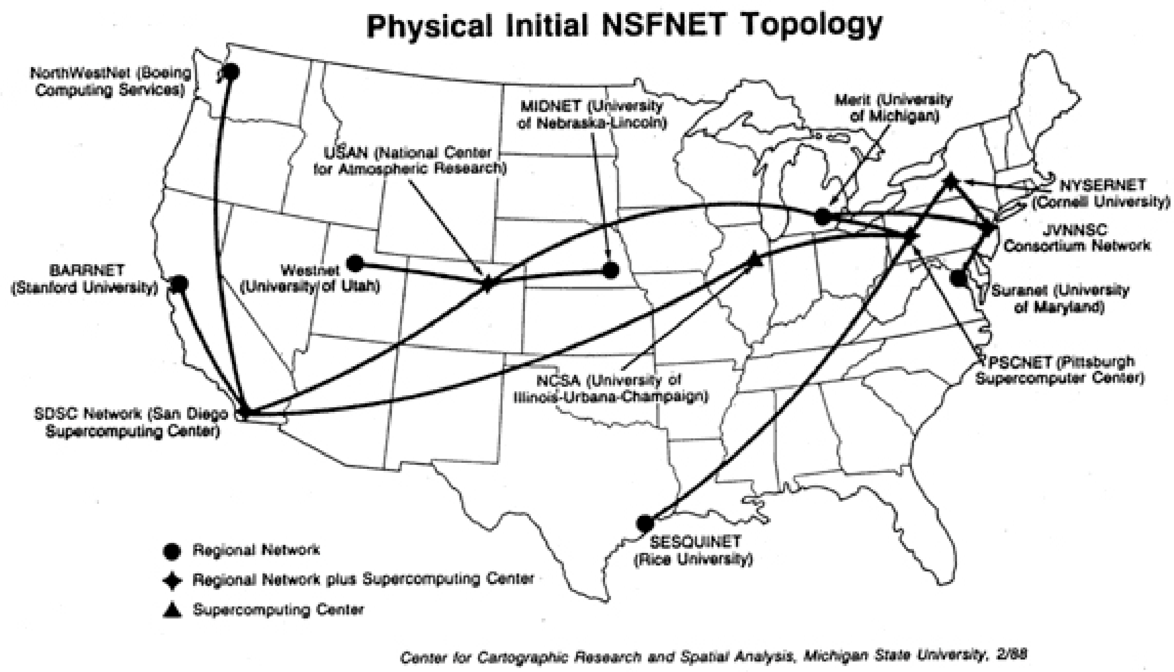


Figure 6 – Internet, 1988 (The Computer Museum History Centre 2001 #235)[14]

Amateur radio operations were suspended following the start of the first World War in 1914, although some nations, including the United States, continued to allow amateur operation as long as it did not violate their neutrality. There were violations, and some commercial stations in particular were taken over by the government (DeSoto 1936 #70). In 1917, with the entry of the United States into the war, American amateur operations were suspended for the duration of the conflict. Seventeen thousand amateurs served as radio operators and radio instructors in the armed forces, and led the advancement of radio technology and operating techniques (DeSoto 1936 #70).

[14] Used with permission.

The American Radio Relay League was to serve a pivotal role in keeping amateurs organized during the war, largely through continued publication of their journal, QST (American Radio Relay League 1965 #2). After the war Hiram Percy Maxim, still president of the ARRL, lobbied successfully for the resumption of amateur radio in the face of strong opposition from the US Navy and commercial wireless service providers (DeSoto 1936 #70; Barnouw 1966 #33). Amateur radio operation resumed in the United States on September 26, 1919 (DeSoto 1936 #70).

Amateur experimentation with "useless" higher frequency waves, following passage of radio regulatory acts in Canada and the United States in 1912, revealed that propagation of signals improved with frequency[15] (American Radio Relay League 1965 #2). Radio communication that took hundreds of thousands of watts and huge antennas at commercial frequencies could be duplicated with tens of watts and much smaller antennas in the new amateur bands below 200 metres (DeSoto 1936 #70; Rowland 1999 #216).

These facts contradicted current radio theory. First discussed in the pages of the journal *QST* in September 1916, the propagation of radio signals was largely a mystery to amateur and professional alike (Maxim and Tuska 1916 #165). The distance that a radio signal would travel seemed to vary randomly with frequency, time of day, and even season of the year. In September 1920 the American Radio Relay League partnered with the National Bureau of Standards and Dr. Albert Hoyt

[15] Figure 4, *"Segregation of amateurs to wavelengths below two-hundred metres leads to important discoveries about radio propagation".*

Taylor of the Naval radio laboratory to conduct formal research into the propagation of radio signals (DeSoto 1936 #70; Welsh 1995 #259). An experiment conducted in March of 1923 demonstrated the capability of "short" waves (at a frequency of about 2.8 MHz) to propagate throughout North America (Mumford 1973 #186). By April 1925, a new theory which characterized the ionosphere as a refractor of radio signals had been developed by amateur hobbyist John Reinartz (Reinartz 1925 #208). This theory[16] is still employed effectively today (Laport, Tilton et al. 1981 #137; Welsh 1995 #259).

Commercial interests observed these discoveries and amateur radio's success below 200 metres with great interest (Rowland 1999 #216), and successfully lobbied for exclusive spectrum allocations in these new "short wave" bands. American amateurs were again regulated into small segments of the short wave spectrum during the national radio conference of October 6 – 10, 1924 (DeSoto 1936 #70).

Specific innovations developed through amateur radio in this period included amplitude modulation (allowing the transmission of voice and music); the super-heterodyne radio receiver, invented by Edwin Armstrong, a radio amateur; several types of transmitting and receiving antennas which are still in use today; the first facsimile and mechanical television systems developed within the amateur community (Dewhirst 1928 #73); radioteletype; and the standardization of operating techniques and abbreviations for radio messaging (American Radio Relay League 1965 #2).

---

[16] In fact, this model is called the "Reinartz Theory".

Canadian-born amateur radio experimentalist and electrical engineer Reginald Fessenden pioneered the wireless transmission of the human voice on December 23, 1900 (Belrose 2000 #34). The technology at this time was crude and invariably burnt out components of the radio transmitter. Fessenden, christened "The Father of Radio Broadcasting" by the Canadian Communications Foundation (Canadian Communications Foundation 2000 #52), worked to improve the technology, and surpassed this achievement with broadcast of a Christmas program, including music, on December 24th 1906 (Rowland 1999 #216).

Radio amateurs marveled at this accomplishment and many worked to duplicate Fessenden's experiments. Amateurs adapted earlier broadcasting techniques[17] to radio, and successfully spun the concept off to form an entirely new industry. Station KDKA in Pittsburgh, Pennsylvania[18], was originally an amateur radio station, and David Sarnoff, the chairman of RCA, was an enthusiastic amateur who continued his support and interest in the hobby for the duration of his life (Lyons 1966 #150; Lewis 1993 #141).

In the early 1920s, the ARRL led industry in promoting the abandonment of spark-gap telegraphy and telephony among radio amateurs[19]. Spark gap was inefficient, wasted power, and caused incredible interference between stations amateur and

---

[17] "Telefon Hirmondo", see (Marvin 1996 #162).

[18] Often touted as the first radio broadcasting station, KDKA was in fact beaten to the airwaves by station XWA (later CFCF) in Montreal, which began operations on May 20th, 1920. KDKA did not become operational until November, 1920.

[19] Figure 4, *"Interference leads to refinement of continuous wave (CW) transmitters".*

commercial alike. A series of articles proclaiming the death of “King Spark” from 1921 informed amateurs of the benefits of continuous wave (CW) transmission (QST Editors 1964 #200; QST Editors 1964 #199). Amateurs also made important contributions to the development of CW transmitters.

Amateur Radio 1930 – 1945

The economic depression which followed the stock market crash of 1929 had impact on many aspects of North American society. Amateur radio was no exception. Sales of commercially manufactured amateur radio equipment dried up, and hobbyists relied more than ever on self-constructed radio equipment and station accessories (Douglas 1999 #76).

Amateur ranks in the United States swelled by almost three times in the period 1929 – 1934 (American Radio Relay League 1965 #2; Douglas 1999 #76). This increase was accompanied by a large increase in the level of activity of previously licensed operators (Bowers 1938 #45). Hobbyists were spending more time on the radio. More leisure time, a consequence of unemployment, drew new hobbyists to the field. Radio schools promised high-paying employment to electronics technicians, and many amateur radio hobbyists considered electrical engineering as a career (Merrill 1937 #181).

In an article in the *American Sociological Review* in 1938, Canadian sociologist Raymond V. Bowers examined the diffusion of amateur radio, as a representative new technology, throughout the United States (Bowers 1934 #44; Bowers 1938 #45). He determined that most hobbyists became involved for “personal” reasons associated with their curiousity about radio technology and their desire to participate in the advancement of a new technology.

Through a series of questionnaires completed by over 300 hobbyists, Bowers charted the rate of diffusion of amateur radio from the American northeast towards the western states, and finally to the deep south.

Bowers' diagram of the number of amateur radio operators per one hundred thousand population by year is reproduced in Figure 7 below. He spends considerable effort in characterizing the three maxima in this figure relative to sociological theory as it existed at the time.

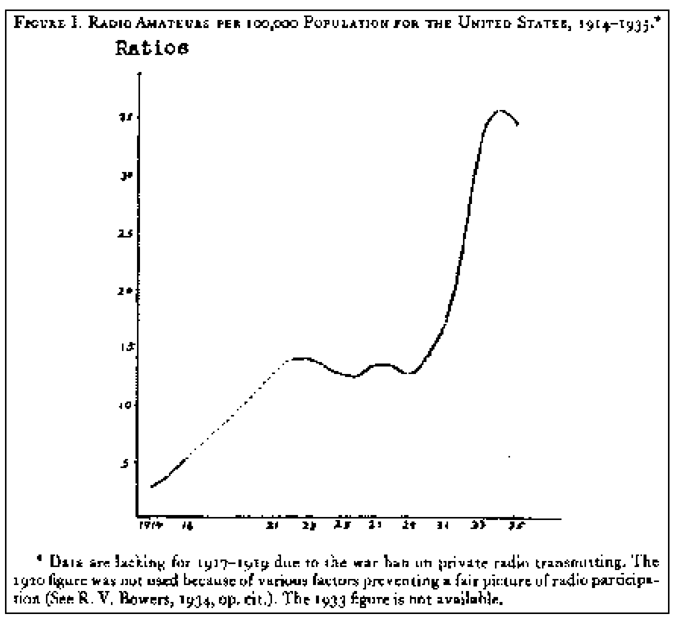


Figure 7 – Amateur Radio Operators per 100,000 of US Population, 1938 (Bowers 1934 #44)

What Bowers' analysis did not consider, however, was the effect of the market crash of 1929, and the subsequent depression, on the presence and quality of leisure time available in America. Bowers' article was written in 1938, and while the link between increased leisure time, amateur radio activity, and the depression may seem obvious today, he did not consider it as a factor which may have contributed to the increase in the amateur population.

During the depression, amateur radio's niche as a leisure activity, and its leverage of common household materials in the fabrication of state-of-the-art radio equipment (Kostenbauder 1976 #131; Douglas 1999 #76) placed the hobby in an enviable position for growth. Amateur radio was a cheap and accessible hobby that emerged from the depression era with many thousands of new participants. In 1934 there were 46,400 amateurs in the United States, compared to 16,800 four years earlier (Douglas 1999 #76). Figures for Canada are not available.

During the 1930s, technical developments within amateur radio continued apace of those within the industry. Radiotelephone (voice) communications supplanted Morse code (also called "CW") and came close to equaling it in popularity. Amateur experimentation with television crossed a bridge from mechanical to electronic techniques (Sleeper 1929 #222; Lamb 1937 #135), and amateurs' moves to ever-higher frequencies provided industry with new information about this unexplored region of the electromagnetic spectrum.

Amateurs in Great Britain played an important role in discovering the eleven-year sunspot cycle through its effect upon radio communications (Fergus 1931 #87; Warner 1931 #256).

Amateur radio operators assisted in disaster response. The great flood of March 1936, now largely forgotten, covered fifteen states in the US, and amateur radio operation provided valuable assistance to victims and government authorities (Warner 1931 #255). A major hurricane in September 1938 and other events wreaked havoc, and amateur radio operators honed their procedural skills, providing health and welfare communications and saving many lives (Handy 1931 #99; Handy 1939 #100; Warner 1943 #257). Operating procedures developed within amateur radio made a successful transition to the military and emergency service agencies. Morse code, amateur "Q" signaling codes, and amateur operating techniques were, for example, adopted by several police agencies throughout the United States (McEwen 1999 #170).

Following initial studies of atmospheric noise within the electromagnetic spectrum, extraterrestrial radio sources were discovered by physicist Karl Jansky of Bell Labs in 1933 (Ghigo 2001 #95). This discovery remained only a curiousity until 1937, when amateur radio operator Grote Reber inaugurated the field of radio astronomy with the construction of a wood-framed, 32-foot parabolic antenna in his backyard in Wheaton, Illinois (Ghigo 1999 #94). Reber's observations of the sky at a wavelength of 187 cm allowed him to detect emissions from the Milky Way galaxy and produce the first radio-contour maps. His antenna is now on display at the Smithsonian Institution in Washington, DC (The National Radio Astronomy Observatory #236).

The World War of 1939 – 1945 again pressed many thousands of amateur radio hobbyists into military service as radio operators, instructors, and researchers (Henderson 1997 #103). Recruitment programs placed advertisements, sometimes co-sponsored by radio manufacturers, in amateur journals (see Figure 8). Also in demand were amateur apparatus such as transmitters, receivers, and even panel meters, used for measuring voltage and current (Davis 1995 #67). The military purchased amateur equipment outright and put it to work both domestically and overseas.

Amateurs continued to dominate in the technical quality of their stations. Military radio equipment of 1941 was of similar quality to amateur gear of 1928 – 1932 (Davis 1995 #67). Hobbyists recruited to the military and research establishments quickly improved the technical standards of non-amateur radio communications (DeSoto 1943 #72). On the domestic front, amateurs brought technical skill to the assembly lines and streamlined the process of manufacture for radio equipment (Davis 1995 #67).

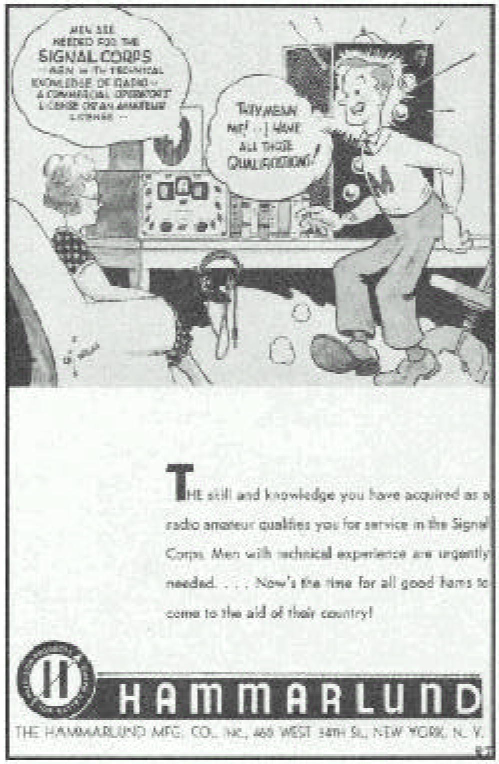


Figure 8 – Amateur Recruitment for Military Service ("QST", Spring 1942, from (Davis 1995 #67))[20]

In most areas of the world, the amateur radio service was closed down for the duration of the war. In Canada and the United States, those amateurs remaining in civilian life nonetheless contributed to the war effort as monitors of domestic and foreign radio communications. These "listening posts" intercepted enemy transmissions and were able to provide information on prisoners of war to the armed services and the prisoners' families. They also served to monitor domestic

[20] Captions: (radio) "Men are needed for the Signal Corps…men with technical knowledge of radio…a commercial operator's license or amateur license"; (young amateur) "They mean me!… I have all those qualifications".

transmissions for information that could jeopardize the war effort (McLellan 1942 #171), and to relay information from other nations to domestic governments and, occasionally, the media (DeSoto 1942 #71). In Canada the Post Office Department assisted listening post stations with postal guides, provided administrative support for the program, and also accepted post cards from the stations detailing health and welfare information on prisoners of war for their families (National Archives of Canada 1939-1945 #188). An example of one of these post cards is shown in Figure 9.

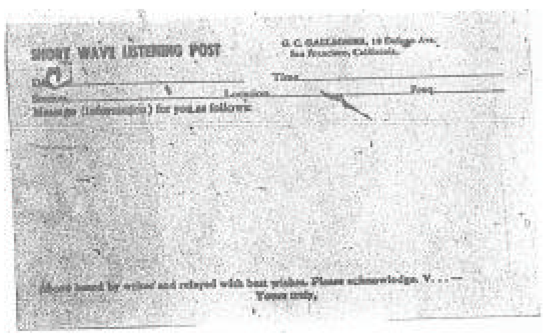


Figure 9 – Amateur Listening Post Family Notification Card (National Archives of Canada 1939-1945 #188)

Amateur Radio 1946 – 1975

The post-war period was one of great expansion for amateur radio. Tens of thousands of military radio operators returned to civilian life, and their former hobby of amateur radio. Many new hobbyists joined the amateur radio ranks because of their military radio experience.

Following the Second World War, the availability of military surplus electronic components fostered growth in the experimentally oriented segment of the amateur community. Projects based on modified military radio equipment, and the use of surplus electronic components to design entirely new pieces of radio gear, were key in development and innovation within the hobby in the years 1945 – 1960 (Cohen 2001 #60).

Surplus military electronic test equipment and parts flooded onto the market. The Heath Company, of Benton Harbor, Michigan entered the radio equipment market with a series of "Heathkits", phenomenally successful kits based on surplus military electronic parts beginning in 1947[21] (Fisher 1992 #88; Penson 1995 #193; Douglas 1999 #76). Radio kits produced by Heath shaped an entire generation of technology workers, and Heath's emphasis on amateur radio products, and grassroots employment of hams reinforced the position of amateur radio in society (Penson 1995 #193).

Cheaper, and in many cases of superior performance to commercial radio gear, Heath's products influenced three decades of amateur radio operators. The kits personified the pragmatic, hands-on culture which had developed over the past four decades within amateur radio (Douglas 1999 #76). Heath continued to produce kits until 1992, when commercially manufactured gear finally eclipsed home-built equipment in both performance and price (Penson 1995 #193). The New York Times mourned the loss of the "Heathkit" as the end of an era:

---

[21] Figure 4, *"Kit building tradition reinforces applied basis of amateur radio culture"*

> "Before there were nerds, before there was a Silicon Valley, there were Heathkits, which let tens of thousands of ambitious amateurs and aspiring engineers build their own radios, televisions and other electronic equipment. … If the end of Heathkits is on one level simply a sound business decision, on another it is also the passing of an American institution that fostered learning-by-doing in its finest form." (Fisher 1992 #88)

Theoretically, kits and home-built electronic equipment underlined the pragmatic nature of the radio amateur. Hams experimented, even through trial and error. The amateur radio hobbyist was, by definition and through training, willing and able to tinker, to modify, and to invent. These characteristics set the hobbyists apart from a new class of engineers with little applied experience. Lack of practical experience is a problem in engineering recruiting today and presents a significant challenge to industry (Rosenauer 2000 #214).

On September 21, 1947 amateur radio operators Oswald Villard and Winfield Wagener inaugurated a new era in voice communications over radio[22]. A new form of radio communication, called "single sideband" or "SSB" was used to conduct an amateur radio contact between Villard and Wagener across the campus of Stanford University (Villard 1948 #252). SSB was revolutionary because not only was the transmitted signal less than one half the bandwidth of a standard AM voice signal of the time, it was also four times more efficient. The amateur journal QST introduced SSB to the amateur community and industry in its January 1948 issue, with three articles on the new technology (Goodman 1948 #96; Nichols 1948 #190; Villard 1948 #252).

---

22 Figure 4, "*Experimentation to improve spectral efficiency of voice transmissions leads to development of single sideband (SSB)*"

SSB eliminated the “carrier” signal and one of the two sub-channels, or sidebands that formed part of a regular AM signal. The power from these eliminated components was re-deployed into the single remaining sideband (Cleveland-Iliffe and Smith 1999 #58). SSB produced a one hundred watt signal in a narrow bandwidth that would have previously only contained twenty-five watts. With SSB, twice as many signals could occupy the radio spectrum.

The US Air Force led adoption of the new mode within the military services[23], and SSB diffused quickly (Douglas 1986 #75). Within ten years SSB had become the dominant mode for voice transmission for all radio services, amateur and commercial, around the world.

Amateur regulations still permit AM operation on certain bands, however (Industry Canada 2001 #123), and a small number of hobbyists continue to use the mode for nostalgic purposes, usually employing vintage radio equipment (The AM Window 2001 #234).

Another significant new technology, called slow scan television or “SSTV”, was developed by amateur radio enthusiast Copthorne MacDonald in August, 1958[24] (MacDonald 1958 #151). MacDonald based his design upon commercial facsimile transmission equipment employed by the telephone network. His new technology

---

[23] SSB was championed within the US military by amateur radio operator General Curtis LeMay (Douglas 1986 #75).

[24] Figure 4, *“Innovative combination of existing technologies leads to new mode of slow scan television”*

allowed pictures to be transmitted over the short wave amateur bands. Previously the bandwidth, or capacity, of the short wave bands had been thought too low to support the transmission of images in this fashion. Slow scan brought image communications within the reach of any amateur operator (MacDonald 1958 #151).

Amateur experimentation on the VHF, UHF, and microwave bands resulted in the discovery and development of advanced modes of propagation. Meteors were discovered to leave ionized trails which could be used to reflect radio signals[25] (Brussaard 1999 #50). Canada led the study of meteor scatter communications through a program at the National Research Council in Ottawa, and established a network of experimental stations ("JANET") between northern Ontario and the maritime provinces (Forsythe, Vogan et al. 1957 #92; Coll 1986 #61; Schilling 1993 #217). Amateur radio observations provided significant theoretical input to this study, and amateur journals were frequently cited as references in formal research papers by the scientists involved in the project, for example (Montgomery and Sugar 1957 #184), (Forsythe, Vogan et al. 1957 #92), and (Eshleman 1957 #81). Many of the scientists involved were amateur radio operators.

The growth of satellite telecommunications proved more reliable than meteor scatter and the mode was discarded by industry in favour of satellite-based communication links. The JANET project was completed and no further work was performed.

However, over the next three decades, amateurs continued this research, and perfected meteor scatter as a practical mode of communication, using high speed,

---

[25] Figure 4 *"Meteor-scatter communication proves commercially viable after research within the amateur radio community"*

machine-generated (later computer-generated) Morse code (McMasters 1998 #172). This odd approach (Morse code has no error detection features or synchronization system) has raised reliability of meteor scatter links to about eighty percent (Ennis 2000 #80). At least two companies now produce commercial turnkey meteor scatter communication systems (Brussaard 1999 #50; Warren and Desourdis 2001 #258). Commercial concerns originally discarded the mode as unusable and unreliable in the 1950s.

January 1946 saw the first "EME" (earth-moon-earth), or "moonbounce" radio communications, when three amateur radio operators succeeded in bouncing 111.5 MHz signals off of the surface of the moon[26]. This effort, sponsored by the US Signal Corps laboratory, used non-amateur radio spectrum and very high power levels (on the order of one million watts), but was nonetheless conceived, staffed and managed by amateur radio hobbyists (Kauffman 1946 #130; Laport, Tilton et al. 1981 #137). This work led to the establishment of twenty-four-hour-a-day radioteletype links via this mode by the US military services.

This success spurred interest in the possibility of communicating via the moon at the much lower amateur power limit of one thousand watts. Amateurs were first successful in hearing their own echoes from the moon in January 1953 (Laport, Tilton et al. 1981 #137; Maxwell 2000 #166). Two-way contact on amateur radio frequencies was achieved by the "Eimac Gang Radio Club" in California and the "Rhododendron Swamp Amateur Radio Club" in Florida on July, 17th, 1960 (Tilton 1960 #240). Eimac was a major manufacturer of high power vacuum tubes, and the

---

[26] Figure 4, *"Radio amateurs communicate by bouncing high-frequency signals off the surface of the moon"*

company's support of amateur radio on this and other leading-edge projects (Eimac 1975 - 1978 #78) fostered several breakthroughs in EME, space, and VHF/UHF communications in the 1960s. Through participation in this project, amateurs made important contributions to industry through development of practical and easily reproduced versions of highly complex and sensitive circuits, such as the parametric amplifier (Troetschel and Heuer 1961 #245).

In 1961, an amateur satellite dubbed "OSCAR 1" (Orbital Satellite Carrying Amateur Radio) was built for under one hundred dollars by a group of hobbyists in California[27]. It was assembled in one of the member's basements and photographed sitting on the front lawn before being launched as ballast on a USAF rocket at Vandenberg air force base. OSCAR 1 survived in orbit for three weeks, and provided simple telemetry on its condition to amateurs around the world (Davidoff 1984 #66).

The development of "repeater" stations beginning in the 1950s effectively increased the coverage of portable amateur VHF and UHF transceivers from tens to thousands of square miles[28]. This allowed practical mobile operation of amateur radio stations in support of community events, civil defense, and emergency response.

---

[27] Figure 4, "*The launch of the first amateur radio satellite emphasizes applied and practical nature of amateur radio"*

[28] Figure 4, *"Use of surplus VHF radio equipment leads development of "repeaters""*

Amateur Radio 1975 – 2000

The popularization of digital electronics and, most significantly, the introduction of the personal computer to the hobby in the mid-1970s initiated a profound change in the nature and use of amateur radio. The increased functionality and performance in radio equipment made possible by advances in electronics placed greater burden on those amateur hobbyists wishing to understand the technology. For the first time in amateur radio's history, the complexity of the equipment eclipsed the average hobbyist's ability to understand how it worked. Nor could malfunctioning equipment be repaired - the high complexity of the new solid state gear precluded repair by the amateur himself. Self-reliance had previously been the hallmark of amateur radio. Amateurs were proud of their ability to build, repair, and modify their own equipment - in many cases, this tinkering resulted in creative new circuits and modes of operation. The period leading up to the new century saw amateurs lose this capability to tinker with their equipment at all but the most basic level.

The introduction of the microprocessor into everyday amateur operation was a pivotal moment for amateur radio[29]. At this moment the hobby broke with the past and entered an arguably much more complex phase. Digital replaced analog, old skill sets became largely redundant, and the computer oddly constrained the future of the hobby while simultaneously enabling incredible new modes, techniques, and social applications of amateur radio. The new skills introduced to the hobby through the personal computer challenged the traditional amateur skill set. Software became the new region in which development and tinkering served to increase amateur communication capabilities.

[29] Figure 4, *"Introduction of the computer to the ham shack initiates paradigm shift"*

Deregulation of amateur licensing distanced federal authorities in Canada and other nations from the amateur radio service. Implicit understanding of the origin, characteristics, goals, and innovative importance of the amateur service within government was lost, to some extent, through restructuring and downsizing. In Canada, the dissolution of the Department of Communications in 1995 (Government of Canada 1995 #97), and the transfer of responsibility for radio issues to Industry Canada, which is largely oriented towards commercial interests, isolated amateur radio. This change presented new challenges to representative amateur associations such as the Radio Amateurs of Canada[30]. The association has risen to this challenge and is currently working to foster understanding for, and support of, the hobby within government and industry (Industry Canada 2001 #122). The Canadian Amateur Radio Advisory Board serves as an informal liaison body between hobbyists and Industry Canada:

> "The Advisory Board is a non profit consultative group consisting of members of the Radio Amateurs of Canada (RAC) and the Radio Regulatory Branch of Industry Canada (IC). Its function is to provide a consultative forum between Canadian radio amateurs and the regulator. Other than provided herein, CARAB is acknowledged as a consultative entity. It is understood that agreed upon action is not binding on either the RAC or IC" (Radio Amateurs of Canada 2000 #203).

Relaxation of amateur licensing in Canada and the United States brought many new hobbyists into the activity. Amateur radio examinations were no longer supervised

[30] The Radio Amateurs of Canada is an association that was formed in 1993 by a merger between two national groups, the Canadian Radio Relay League (a section of the ARRL), and the Canadian Amateur Radio Federation (CARF) (Radio Amateurs of Canada 2001 #206).

by the government, but outsourced to local amateur radio clubs through an accredited examiner program. The motivation of many of these new amateurs proved distinct from that of hobbyists in earlier eras: with no interest in radio technology or public service, they viewed amateur radio as a commodity, as a cheap method of personal communication.

Nonetheless, the period 1975 – 2000 has generated several significant new technologies. Computers are now integral components in the ham shack. Digital signal processing (DSP) is common in many new radio components. Public service amateur radio activities such as traffic handling and emergency management depend on computer databases, and amateur messaging is interconnected with that of the Internet.

The amateur satellite service pioneered the "Microsat" program in the late 1980s with the design and launch of a series of tiny satellites that were coined "flying personal computers" (Magliacane 1992 #154; American Radio Relay League 2001 #11). The original Microsats ran the popular DOS operating system and were based on hardened versions of comparable architecture to the Intel 80286 microprocessor. These satellites supported voice and data communications at data rates up to 9600 bits per second (BPS) (Bible 2001 #36). Originally designed for an operational lifetime of two years, three out of four of the original amateur radio satellites are still operating. Space experts had declared that fabrication of functional satellites "could not be accomplished using off-the-shelf commercial parts" (Porfiry 2000 #195).

The micro-satellite model was adopted by industry and several governments, and over a dozen commercial Microsats had been launched through 1999. In November

2000, One Stop Satellite Solutions, Inc. of Ogden, Utah announced the availability of the "personal satellite", a 4x4x4 inch cube-shaped device containing sophisticated computer and radio communications equipment, that can be purchased and launched for $45,000 (Porfiry 2000 #195). One Stop Satellite Solutions is a spin-off from Weber State University, which was responsible for the development of the original amateur radio Microsats (One Stop Satellite Solutions 2000 #192; One Stop Satellite Solutions 2000 #191).

Amateur creativity during this period spawned other new technologies such as the first practical implementation of packet radio[31] (Ball 1989 #31; Lockhart 2000 #147). Canadian amateur groups developed earlier academic research that had been conducted on data communications into practical systems. Packet radio networks were deployed in Vancouver, Montreal, and Ottawa. This new digital mode introduced reliable data communications (Wade 1992 #254), store-and-forward messaging, and laid the foundation upon which amateur experimentation with wireless TCP/IP could take place (Lynch 1987 #148). This research facilitated the connection of amateur wireless networks to the Internet (American Radio Relay League 2001 #15). Amateurs have recently integrated packet radio communication with the Internet and the global positioning system (GPS) satellites to produce APRS, a free worldwide vehicular tracking system (Bruninga 1994 #49). The development of packet radio marks a significant change in the hobby, which I will examine below.

---

[31] Figure 4, *"Amateurs lead in the development of practical wireless data communications"*

Digital techniques were applied as well to modes such as microwave experimentation, amateur television, and high speed meteor scatter, advancing upon the work done in previous decades.

Finally, there are three developments during this period that will be examined in detail in chapter V:

- In 1994, amateurs at Carleton University in Ottawa, and Simon Fraser University in Burnaby, BC experimented with the use of Internet protocols and standards over amateur packet radio[32]. Coupled with a new design for high speed data radios, a regional network was established and further research was conducted into the application of amateur radio to emergency communications and disaster mitigation. The United Nations expressed interest in use of this technology in developing regions (Anderson 2001 #26).

- A new mode called PSK31 was developed by a British amateur in 1997 (Ford 1999 #89). It used digital signal processing to dramatically increase the sensitivity and selectivity of shortwave communications (Martinez 1998 #159)[33]. Popularized by amateur publications and the Internet, the new mode diffused worldwide within twenty-four months and can now be heard on popular amateur bands twenty-four hours a day. Commercial services are considering adoption of this technology to replace their now obsolete radioteletype (RTTY) equipment.

---

[32] Figure 4, *"Leverage of existing data communications standards and protocols enables high-speed packet radio"*

[33] Figure 4, *"Creative use of cheap personal computer hardware results in ten-fold increase in spectral efficiency of shortwave amateur communications"*

- Amateur fast scan television (technologically similar to commercial television) had existed since the 1940s (Tilton 1950 #238). The BC Amateur Television Group, in Burnaby, BC developed a system of television repeaters that combined several different analog and digital technologies into a regional television network that has extremely sophisticated functionality[34]. AM and FM television equipment was coupled with streaming video technologies, and linked to the Internet. System control was provided by custom software and a unique command bus approach allowed control via standard VHF/UHF amateur radio, the Internet, or 56K packet radio. Amateur television signals were relayed on several microwave amateur bands as well as UHF, and could be interconnected with either the Internet or consumer satellite equipment. Applications of the system stressed emergency preparedness and community service. Commercial television technicians in the Vancouver area expressed interest in this system and its capabilities (Schouten 2000 #218).

[34] Figure 4, *"Amateur television networks combine off-the-shelf technologies to produce interoperable systems that outperform commercial counterparts"*

Chapter IV

Innovation

The terms "invention" and "innovation" within telecommunications are related but distinct: ***invention*** is the discovery or development of a new technology or technique; while ***innovation*** is the application of existing technology or operating technique in new, previously unheard of way, to achieve a unique communicative advantage over other methods. Innovation is also often characterized as commercialization; bringing a new product or technology to market (Statistics Canada 2000 #225). These definitions are similar to those employed by well-known academic sources such as Rogers and Von Hippel, and will be used throughout this paper (Rogers 1962 #211; von Hippel 1988 #253).

Amateur radio is both an inventive and an innovative activity. Amateurs either invent new technologies, or apply their creativity to pre-existing technologies and innovate with them. Often, through partnership with industry or entrepreneurial effort, amateurs market their research findings. This does not imply commercialization of amateur discoveries: many new technologies (slow scan TV, packet radio, PSK31) are marketed without any financial motive on the part of the inventor[35]. In this characteristic amateur radio is quite similar to the "free software" movement.

[35] Some innovators do however seek to commercialize their new technologies. "One Stop Satellite Solutions" is a commercial adaptation of the Microsat program of the 1980s (One Stop Satellite Solutions 2000 #191); CLOVER is a commercialized packet radio technology (Ford 2001 #91); and Starcom Technologies builds on amateur research into meteor scatter communications (Brussaard 1999 #50).

In the previous chapter, I described several innovations that have been associated with amateur radio. In this chapter I will examine amateur radio as a tool for communications research and innovation, and contrast the differences in both method and approach that exist within the hobby to those used within the wireless industry.

Amateur radio operates in a unique environment. As a centre for research and development (R&D), it is neither affiliated with, nor obligated to, any corporate sponsorship. While amateur radio R&D often takes place in partnership with government (the JANET project), the military (EME research), or commercial interests (personal satellites), this is the exception rather than the rule. The pragmatic approach of the hobbyist has broken many governmental and corporate R&D logjams[36]. Amateur radio's independence is one of the activity's strengths: hobbyists can choose which areas of communication to explore, and, beyond legal restrictions such as non-interference to other services, are obligated to no one. The hobbyists involved in R&D within amateur radio have diverse backgrounds. They come from a wider cross section of society than those scientists and engineers employed in the corporate R&D world.

Amateur radio has an impressive legacy of creativity. What surprised me in my research is that despite the exponential growth in technological complexity, deregulation, and the commercial pressures which have had the cumulative effect of

---

[36] Examples: Amateurs discovered global propagation via the ionosphere and paved the way for commercial wireless services; Amateur transmitting and receiving circuits were adopted with only minor changes by military services at the beginning of World War II; Amateurs proved that functional satellites could be built for thousands rather than millions of dollars.

de-skilling amateur radio hobbyists, that creativity within the avocation is still very much in evidence. I will give three examples of current innovative development within amateur radio below.

Theoretical Considerations

Invention, innovation, and the diffusion of innovation have been widely studied in the commercial environment. Little research exists, however, in relation to non-commercial innovative activities such as amateur radio. Some similarity appears to exist in the diffusion of new forms of music and that of amateur radio, in that both appeal to a similar demographic (young adults) and spread quickly, but such a comparison should rather be examined as part of further research. Stronger similarities exist in the comparison of amateur radio to the "free software" phenomenon and the growth of the Internet (Ross 1991 #215). An interesting comparison of early public policy on radio and the regulation of the Internet by John Stevenson of Concordia University illustrates many similarities between amateur radio and computer hobbyists (Stevenson 1996 #227), but a detailed examination of this subject is beyond the scope of this paper.

In my research I reviewed much of the available literature on innovation. While several excellent texts have been written on the topics of invention, innovation, and the diffusion of innovation, virtually all of the reported research is grounded in the corporate environment. Commercial innovation and research and development processes are treated to the exclusion of other modes of innovation such as those which I have observed within the hobby of amateur radio.

Formal research centred on amateur radio is not common. As outlined above, in his dissertation at the University of Minnesota in 1934, Raymond V. Bowers documented the diffusion of early radio communication technologies amongst a sample of amateur radio operators in the United States (Bowers 1934 #44; Bowers 1938 #45). Scott Kostenbauder studied amateur radio as it related to the choice of a technical career (Kostenbauder 1976 #131). A dissertation by Donald H. Smith examined the role of amateur radio in education and institutions of higher learning (Smith 1975 #223). Susan Douglas of the University of Michigan identified amateur radio as an innovative activity in (Douglas 1999 #76) and (Douglas 1986 #75). Laport, Tilton, and Rowe characterized amateur radio operators as having contributed to the art and science of radio (Laport, Tilton et al. 1981 #137), and engineering professor Yuzo Takahashi of Tokyo University examined the primary innovative role of the amateur “radio tinkerer” in the development of the electronics manufacturing industry in post-war Japan in (Takahashi 2000 #230).

The primary role of amateur hobbyists in the development of long-distance radio communication is acknowledged by Paul Ceruzzi (Ceruzzi 1998 #54). Interestingly, hobbyists also played a pivotal role in the development of the personal computer, and many early microcomputer enthusiasts were also amateur radio operators (see, for example, (US Patent and Trademark Office 2001 #251)). However, the strongest source of information on amateur radio innovations is the hobbyist literature itself, for example (Maxwell 2000 #166).

Patterns of innovation within amateur radio, and the diffusion of new techniques within the hobby, parallel the findings of the general literature, such as the extensive research of Everett M. Rogers (Rogers 1962 #211). A small percentage of amateurs are responsible for most of the innovative activities within the hobby[37]. Based on extrapolation of the data gathered by Bowers (Bowers 1934 #44), interviews with prominent amateur innovators (Lockhart 2000 #147; Martinez 2000 #161), other hobbyists (Rosenauer 2000 #214; Craig 2001 #63), and my experience over the past twenty-four years in the hobby, I have estimated this figure at five to ten percent. This agrees with Rogers and his colleagues in their study of innovation within the farming and pharmaceutical industries (Rogers 1962 #211).

Amateur radio is also consistent, in my research and experience, with Rogers' findings in regard to classification of the population as innovators, early adopters, late adopters, and laggards. Very few hams are innovators, and most fall within the early to late adopter categories. Stalwarts exist to this day that refuse to acknowledge the new digital amateur radio technologies, cling to the past, and view recent regulatory changes and the changing demographic within amateur ranks as indicative of the demise of the hobby (Engel 2001 #79).

The validity of this adoptive model is evident at this writing with the spread of the new digital mode PSK31 throughout the worldwide amateur population (Ford 1999 #89; Ford 2000 #90). PSK31 will be examined in detail below.

According to Rogers' theory, opinion leaders and innovators are key both to the acceptance of new communications technologies, and the rate of technological diffusion. Strong grass-roots organizations such as the Radio Amateurs of Canada, and its American counterpart, the American Radio Relay League, play leading roles

[37] Quantification of this figure could be the subject of further research.

in the popularization of new communication modes and techniques[38]. The cross-sectional nature of amateur radio hobbyists, and the fact that the amateur population is drawn from a wide range of society, serves to accelerate the diffusion of new communication technologies, or in the least, awareness of these new technologies, to the general public.

Ironically, amateur radio has developed into a unique collaborative activity both in spite of regulation, and because of it. The banishment of amateur operations to wavelengths below 200 metres in 1912 was responsible for the discovery of a valid theory of propagation, and global communications itself. Cooperative usage of internationally regulated frequency bands by amateurs throughout the world forged a trans-national, arguably global identity for all participants. Until recently, with the popularization of the Internet, amateur radio operators were the only segment of ordinary society permitted to conduct direct, international, uncensored and unmediated communications, free of charge, with other hobbyists around the world. Researchers studying the development of the Internet and theorizing its future could learn much from the history of amateur radio[39].

---

[38] See http://www.rac.ca and http://www.arrl.org.

[39] Much of the current communications research on the Internet focuses on the concept of the medium as a revolutionary new "space". The physically disconnected yet communicatively linked, anonymous, unmediated, two-way characteristics of the Internet have much in common with amateur radio. I will return briefly to this subject in the conclusion of this paper. See (Stevenson 1996 #227).

Research and Development

Research and development, or R&D, is both a formal and an informal activity. In the corporate arena, R&D is an important means of achieving competitive advantage over rival firms. Companies are continually in search of new products, new technologies, and improvements to existing processes and techniques. The incredible advance in microelectronics over the past half-century is one of the clearest examples of the benefits of corporate R&D.

R&D also takes place in non-corporate arenas such as amateur radio. Here the motive is rarely profit, but rather a desire to learn, or to meet a specific communicative goal. R&D may be forced upon the amateur. The discovery of ionospheric propagation, as discussed above, is an example of how amateurs forged ahead when placed in a disadvantaged situation, and made important scientific discoveries (Laport, Tilton et al. 1981 #137; Welsh 1995 #259).

Invention and innovation are closely entwined with the research and development process. R&D traditionally leads to new commercial products or technologies. In some cases amateurs have taken their discoveries to market, but in most cases the output of the amateur R&D process is simply shared with other hobbyists. Corporate innovation differs markedly from that within amateur radio.

Research and Development and Commercial Telecommunications

R&D is a condition of licensing for telecommunications companies in Canada. One of the policy objectives enumerated in section 7 of the *Telecommunications Act* is:

> "to stimulate research and development in Canada in the field of telecommunications and to encourage innovation in the provision of telecommunications services" (Industry Canada 1999 #116).

Commercial carriers are required by the Minister to invest 2 to 2.5 percent of their annual adjusted gross revenues in R&D activities. Eligible activities are defined in subsection 248(1) of the Income Tax act:

> "scientific research and experimental development means systematic investigation or search that is carried out in a field of science or technology by means of experiment or analysis and that is
>
> a) basic research, namely, work undertaken for the advancement of scientific knowledge without a specific practical application in view,
>
> b) applied research, namely, work undertaken for the advancement of scientific knowledge with a specific practical application in view, or
>
> c) experimental development, namely, work undertaken for the purpose of achieving technological advancement for the purpose of creating new, or improving existing, materials, devices, products or processes, including incremental improvements thereto,
>
> and, in applying this definition in respect of a taxpayer, includes
>
> d) work undertaken by or on behalf of the taxpayer with respect to engineering, design, operations research, mathematical analysis, computer programming, data collection, testing or psychological research where the work is commensurate with the needs, and directly in support, of the work described in paragraph (a), (b) or (c) that is undertaken in Canada by or on behalf of the taxpayer,
>
> but does not include work with respect to
>
> e) market research or sales promotion,
>
> f) quality control or routine testing of materials, devices, products or processes,

g) research in the social sciences or the humanities,

h) prospecting, exploring or drilling for, or producing, minerals, petroleum or natural gas,

i) the commercial production of a new or improved material, device or product or the commercial use of a new or improved process,

j) style changes, or

k) routine data collection;" (Industry Canada 1999 #116, Appendix A).

Carriers must file a report with Industry Canada on their R&D activities annually. The total reported expenditure for 1999 was $14.9 billion, with sixty-three percent of this figure coming from industry-sponsored R&D (Statistics Canada 2000 #226).

The issue with this type of investment, however, is the purely economic basis on which such investment in R&D is made. The highly competitive environment which has developed over the past two decades in the wireless industry favours short business cycles and constant new products. The emphasis of industrial R&D is strongly biased against "research" in favour of "development", specifically, that development which can be leveraged in the short term in the creation of a new product. Industry today prefers short term gain over long term strategic investment. A negative consequence of this approach is that important discoveries that would be generated by more general research, such as that arising from non-traditional sources such as amateur radio, will be lost.

In their book *Competitive Advantage Through Diversity*, authors Herriot and Pemberton make ten propositions geared to improve the innovative process. They advocate a broad-based, diverse, knowledge-based approach to innovation that stresses people over organizational structure and markets (Herriot and Pemberton 1995 #106). In their view, a new emphasis on knowledge, learning, and information and power sharing is key. Amateur radio and the amateur R&D environment personify many of Herriot and Pemberton's concepts. Amateur radio is a positive role model for industry. The mode of innovation that exists within amateur radio has much to contribute to industry.

Economic influence is cutting amateur radio out of the picture. Industry Canada's re-definition of "innovation" in this climate has taken on a peculiar economic tone. A recent issue of Industry Canada's Innovation Analysis Bulletin states:

> "Fuelled *(sic)* by rapid technological change and the emerging global marketplace, the need for a stream of new and improved products – in other words innovation – is growing" (Statistics Canada 2000 #225).

Such a definition, and its focus on commercial products, marginalizes non-commercial R&D. Amateur radio is an able contributor to radio research, with a strong tradition of discovery and innovative activities. In the literature, recognized authors such as W. Rupert MacLaurin of the Massachusetts Institute of Technology relegate amateur contributions to radio technology to little more than a footnote, as a short prelude to "real" R&D carried out by companies such as AT&T, General Electric, Westinghouse and RCA (MacLaurin 1971 #152).

If the value of amateur R&D goes unrecognized, then radio hobbyists may very well lose access to the electromagnetic spectrum, and with that, their ability to experiment, invent, and innovate. Amateur radio will not be able to feed discoveries gleaned from its unique collaborative environment back to industry for further development and commercialization, as it has done with many discoveries and creative new technologies over the past century.

Whether Canada's R&D policies in the area of high technology are successful is a matter of debate. Certainly Canada understood the importance of the new wireless technology in 1902. Following his successful transatlantic tests, Guglielmo Marconi was in search of a site for his first North American wireless station. In a period of only a few days, Marconi was intercepted in Nova Scotia while en route to the United States, and courted by both the federal and the Nova Scotian governments. Whisked to Ottawa, Marconi was offered $75,000 in startup funding by the federal government, given land, and provided with other assistance that allowed him to establish the first North American wireless station, at Table Head, Nova Scotia (Rowland 1999 #216).

Current Canadian R&D policies are much less demonstrative. Although no definitive answers are possible, statistical data gathered in 1995 shows Canada at least fifteenth, and at worst thirty-sixth of all nations in "competitiveness" (Lazar 1996 #140). Lazar argues that current federal policy dealing with R&D and innovation needs to be revisited. Amateur radio has a role to play in national R&D policy. In the conclusion to this thesis I will suggest that greater support of amateur radio groups and amateur R&D by industry has significant innovative and economic potential, and may help improve Canada's competitiveness.

Industrial R&D dollars could wisely be invested in support of promising non-institutional research groups such as those found in amateur radio. From an examination of amateur radio's history, innovative new technologies would surely be the result.

Ironically, many engineering departments within industry today view amateur radio as a convenient method of accessing spectrum in which to develop new commercial equipment. Engineers on staff who possess amateur radio licences can conduct testing of new equipment or techniques on amateur frequencies, bypassing sometimes tedious permissions from government bodies. When the technology is perfected, it is moved to commercial regions of the spectrum. In fact, as amateur allocations at UHF and above are commonly of a secondary nature, all that may be required is commercial licensing of the new equipment. Industrial R&D is not held up by licensing, but the use of amateur spectrum under dubious motivation is contrary to the standards of the amateur service (Rosenauer 2000 #214).

Comparative Innovation

Raymond Bowers' study of the diffusion of amateur radio technology throughout the United States (Bowers 1934 #44; Bowers 1938 #45) concluded that it spread in a similar manner, but at a slightly higher rate, than other new technologies. Bowers theorized that it was the technical inclination of the target community that was responsible for this higher rate of diffusion, along with the concentration of amateur hobbyists in metropolitan areas (Bowers 1934 #44). Potential amateur radio operators, at least in 1938 when Bowers published his study, prepossessed technical curiousity that assisted in rapid adoption and transference of radio technology to other potential amateurs, especially those in the same metropolitan area (Bowers 1938 #45). Interestingly, Bowers did not consider the communicative nature of the hobby itself, the real-time interaction which takes place between amateurs on the air while separated by many hundreds or thousands of miles, as a factor that might have affected the diffusion of the activity.

In this section, I would like to compare and contrast the innovative process as it is constituted within industry and amateur radio. Innovations diffuse similarly regardless of their source (Rogers 1962 #211; von Hippel 1988 #253). New technologies and operating techniques spread throughout their respective user communities in similar ways. In this sense one could fairly compare the diffusion of the video cassette recorder throughout the globe, for example, with the diffusion of packet radio throughout the amateur radio community[40].

Where amateur radio and industry differ markedly, however, is in the process of innovation itself; the environment, the goals, and the motivating factors that drive creative activity. As noted above, innovation within the industrial sphere in Canada is defined as the first commercial application of an idea, and “the need for a stream of new and improved products” (Statistics Canada 2000 #225). This emphasis on the economic objective is highly structured and significantly different from innovation as exemplified by amateur radio.

Table 6 lists several characteristics of the innovative process and indicates the approach to these characteristics taken in industry, and in amateur radio. Industry and amateur radio clearly have differing points of view on motivation, method, goals, and organization of the innovative process. Indeed, as can be seen in Table 6, these views are often orthogonal, yet both approaches have proven successful. Amateur radio’s fuzzy approach to research, in the industrial frame of reference, has nonetheless discovered and developed many valuable new communication

[40] Such a comparison has not been made, but could be an interesting subject for future research.

technologies. Amateur radio is good at solving problems often unsuited to the profit-driven corporate R&D environment.

Industrial innovation is economically driven and focused towards a specific goal. Very often this goal is embodied in the form of a product or service which can be successfully marketed to produce profit for the organization. Workers with skills specific to the industry, service, or product are contractually obligated to work towards this goal in exchange for a paycheque. The organization itself is centred on the objective of efficient production towards the goal, and the generation of profit. Management and supervisory structures reflect the corporate objective. Advancement for workers within this structure is based on furtherance of the goal. The organization rewards and emphasizes individuality and competition, rather than teamwork, although references to “the team” are frequently employed by management when the term is felt to assist achievement of the goal. Internal standards for personal success reflect the external, competitive, market-driven environment.

Characteristic	Industry	Amateur Radio
Motivation	Profit driven	Non-profit
Individual goals	Cash bonus, raise, promotion	Pride, community service
Scheduling	Strict time lines	Flexible time line, volunteer effort
Staffing	Specialized workers	Anyone interested in the project
Structure	Tightly structured	Flexible
Project goals	Towards a specific product or service	General, "it would be neat to be able to…"
Intellectual property	Patents sought	Free exchange of ideas towards common goal
Organization	"Team" oriented, transparent sociability	Social activity, no false loyalties
Documentation	All phases highly documented	No formal record keeping, largely verbal record
Developmental climate	Structured, managed creativity, secrecy	Unstructured exploration, openness
Strength	Efficient at solving a specific problem or reaching a well defined goal. Not good at ad hoc exploration	Good at solving vaguely defined problems and dealing with unexpected challenges en route. Ad hoc by nature
Weakness	Specialization	Generality

Table 6 – Comparison of Factors Relevant to Innovation: Industry versus Amateur Radio

Competition within the industrial framework exists both at the personal and corporate level. Secrecy is key. Competing organizations have internal security policies, clearance levels for employees that mimic those used within government, and "top secret" programs and laboratories[41]. The purpose of all of these standards and policies is to gain, or in the least preserve, competitive advantage over rival organizations. Joseph Schumpeter wrote:

> "In capitalist reality, the competition which counts is the competition from the new commodity, the new technology, the new source of supply, the new type of organization…" (Schumpeter 1942 #220)

Secrecy at the personal level, between employees, is likewise used by one individual over others in order to attain advancement within the organization. Schumpeter continues:

> "The first thing a modern [large-scale] concern does as soon as it feels it can afford it, is to establish a research department, every member of which knows that his bread and butter depend on his success in devising improvements." (Schumpeter 1942 #220)

It is in this environment that industrial innovation seeks to extend the state of the art.

Innovation within amateur radio is different. Amateur innovation is characterized by unstructured exploration from a variety of directions. Individuals choose to participate in solving a problem or answering a question out of curiousity or out of a desire to collaborate and serve the amateur community or the public. Knowledge or service itself *is* the goal of the exercise, rather than the device *through which* the

[41] Self-serving corporate goals of profit are inconsequential when compared to the serious nature of real national and international security issues.

goal, profit, is attained. The free exchange of ideas builds trust and fosters team building without the self-centred motivation of industry.

Amateurs are often generalists rather than specialists in the field of radio communication. Although some hobbyists specialize in particular segments of the activity (e.g. low power operation, public service, microwave experimentation) and make major contributions in these areas, most amateurs regularly undertake operation on many frequencies and modes. Even specialists regularly participate in alternate methods of communication and applications of amateur radio, the most prominent being public service activity. Forty-nine percent of amateurs reported participation in a public service activity at least once a month in a recent survey conducted by the American Radio Relay League (American Radio Relay League 2000 #6). This contrasts with the industrial model in which employees are recruited with a specific, and often very narrow, set of skills. The diversity of the amateur radio community, and consequently the wide variety of tool sets that are brought to bear on a problem or question, is one of the activity's strengths. The very naiveté that a non-specialist amateur brings to a question can be the key to a new approach that effectively answers it.

Industrial innovation exhibits different strengths and weaknesses than innovation within amateur radio. As described in Table 6, industry's weakness is invariably amateur radio's strength. Through support of and partnership with amateur radio research groups, industry could cut costs, solve seemingly intractable problems, foster new technologies, benefit society, and generate profit.

Industrial innovation is very effective at answering specific questions or solving well defined problems. Profit is a strong motivator. It encourages industry to bring incredible resources to bear on a problem. Even when faced with projections of huge profits, however, specialized workers and corporate structures can lack creativity. David Sarnoff's proposal regarding a "radio music box" and the immense potential of radio broadcasting for both profit and public service, directed to the vice president and general manager of the Marconi Company in the autumn of 1916 was left unanswered (Lewis 1993 #141). In the mid-1970s, IBM did not regard the microcomputer as a product with significant potential, and was late to become involved in "amateur" computing[42] (Ceruzzi 1998 #54). Meteor scatter communication systems were discarded by industry as unreliable (Coll 1986 #61), and most important discoveries into the nature of radio signal propagation above 50 MHz were made primarily by amateur radio operators (Tilton 1960 #241; Tilton 1963 #242).

Amateur radio lacks the specialized human resources and capital of industry, but due to its informal organizational structure, non-commercial nature, and generalist population, the activity excels in the solution of vaguely defined problems. The lack of a clear objective and a well-defined goal limits corporate interest in the problem. The highly structured "innovation machine" within industry is not designed to solve problems of this type.

Industrial and amateur processes of innovation are in fact complimentary: each approach is fashioned (optimized) to address different circumstances. Both are good at solving certain problems, and bad at solving others. Each has a different

[42] Steve Wozniak, co-founder of Apple Computer and of personal computer fame, was an amateur radio operator (US Patent and Trademark Office 2001 #251).

set of goals. Industrial R&D cannot solve every problem, nor can amateur R&D. This is precisely why amateur radio is important, and why it must be nurtured both by enterprise and by government. Amateur radio's unique approach to problem solving complements that of industry - to restrict the hobby's access to spectrum would nullify an important method of problem solving.

The development of amateur packet radio exemplifies the strengths of non-professional R&D. Driven by three Canadian amateur research groups, packet radio initiated a revolution in the hobby that I examine in detail in the next section.

Packet Radio: A Key Technology

In my research, and in my personal experience as an amateur, the invention of amateur packet radio can be described as a key moment of re-definition, as a pivotal event in the development of the hobby. The introduction of the computer into the ham shack through the emergence of packet radio forever changed the nature of amateur radio. Packet radio created a clear division between the hobby's past and future that is termed these days a paradigm shift. This section examines the characteristics of this most important development in some depth.

Computer-mediated wireless data communications was introduced into amateur radio through Canada's creation of the Amateur Digital Radio Operator's Certificate in 1978 (Department of Communications 1985 #69). Colloquially known as "packet radio", this new mode was developed by Canadian amateur radio operators with experience in commercial data communications (Borden and Rinaldo 1981 #43; Ball 1989 #31; Lockhart 2000 #147). The mode was not legalized by other nations until the early 1980s. It proved so reliable that it was quickly adopted within the amateur community and, typically for radical innovation, within Canadian military services[43], and in the academic and commercial environment (Borden and Rinaldo 1981 #43).

Packet radio was based on a new specialized microcomputer called a terminal node controller. The "TNC" (Figure 10, top) was a small device that connected an

[43] I recall reading an article in an amateur journal in 1987 or 1988 about the use of amateur radio TNCs within the naval service of the Canadian Forces. Amateur packet radio technology was used on military radio frequencies for intra-vessel messaging. Despite extensive research I was unable to locate the article in question.

amateur radio transceiver to a teletypewriter or “dumb terminal”. A microprocessor inside the TNC (Figure 10 bottom, highlighted) translated characters typed on the keyboard into audible tones that were then fed to the radio transmitter. Conversely, audible tones received from amateur stations over the air were processed by the TNC into text, and displayed on the terminal (Price 1985 #196).

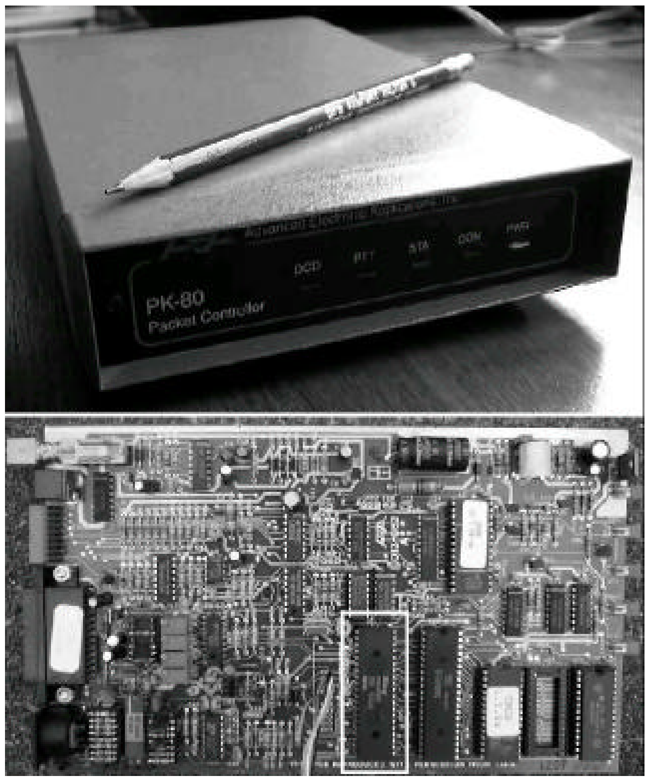


Figure 10 – A Terminal Node Controller (TNC)[44]

What was so innovative about this? Text-based communication had been possible for decades via radioteletype (RTTY).

[44] Photo taken by the author, 2001.07.22 in Burnaby, BC.

The most important difference between RTTY and packet radio was that text processed by the TNC was guaranteed, by a small computer program running on the microprocessor that implemented a language or protocol called “AX.25”, to be transferred without error between the two communicating stations (Price 1985 #196; Price 1985 #197). The microprocessor handled the translation of text to and from audible format, and worked with the TNC on the other end of the radio link to ensure that each message, or packet, was transmitted correctly and received without error (Price 1985 #196).

Of much greater significance was the very *existence* of this microprocessor within the TNC. Through this seemingly innocuous introduction of a small computer into the ham shack, amateurs were unknowingly taking their first steps down a road that would prove to completely revolutionize the hobby over the next twenty-five years. Packet radio exhibited the following characteristics:

Change of focus from content-centric to data-centric

The introduction of the microprocessor into amateur radio shifted the focus from a messaging and content oriented framework to one of data transmission. Terminal node controllers and packet radio “exchange data” rather than “handle traffic” or “pass messages”. Automatic transmission and reception of packetized data, with transparent error detection and correction by the TNC, relieved the human operator of an important (and traditional) role in management of the communicative process. This change of viewpoint marginalized the human operator. This characteristic was subtle and not recognized by early adopters of the new technology. Packet radio de-emphasized content over method, alienating or at least distancing the human element on which much of amateur radio had previously been based. This is a significant point, and one to which I will return below in discussion of another new digital technology, PSK31.

The introduction of the microprocessor brought unprecedented accuracy to amateur radio communication

Messages transmitted via packet radio are guaranteed to be received without error. The TNC detects and corrects errors automatically. The receiving station will not accept data that has been corrupted in transit. Implications are twofold: data is received exactly as sent; and this guaranteed accuracy adds overhead to the communicative process. With earlier modes such as Morse code, voice, radioteletype, and even television, the operator provided an important interpretive and interpolative function, and was able to fill in missing content and correct transmission errors by drawing on experience, context, and related factors. The microprocessor removes the human from this loop, devaluing and in effect de-skilling this important, participative aspect of communication.

Packet radio trades off interactivity for accuracy

The unprecedented accuracy of packet radio communication comes at a cost. Packet radio provides guaranteed one hundred percent accuracy in data transfer. A consequence of this accuracy, however, is reduction in the throughput, or bandwidth, of the communication. Typical early packet radio systems operated at 1200 BPS (Price 1985 #196). The ability of the TNC to detect and correct data errors in received packets adds overhead to each transmission. Extra bytes must be appended to each transmitted packet for this purpose. Additional bytes indicate the sender and destination for the packet. Calculations place this overhead at 18 percent for 80-character packets and even higher for shorter length packets (McQuiggin 1989 #173).

The AX.25 communications protocol provides for up to eight intermediate relays of a data packet between the sender and receiver (Tucson Amateur Packet Radio Group 1984 #246). Known as “digipeaters”, these intermediate nodes help route packets to their destination. Digipeaters to be used must be specified by the sender of the packet. This is similar to the concept of source-routed packets in the TCP/IP environment (Wright and Stevens 1995 #264). The definition of the AX.25 protocol dictates that packets traveling via digipeaters must be acknowledged between each intermediate node, rather than a single acknowledgment from the ultimate destination back to the sender. This characteristic adds incredible overhead to the process of communication and can quickly reduce the bandwidth of the sender-receiver connection to less than 10 percent of its nominal value (Clark 1986 #57). Channel congestion was recognized in the literature as a major problem when packet radio increased in popularity in the late 1980s (Horzepa 1989 #108).

Slow speed packet radio, as introduced at the data rate of 1200 BPS, was not well suited to real-time human-to-human communication: it was designed for computers to talk to other computers. Amateur journals decried the loss of real-time, interactive communications (Horzepa 1994 #109). “Keyboarding” died out.

Packet radio relied on a new set of tools and a skill set foreign to amateur radio experience

Packet radio invalidated established amateur practice and introduced complexity to the hobby from a previously unrelated field: computing science. It introduced a new set of skills that had to be mastered, or at least well understood, by amateurs in order to become active on the new mode[45]. Introductory articles in the popular amateur journal *QST* presented the new mode and emphasized the need to learn about computers and computing terminology (Price 1985 #196; Price 1985 #197).

As a *digital* mode, packet radio also represents a significant departure from past amateur operating practice. Earlier modes, such as Morse code or CW, and radioteletype (RTTY), while arguably "digital", were, in practice, *analog* modes of communication. The ham operator, specifically the human ear, represents a key component in the communicative process. Transmissions are decoded by ear, in the case of CW, and RTTY signals are regularly "tuned in" by ear so that the Teletype machine could produce readable copy. Radioteletype signals sound *pleasant*[46], and with experience, are easy to properly tune in. The volume on the amateur's receiver is routinely left up to monitor the quality of the communication channel. In fact, many RTTY operators (myself included) are able to recognize common abbreviations, and even station call signs, by ear – no Teletype machine required!

---

[45] Examples: serial ports, handshaking, error correction, state tables, routing, "store-and-forward" versus "real-time" communication, operating systems, even new types of connectors.

[46] Radioteletype signals are reminiscent of the sound of warbling birds.

Packet radio is a passive method of communication

Packet radio was the first mode to remove the human from an active role in managing the process of radio communication. The TNC required a connection to a radio transceiver, and then managed transmission and reception itself. No human monitoring of the radio channel was required. Packet radio signals sounded *harsh*[47]*.* Significantly, it was the first time that volume controls on amateur transceivers were purposely turned *down*. As a novice packet radio operator in the mid-1980s, I missed the participative role in managing the communication, and recall thinking that the new mode, while certainly accurate and interesting, was somehow "colder" than radioteletype, CW, and other amateur modes.

The issues of packet radio network topology and standardization of on-air protocols were particularly contentious, and caused a significant amount of disharmony within amateur ranks (Lockhart 2000 #147). These disagreements are, notably, absent from the mainstream amateur radio literature, which seeks to present a unified and positive view of the hobby (Rinaldo 1984 #210).

Canada led other nations in permitting amateur experimentation with wireless computer networking from the mid-1970s (Hesler 1978 #107), largely through the efforts of the Director General of the federal Department of Communications, Dr. John DeMercado, himself an amateur radio operator (Krigbaum 1999 #132; Lang

---

[47] Packet radio signals sound very unpleasant due to their higher data rate and the protocol used. The sound is reminiscent of a high speed circular saw. The human ear can provide no guidance for proper reception of these signals, hence most amateurs turned the volume of their transceivers right down.

2000 #136). The first amateur packet radio transmissions took place on May 31, 1978 in Montreal (Lang 2000 #136). Amateur packet radio research groups were active in Vancouver, Montreal, and Ottawa. Canadian amateurs with professional computer networking experience, led by Douglas Lockhart of Vancouver, British Columbia, invented three flexible packet radio protocols called V1, V2, and V3. Lockhart was recognized as Canada's "Amateur of the Year" for this work in 1984 (MacLean 1985 #153; Ball 1989 #31).

The V1 – V3 protocols, however, were met with skepticism by American amateurs, who preferred a domestic standard called AX.25 (Lockhart 2000 #147). AX.25 traded off communications efficiency for ease of deployment (no network control hub was required as with the Canadian protocols), and despite compelling technical arguments against it[48], the protocol was sanctioned by the American Radio Relay League in 1984 (Rinaldo 1984 #210).

The decision to adopt AX.25 was achieved through political economic means. American amateur associations, led by the ARRL, marginalized the Canadian amateur groups and ignored analyses pointing out the protocol's problems and long-term unsuitability (Lockhart 2000 #147). Lockhart and the Canadian amateur groups had designed a packet radio system that would accommodate growth in number of users, services provided, and bandwidth over time. The V1 – V3 protocols embodied many of the concepts and services later developed by the ARPANET/Internet, such as dynamic routing (Lockhart 2000 #147). Had these protocols been allowed to dominate rather than AX.25, amateur packet radio could

[48] See (Clark 1986 #57) for a thorough analysis of the problems experienced with AX.25 in practice.

have precipitated the development of global networking and the Internet years before it actually took place. As for AX.25, after being popularized by the ARRL and associated groups, the protocol became the only packet radio standard recognized in the United States in October, 1984 (Rinaldo 1984 #210).

The TNC was the first component of the amateur radio station that was conceived in solid state form

Packet radio marked the start of a new phase in amateur radio. The terminal node controller had no earlier, vacuum tube-based analogue, nor was it an import of earlier equipment or operating practices. The TNC marked the introduction of the computer as a key component in an amateur radio station.

Summary

Invention and innovation are important components of the research and development process. Corporate R&D tends to focus on products, while non-industrial R&D, such as that exemplified by amateur radio, focuses more on communicative needs or personal interest.

The two approaches have contrasting and sometimes contradictory methodologies. With its focus on products and profit, corporate R&D does not have the broad-based resources, nor the point of view, of amateur radio. Amateurs have proven adept at solving vaguely defined problems, and at finding answers to questions that were not known to exist. As such, industry, government, and ultimately the public, benefit from amateur radio research. Strong partnerships with amateur radio research groups could allow industry to meet their economic goals while preserving this interesting leisure activity.

Chapter V

Current Innovative Activities in Amateur Radio

The creative spirit is still very much alive and well within amateur radio. In this chapter I would like to describe three ongoing projects that typify current innovative activities within the hobby. Two are based in Burnaby, British Columbia, while the third is based in the United Kingdom.

The *56K*[49] *Packet Radio Project* is based at the Telematics Research Laboratory of Simon Fraser University, and is concerned with research into inexpensive, high speed digital radio systems that employ standard protocols (Anderson 2000 #25). As an example of amateur radio digital technology, the project has several characteristics in common with earlier, lower speed, packet radio protocols. From a technological point of view, like low speed packet radio, the mode is non-participative: the operator is removed from the process of communications management. Applications of 56K packet include disaster response and deployment of the equipment as basic communications infrastructure in the developing world (Anderson 2000 #24). The project has several innovative aspects that will demonstrate the unique non-corporate R&D advantages of amateur radio.

---

49 As an excellent example of technical vagary, “K” stands either for 1000 or 1024. Prior to the digital age, “K” was used in the electronics (and amateur radio) field as shorthand for the number 1000. Digital computers work most efficiently with numbers that may be expressed as powers of 2; “K” in the computing realm is therefore 1024, which is 2^{10}. “56K” represents either 56,000 or 57,344 BPS, the throughput or data rate of communications through the system.

The *British Columbia Amateur Television Group (BCATV)* is also based in Burnaby, British Columbia. This informal association is developing a world-class amateur television repeater system that has applications to public service (Boekenkruger 2001 #40). The BCATVG typifies the historical innovative spirit within amateur radio, and the ability of amateurs to integrate existing technologies in creative new ways. I define this project as participative, because the technology is primarily analog and the operator is fully involved in interpreting and interpolating received video signals. If a TV picture is fuzzy, then the human eye and brain are used to make sense out of it.

The third technology that I will examine is called *PSK31.* It is a new low speed digital communications mode that is suitable for use on the international shortwave bands (Martinez 1998 #159; Jacob 2000 #129). The technology demonstrates the tendency within the hobby of combining existing technologies, in this case radio and the home computer, in exciting new ways to solve long-standing communication problems. PSK31 takes advantage of cheap computing technology to increase spectral efficiency on the airwaves by a factor of at least ten. From a communicative standpoint, PSK31 is interesting because it is a hybrid technology: it combines digital and analog techniques. Digital signal processing and the home computer provide unprecedented signal decoding capability and spectral efficiency. The lack of error detection and correction in the mode, however, places the operator back in the loop where he provides interpretive and interpolative functions. What is especially interesting is that PSK31 places the human back into the communicative process *by design*[50].

---

[50] One interesting possibility is that this characteristic, which has made PSK31 very appealing to amateurs, will be noticed by industry and incorporated into future commercial products.

Technology and engineering practice from these projects is spreading throughout the amateur community, has drawn the attention of government, and, to a limited extent, that of industry.

I will now examine each of these projects in detail. Each project has distinct innovative characteristics, and each supports my thesis that amateur radio defines a unique R&D environment, distinct and complementary to that circumscribed by industrial R&D. These projects show that the amateurs' special approach to problem solving is alive and well. Each is indicative of why amateur radio must be supported by government and by industry as a source of innovation.

The 56K Packet Radio Project

Object:

The object of this project is to develop a wireless digital communications network that operates in a regional area of up to a few thousand square miles, at a data rate of 56,000 bits per second (Anderson 2000 #25).

The network is used for experimentation with wireless TCP/IP, and for research into interoperability of the network with other emerging technologies. Driving applications include disaster mitigation, emergency preparedness, space communications research in partnership with the Canadian Communications Research Centre (CRC), and application of the technology to developing nations' infrastructure deployment.

Background:

The 56K project began in 1994 at Simon Fraser University in Burnaby, British Columbia. Participants in the project represent the university, the private sector, and amateur radio. The radio equipment designed for the project was made available in kit form to approximately twenty participants, as was software and associated networking tools. A high level of dedication and technical skill in hardware, software, and networking is required of participants due to the complexity of the project.

The larger goal of this project is to conduct research into emergency communications and disaster mitigation using wireless networking technologies. At a personal level, however, the impetus of the project for most of the participants was to extend Internet and electronic mail access to home. This project began in an era before the existence of the Internet Service Provider, so the novelty of this sparked great interest within the amateur community. This aspect of the project is reminiscent of the growth of private electrical grids and telephone companies in the period prior to mandated nationalization of these services in the 1930s.

Technology:

The 56K packet network is built using, as far as possible, off the shelf hardware and software components that are compatible with the standards established by the Internet. Individual connections to the wireless network are made using relatively inexpensive modems and radio equipment. A network backbone ties all user stations together and provides connection to the Internet, and potentially to 56K backbones in other regions. The Internet's TCP/IP protocol is used on the 56K network, maximizing interoperability with other applications and equipment (Rosenauer 1997 #212). Current work is focusing on interconnection of this backbone with other higher speed commercial wireless equipment.

Leverage of existing standards such as TCP/IP speeds development, enhances reliability, and ensures interoperability of the packet network with the Internet and other similar networks (Rosenauer 1997 #212).

Hardware:

Network equipment is composed of IBM-compatible personal computers that are connected to project-specific serial cards, modems and 430 MHz radio gear (Rosenauer 1997 #213). These computers operate as routers. The radio gear consists of a transceiver that operates in the 70 cm amateur band. This transceiver was custom designed for this project. The modem and serial card were designed for other amateur packet radio projects based in Ottawa, Ontario, and in the state of Georgia in the United States. A typical 56K station setup is shown in Figure 11.

Figure 11 – 56K Station Setup[51]

User equipment beyond the router may be any other type of computer or device that can communicate using the TCP/IP protocol. Macintosh personal computers, VAX and pdp-11 minicomputers, Sun workstations and self-contained devices such as web cameras are examples of some of the equipment that is connected to the 56K backbone.

Software:

The network infrastructure is based upon free software and associated free tools, specifically TCP/IP networking, and the Linux and FreeBSD versions of the UNIX operating system[52]. The use of these Internet-standard protocols and tools allows the 56K network to connect to and interoperate with the Internet in a seamless

---

51 Photo taken by the author, 2001.07.24 in Burnaby, BC.

52 See http://www.linux.org and http://www.freebsd.org.

fashion. Users may employ standard email packages, web browsers, news readers, and other utilities in exactly the same manner as they do on the Internet. In fact, the 56K wireless network is *part* of the Internet and can be accessed from anywhere in the world.

Most users have been assigned sub-networks from the range of IP addresses assigned to this project[53], and manage their own group of machines. Internet connectivity has exposed the machines on the wireless network to probes and attacks from unscrupulous users on the Internet. Connected machines must be secured against attack, and some 56K project participants have isolated their assigned sub-networks from the Internet through deployment of firewalls and proxy servers.

Topology:

Figure 12 shows the topology of the 56K packet network. Repeater stations on Mount Seymour, north of Vancouver, and Sumas Mountain, east of Vancouver in the Fraser Valley, link local users on two frequency pairs together. A main router at Simon Fraser University links the two halves of the 56K network together, and provides a connection to the Internet for all participants. Internet users can also access computers on either half of the 56K network through this router. About twenty users are connected to the network, and to the Internet, twenty-four hours a day.

---

[53] Two IP class C networks have been assigned to this project, 207.23.85.0 and 207.23.86.0.

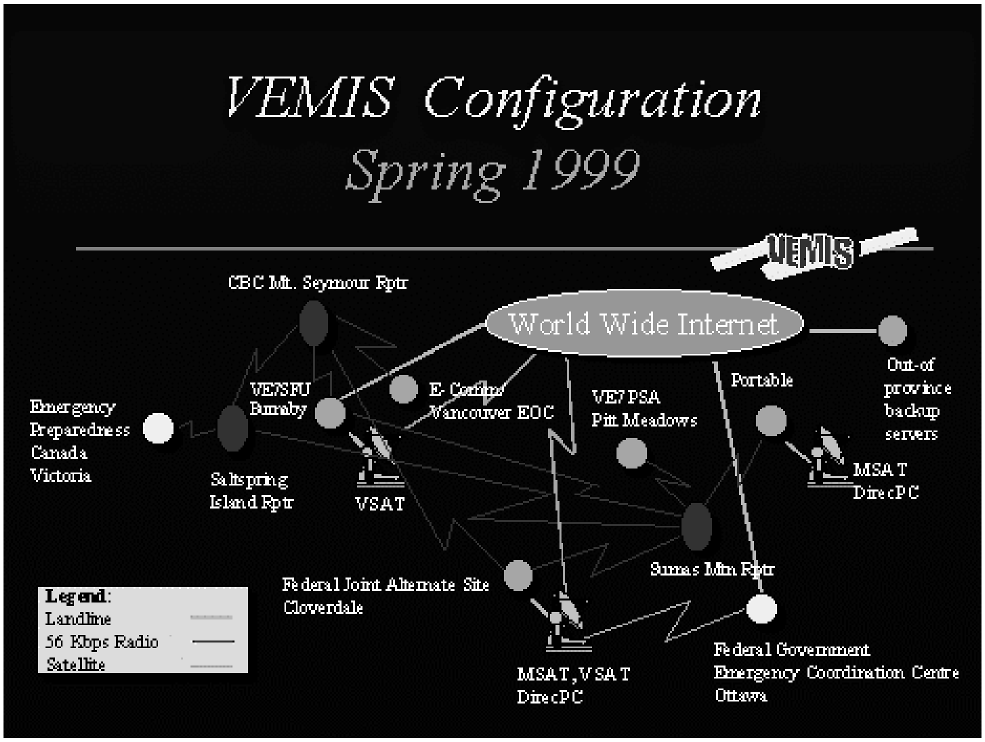


Figure 12 – Topology of the 56K Packet Radio Network (Anderson 1999 #23)[54]

Applications:

Casual uses of the 56K system include electronic mail and web surfing, but telecommunication research takes priority over these activities. Research projects using the network have centred on experiments with interoperability of new technologies such as video and audio streaming, emergency management incident systems, and repeater control systems for amateur television. Experimentation with real-time collection of seismic data for the US Geological Survey was conducted in partnership with the Department of Geophysics at the University of Washington, and provided insight into network performance (McQuiggin 1998 #174). Other research

[54] Used with permission.

has been conducted linking the 56K packet network to other services via commercial satellite services (Anderson 2000 #25).

Future applications will study connection of the network to other high-speed commercial wireless services and the viability of virtual private networks over medium-speed radio links.

Cost:

The 70 cm amateur radio gear for this project was approximately $600 in kit form. Kits are no longer available. The modem employed is approximately US$250, and the serial card required for the IBM-compatible personal computer cost approximately $125. Power supplies, antennas, and coaxial cable round out the hardware requirements to a total of slightly more than $1000.

The software components of this project are free. The project is based on the Linux and FreeBSD versions of the Unix operating system.

Simon Fraser University provides Internet connectivity and network support for this project at no cost to the participants.

Innovative Specifics:

Wireless networking at this data rate was unavailable commercially when this project first became operational. The use of standard Internet protocols on a private network, specifically TCP/IP-based networking, predated the ever-present “intranets” of today and was years ahead of its time. Amateur packet radio networks had previously been based on AX.25, a source-routed protocol. The introduction of dynamic routing increased network performance and improved reliability. The capability of using standard tools based on TCP/IP, such as those employed on the then-nascent Internet, increased interoperability and collaborative possibilities. A generalized approach such as this to solving emergency communication problems with pre-existing standards was a new idea at the time. Interest remains high in the application of this technology to communication requirements in the developing world.

This project pioneered wide-band amateur communications and was a novel use of the 70 cm amateur band. New technology and skill sets met old face to face. Few amateurs possessed the computing and the electronic assembly skills required to complete assembly and setup of the equipment, and this was reflected in the small percentage of participants who actually made it onto the air. Of approximately twenty 56K kits distributed to interested hobbyists in 1995, only eight reached operational status.

While admittedly a negative aspect of the 56K project, this low completion rate correlates with earlier research findings on adoption of innovation, such as those of Rogers (Rogers 1962 #211). 56K was a new technology in 1994. Amateurs participating in the project were risk-takers, innovators and early adopters. A technologically-positive and leading edge group, they represented a very small segment of the amateur community. Even then, only twenty-five percent of these individuals completed the project and got their new packet radio equipment on the air.

Dennis Rosenauer, designer of the radio equipment used in this project, moved to Seattle, Washington in 1998. Word of the 56K project spread to Seattle area amateurs, and they envisioned a 56K network for their region. Although initial interest appeared high, even less progress was made than by the Canadian amateurs. Only one station, on Camano Island about twenty-five miles north of the city, made it to operational status (Rosenauer 2000 #214).

From a regulatory perspective, the interconnection of the amateur wireless network with the Internet raised some issues of remote controlled operation of amateur transmitters by unlicensed persons. Non-licensed users on the Internet were able to access computers on the 56K wireless network. This implies that these non-amateurs were activating amateur radio transmitters. While such operation is addressed in Canadian amateur radio regulations (Industry Canada 2001 #123), the issue of these parties being at an unknown location in the world (due to the global characteristic of the Internet) raised some concerns among both project members and Industry Canada. These issues were resolved through discussion and cooperative effort between project personnel and Industry Canada, and some subsequent restriction of access to the network's services.

In 1999, when the 56K packet network was extended to the Seattle, Washington area via Camano Island, American users were able to access the system through the repeater on Mount Seymour, just north of Vancouver. These users hold US amateur licences, rather than Canadian. While reciprocal operating agreements are in place between the United States and Canada, this type of operation was not envisioned when the agreements were made. The expansion of the 56K network to another nation may break further new ground in the regulatory area.

Discussion:

The complex nature of this project, and its radical emphasis, that of using amateur radio simply as a transport-level service for Internet protocols, distanced the project from mainstream amateur radio operators. The majority of amateur packet users in 1994 were enduring 1,200 and 9,600 BPS operation[55]. The steep learning curve in order to participate in the project for most hams limited participation in this truly innovative project. Several kits that were purchased by potential users remain unfinished or were never assembled at all.

The 56K project has suffered from a reduced level of activity over the past two years due to various factors, including the loss of technical resource people to higher paying jobs in the United States. This drain on resources has slowed the development of applications for the network and focused the remaining core members of the team on tasks of infrastructure management.

A second limiting factor for the 56K project was the introduction of high speed Internet access to the home and office by commercial service providers. At the inception of the 56K project, most home and office users were limited to 9,600 BPS access to the Internet, via telephone lines. 14,400 BPS was an expensive alternative. Wireless 56,000 BPS Internet access was unheard of, and far superior to a short list of commercial wired services that cost thousands of dollars per month[56]. Here was a project that quadrupled the data rate, and bypassed the need to use a telephone line or a leased line to access the Internet. This excited many amateurs and provided a strong incentive for involvement in the 56K project.

---

[55] Unfortunately, these low data rates remain prevalent today. The complexity of higher speed packet radio has severely limited adoption of new technology to replace older, slower equipment.

[56] Higher data rates (more bits per second) consume more bandwidth, or channel capacity, and are therefore more expensive when purchased commercially.

The deployment of wired commercial services such as cable modems and ADSL that provided data rates in excess of 1,000,000 BPS for less than fifty dollars per month[57] damped the enthusiasm of some of the non-core project participants. Commercial wireless providers also began offering Internet access via CDPD and other wireless technologies at affordable rates. This further eroded interest in 56K packet radio.

A third limiting factor in this project is the proprietary nature of the radio equipment used in the project. The 430 MHz transmitter and receiver are of custom design and are not available commercially (Rosenauer 1997 #213). They must be purchased as kits. Project participants have to build these units from scratch, based on schematic diagrams produced by two members of the project team. Although unpopulated circuit boards and parts kits were made available in 1995, the assembly and adjustment of the equipment was sophisticated, and not all participating amateurs had the ability and experience to successfully build these units. This greatly limited the scope of potential amateur participants in the 56K project. A dozen 56K units remain unassembled, or only partially assembled, due to the unanticipated complexity of their construction. Obviously, the complexity and proprietary nature of the equipment made it very difficult for most amateurs to participate in this project.

[57] As I began writing of this thesis, ADSL and cable modem rates were about $100 per month. ADSL is currently available for $34.95 per month and will likely drop further in price.

Despite these limiting factors, commercial interest in the 56K project began in 1995, and this was accelerated by presentations made to the United Nations. Project principals Peter Anderson and Dennis Rosenauer spoke to representatives of the Development Program, IDNDR[58] and the UN Working Group on Emergency Telecommunications in 1996. Other factors came into play, however, and the advance of wireless technology on other fronts (such as spread spectrum and OFDM) eventually eclipsed 56K packet as a leading-edge technology. Simon Fraser University and the Telematics Research Laboratory continue to lead research in application of these new technologies in the fields of emergency communications and aerospace (Braham 2000 #46).

However, the 56K technology that was developed for this project remains relevant within its intended frame of reference, and research focusing on the application of the technology to emergency communications and disaster mitigation is ongoing. The network has recently been extended southward down to the region of Seattle, Washington. 56K networking is also being integrated with the repeater control requirements of the BC Amateur Television Group, as described in the next section.

The British Columbia Amateur Television Group

Object:

[58] International Decade for Natural Disaster Reduction, a UN initiative that ended in 1999. See (United Nations 1999 #250).

The objective of this project is to develop a regional amateur television network using cost-effective equipment, for recreational, emergency response, and community service purposes.

Background:

Amateur experimentation with television has a history that dates to 1927 (Kruse 1927 #133). Construction articles date from May of 1928 (Thomsen 1928 #237), and in the United States amateur television was permitted by regulation beginning on August 3, 1928 (American Radio Relay League 1928 #1). Amateurs were among the first groups transmit and receive pictures, and first to recognize the impracticality of mechanical transmission and reception techniques, and the superiority of the electronic method for television invented by Philo T. Farnsworth (Sleeper 1929 #222).

Television in amateur radio today is of two forms: slow scan television, which transmits still pictures on the shortwave bands at a rate of two to three frames per second; and fast scan, which transmits standard television signals (American Radio Relay League 2001 #11). Due to the 6 MHz bandwidth required, fast scan amateur television is limited to the amateur bands at 430 MHz and above (American Radio Relay League 2001 #11; Industry Canada 2001 #123).

This project is concerned with the development of a new, interoperable amateur fast scan television network on the UHF and microwave amateur bands.

The BC Amateur Television Group (BCATVG) has existed as an informal club for about fifteen years (Boekenkruger, Wiejak et al. 2001 #42). A few members of the group have been involved with amateur television for more than twenty-five years.

There are currently about twenty participants. The group meets only informally and decisions are made by consensus. Approximately five members have extensive electronic experience, and these are the people that are responsible for most of the development of the system. The rest of the members provide a support function and comprise the “audience” (McQuiggin 2000 #176).

Over the years, the group’s activities have evolved from simple point-to-point experimentation with television, to the installation of a single channel repeater used to re-broadcast content to group members, to the sophisticated multi-band and multi-channel, inter-linked system that is currently under development. This system is the subject of this discussion.

Technology:

The BC Amateur Television Group network broadcasts fast scan television in full colour, with dual audio channels. Frequency modulation (FM) is used as it provides superior performance within the coverage area. The choice of FM as a network standard also allows the use of surplus commercial analog satellite television components, which are common in the Vancouver area[59]. This differs from mainstream amateur fast scan TV, which uses amplitude modulation (AM) (American Radio Relay League 2000 #5). AM television gear cannot interoperate with these FM television surplus components.

---

[59] With increased marketing of direct-to-home digital satellite services such as Bell ExpressVu, older analog equipment turns up frequently at affordable prices. BCATVG members frequent surplus electronic sales looking for suitable equipment.

A distributed switching centre allows up to four users to communicate at one time. System output can be arranged so that each user occupies one quarter of the repeater output screen (see Figure 13). Participants can then see and hear one another. A sophisticated control system, which is described below, allows users to operate the switching centre remotely, and patch audio and video inputs from up to sixteen separate sources together. Audiovisual output from the television repeater system can be directed to one or more output frequencies, transmitter sites, and/or the Internet. The control system may be operated remotely from standard amateur portable radios as described below, or over the Internet.

Figure 13 – BCATVG Television Repeater Output (Boekenkruger 2001 #41)

This project makes use of several VHF, UHF, and microwave amateur bands. Control inputs are on the 144 MHz and 430 MHz amateur bands, while video inputs and outputs are on 0.9, 1.2, 2.4, 10.23, and 24 GHz. Output of the system is also streamed onto the Internet. Internet sources can also serve as audiovisual inputs into the network: one system input is connected to the Internet's Multicast backbone (Mbone). The Mbone input has been used to relay ongoing NASA research through the BCATVG television network.

Interoperability with other amateur television systems using AM, such as one coordinated out of the Fraser Valley, is achieved through the conversion of the NTSC (standard video) signals from FM to AM at a designated gateway station in Langley, BC. The FM signals of the BCATVG system are converted to AM at this gateway station, and re-transmitted over the Fraser Valley system, and vice versa.

This ability to interconnect the AM and FM networks has been used for several regional amateur television broadcasts and emergency communications exercises.

Hardware:

A. User Station Equipment

BCATVG system equipment is based on inexpensive FM commercial audio/visual equipment that has been modified for amateur use. Most users transmit television signals in the 2.4 GHz amateur band, and watch system output on the 1.2 GHz band. Transmitter and receiver are separate units.

Transmitters operate in the 2.4 GHz amateur band[60]. These units were originally designed for retransmission of television signals within a home: for example, from a primary television set to other sets around the home[61]. For BCATVG use, the transmitter is removed from its commercial plastic enclosure, and re-housed in a rugged weatherproof metal container. The transmitter can then be mounted outside, next to the antenna, to reduce feedline losses.

Tuning capability is added to the transmitter through the addition of a small circuit board designed by members of the BCATVG. This allows the unit to operate on any one of hundreds of “channels” or frequencies, instead of the four pre-

---

[60] This amateur spectrum is shared between the amateur radio service and low power commercial equipment. The amateur service is permitted higher power levels, therefore these units may be modified by amateurs to produce greater power output, which will cover greater distance.

[61] These units are marketed under the brand name WaveCom. See http://www.wavecom.ca.

programmed settings allowed in the commercial units. Modifications to commercial equipment to improve its performance is one of the hallmarks of the radio amateur.

The commercial television equipment is supplied with very inefficient antennas. The "patch" antenna on the transmitter unit is removed and replaced with a parabolic antenna of one-half to one metre in diameter. An MMIC[62] on the transmitter board is replaced with a higher power amplifier. This modification increases the communication range of the transmitter from about 50 metres to a few tens of kilometres[63].

Reception of the main BCATVG television repeater takes place in the 1.2 GHz amateur band. Obsolete analog satellite receivers are modified by group members to cover the required frequency range. These are purchased at yard sales, flea markets, or surplus dealers in the Vancouver area for under $10. Suitable microwave antennas for these receivers are fabricated out of empty 2-Kg coffee cans. See Figure 14 for an example of one of these antennas.

---

[62] Monolithic Microwave Integrated Circuit: a tiny (5mm by 5mm) chip that amplifies its input signal to produce an output signal approximately one hundred times greater.

[63] Amateur operations in the 2.4 GHz band are secondary in nature. The BCATVG system has been subjected to interference from wireless LAN cards, commercial broadcasters using similar frequencies, and government agencies over the past two years. As secondary users of the band, little recourse exists.

Figure 14 – 2 Kg “Maxwell House” Amateur Microwave Antenna[64]

B. Television Repeater Equipment

The television repeater system is complex, with many receivers, transmitters, and sources of input and output. The control system is key to managing the amateur television (ATV) network, and an important example of amateur innovation in this project.

System control is achieved through use of standard DTMF[65] tones. These are the same tones used in common telephone touch-tone dialing. All components of the ATV system are assigned a unique “address” and programmed to respond to a particular series of DTMF tones. These tones form command sequences for the attached devices. There are about four dozen commands available. In this way, audio and video can be turned on and off, certain inputs can be switched to certain outputs, and repeater antennas automatically rotated to favour certain directions. All devices on the ATV network listen to a common control channel and respond to

[64] Photo taken by the author, 2001.07.23 in Vancouver, BC.

[65] Dual-tone multi-frequency. See glossary and (American Radio Relay League 2001 #11).

these DTMF sequences, but devices ignore commands that are not addressed to them.

The choice of audio tones as a control mechanism for the BCATVG network was very creative. This differs from the approach industry has taken to similar problems and has several advantages. DTMF, as a pre-existing standard, allows use of commonly available integrated circuits and other equipment. Touch-tone signals can even be generated and decoded easily by a computer with a standard sound card. Alternatively, integrated circuits such as the CD22204E can be purchased that perform this function for about three dollars[66].

The BCATVG repeaters, transmitters, and receivers support stereo audio. One of the two audio channels is sacrificed and reserved for use as a control channel. Monaural sound is sufficient for all ATV applications. Control signals can therefore be distributed throughout the ATV network easily, without the need for any additional equipment. One audio channel carries DTMF tones and is used as the control channel for the television network, while the other channel carries audio associated to the television picture.

Use of DTMF has other advantages. Most modern amateur hand-held radios include a DTMF keypad. Typically, inclusion of this keypad allows the amateur operator to make telephone calls via an “autopatch”, an interface between the

---

[66] See http://www.digikey.com.

telephone network and the amateur radio VHF/UHF network that may be provided by local amateur repeaters[67].

The existence of DTMF keypads on these hand held radios is leveraged to allow the control of the amateur television system. The BCATVG system includes receivers and DTMF decoders on the 144 MHz and the 430 MHz amateur bands[68]. Group members can transmit DTMF tones on these frequencies that are received and acted upon by the repeater control system. Group members also use these frequencies to talk to one another.

The BCATVG television repeaters are on the air twenty-four hours a day. All amateur radio stations in Canada are required to identify themselves when they transmit. The Radiocommunication Act dictates that transmitting stations must identify themselves at least once every thirty minutes (Industry Canada 2001 #123). This legal requirement needed to be addressed for the ATV network. Obviously, some sort of automatic identification beacon or device had to be built, and doing so presented a challenge to the technical membership of the group.

The problem of how to build this identification device was creatively solved through the purchase of a "talking" Hallmark greeting card. These greeting cards contain a small microprocessor, a transducer that acts as a speaker and microphone, two

---

[67] Such linkage between amateur radio and the telephone network is sanctioned in amateur regulations throughout the world, and has application to emergency response operations.

[68] 147.525 and 447.325 MHz.

switches, and a battery. They allow a personalized greeting to be recorded "in" the card and played back when the card is opened. Cost is about $7[69].

BCATVG members purchased one of these cards, removed the electronic components, and recorded an appropriate station identification message[70] on the chip. Battery connections were replaced with connections to a proper power supply, the microphone/speaker leads were wired into the audio circuitry of the television repeater, and the switch (used to trigger message playback when the greeting card is opened) wired to a timer set to activate playback every thirty minutes.

The problem of station identification was therefore solved with some creativity and an expenditure of under $10. This is an excellent example of the innovative spirit of amateur radio, and the pragmatic nature of the hobby.

Software:

Software is an integral component of this project. The reliance on computing and software throughout this project exemplifies the shift from purely analog to digital techniques that has taken place within amateur radio since 1975. A high level of understanding of computing, modern electronics, and related technologies are a prerequisite to being able to contribute to this project.

---

[69] Unfortunately, my enquiries of Hallmark in early 2001 determined that these greeting cards are no longer manufactured.

[70] "This is amateur radio station VE7RTV, Burnaby, British Columbia".

Software is key to this project at several levels. First, software controls the modified commercial in-house FM television transmitters, to make them more frequency agile[71]; secondly, software is key to the operation of the network control hub; and thirdly, a computer application is used to control the ATV system from any computer on the Internet. Leverage of standards, including DTMF, TCP/IP, and video streaming is also key to the success of this project.

As described in the section on hardware above, custom designed amateur television repeater control units are grafted onto the commercial FM transmitter units: basic circuitry is replaced by a sophisticated single-chip computer called a micro-controller. Firmware[72] is written for these units that allows the transmitter to function on *hundreds* of frequencies rather than the four it was manufactured for. The firmware also adds capabilities to the transmitter that allow it to be controlled by system users: the modified units understand and can respond to DTMF sequences. With its new-found intelligence[73] the transmitter unit proves to be a very flexible device. Computing and software are key to this result.

The control hub of the television network is a sophisticated device. A personal computer acts as the coordinator for DTMF signals to and from devices connected to the network, and connects all system inputs and outputs together. The control hub

---

[71] That is, capable of operation on more frequencies.

[72] Software that is pre-written by project team members and encoded directly into the silicon of the micro-controller chip. The chip then becomes a computer customized for a particular purpose.

[73] Or, in the least, responsiveness.

also has a presence on the Internet, a powerful capability that allows the system to interact with users on a global basis. Through this connection video from the network is streamed to Internet users, and commands from users with the system control application, to be described below, are received and transmitted to the devices on the ATV network.

Lastly, a repeater control application that runs on any personal computer is widely used by members of the television group. This custom "GUI"[74] application (shown in Figure 15) was written by the participants and will run on many different hardware platforms. Participants may use this application to control the entire television repeater system from their computer. They may choose audio and video sources, turn transmitters and receivers on or off, set transmit and receive frequencies, and even point repeater antennas in any direction, through an interface to rotating devices on the towers holding BCATVG antennas. The repeater control application interacts with the network control hub, where these point-and-click commands are translated to the equivalent DTMF sequences and dispatched to ATV devices.

[74] Graphical User Interface. Microsoft Windows is used.

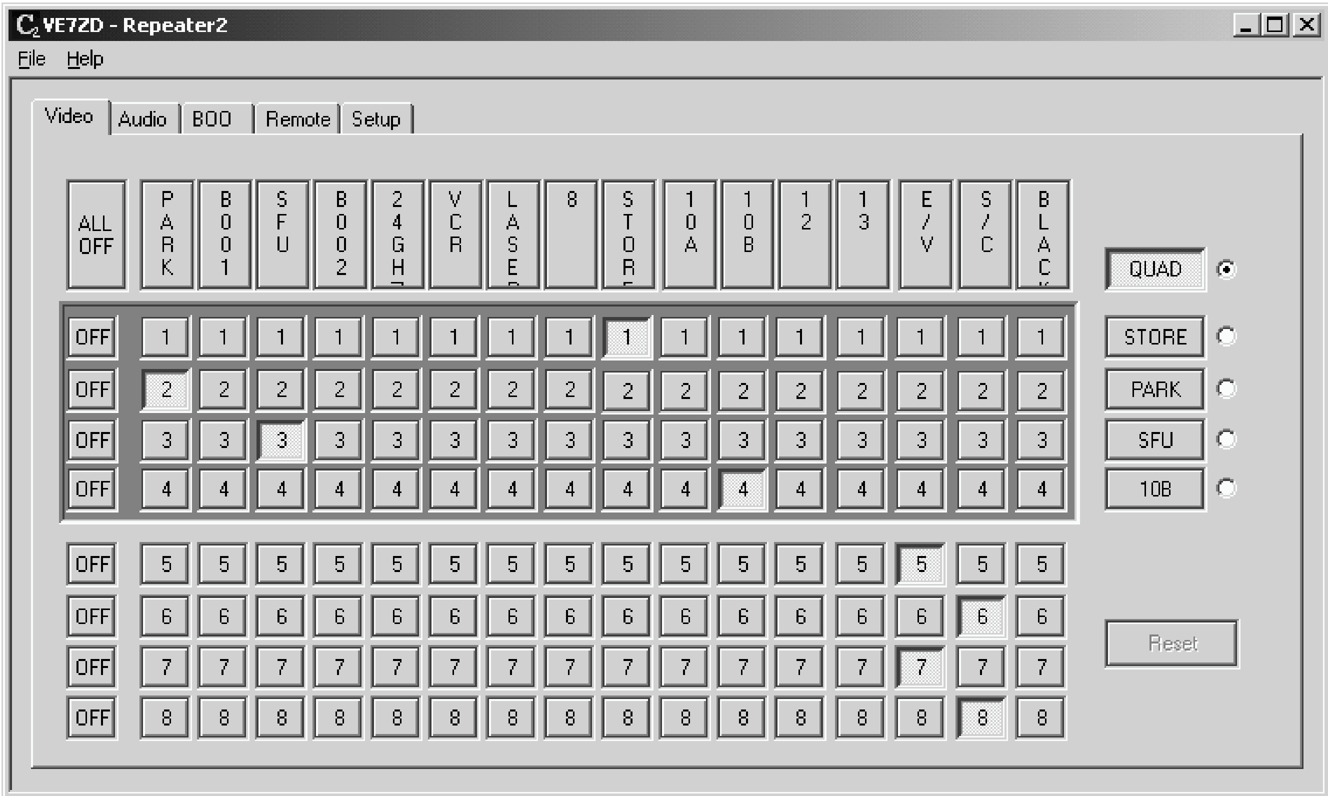


Figure 15 – Amateur Television Repeater Control Application (Wiejak 2001 #260)

As noted above this control channel is also accessible on the 144 and 430 MHz amateur bands.

Topology:

The BCATVG system has tremendous flexibility. System topology is shown in Figure 16. Two repeaters are tied together by multiple radio links, and controlled by a single command processor that receives direction from users either on the 144 or 430 MHz amateur bands, or via the Internet. Figure 17 shows the frequency usage of the repeaters used in the BCATVG system.

VE7RTV Repeater Computer Control

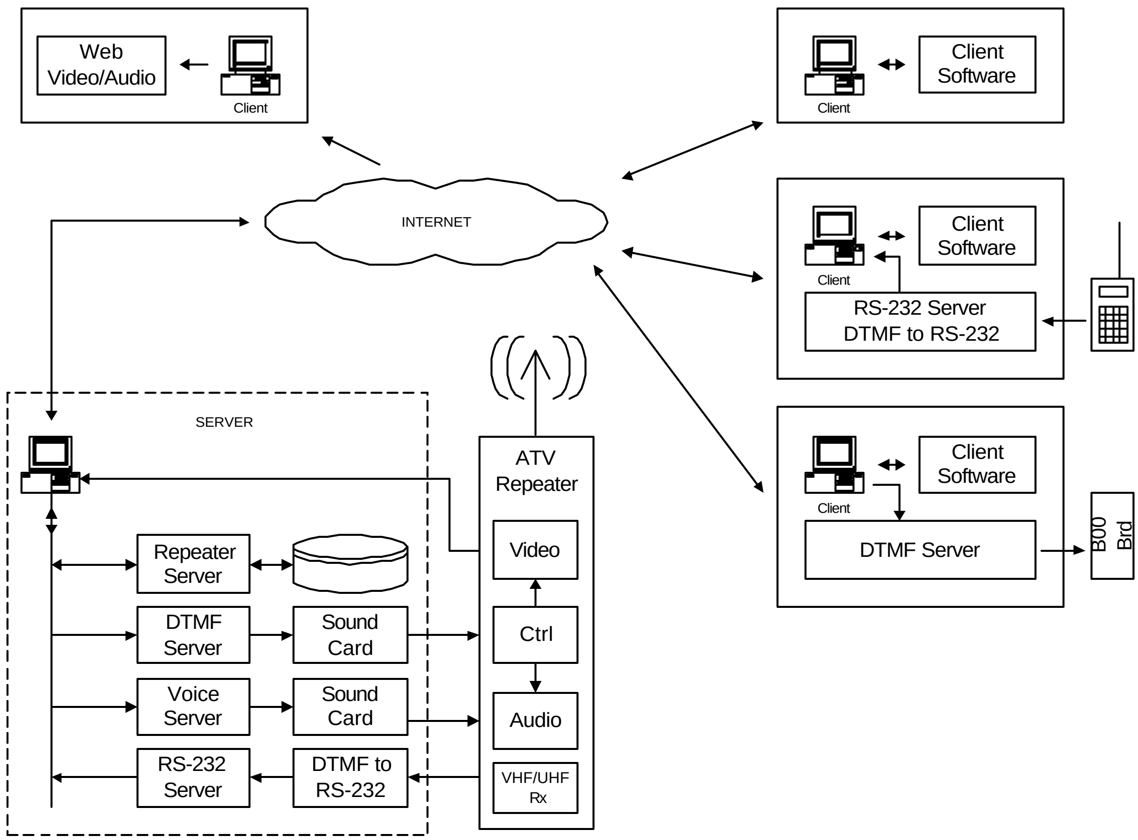
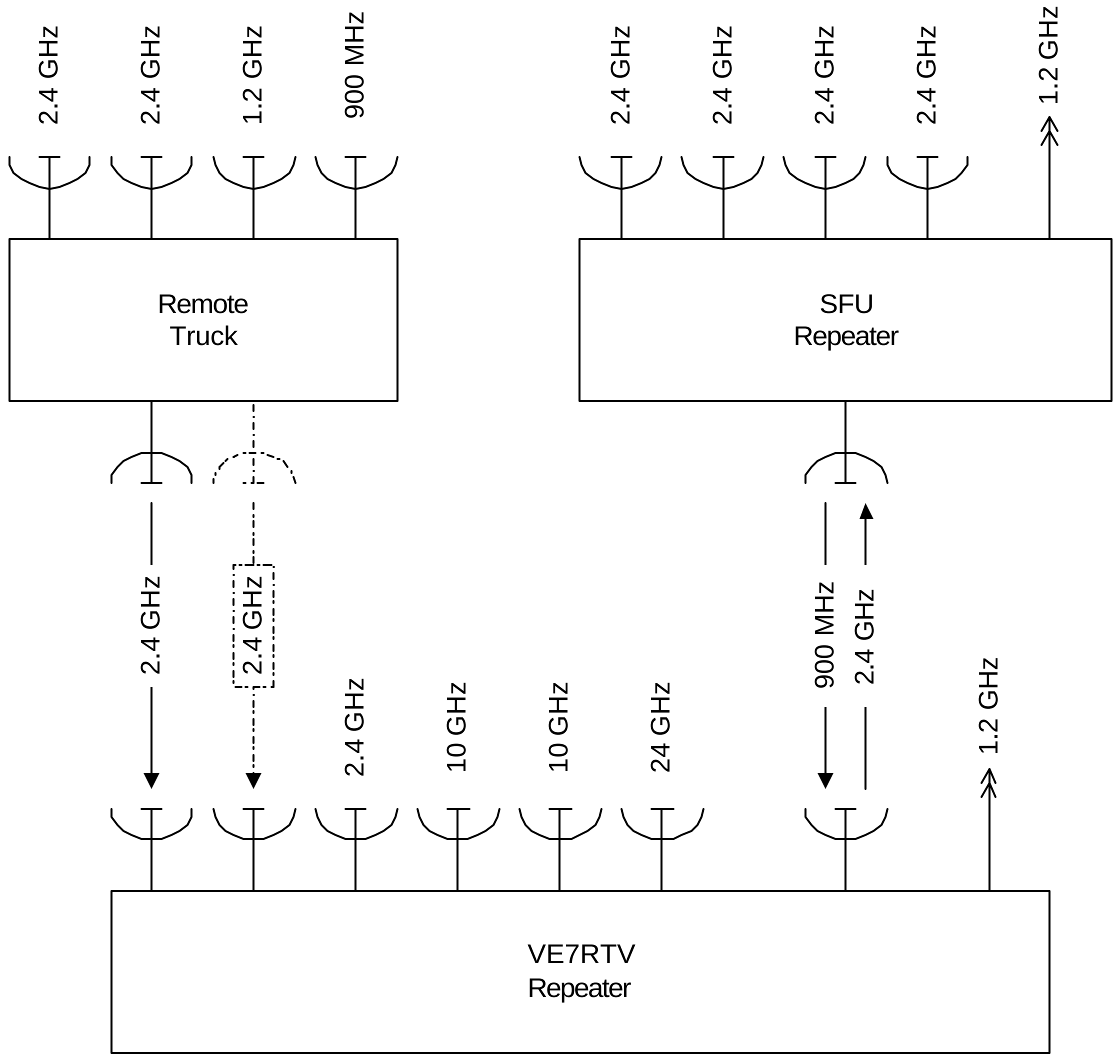


Figure 16 – BCATVG System Topology (Wiejak 2001 #261)



ATV Repeater System - RF

Figure 17 – BCATVG Repeater Frequencies and Control Channels (Wiejak 2001 #261)

Users access the system through one of the repeater sites: either at Simon Fraser University in Burnaby, located at the top of the main library building; at the main control hub, located at a radio store in north Burnaby; or via a portable, truck-mounted repeater. Users transmit audio and video on one frequency, and listen on another. They may control the repeater through the use of hand held radios or over the Internet. The antennas at the main repeater sites are remotely controlled: users can send the system commands to point the antennas in a chosen direction, and thus improve coverage and performance.

An interesting partnership between 56K packet users and the ATV group began in 2000. The use of the Internet by the BCATVG control hub allowed participants in the 56K packet radio project to control the amateur television repeaters via a wireless radio link. This new functionality demonstrated the flexibility of both systems and was employed during an emergency preparedness exercise in June 2000. Interoperability such as this emphasizes the benefits of adherence to open standards.

Applications:

The ATV repeater system is used to broadcast television signals from community events such as parades, festivals, and fireworks displays. Group members are involved with emergency preparedness and have broadcast video between simulated disaster scenes and management centres, aiding public service response. Canadian Space Agency and NASA programming are also periodically re-broadcast over the BCATVG network, as most project participants follow the space program closely. Other regular activities on the network are roundtables, discussions between project members on technical issues, testing, and general interaction in other areas of common interest.

The BC ATV Group is also working with the Telematics Research Lab and its PolyLab at Simon Fraser University to test and evaluate image communications systems in conjunction with NASA and the Canadian Space Agency. A project over the summer of 2000 linked group members with a joint CSA-NASA/Ames team at Haughton Crater, Devon Island, Nunavut, where they were conducting research relative to a proposed manned Mars mission in 2014.

Cost:

The commercial Wavecom 2.4 GHz transmitting and receiving equipment may be purchased and modified for amateur use for approximately $300. A 1.2 GHz surplus satellite receiver for monitoring the main repeater output can be bought for under $50. Receiving antennas are built from empty 2 Kg coffee tins. A small parabolic dish for transmitting television signals on 2.4 GHz costs approximately $100. The addition of coaxial cabling and a small standard television will bring total expenditure for the new amateur television user to approximately $500.

Innovative Specifics:

This project excels at technological integration. Off the shelf components are modified and used together in interesting new ways to provide innovative video communication capabilities.

BCATVG members come from many walks of life. Age and experience vary widely. The youngest member of the group is under 25 years of age, while the oldest is over 70. Some are engineers while others are self-taught hobbyists. The diverse background of the participants results in a rich collaborative environment where a lack of formal technical training is overcome by enthusiasm and a synergy of skills that allows the project to proceed with a surprisingly high level of sophistication.

Interest in the BCATVG's television repeater system has been expressed by public service agencies (police and fire departments in the area), municipal governments considering civic response options, and the provincial government through the Provincial Emergency Program. The system has been used effectively by special event planners and emergency response personnel (Martin 2000 #157). The City of Vancouver has budgeted for a full time amateur television receiving station, and sponsored amateur radio qualification classes for city staff (McQuiggin 2001 #177).

Representatives of the Canadian Space Agency have also noted the integrative aspects of the project, and preliminary steps have been made towards further collaborative work in 2002 and beyond.

Discussion:

The use of several of the higher frequency amateur radio bands is one of the most important aspects of this project. The project utilizes seven of the ten amateur bands between 144 MHz and 24 GHz. The use of amateur microwave allocations makes a strong case for their continued assignment to the amateur service – to quote an old amateur adage, “use it or lose it”. Use of amateur allocations makes it easier for Industry Canada to support the amateur service, and, more importantly, gives amateurs important experience in this region.

Future planning for the BCATVG envisions expansion of the network to allow wider coverage, and the upgrade of the existing repeater sites to allow for a greater number of simultaneous inputs (Boekenkruger, Wiejak et al. 2001 #42). Currently a maximum of four users may use a single repeater simultaneously. This is a limitation of the current (surplus) equipment.

Much interest also exists in the examination of digital television as an alternative to the analog mode currently employed. Issues here include the complexity of the technology, lack of availability of surplus equipment (at least, lack of equipment at a reasonable price), and, significantly, the viability of digital television in comparison to analog. BCATV members are thinking seriously of possible applications or adaptations of inexpensive DBS satellite receivers[75].

Analog television equipment is cheap and readily available, requires minimal support infrastructure, and most importantly, meets members' needs and those of the communities that they wish to serve. Digital television requires higher power levels and is more prone to interference, both man-made, and that caused by the terrain over which the signal travels. Performance in weak signal conditions has been demonstrated to be much better on analog than with digital, but nonetheless, DBS receiving equipment is so inexpensive that some amateur use of it is likely on the horizon.

PSK31

Object:

The objective of this project is to improve the performance of real-time digital communication between amateur radio operators on the short wave bands. Interestingly, PSK31 achieves this objective through a reliance on analog techniques, which are used to complement its digital basis.

---

[75] Amateurs are good at dreaming up interesting new applications of existing technologies. The high quality low noise amplifiers of these small satellite dishes have application to weak signal work, spread spectrum communications, and possibly EME and amateur satellite work.

Since its invention in the United Kingdom in 1997, PSK31 has evolved very quickly and has diffused to all corners of the world (Ford 1999 #89; Ford 2000 #90). PSK31 is a real-time digital mode. This technology differs from packet radio in its approach to digital communication, and from traditional radioteletype in its technology, specifically by leveraging the signal processing capabilities of the modern personal computer (Ford 1999 #89). There has been significant amateur development within this area in recent years (Ford 2001 #91; Greenman 2001 #98), and several new modes rely on this type of approach. PSK31 is typical of this innovative activity and is the most popular of these new digital modes.

A secondary objective of the PSK31 project, one which I will examine in detail in this thesis, is to deconstruct digital communication in amateur radio, and reintroduce the human operator as an active participant in the process of communication between individuals (Martinez 2000 #161). This uncommon goal arose out of the inventor's desire to rekindle support for real-time unmediated communication in amateur radio. With the growth of packet radio and other digital communications modes beginning in the 1970s, he had noted with discontent the loss of the personal, the loss of a sense of "connectedness" and shared experience between the participants in amateur radio communications. An avid "keyboarder" on RTTY in the 1960s, he missed the real-time, interactive nature of that activity. With PSK31 he hoped to revitalize the hobby through re-emphasis of the human as a fundamental component and key part of the communicative process (Martinez 1998 #160). PSK31 may be termed a hybrid technology, in that it combines digital and analog techniques, and through this hybridization, the new mode generates an enhanced communicative experience for the amateur operator.

Background:

PSK31 was developed by British amateur radio operator Peter Martinez in 1997 as an enhancement of basic work that had been done by Pawel Jalocha, a Polish hobbyist (Jacob 2000 #129; Ford 2001 #91). Traditional radioteletype modes such as RTTY, which had been in use on the shortwave bands since the 1930s, were susceptible to interference and did not perform well under marginal conditions of propagation. Packet radio incorporated error detection and correction, but as a consequence introduced overhead - a time delay in processing, a characteristic that was detrimental to real-time, interactive conversation. As we have seen, packet radio removed the human operator from management of the communicative process. PSK31 was designed to address these interference and propagation issues, yet still provide real-time performance suitable for interactive, human-based communication (Martinez 1998 #160).

Technology:

PSK31 is named after the technical characteristics of its modulation. “PSK” stands for “phase shift keying”, a method of modulating or impressing information upon a carrier wave, while “31” stands for the baud rate, or signaling rate, of the transmission[76].

Let’s examine these technical terms in a bit more detail.

Phase shift keying is a method of modulation that is remarkably resistant to interference and fading problems. It is thus very well suited to use on the shortwave

---

[76] More specifically, the baud rate of PSK31 is 31.25 BPS. This unusual number fits quite well into PSK31’s signal processing equations. See (Martinez 1998 #159) for a full explanation.

bands, where conditions of propagation can change on an hourly basis. Traditional radioteletype, as employed in the amateur and commercial shortwave services, uses frequency shift keying, or FSK (American Radio Relay League 2001 #11). It is far more susceptible to changing conditions. The superiority of PSK over FSK had been known among scientists and technologists, even amateurs, for many years, but until recent advances in computing technology the generation of PSK signals had been problematic (Ford 2001 #91).

PSK31 transmits and receives at a baud rate of 31.25 Hz[77]. This means that only a few characters can be processed per second. This is far below the baud rate of even the slowest packet radio or Internet service provider connections today[78]. How can such a mode, with such a low data rate, be useful? To answer this question, one needs to consider the philosophical basis of PSK31.

PSK31 is designed for real-time interactive communications between human operators (Martinez 2000 #161). A baud rate of 31.25 Hz is quite suitable for this application: it matches average human typing speed! PSK31 was not designed for high speed, nor computer-to-computer, nor store-and-forward operation. It was designed to allow human operators to type back and forth in real-time: to “keyboard”, using historical terminology.

---

[77] Or the equivalent, 31.25 BPS!

[78] Packet radio typically operates at 1200 or 9600 BPS. Internet service providers rarely support data rates below 56000 BPS at this writing.

Unlike packet radio, PSK31 data is transmitted a single character at a time. Automatic error detection and correction are sacrificed in favour of acceptable real-time, interactive performance. Error detection and correction are off-loaded onto the human operator. The human operator fills this gap, and provides error detection and correction himself!

> Tha avqrxage humzn isz pwrfec%ly capab)e of perf%(O)rming this inte&polaive f@3unct+on with a h.gh degreeee pf ackur:cy.

The exceptional performance of PSK allows the mode to “get through” in even poor conditions of propagation. Human error correction and interpolation takes place with reasonable accuracy. The technology is well matched to the application.

Another significant consequence of this low baud rate is the narrow bandwidth required for a PSK31 radio signal. At 31.25 Hz per signal, *fifteen to twenty* PSK31 signals easily can be accommodated in the space of a *single* voice channel[79]. The use of digital signal processing[80] (DSP) to separate these PSK31 signals allows much more efficient use of amateur spectrum. Software makes filtering and separation of PSK31 signals easy. To perform this processing in the analog domain was difficult, and very expensive (Greenman 2001 #98). Unprecedented spectral efficiency is one of the most innovative characteristics of PSK31 (Martinez 1998 #159).

---

[79] A typical single-sideband signal will occupy 1000 to 1500 Hz. While I have observed over ten PSK31 signals occupying this bandwidth on the 20-metre amateur band, the theoretical limit is 48.

[80] For an excellent introduction to digital signal processing, see (Lynn and Fuerst 1998 #149).

The mode also displays exceptional weak signal performance and greatly exceeds RTTY in this regard (Brooks 2001 #48; Greenman 2001 #98). PSK31 is optimized for operation on the noisy shortwave amateur bands. Power levels under ten watts and simple wire antennas can achieve global communication (Dolan 2001 #74; Ford 2001 #91; Mitchell 2001 #183).

Hardware:

Audio signals from the amateur receiver are routed to the “microphone” input of a personal computer’s sound card. The “line output” of the computer’s sound card is connected to the microphone input of the amateur transmitter. In this way, audio received can be processed by software running on the personal computer, and audio signals generated by the PSK31 software transmitted over the air by the amateur’s transmitter. The human operator controls the transmitter and receiver by setting the frequency on which they operate. The most popular frequency for PSK31 operations is 14.070 MHz, in the 20 metre amateur band.

PSK31 is totally dependent on the signal processing capabilities of the sound card that is present in just about every modern personal computer. To summarize, the sound card is used to *decode* data received as audible tones by a radio receiver, and to *encode* data typed by the user into audible tones which are transmitted on the amateur bands (Ford 1999 #89). The audio output of the receiver is connected to the microphone input of the computer’s sound card, and the audio output of the sound card is connected to the microphone input of the transmitter. For most users, two simple cables to connect the computer to their amateur transceiver are all that is required (Ford 1999 #89; Lindquist 1999 #142). Figure 18 shows a typical PSK31 setup.

Figure 18 – PSK31 Station Setup[81]

Software:

PSK31 is dependent on digital signal processing (DSP). As such, it is also dependent upon software, either running on a personal computer as is typical for the mode today, or as firmware running on specialized hardware. This approach was used for the early implementation of the mode in 1997 (Ford 1999 #89).

The narrow bandwidth used by a PSK31 signal requires great sophistication in the analysis of the received signals. These calculations are performed by software running on the amateur's personal computer. DSP recovers data from received audio signals (Martinez 1998 #159). Data to be transmitted is converted using DSP techniques to a phase-shift keyed audio signal, which is then sent to the transmitter. Sophisticated software performs these conversions in conjunction with the sound card on the personal computer[82]. Previously, specialized hardware,

---

[81] Photo taken by the author, 2001.07.24 in Burnaby, BC.

[82] Popular programs which incorporate this processing include Digipan (http://members.home.com/hteller/digipan) and WinPSK (http://www.mindspring.com/~ae4jy/).

available only at considerable expense, would have been required to accomplish this task (Greenman 2001 #98).

In the past year almost a dozen PSK31 signal processing programs have appeared on the scene (Jacob 2000 #129). Most run under Microsoft Windows, and all are freely available from the Internet (Jacob 2000 #129). One of the most popular of these programs is *Digipan*[83] (Ford 2000 #90). Sample output from the program is shown in Figure 19. An interesting characteristic of *Digipan*, and other sound card-based signal analysis programs, is the "waterfall" display visible in the bottom half of Figure 19. This display changes in real-time and highlights PSK31 signals that appear in the current audio passband (the range of audio frequencies that can be heard at this setting of the receiver's dial). Note that in Figure 19, approximately **ten** PSK31 signals can be discerned (the vertical traces on the waterfall display), and bandwidth exists for many more. Only one, or possibly two, RTTY or SSB signal could fit within this passband.

---

[83] http://members.home.com/hteller/digipan.

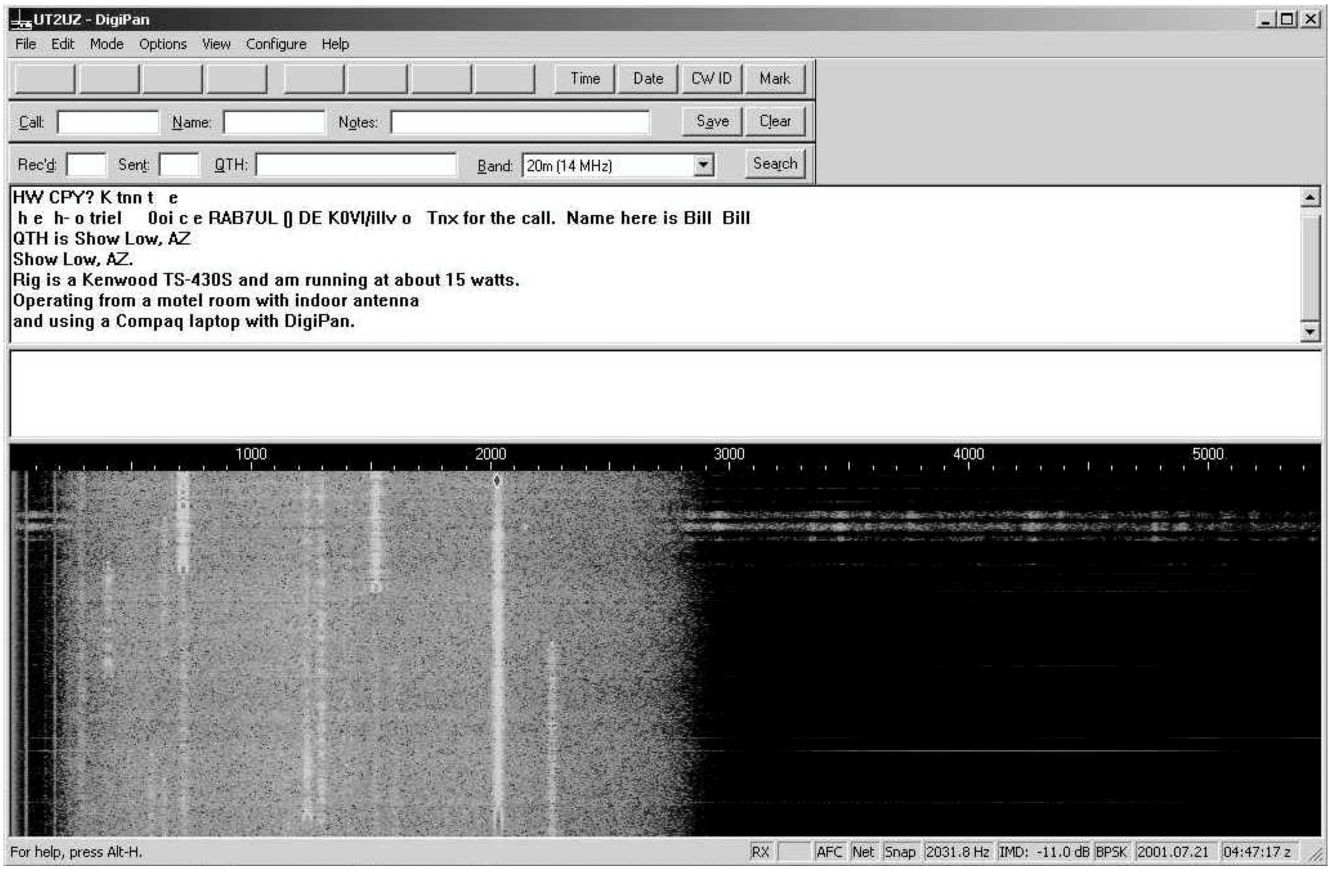


Figure 19 – *Digpan* PSK31 Program in Operation[84]

These programs incorporate the required DSP and emphasize a simple user interface. Users rarely have to "tune in" a PSK31 signal: the software identifies up to twenty signals on the real-time "waterfall" display, and the amateur simply clicks on the desired signal with his mouse (Ford 2000 #90). In a manner reminiscent of radioteletype, and unlike packet radio, PSK31 signals have a distinctive and not unpleasant sound[85], which can be tuned in quite accurately by ear.

---

[84] Screen capture from 14.070 MHz, at 2001.07.21, 0447 UTC, in Burnaby BC.

[85] PSK31 signals sound like whistling which varies in character, producing a warbling sort of sound.

Topology:

Like RTTY, PSK31 is a connectionless, peer to peer mode of communication. Any number of amateur operators may congregate and communicate on a single frequency. Packet radio, on the other hand, requires certain information be exchanged in a formal manner before communication can take place. The AX.25 protocol dictates the manner in which the communication proceeds. As I have described, while this ensures accuracy in data transfer, it adds overhead and distances a human operator from the communicative process. PSK31 trades this overhead for better interactivity and an acceptable reduction in accuracy of data transmission. By design, it also reintroduces the operator into the communicative process.

The connectionless nature of PSK31 allows more than two users to converse at one time[86]. Many stations may converge on the same frequency and interact informally. What is typed by one user will be received by everyone else on the frequency. This permits "roundtable" discussion by groups of amateurs from all points of the globe, and greatly enhances the communicative experience for all participants (Meltz 1999 #179).

Applications:

---

[86] In standard packet radio practice, a station must establish a "connection" to another station before error-free data exchange can take place. A connection is allowed between two stations only. Three or more stations may not be connected at once. While some complicated workarounds were developed to circumvent this, the limitation is a characteristic of the AX.25 packet protocol and cannot easily be defeated. Packet radio also supports a "connectionless" mode ("UNPROTO" packets (Tucson Amateur Packet Radio Group 1984 #246)) but the overhead of AX.25 makes this mode impractical for real-time group communications. PSK31's design avoids these problems.

PSK31 was envisioned as a more efficient alternative to traditional radioteletype amateur radio operation, and as an enabler for the inventor's goal of reintroducing the human to the process of digital radio communication. As such, application of the new technology was expected to mirror current activity on amateur radioteletype frequencies. Like RTTY, PSK31 users "chat" on an unlimited variety of topics in a highly unstructured manner.

So, why was there a need for PSK31 if RTTY already provides these capabilities? As a technology rooted in the 1930s, RTTY is based on frequency-shift keying (FSK), which is far less efficient than PSK. Equivalent reliability of communication with RTTY requires hundreds of times more power than with PSK31, and ten to twenty times as much bandwidth. PSK was not practicable in the 1930s due to the complexity of the required analog circuitry. Digital techniques were not available. Today, the availability of the personal computer allows PSK signals to be generated and decoded with relative ease, and at minimal expense.

PSK31 improves the efficiency of shortwave data communications and puts the operator back into the loop. There is a significant amount of PSK31 activity on the shortwave amateur radio bands, and the popularity of the new mode irks some long-time RTTY operators. Often RTTY enthusiasts are senior amateurs, many having been active on the mode for fifty years or more. Many are still using mechanical Teletype equipment. Internet sites such as "RTTY.COM" act as resources for maintenance of old, mechanical Teletype equipment (Hutchison 2001 #110). The "old guard" of RTTY complains of interference from these newcomers, and the erosion of "keyboard etiquette".

PSK31 has served to introduce many thousands of new amateurs to “keyboarding”. With this influx of new participants have come new PSK31 software applications with interesting features such as multiple channel operation (allowing users to carry on several keyboard to keyboard conversations at once). Low cost transceivers designed specifically for PSK31 have been designed (Teller and Benson 2000 #233), as have simple PSK31 bulletin board systems that incorporate store-and-forward messaging[87]. The latter topic is particularly interesting as its goal is in fundamental conflict with PSK31’s philosophy. I will say more about this below.

Cost:

Amateurs active on the shortwave bands and possessing a personal computer with a sound card need only assemble a cable to connect their radio to the sound card’s input and output ports. PSK31 software is available on the Internet free of charge. The total cost to get equipped for PSK31 is approximately $10.

Innovative Specifics:

This project introduces a new technology to amateur radio. PSK31’s innovative use of the popular personal computer and sound card allows effective radio communication to take place with incredible spectral efficiency. The mode represents the first application of DSP techniques to the hobby in other than a superficial manner[88]. This will prove key to evolution of amateur software-defined

[87] This characteristic is interesting as it again removes the human from the communicative process and introduces computer-based protocols to digital communication. Inventor Martinez finds this particularly ironic (Martinez 2000 #161).

[88] Major amateur equipment manufacturers used DSP techniques to enhance audio output and reject interference, but this functionality augmented existing analog modes rather than defining totally new ones as PSK31 did.

radios, those in which the characteristics of the radio are defined not in hardware and analog circuitry, but as mathematical equations and algorithms running on a microprocessor. The software defines the capabilities of the radio, rather than the static analog components. A software-defined radio can be completely "rewired" through loading of new software into the device. I'll have more to say on this important concept below.

There is significant interest within amateur radio in this new mode both for its technical advantages over older RTTY, and for the interpersonal, communicative aspects of the activity. In my research I noted that PSK31 is deemed interesting by the amateur community because of its performance, its simplicity, and, most significantly, for the human interactivity which it puts back into a computer-based mode[89]. Amateurs are eager for the real-time conversation PSK31 facilitates, and were unexpectedly enthusiastic, in my observations, about getting "back in the loop" and performing the error detection and extrapolative tasks that the mode demands. Comments included:

- "… I have been inactive for [many] years because it became boring. This PSK31 is exciting and brought me back" (Dolan 2001 #74)
- "I have heard BPSK described as the equivalent of the old 10 – 15 WPM ragchew[90]. I really think we hams miss ragchewing" (Dolan 2001 #74)

---

89 As an early adopter of PSK31, I have introduced other amateurs to this mode and been in a position to informally measure their response. My findings are supported by the PSK31 literature. See, for example, (Ford 1999 #89)

90 This term dates from the early period of amateur radio and signifies "an informal discussion". See (DXing.com 2001 #77).

- “My age is 68 and I have been a ham since 1958. I find this to be the most exciting mode I have ever used” (Mitchell 2001 #183)
- “I’ve been in ham radio since ’57 – ’58 and have never seen anything like it” (Brooks 2001 #48)
- “[PSK31] is the intersection of the amateur radio home-brew tradition with the software gift culture” (Bernstein 2001 #35)
- “… the first few weeks [of PSK31] were fantastic and probably epitomize the basic need of amateur radio, a need thought long dead and buried in modern technology. The need to be innovative and experimental” (Mills 2001 #182)

I believe that it is the social factor of this new mode that is more innovative, or at least of more significance, and which is indicative of a general trend in society which is critical of digital technology as an answer to all of our needs.

Discussion:

I corresponded with Peter Martinez about his development of PSK31 and the mode’s unprecedented popularity[91]. PSK31 has taken that portion of amateur operators active on the shortwave bands by storm (Ford 1999 #89; Ford 2000 #90), and is gaining on both more traditional radioteletype (RTTY) modes, and other computer-based digital modes such as AMTOR[92] (Henry 1992 #105) and CLOVER (Ford 2001 #91) that utilize forward error correction, and are philosophically grounded on a store-and-forward methodology (Greenman 2001 #98). The re-introduction of the human as an active participant is one of PSK31’s greatest innovative characteristics.

---

91 Martinez has been chosen to receive Dayton Hamvention's Technical Excellence award for 2001. The Dayton conference is the preeminent event for amateur radio in North America. “PSK31's elegant and effective design has helped revitalize interest in HF digital modes.” (American Radio Relay League 2001 #12)

92 Interestingly, this FEC mode was also invented by Mr. Martinez (Martinez 1979 #158).

In our correspondence, Martinez emphasized the importance of live interactivity in amateur communications:

> "…[digital modes] took the hobby into a different area, away from the traditional two-way conversation between operators and towards unattended forwarding of messages… I saw this as a threat to the social structure of ham radio. It would take away the one strength that the hobby has, namely that it has at it's very heart the most ideal mechanism for the interchange of knowledge between it's followers worldwide. Think of almost any other hobby or leisure pastime, and it has to have it's newsletters, magazines, annual fairs etc., in order for the fans to meet each other and exchange ideas, but in ham radio the main activity of the hobby itself inherently contains this feature. The ham radio hobby contains within itself the social interaction mechanism which counteracts the tendency for radio hams and similar innovators to become hermits. I saw this change to digital amateur radio which removed the social interaction element as a slippery slope towards a dead end." (Martinez 2000 #161)

Martinez identifies the elimination of the human from the communicative loop, his reduction to a passive observer of the process of radio communication, as a threat to amateur radio and, therefore, to its role in innovation.

In my research I noted that there is a desire by a growing number of amateurs to re-insert themselves into the process, and become less dependent upon computer-based mediation in their amateur radio activities. This is interesting because it contrasts sharply with most amateurs' strong support of the Internet as a tool for information sharing. I conclude that while the Internet and, to a lesser extent, computer-mediated modes such as packet radio have a role in giving amateurs access to news and information, most hobbyists feel that these modes get in the way of real-time interaction with other amateurs.

Store-and-forward digital messaging has largely replaced real-time interactive chatting, the foundation of the amateur radio. This characteristic alone has impersonalized the hobby and is a matter of much debate within the amateur community. Email and mailing lists contrast negatively with the interactivity and spontaneity of real-time amateur radio communication.

Low speed packet radio, with a data rate of typically 1200 BPS, is not well suited to real-time communications. As we have seen, the AX.25 protocol adds considerable overhead and limits the effective bandwidth of the mode to a fraction of this figure.

Amateur bulletin board systems (BBSes), utilizing store-and-forward techniques, underwent a strong development cycle in the late 1980s to meet this dissatisfaction with packet radio real-time communications. It is ironic that the path taken to alleviate hobbyists' frustration with the inefficiencies of AX.25 had the more significant effect of distancing the amateur from the communicative process. Before amateur BBSes, keyboarding was a popular, if frustrating, activity.

Essentially mail servers, hobbyists checked amateur BBSes at their convenience to pick up waiting messages and leave mail for other amateurs. These bulletin board stations typically operated on the 2 metre amateur band. Over time, more sophisticated TNCs were developed with built-in electronic mailboxes. Mail for the user was then stored and retrieved automatically by the TNC itself. This reduced the burden on centralized BBS systems, but further removed the hobbyist from the process of communicating.

Many amateur packet networks moved to a higher data rate of 9600 BPS in the early to mid-1990s. However, due to the AX.25 standard, effective throughput remained much lower, and person-to-person live amateur communication ("keyboarding") did not gain any ground. The role of real-time interactive communication was debated in the amateur literature (Horzepa 1994 #109). A recent informal survey I conducted of Vancouver area packet operators revealed that none had had a "keyboarding" contact for many years (McQuiggin 2000 #175). The inefficiency of AX.25 had promoted development of, and later reliance on, the BBS and store-and-forward methodologies, and the fact that 9600 BPS packet communication was now available was moot. Amateurs had rejected "keyboarding" as unworkable. Low (and moderate) speed packet radio remains stagnant today.

With the development of even higher speed packet radio systems, such as the 56K project, real-time amateur communication is now practical. Higher data rates can provide effective real-time communication despite the overhead still imposed by the underlying AX.25 protocol. The members of the 56K project group experimented successfully with real-time applications, and "keyboarding" proved not only practical, but even popular.

It is ironic that one of the newest digital amateur radio modes, PSK31 (described in the last section), is totally dependent upon digital signal processing techniques and computer processing, yet was founded in part out of a desire by the inventor to address this loss of the personal in the hobby. PSK31 is a real-time, person-focused, interactive mode. Amateurs participating in a PSK31 communication type messages to each other and converse interactively at a speed constrained primarily by their typing ability.

Using PSK31, characters are transmitted as soon as they are typed. This is a form of digital streaming, but more significantly, a process in which the amateur is re-engaged and re-enabled as part of the communicative process. Copying (amateur vernacular for successfully reading and interpreting) another amateur station through interference and poor conditions of propagation is challenging and fun!

The brain is quite capable of detecting errors caused by interference on the radio frequency in the received text, and correcting those errors through contextualization and interpolation. It is the reintroduction of the human into this process that has drawn amateurs across the globe to PSK31 and revitalized “keyboarding” and amateur roundtable discussions.

With PSK31, amateur radio is shown to be resisting the move to digitally managed networks that depend on complex infrastructure. Amateurs are eager to forego overhead-intensive modes of communication that package and de-personalize their experience and distance them from other participants. People value unmediated communication. The use of simpler protocols enhances the communicative experience.

This is not to imply that the underlying complexity of PSK31 is under-appreciated: it is the complicated processes of phase-shift keying, digital signal processing and variable length encoding of characters that allows PSK31 to outperform older digital modes. The lack of a link-level protocol in PSK31 appeals to amateurs because it allows, indeed requires, them to take a more active role in the process of managing the communication.

This is a dichotomy. PSK31 depends on advanced technology, but its appeal to the amateur community is based largely on the lack of technological bells and whistles. The new mode strikes a balance. This is PSK31's essential element. With technology, more is not always better.

I theorize that with these observations amateur radio is once again demonstrating its prescience, and that in the near future a similar flight from some forms of highly managed digital technologies will be observed in other areas of society. Perhaps exciting new commercial products which put the human back into the communicative loop, with consequent consumer appeal and profit potential, will result.

Software-Defined Radios

PSK31 is a mode dependent upon computer software for its viability. Without partnership between the conventional analog receiving and transmitting equipment, and the digital signal processing and control functions provided by software, in this case running on any personal computer, PSK31 would not exist. PSK31 exemplifies a software-defined radio.

The subject of software-defined radios (SDRs) is of great interest to both industry (Schreier 2001 #219) and government (Hatfield 2000 #102). An SDR's operating characteristics are dependent on the software running on the microprocessors that are at the heart of the radio. Through use of computer technology, a single piece of hardware can serve in many roles and support many modes[93]. By loading different operating software into the radio, an AM broadcast receiver can double as an FM amateur radio transceiver, a spectrum analyzer, a signal generator, or even a military spread-spectrum communications device. This incredible flexibility is possible because of the recent advances in DSP technology.

This versatility, when applied to basic radio circuitry controlled by digital signal processing routines, allows the radio to assume many different roles. Additionally, the user interface, the "front panel" on the radio, is under software control, is easily customized for different uses, or even for personal preference. Such an approach is of great interest to industry, as a single device that can be conveniently mass-produced can be used to create many different end products.

In the United States, the Office of Engineering and Technology, part of the FCC, sees the SDR as an important technology that will be key to the evolution of radio communications in the next century, and to the issues of spectrum allocation and management (Hatfield 2000 #102). Amateur radio hobbyists have been encouraged by government to explore this technology and contribute to the body of knowledge in this area (Hatfield 2000 #101). The American Radio Relay League filed comments supportive of the technology in response to an FCC "Notice of Inquiry" into software-defined radios in March, 2000. The ARRL called amateur radio a "fertile testing ground" for SDR-related research, especially in the area of disaster communications (Lindquist 2000 #143). Said the organization:

---

93 Much as through choice of software a personal computer can become a word processor, a manipulator of scientific data culled from astronomical observations, a communications device, and a game machine.

> "Amateur radio is not constrained by limitations imposed on other services and serves as a reasonable paradigm for a regulatory structure that might be adapted to other services" (Lindquist 2000 #143).

PSK31 and similar new technologies enjoy support from the FCC because of the contributions amateurs can make into their development and application (Maia 2000 #155). The ARRL maintains a web page on software-defined radio technology (Technical Information Service 2001 #232), and encourages its development as part of the organization's mandate to support experimentation towards the advancement of the radio art (American Radio Relay League 2001 #10).

The DSP-10 Project

Another significant new technology, which I will consider briefly as it exemplifies SDR development within amateur radio, is the *DSP-10* project[94]. The DSP-10 is a software-defined radio that operates on the 144 MHz amateur band (Larkin 2001 #139). Required hardware is available as a kit, and software is freely available via the Internet. The radio was featured in a series of articles in the amateur journal QST in the autumn of 1999 (Larkin 1999 #138). Amateurs may modify the software as desired to change the characteristics of the radio or improve its performance.

Digital signal processing is used to achieve unprecedented sensitivity and selectivity in the radio. Communications have been achieved at certain frequencies

---

[94] See http://www.proaxis.com/~boblark/dsp10.htm.

and power levels that were truly impossible using older analog technology. An example is the recent achievement of EME communications between two amateur stations at a power level of 5 watts[95] (Larkin 2001 #139, "QRP 5-Watt 1296 EME QSO"). Creator Larkin received an ARRL technical innovation award for his work on this project (QST Editors 2001 #202).

Amateur experimentation with these new technologies shows that creativity and innovation within the activity are alive and well, that amateur radio still has relevance as a site of communications research, and that it is making significant contributions to advancing the art and science of radio. The hobby needs to be supported by industry and government as a source of new technologies, new ideas and approaches to problems, and as a provider of technically trained personnel (Laport, Tilton et al. 1981 #137).

Summary

The three examples considered in this chapter exemplify the innovative activities that are currently underway in amateur radio. The 56K packet radio project, as a digital technology, is a good example of cost effective digital communications and the leverage of open standards to meet communicative needs for emergency communication and other situations. The BC Amateur Television Group's repeater network is an example of an effective new analog technology that meets communicative needs, has wide application, and relies on cleverly modified

---

[95] Using analog techniques a minimum of 500 – 1000 watts, and very large antenna arrays are required. Cost for such equipment could easily run to thousands of dollars.

commercial and surplus equipment. This project makes effective use of several of the under-utilized amateur bands in the microwave region. Finally, the new mode PSK31 is an interesting hybrid (analog-digital) technology, that makes leading-edge use of the personal computer to achieve unprecedented spectral efficiency, while simultaneously reinserting the human brain into the communicative loop. PSK31 has diffused at an extraordinary rate and now enjoys global popularity due to both its technical efficiency, and the renewed participative role it gives the amateur herself.

Collectively, these projects show the interesting and creative work that is currently ongoing within the purview of amateur radio. Commercial or governmental interest has been expressed in each of these new technologies: 56K has been presented to the United Nations as an effective and appropriate digital technology for use in developing regions, and for disaster response (Anderson 2001 #26); the BCATVG television repeater system has received positive reviews from commercial television technicians (Schouten 2000 #218); and PSK31's hybrid approach, it's mix of analog and digital technologies, has generated positive feedback from the Federal Communications Commission in the United States, where it has served as an example of futuristic radio technology (Maia 2000 #155).

Great potential exists in the use of new digital signal processing techniques in the design of amateur and commercial radio equipment. Analog devices and techniques are represented mathematically and implemented by specialized microprocessors. With this approach, the division between analog and digital approaches to radio communication is simultaneously emphasized and blurred. The ease of reconfiguration of a DSP-based radio (by simply changing the software that defines how the radio operates) means that new modes, operating techniques, and changing regulations, can be implemented efficiently. Perhaps the only difference between commercial and amateur radio equipment in years to come will be in the software that defines the device itself.

Chapter VI

Amateur Radio and the Internet

Much of the current popular literature on the Internet centres on the idea of the Internet as a "space", and as a new form of communication that will foster global understanding and cooperation through the elimination of distance and time. This has been argued as being without precedent.

In fact, striking similarities exist between the Internet and other, earlier, forms of electronic communication such as the international telegraph networks built in the mid-19^{th} century, and amateur radio (Mattelart 1994 #163). In his recent book, *"The Victorian Internet*", author Tom Standage studies the development of the telegraph, and how the new technology was to educate, inform, and promote global understanding and world peace (Standage 1998 #224). Broadcast radio, in its nascent form, was promoted to have similar promise (Lewis 1993 #141). Wade Rowland dwells on the birth of radio, amateur radio, broadcasting, and the introduction of advertising as a means of financial support for the new medium. He notes that this is eerily similar to recent commercial development on the Internet (Rowland 1999 #216).

Despite the popular literature, the physically disconnected yet communicatively linked, unmediated two-way characteristics of the Internet have much in common with amateur radio. Internet researchers can learn much from this.

Ham radio operators have populated this "space" for almost one hundred years. Amateur communication takes place both in real-time, and on a store-and-forward basis. Users may be widely separated geographically, yet collaborate on projects or work towards common goals. Amateurs meet, learn, argue, and pursue their own agendas over the airwaves. The physically disconnected nature of the communication blurs social and economic boundaries. Communities expand and contract, debate is frequent, and no geographic borders exist.

Amateur radio has decades' experience with the sort of cross-cultural and regulatory issues facing the Internet. Participants hail from a similarly diverse social, economic, and educational cross-section as the class of Internet users. Bandwidth issues reflect early struggles over interference. Like radio in the 1920s, with lobbying and regulatory pressures, the voice of the individual on the Internet is being overwhelmed by the corporation in search of a sustainable business model for the new medium (Ross 1991 #215).

Standards developed within amateur radio to address linguistic barriers in an effective manner, something that is still problematic on the Internet. Amateur radio chose to address language issues through the development of a common standard. The "Q" signals and other abbreviations and operating conventions described above are today embodied in technologically based protocols such as TCP/IP and XML. These computationally based standards could not have been developed in the early twentieth century.

In its formative period amateur radio attracted technically literate people, the "boy wonders" alluded to by DeSoto, Ross, and Douglas (DeSoto 1936 #70; Ross 1991 #215; Douglas 1999 #76). New technologies, large corporations and "radio millionaires" grew out of basement workshops (Lewis 1993 #141). The parallels with the development of personal computing and the Internet are remarkable.

Researchers interested in the Internet, and its future as a communication technology, may wish to study the development of amateur radio through the past century. From a social perspective, the similarities of the two technologies may provide researchers with insight into how the Internet will evolve over the next one hundred years.

Conclusion and Recommendations

Amateur radio represents a unique research and development environment. The contributions made by amateurs over the past one hundred years include several significant new technologies. These new modes and operating techniques have been widely adopted outside of the amateur radio community. Both the telecommunications industry and public sector communications services owe a significant debt to amateur radio, which has served as the source of many of their ideas and operating techniques.

Significant creativity continues within the hobby today. Amateur radio needs to be protected by government, and fostered by industry, so that it is allowed to continue as a source of creative ideas, radical inventions, and conservative innovation. The Canadian government needs to emphasize the contributions of amateur radio to industry, preserve amateur spectrum allocations, and support cooperative efforts between amateurs and industry that can result in new socially or commercially viable technologies.

Academic research into the Internet may also benefit from an examination of the history and characteristics of amateur radio. The two activities (or technologies) have comparable social origins and many other interesting similarities. A comparative study of the two may enable more accurate prediction of how this newer global communications medium will evolve in the coming decades. Amateur radio has already trodden the “uncharted” paths of the Internet’s future, and researchers may find predictive validity in a study of the century-old history of amateur radio.

The diverse cultural and educational background of amateur radio operators serves to imbue the research and development environment within the hobby with motivation, pattern of thought, and investigative insight, which is usually not captured within institutionalized R&D environments.

The relevance of this non-traditional R&D is self-evident, in the diversity and type of innovation that has arisen out of the hobby over the past century. Industry and the public have benefited from the unstructured investigative system of amateur radio. The hobby serves as a source of creativity, new ideas, technologies and in the innovative application of existing technologies, all of which have been adopted and commercialized, or put to work in the public sector for improved quality of life. Such an environment cannot be duplicated in either the private or governmental sectors.

As such, a strong amateur radio service is beneficial to both the telecommunications industry and the public. Pressures from industry for reallocation of amateur spectrum allocations, especially in the VHF, UHF, and microwave bands, to their exclusive use, may shut off amateurs from further experimentation in these regions.

The recent trend by some national communications authorities, and to a lesser extent by Industry Canada, to use auctions as a method of spectrum allocation lacks vision and promotes concentration of ownership. Loss of the amateur radio bands would hurt Canada's competitive position in world markets. Governmental support of technical hobbies like amateur radio also ensures a reserve of technically trained citizens and serves to feed the post-secondary educational system with more highly trained students. Better engineers and scientists build a stronger Canadian economy.

The oblique approach to problem solving by amateur radio complements industrial R&D efforts, and an effective partnership between industry and amateur research and development groups could help Canada be more competitive. Current R&D policy in Canada does not acknowledge the existence of non-traditional research communities like that of amateur radio. Industry Canada may wish to explore methods of formalizing support for non-traditional R&D through sponsorship and by partnership between industry and non-industrial groups.

Amateur radio groups could be formally recognized by Industry Canada as able contributors to technological and social development, and given the opportunity to receive R&D funding. Federal policy changes could specify standards and ensure proper oversight of amateur research and development. With financial support and beneficent oversight, what interesting new discoveries will result?

Industry could be given incentives by government for partnership and investment in non-traditional R&D. In this way the telecommunications industry could leverage the unique problem solving approaches employed by amateur radio hobbyists. Perhaps a percentage of the required R&D re-investment by industry could be directed specifically to non-industrial research. Cooperative partnerships between industry and qualified amateur radio research groups would generate creative new products and benefit the hobby, the telecommunications industry, our economy, and Canadian society.

If government support is lost, and industry continues pressure for access to more spectrum, while losing sight of these greater goals, then amateur radio, as a hobby with little coordinated representation, and no financial means, cannot compete. With the demise of amateur radio, what new discoveries, communication modes, or operating techniques will be lost?

Bibliography

1. American Radio Relay League (1928). “Amateur Television Waves.” QST(October 1928): page 8.

2. American Radio Relay League (1965). Fifty Years of A.R.R.L. Newington, CT, American Radio Relay League.

3. American Radio Relay League (1976). The Radio Amateur's Handbook. Newington, CT, The American Radio Relay League.

4. American Radio Relay League (1997). LITTLE LEOs NARROW 2-METER FOCUS TO 146-148 MHZ, American Radio Relay League. http://www.arrl.org/arrlletter/97/970117/#little_leos.

5. American Radio Relay League (2000). The ARRL Operating Manual. Newington, CT, American radio Relay League.

6. American Radio Relay League (2000). ARRLWeb Survey Results: How often do you participate in public service nets or activities? http://www.arrl.org/survey.php3?pollnr=18.

7. American Radio Relay League (2000). FCC Set to Authorize MURS. http://www.arrl.org/arrlletter/00/1013/.

8. American Radio Relay League (2000). Threats to Our Amateur Bands, American Radio Relay league. http://www.arrl.org/news/bandthreat/.

9. American Radio Relay League (2000). Why It's Called Ham Radio. http://www.arrl.org/whyham.html.

10. American Radio Relay League (2001). About the ARRL, American Radio Relay League. http://www.arrl.org/aarrl.html.

11. American Radio Relay League (2001). The ARRL Handbook for Radio Amateurs. Newington, CT, American Radio Relay League.

12. American Radio Relay League (2001). The ARRL Letter: Hamvention 2001 Award Winners Announced. http://www.arrl.org/arrlletter/01/0323/.

13. American Radio Relay League (2001). ARRL to FCC: Stop the Encroachments! http://www.arrl.org/w1aw/2001-arlb034.html.

14. American Radio Relay League (2001). ARRL, AeroAstro Square Off Over 2300-2305 MHz. http://www.arrl.org/w1aw/2001-arlb029.html.

15. American Radio Relay League (2001). CQ Amateur Radio Hall of Fame Inaugural Class Announced. http://www.arrl.org/news/stories/2001/05/23/3/.

16. American Radio Relay League (2001). FCC Action Puts Amateur Allocation in Peril. http://www.arrl.org/w1aw/2001-arlb032.html.

17. American Radio Relay League (2001). FCC Denies LA County 2.4 GHz Application, Cancels Experimental Grant to City. http://www.arrl.org/news/stories/2001/03/15/2/.

18. American Radio Relay League (2001). FCC Part-15 Rules: Unlicensed RF Devices, American Radio Relay League. http://www.arrl.org/tis/info/part15.html.

19. American Radio Relay League (2001). IARU Administrative Council Calls for End to Morse Requirement. Newington, CT, American Radio Relay League: press release.

20. American Radio Relay League (2001). Part 97 Amateur Radio Service, ARRL. http://www.arrl.org/FandES/field/regulations/news/part97/.

21. American Radio Relay League (2001). The Q Code, American Radio Relay League. http://www.arrl.org/tis/info/history.html#q.

22. American Radio Relay League (2001). Welcome to Amateur Radio. http://www.arrl.org/hamradio.html.

23. Anderson, P. (1999). Virtual Emergency Management Information Systems, Emergency Preparedness Information Exchange. http://hoshi.cic.sfu.ca/epix/vemis/ppt/sld025.htm.

24. Anderson, P. (2000). VEMIS Background Information, Emergency Preparedness Information Exchange. http://hoshi.cic.sfu.ca/epix/vemis/backgrnd.html.

25. Anderson, P. (2000). Welcome to the Virtual Emergency Management Information System Prototype, Emergency Preparedness Information Exchange. http://hoshi.cic.sfu.ca/epix/vemis/index.html.

26. Anderson, P. (2001). Information on IDNDR and UN Working Group on Emergency Telecommunications. Personal communication. K. McQuiggin. Burnaby, BC.

27. Archer, G. L. (1971). History of Radio to 1926. New York, Arno Press.

28. ARRL Technical Information Service and C. B. DeSoto (2001). The American Radio Relay League: How it Came to Be, American Radio Relay League. http://www.arrl.org/members-only/tis/info/Html/hamradio-hist/arrlhist.html.

29. Australian Communications Authority (2001). Amateur Licence Information Paper. http://www.aca.gov.au/publications/info/amateur.htm.

30. Australian Communications Authority (2001). What We Do - Spectrum Marketing Group. http://auction.aca.gov.au/about.htm.

31. Ball, S. H. (1989). “Douglas Lockhart, VE7APU, Packet Radio Pioneer.” QST(March, 1989): pages 49 - 50.

32. Barnhart, R. K. (1988). The Barnhart Dictionary of Etymology, H. W. Wilson.

33. Barnouw, E. (1966). A History of Broadcasting in the United States. New York, Oxford University Press.

34. Belrose, J. S. (2000). Amateur Radio and Innovation. Personal communication. K. McQuiggin. Ottawa.

35. Bernstein, D. H. (2001). Re: Looking for PSK31 Statistical Info. Personal communication. K. McQuiggin.

36. Bible, S. R. (2001). A Brief History of Amateur Satellites, AMSAT. http://www.amsat.org/amsat/sats/n7hpr/history.html.

37. Bible, S. R. (2001). What is Amateur Radio Spread Spectrum?, Tuscon Amateur Packet Radio. http://www.tapr.org/tapr/html/ssf.html.

38. Bird, R. A., Ed. (1988). Documents of Canadian Broadcasting. Don Mills, ON, Carleton University Press.

39. Bixby, E. and S. Horzepa (1999). CLOVER Inventor Ray Petit, W7GHM, SK (Obituary), American Radio Relay League. http://www.arrl.org/news/stories/1999/06/18/2/.

40. Boekenkruger, D. (2001). VE7RTV - Amateur Television Repeater, BC Amateur Television Group. http://www.burnabyradio.com/ve7rtv/ .

41. Boekenkruger, D. (2001). VE7RTV Screen Shot. Burnaby, BC, BC Amateur Television Group.

42. Boekenkruger, D., R. Wiejak, et al. (2001). VE7RTV Future Planning (Interview), BC Amateur Television Group.

43. Borden, D. W. and P. Rinaldo (1981). "The Making Of An Amateur Packet-Radio Network." QST(October 1981): pages 28 - 30.

44. Bowers, R. V. (1934). Genetic Study of Institutional Growth and Cultural Diffusion in Contemporary American Civilization: An Analysis in Terms of Amateur Radio. Ph.D. Dissertation, Department of Sociology, University of Minnesota.

45. Bowers, R. V. (1938). "Differential Intensity of Intra-Societal Diffusion." American Sociological Review III(Nos. 1-6): 21-31.

46. Braham, S. (2000). PolyLAB SpaceSystems Group, Simon Fraser University. http://polylab.sfu.ca/spacesystems/.

47. Brewin, B. (2001). 3G Requirements Raise Stakes in Spectrum Battle. Computerworld August 20, 2001**:** page 15.

48. Brooks, J. (2001). Re: Looking for PSK31 Statistical Info. Personal communication. K. McQuiggin.

49. Bruninga, B. (1994). "Automatic Packet Reporting System (APRS)." QEX(February 1994): page 10.

50. Brussaard, G. (1999). "Meteor Burst" Technology for the Civilian Market, University of Eindhoven. http://www.starcomwireless.com/technology/articlereader.asp?tf=StarCom_Technology.txt.

51. Campbell, L. and W. Garnett (1882). The Life of James Clerk Maxwell. London, MacMillan.

52. Canadian Communications Foundation (2000). Biographies of Canadian Broadcasting, Canadian Communications Foundation. http://www.rcc.ryerson.ca/ccf/personal/hof/fessen_r.html.

53. Canadian Wireless Telecommunications Association (2001). Wireless Facts, CWTA. http://www.cwta.ca/industry_guide/facts.php3.

54. Ceruzzi, P. E. (1998). A History of Modern Computing, Massachusetts Institute of Technology.

55. Charron, G. (2001). Full HF privileges for B + 5, Radio Amateurs of Canada.

56. Cheney, M. (1981). Tesla, Man Out of Time. Englewood Cliffs, New Jersey, Prentice Hall.

57. Clark, T. (1986). “The Problem With Digipeaters.” Fidonet HAM/PACKET Digest Volume 1, Number 6.

58. Cleveland-Iliffe, J. and G. R. Smith (1999). RAC Study Guide for the Basic Exam. Ottawa, Ontario, Radio Amateurs of Canada.

59. Coffee, P. (1999). “Sharpening the Edge of Amateur Innovation.” QST(November, 1999): page 57.

60. Cohen, T. J. (2001). A CQ Exclusive Interview with Leo I. Meyerson, W0GFQ. CQ Amateur Radio November, 2001**:** pages 20 - 26.

61. Coll, D. C. (1986). Notes on Some Significant Canadian Telecommunications Activities. Canadian Developments in Telecommunications. T. L. McPhail and D. C. Coll. Calgary, AB, University of Calgary.

62. CQ Communications (Editors) (2001). “Reader Survey - What You've Told Us.” CQ Amateur Radio(August, 2001): page 40.

63. Craig, A. M. (2001). Amateur Radio and Innovation (Interview). Langley, BC.

64. Dalton, W. M. (1975). The Story of Radio, Part 1: How Radio Began. Bath, Great Britain, Hilger.

65. Dalton, W. M. (1975). The Story of Radio, Part 2: Everyone an Amateur. Bath, Great Britain, Hilger.

66. Davidoff, M. R. (1984). The Satellite Experimenter's Handbook. Newington, CT, American Radio Relay League.

67. Davis, D. T. (1995). “Amateur Radio and World War II.” QST(August, 1995): pages 40 - 44.

68. De Vany, A. (1998). Property Rights in the Electromagnetic Spectrum. London, Macmillan.

69. Department of Communications (1985). Discussion Paper on a Possible Restructuring of the Amateur Radio Service in Canada. Ottawa, Government of Canada.

70. DeSoto, C. B. (1936). Two Hundred Meters and Down. West Hartford Connecticut, American Radio Relay League.

71. DeSoto, C. B. (1942). “W6GRL is China's U.S. Listening Post.” QST(May, 1942): page 53.

72. DeSoto, C. B. (1943). “Concerning Military Radio Developments and the Amateur.” QST(September, 1943): pages 7 - 8.

73. Dewhirst, T. P. (1928). “Radiovision.” QST(September, 1928): pages 15 - 18.

74. Dolan, D. H. J. (2001). Re: Looking for PSK31 Statistical Info. Personal communication. K. McQuiggin.

75. Douglas, S. J. (1986). Amateur Operators and American Broadcasting: Shaping the Future of Radio. Imagining Tomorrow: History, Technology, and the American Future. J. J. Corn. Cambridge, MA, MIT Press**:** pages 35-55.

76. Douglas, S. J. (1999). Listening In: Radio and the American Imagination. New York, Random House.

77. DXing.com (2001). Radio Terms and Abbreviations, Universal Radio Research. http://www.dxing.com/radioterms.htm.

78. Eimac (1975 - 1978). "Successful 144 MHz EME Antennas",
"A Small, Inexpensive Moonbounce Antenna System for 144 MHz",
"Two More Moon Tracking Computer Programs". EME Notes. San Carlos, CA.

79. Engel, F. (2001). Re: Full HF Privileges for Basic + 5 WPM. Personal communication. K. McQuiggin. Burnaby, BC.

80. Ennis, S. (2000). “Utilizing the Constant Bombardment of Cosmic Debris for Routine Communication.” QST(November, 2000): pages 28 - 32.

81. Eshleman, V. R. (1957). “On the Wavelength Dependence of the Information Capacity of Meteor-Burst Propagation.” Proceedings of the IRE(December 1957): pages 1710 - 1714.

82. Ewald, S. (2000). Chapter One: The National Traffic System, American Radio Relay League. http://www.arrl.org/FandES/field/pscm/sec2-ch1.html.

83. Federal Communications Commission (1999). All About Auctions. http://www.fcc.gov/wtb/auctions/papers/allabout.pdf.

84. Federal Communications Commission (2000). General Auction Data/Summary Matrix, Federal Communicaions Commission,. http://www.fcc.gov/wtb/auctions/summary/aucsum.pdf.

85. Federal Communications Commission (2001). Re: Experimental Radio Station WB2XEN, File No. 0247-EX-PL-1999. a. a. c. Letter to petitioners. Washington, DC.

86. Federal Communications Commission (2001). Who We Are. http://www.fcc.gov/wtb/organization/.

87. Fergus, A. M. H. (1931). “The Sun and DX.” QST(May, 1931): pages 48 - 49.

88. Fisher, L. M. (1992). Plug is Pulled on Heathkits, Ending a Do-It-Yourself Era. New York Times. New York**:** pages D9 - D10.

89. Ford, S. (1999). “PSK31 - Has RTTY's Replacement Arrived?” QST(May, 1999): 41-44.

90. Ford, S. (2000). “PSK31 2000.” QST(May, 2000): 42-45.

91. Ford, S. (2001). “The HF Digital "Tower of Babel".” QST(January, 2001): pages 50 - 53.

92. Forsythe, P. A., E. L. Vogan, et al. (1957). “The Principles of JANET - A Meteor Burst Communication System.” Proceedings of the IRE 45(12): pages 1642 - 1657.

93. Frame, J. D. (2000). The Canadian Amateur Radio Callsign Database, Radio Amateurs of Canada. http://www.rac.ca/callbook/.

94. Ghigo, F. (1999). Grote Reber and his Radio Telescope, National Radio Astronomy Observatory. http://www.gb.nrao.edu/~fghigo/fgdocs/reber/greber.html.

95. Ghigo, F. (2001). Karl Jansky and the Discovery of Cosmic Radio Waves, National Radio Astronomy Observatory. http://www.gb.nrao.edu/~fghigo/fgdocs/jansky/jansky.html.

96. Goodman, B. (1948). “What is Single-Sideband Telephony.” QST(January 1948): pages 13-15.

97. Government of Canada (1995). Department of Communications Act. C-35.

98. Greenman, M. (2001). “MFSK for the New Millenium.” QST(january, 2001): pages 33 - 36.

99. Handy, F. E. (1931). “The Viking Disaster.” QST(June 1931): page 41.

100. Handy, F. E. (1939). “Fire Disaster, Val D'Or, Quebec.” QST(April 1939): page 67.

101. Hatfield, D. N. (2000). The Role of Amateur Radio in the New Century. Falls Church, VA.

102. Hatfield, D. N. (2000). Software Defined Radio: A Regulator's Perspective. Seattle, Washington.

103. Henderson, R. (1997). “Brass Under Fire: World War II Army Signalmen in the Amateur Radio Service.” QST(November 1997): page 28.

104. Hennessee, J. C. (1990). “Canada Adopts New Rules.” QST(December, 1990): page 73.

105. Henry, B. (1992). “Getting Started in Digital Communications - Part 4 - AMTOR... and Beyond.” QST(June 1992): pages 34 - 45.

106. Herriot, P. and C. Pemberton (1995). Competitive Advantage Through Diversity: Organizational Learning from Difference. London, Sage.

107. Hesler, R. (1978). “DOC Creates New Amateur Licence Class.” QST(December, 1978): page 61.

108. Horzepa, S. (1989). “Can Packet Radio Be Saved?” QST(August, 1989): page 42.

109. Horzepa, S. (1994). “Wanted, Dead of Alive: Real-Time Packet QSOs.” QST(April, 1994): page 108.

110. Hutchison, G. (2001). RTTY.COM. http://www.rtty.com.

111. Hyder, H. R. (1992). “The Final Days of Ham Spark.” QST(March, 1992): pages 29 - 32.

112. Industry Canada (1995). Radio Spectrum Allocations in Canada. Ottawa, Ministry of Supply and Services Canada.

113. Industry Canada (1995). Spectrum Utilization Policy for the Mobile, Broadcasting and Amateur Services in the Frequency Range 30-896 MHz, Part II (SP 30-896
MHz, Part II). Radio Communication Act.

114. Industry Canada (1998). Framework for Spectrum Auctions in Canada, Industry Canada. http://spectrum.ic.gc.ca/auctions/engdoc/frame.pdf.

115. Industry Canada (1999). Discussion Paper: Streamlining the Authorization Process for the Amateur Radio Service, Government of Canada. http://strategis.ic.gc.ca/pics/sf/amateur.pdf.

116. Industry Canada (1999). Guidelines for Compliance with the Radio Authorization Condition of Licence Relating to Research and Development. Ottawa, Government of Canada: 28.

117. Industry Canada (1999). MINISTER MANLEY ANNOUNCES PROVISIONAL LICENCE WINNERS OF CANADA'S FIRST SPECTRUM AUCTION. E. Hoeg. Ottawa, Industry Canada - News Release.

118. Industry Canada (2000). INDUSTRY CANADA APPROVES SALE AND USE OF FAMILY RADIO SERVICE DEVICES IN CANADA, Government of Canada. http://strategis.ic.gc.ca/SSG/sf02120e.html.

119. Industry Canada (2000). Notice No. DGTP-004-2000 — Spectrum Utilization Policy to Permit Licence-Exempt Family Radio Devices in the Land Mobile Frequency Sub-bands 462-467 MHz (SP-462 MHz), Government of Canada. http://strategis.ic.gc.ca/SSG/sf02117e.html.

120. Industry Canada (2000). Radiocommunication Information Circular 3: "Information on the Amateur Radio Service. Ottawa, Government of Canada.

121. Industry Canada (2001). Acts Under the Responsibility of the Minister of Industry. http://www.ic.gc.ca/cmb/Welcomeic.nsf/ICPages/Acts.

122. Industry Canada (2001). CANADIAN AMATEUR RADIO ADVISORY BOARD MINUTES OF MEETINGS, Industry Canada. http://strategis.ic.gc.ca/SSG/sf01778e.html.

123. Industry Canada (2001). Radiocommunication Information Circular 2: "Standards for the Operation of Radio Stations in the Amateur Radio Service. Ottawa, Government of Canada.

124. Industry Canada (2001). Software to Generate Amateur Examinations, Industry Canada. http://strategis.ic.gc.ca/SSG/sf05378e.html.

125. International Amateur Radio Union (2000). Home page, IARU. http://www.iaru.org.

126. International Telecommunication Union (1998). Radio Regulations - ARTICLE S1 Terms and Definitions, International Telecommunication Union. http://www.itu.int/plweb-cgi/fastweb?getdoc+view1+www+25678+2++amateur%20radio%20definition.

127. International Telecommunication Union (2000). Home Page, ITU. http://www.itu.int/home/index.html.

128. International Telecommunication Union (2000). Membership, ITU. http://www.itu.int/members/index.html.

129. Jacob, E. (2000). The Official PSK31 WWW Homepage. http://bipt106.bi.ehu.es/psk31.html.

130. Kauffman, H. (1946). "A DX Record: To the Moon and Back." QST(May, 1946): pages 65-68.

131. Kostenbauder, S. I. (1976). AMATEUR RADIO AS AN AVOCATIONAL INFLUENCE ON THE SELECTION AND DEVELOPMENT OF TECHNICAL CAREERS BY INDIVIDUALS. Ph.D Dissertation, Education, University of Pennsylvania.

132. Krigbaum, J. (1999). Packet Radio Training Course Reference Manual, Ventura County ARES AREA 6 Training Group. http://www.rain.org/~jkrigbam/packet.htm.

133. Kruse, R. S. (1927). "Amateur Telephotography." QST(June 1927): 41.

134. Labaton, S. (2000). Clinton Orders A New Auction Of the Airwaves. New York Times. New York.

135. Lamb, J. J. (1937). "Radio Amateurs in the Television Picture." QST(December, 1937): page 8.

136. Lang, B. (2000). “20th Anniversary of Amateur Packet Radio.” White Noise(June/July 1998): page 4.

137. Laport, E. A., E. P. Tilton, et al. (1981). “Amateur Radio: Contributions to the Art and Science of Communications.” IEEE Communications Magazine(July 1981): pages 16 - 24.

138. Larkin, B. (1999). “The DSP-10:An All-Mode 2-Meter Transceiver Using a DSP IF and PC-Controlled Front Panel.” QST(September, 1999): pages 33 - 41.

139. Larkin, B. (2001). DSP-10 Project. http://www.proaxis.com/~boblark/dsp10.htm.

140. Lazar, F. (1996). How Ottawa Rewards Mediocrity. Toronto, University of Toronto.

141. Lewis, T. S. W. (1993). Empire of the Air. New York, NY, Harper Collins.

142. Lindquist, R. (1999). PSK31--A New Mode for HF, American Radio Relay League. http://www.arrl.org/news/features/1999/0201/3/.

143. Lindquist, R. (2000). “ARRL Says Amateur Service is Fertile Testing Ground for SDR Technology.” QST(September 2000): page 70.

144. Lindquist, R. (2000). “Restructuring is Here: Three License Classes, One Code Speed.” QST volume 84, number 2(February 2000): pages 68 - 69.

145. Lindquist, R. (2001). Ham Radio Experiences Post-Restructuring Growth Spurt. QST June 2001**:** page 82.

146. Livesey, D. (2000). VE Stats. Personal communication. K. McQuiggin. Burnaby, BC.

147. Lockhart, D. (2000). Conception and Development of Packet Radio (Interview). Surrey, BC.

148. Lynch, C. A., Brownrigg, Edwin B. (1987). Packet Radio Networks: Architectures, Protocols, Technologies and Applications. Oxford, Pergamon.

149. Lynn, P. A. and W. Fuerst (1998). Introductory Digital Signal Processing with Computer Applications, Wiley.

150. Lyons, E. (1966). David Sarnoff, a Biography. New York, Harper & Row.

151. MacDonald, C. (1958). “A New Narrowband Image Transmission System.” QST(August 1958): pages 11 - 15, 140.

152. MacLaurin, W. R. (1971). Invention and Innovation in the Radio Industry. New York, Arno Press.

153. MacLean, H. (1985). “Doug Lockhart: 1984 CRRL Amateur of the Year.” QST(January 1985): page 61.

154. Magliacane, J. A. (1992). “Spotlight on the Microsats.” The AMSAT Journal 15(4).

155. Maia, F. O. (2000). “Washington Readout.” CQ Amateur Radio 56(9): pages 22- 26.

156. Markey, H. K. and G. Antheil (1942). Secret Communication System. US Patent and Trademark Office. United States.

157. Martin, R. (2000). EOC Summary of Activities, 1999. Vancouver, BC, City of Vancouver.

158. Martinez, P. (1979). “Amtor, an Improved RTTY System Using a Microprocessor.” Radio Communication(August 1979).

159. Martinez, P. (1998). PSK31 Fundamentals. http://bipt106.bi.ehu.es/psk31theory.html.

160. Martinez, P. (1998). PSK31: A new radio-teletype mode with a traditional philosophy. http://bipt106.bi.ehu.es/psk31theory.html.

161. Martinez, P. (2000). Re: Questions on PSK31 Development. K. McQuiggin. Burnaby, BC.

162. Marvin, C. (1996). Early Uses of the Telephone. Communication in History. D. Crowley and P. Heyer. White Plains, NY, Longman: pages 173 - 180.

163. Mattelart, A. (1994). Mapping World Communication: War, Progress, Culture. Minneapolis, MN, The University Of Minnesota Press.

164. Maxim, H. P. (1916). “Practical Relaying.” QST(February 1916): 19 - 22.

165. Maxim, H. P. and C. Tuska (1916). “The Propagation of Wireless Waves.” QST(September, 1916): pages 235 - 236.

166. Maxwell, J. (2000). “Amateur Radio: 100 Years of Discovery.” QST(January, 2000): pages 28 - 34.

167. Maxwell, J. (2001). Report of the Ad Hoc Spectrum Strategy Committee. Newington, CT, American Radio Relay League.

168. McElroy, G. (1994). “Before Spark.” QST(January, 1994): pages 57 - 59.

169. McElroy, G. (1995). “Remembering Hugo Gernsback.” QST(February, 1995): pages 37 - 39.

170. McEwen, N. (1999). Police Radiotelegraph Networks. http://www.metronet.com/~nmcewen/police_radio.html.

171. McLellan, R. B. (1942). “Listening Post - Correspondence.” QST(August, 1942): page 79.

172. McMasters, J. R. (1998). “High-Speed CW and Meteor Scatter--An Excting VHF DX Medium!” QST(April, 1998): page 34.

173. McQuiggin, K. (1989). Packet Radio Protocol. Burnaby, BC.

174. McQuiggin, K. (1998). Seismic Monitoring and Reporting Computer Program. Burnaby, BC.

175. McQuiggin, K. (2000). Meeting with VAPO Membership. Surrey, BC.

176. McQuiggin, K. (2000). Research: Informal Interviews, BCATVG Membership.

177. McQuiggin, K. (2001). Discussions re VECTOR Amateur Radio Association. Vancouver, BC.

178. Melnyk, M. E. (1997). Inappropriateness of Spectrum Auctioning in a Canadian Context. Ottawa, ON, The Public Interest Advocacy Centre**:** 113 pages.

179. Meltz, S. (1999). “The "New" HF Digital Modes.” QST(April, 1999): 50-51.

180. Merriam-Webster Inc. (2000). Merriam-Webster Online Dictionary. http://www.m-w.com/cgi-bin/dictionary.

181. Merrill, F. D. (1937). “Should You Choose Radio Engineering as a Career?” QST(April, 1937): page 52.

182. Mills, E. (2001). Re: Looking for PSK31 Statistical Info. Personal communication. K. McQuiggin.

183. Mitchell, D. L. (2001). Re: Looking for PSK31 Statistical Info. Personal communication. K. McQuiggin.

184. Montgomery, J. F. and G. R. Sugar (1957). “The Utility of Meteor Bursts for Intermittent Radio Communication.” Proceedings of the IRE(December 1957): pages 1684 - 1687.

185. Moseson, R. (2001). “Lies, Myths, and Marketing.” CQ Amateur Radio(August 2001): pages 6 - 7.

186. Mumford, R. (1973). “How Hams Discovered Short Waves.” QST(October, 1973): page 93.

187. NASA (2001). Sunspots and the Solar Cycle, NASA. http://www.sunspotcycle.com/.

188. National Archives of Canada (1939-1945). Radio Messages Picked Up by Amateur Radio Stations. War Series 1939-45-P.O.W. Ottawa, Government of Canada. RG3, volume 2761, file 35-26-9, series C-2, reel T-1689**:** 12 pages.

189. National Telecommunications and Information Administration (2001). National Telecommunications and Information Administration, NTIA. http://www.ntia.doc.gov/.

190. Nichols, A. H. (1948). “A Single-Sideband Transmitter for Amateur Operation.” QST(January 1948): pages 19-22.

191. One Stop Satellite Solutions (2000). One Stop Satellite Solutions. http://www.osss.com.

192. One Stop Satellite Solutions (2000). OSSS CubeSat Kit. http://www.osss.com/products/cubesat.html.

193. Penson, C. (1995). Heathkit: A Guide to the Amateur Radio Products. Durango, CO, Electric Radio Press.

194. Pollak, M. and J. E. Jankowski (1999). U.S. and International Research and Development: Funds and Alliances: National Trends in R&D Expenditures, National Science Foundation. http://www.nsf.gov/sbe/srs/seind98/access/c4/c4s1.htm.

195. Porfiry (2000). The Personal Satellite?, ExoSci.com. http://www.exosci.com.

196. Price, H. K. (1985). “A Closer Look at Packet Radio.” QST(August 1985): pages 17 - 20.

197. Price, H. K. (1985). “What's All This Racket About Packet?” QST(July 1985): pages 14-17.

198. Price, L., D. Sumner, et al. (2000). “World Radiocommunication Conference 2000.” QST(August 2000): 51-54.

199. QST Editors (1964). “The Coming of C.W.” QST(March 1964): pages 71-74.

200. QST Editors (1964). “King Spark: Crescendo and Diminuendo.” QST(March 1964): pages 74-76.

201. QST Editors (1975). “Canada Adopts Multiple Choice Test.” QST(August, 1975): page 76.

202. QST Editors (2001). “W7PUA Wins ARRL 2000 Technical Innovation Award.” QST(September, 2001): pages 67 - 68.

203. Radio Amateurs of Canada (2000). CANADIAN AMATEUR RADIO ADVISORY BOARD (CARAB), Radio Amateurs of Canada. http://rac.eton.ca/mo/racmemberfiles/carab.htm.

204. Radio Amateurs of Canada (2000). WRC 2000 Highlights, Radio Amateurs of Canada. http://www.rac.ca/wrc2000.htm#Overview.

205. Radio Amateurs of Canada (2001). Amateur Radio for Non-Amateurs and Members of the Media, Radio Amateurs of Canada. http://www.rac.ca/faqham.htm.

206. Radio Amateurs of Canada (2001). Merger of CRRL and CARF, Radio Amateurs of Canada. http://rac.eton.ca/mo/racmemberfiles/carab.htm.

207. Raymond, E. (2001). The Halloween Documents, The Open Source Initiative. http://opensource.org/halloween/.

208. Reinartz, J. L. (1925). "The Reflection of Short Waves." QST(April, 1925): pages 9 - 12.

209. Rinaldo, P. (2001). "Protecting Our Bands: More then Meets the Eye." QST(July, 2001): pages 59 - 63.

210. Rinaldo, P. F. (1984). "ARRL Board Approves AX.25 Packet-Radio Link-Layer Protocol." QST(December 1984): pages 35 - 36.

211. Rogers, E. M. (1962). Diffusion of Innovations. Toronto, Collier-Macmillan Canada.

212. Rosenauer, D. (1997). The Layperson's Guide to High Speed Amateur Packet Radio, Emergency Preparedness Information Exchange. http://hoshi.cic.sfu.ca/epix/vemis/tcpip.htm.

213. Rosenauer, D. (1997). RF System Information, Emergency Preparedness Information Exchange. http://hoshi.cic.sfu.ca/epix/vemis/rfdeck.htm.

214. Rosenauer, D. (2000). Amateur Radio and Engineering (Interview). Seattle, WA.

215. Ross, A. (1991). Strange Weather : Culture, Science, and Technology in the Age of Limits. London, Verso.

216. Rowland, W. (1999). Spirit of the Web: the Age of Information from Telegraph to Internet. Toronto, Key Porter.

217. Schilling, D. L. (1993). Meteor Burst Communications. Toronto, John Wiley & Sons, Inc.

218. Schouten, J. (2000). "VECTOR Millennium Field Day." The Canadian Amateur(November/December 2000): pages 44-45.

219. Schreier, P. G. (2001). Missing No Links, CommVerge. http://www.e-insite.net/commvergemag/index.asp?layout=article&articleid=CA149525&pubdate=8/1/01&.

220. Schumpeter, J. A. (1942). Capitalism, Socialism and Democracy. New York, Harper.

221. Simpson, J. A. and E. S. C. Weiner (1989). The Oxford English Dictionary, Oxford University Press.

222. Sleeper, M. B. (1929). “What Price Television?” QST(March 1929): 48-49, 90.

223. Smith, D. H. (1975). The Present Status of Amateur Radio Communications in Institutions of Higher Education in California. Dissertation, Faculty of Education. Los Angeles, University of California.

224. Standage, T. (1998). The Victorian Internet. Markham, Ontario, Thomas Allen & Son.

225. Statistics Canada (2000). “Innovation in the Engineering Services Industry.” Innovation Analysis Bulletin Volume 2 no. 2(May 2000).

226. Statistics Canada (2000). “Total Spending on Research and Development in Canada.” Innovation Analysis Bulletin Volume 2 no. 1(January 2000).

227. Stevenson, J. (1996). The Silencing of a Democratic Medium: Early Public Policy on Radio and the Regulation of the Internet. INET '96, Montreal.

228. Sumner, D. (1999). Status Summary of Radio Amateurs & Amateur Stations of the World, International Amateur Radio Union. http://www.iaru.org/statsum99.html.

229. Sumner, D. (2000). “Forty Meters: A Gordian Knot?” QST(November 2000): page 9.

230. Takahashi, Y. (2000). “A Network of Tinkerers: The Advent of the Radio and Television Receiver Industry in Japan.” Technology and Culture 41(3): pages 460 - 484.

231. Technical Information Service (2001). Automatic Packet Reporting System (APRS), American Radio Relay League. http://www.arrl.org/tis/info/HTML/aprs/.

232. Technical Information Service (2001). Software Defined Radio, American Radio Relay League. http://www.arrl.org/tis/info/sdr.html.

233. Teller, H. S. and D. Benson (2000). “A Panoramic Transceiving System for PSK31.” QST(June, 2000): pages 31 - 39.

234. The AM Window (2001). The AMers Hangout on the Web. http://www.thebizlink.com/am/.

235. The Computer Museum History Centre (2001). Internet History - 1986, The Computer Museum History Centre. http://www.computerhistory.org/exhibits/internet_history/internet_history_80s.page.

236. The National Radio Astronomy Observatory (2000). Early Radio Astronomy: The Ham Radio Connection, US Government. http://www.aoc.nrao.edu/intro/ham.connection.html.

237. Thomsen, P. H. (1928). "Amateur Television." QST(May 1928): 17-18.

238. Tilton, E. P. (1950). "Amateur Television - A Progress Report." QST(June, 1950): pages 11 - 15.

239. Tilton, E. P. (1950). "History of VHF Work." QST(May, 1950): page 49.

240. Tilton, E. P. (1960). "Coast to Coast Via the Moon on 1296 Mc.!" QST(September 1960): pages 10 - 11.

241. Tilton, E. P. (1960). "The World Above 50 Mc." QST(January 1960): pages 66 - 67.

242. Tilton, E. P. (1963). "TE Propagation - V.H.F Discovery Extraordinary." QST(April 1963): pages 11 - 13.

243. TiVo Incorporated (2001). Yep... TiVo Runs LINUX!, TiVo, Alviso CA. http://www.tivo.com/linux/index.html.

244. Treasury Board of Canada (2001). Treasury Board of Canada Secretariat, Population Affiliation Report - Section 7, "Dissolved Organizations", Government of Canada. http://www.tbs-sct.gc.ca/pubs_pol/hrpubs/popaffrep/sect7_e.html.

245. Troetschel, W. O. and H. J. Heuer (1961). "A Parametric Amplifier for 1296 Mc." QST(January, 1961): pages 13- 19.

246. Tucson Amateur Packet Radio Group (1984). AX.25 Amateur Packet-Radio Link-Layer Protocol Version 2.0. Tucson, AZ, TAPR.

247. United Kingdom Radio Communications Agency (2000). Amateur Radio Licence (A) or (A/B) or (B) Terms, Provisions and Limitations Booklet BR68. http://www.radio.gov.uk/publication/ra_info/br68/br68.htm.

248. United Kingdom Radio Communications Agency (2001). Spectrum Auctions - Radiocommunications Agency. http://www.spectrumauctions.gov.uk/3gindex.htm.

249. United Kingdom Radiocommunications Agency (2001). A New Structure For Amateur Radio Licensing In The United Kingdom, UK Radiocommunications Agency. http://www.radio.gov.uk/.

250. United Nations (1999). SECRETARY-GENERAL TO DECADE FOR NATURAL DISASTER REDUCTION: DESPITE DEDICATED EFFORTS, NUMBER AND COST OF NATURAL DISASTERS CONTINUE TO RISE, United Nations. http://www.un.org.

251. US Patent and Trademark Office (2001). National Inventors Hall of Fame - Steve Wozniak, US Patent and Trademark Office. http://www.invent.org/book/book-text/wozniak.html.

252. Villard, O. G. (1948). "Single-Sideband Operating Tests." QST(January 1948): pages 16-18.

253. von Hippel, E. (1988). The Sources of Innovation, Oxford University Press.

254. Wade, I. (1992). NOSintro: TCP/IP Over Packet Radio; An Introduction to the KA9Q Network Operating System, Dowermain.

255. Warner, K. B. (1931). "The 1936 Floods." QST(May, 1936): pages 7 - 8.

256. Warner, K. B. (1931). "Atmospheric Conditions Seemingly Dependent on Solar Activity." QST(May, 1931): pages 7 - 8.

257. Warner, K. B. (1943). "When Disaster Strikes." QST(April 1943): page 11.

258. Warren, D. E. and R. Desourdis (2001). Meteor Burst Communications - The Gap Filler, ARPA - Air Force Research Laboratory. http://www.borg.com/~warrend/metburdu.html.

259. Welsh, R. H. (1995). "Propagation Pioneers: The ARRL - Bureau of Standards Experiment." QST(October 1995): pages 46 - 49.

260. Wiejak, R. (2001). ATV System Control Program, Version 2.2. Burnaby, BC, BCATVG.

261. Wiejak, R. (2001). BCATVG System Diagrams. Burnaby, BC, BCATVG.

262. Wireless Institute of Australia (2001). ITU to Review Amateur Regulations, Wireless Institute of Australia. http://www.wiavic.org.au/mcw/mcwb.html#k.

263. Wireless Institute of Australia (2001). Morse Code Watch, Wireless Institute of Australia. http://www.wiavic.org.au/mcw/.

264. Wright, G. R. and W. R. Stevens (1995). TCP/IP Illustrated. Reading, MA, Addison-Wesley.

265. Zysman, G. I. (1995). “Wireless Networks.” Scientific American(September, 1995): pages 68 - 71.