Amateur Radio – from Boat-Anchors to DSP

an historical overview of ham radio from 1945 to the present

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Structure of presentation

- The following time periods will be covered:
  - 1945 – 1955
  - 1955 – 1965
  - 1965 – 1975
  - 1975 – 1985
  - 1985 – 1995
  - 1995 – 2009
- For each time period, we will consider:
  - Techniques
  - Equipment

1945–1955: Post-War Decade

- Techniques
  - HF: 3.5, 7, 14, 28 MHz (later also 1.8 and 21 MHz).
    - Morse radio-telegraphy (CW), radio-telephony (AM).
    - Some HF NBFM (narrow-band FM) experimentation.
    - Baudot radio-teletype (RTTY) after 1950.
    - Some HF mobile operation with war-surplus and DIY.
    - First commercially-built HF mobile gear in 1950's.
  - VHF/UHF: 50, 144, 220, 420 MHz.
    - Mainly AM radio-telephony, some experimental FM
    - Light band usage – parts & equipment scarce, but many experimenters used war-surplus material.
    - First moonbounce (EME) contacts, using WW2 surplus.

1945–1955 (continued)

- Techniques
  - Bell Labs patented the transistor in 1948.
    - Early transistors were low-frequency and very costly for amateur use. First used in mobile/portable stations.
  - Directional multi-element antenna arrays:
    - First proposed by John Kraus W8JK (multiple driven elements, fixed & rotatable versions).
    - Yagi & Uda of Japan developed a rotatable antenna with driven & parasitic elements; it came into wide use among amateurs after WW2.
  - WW2 surplus coaxial cable and connectors:
    - These began to replace symmetrical feedlines at HF, and were the standard at VHF/UHF.
    - This led to displacement of push-pull transmitter output stages by single-ended (asymmetrical) designs.

1945–1955 (continued)

- Equipment
  - WW2 military surplus plentiful and inexpensive.
    - HF receivers often usable with minimal modification.
    - HF transmitters either modifiable for amateur use, or parts sources for DIY transmitter and RF power-amplifier projects.
    - Teleprinters and channel modems spurred RTTY.
    - Cheap surplus slowed return of commercial radio manufacturers to amateur sector.
    - Large, bulky ex-WW2 gear humorously called "Boat-Anchors."
    - VHF: transmitters mainly DIY, receivers used low-noise down-converter feeding IF to station HF receiver or car broadcast radio. Excellent VHF/UHF tubes with low noise figure on surplus market.

1945–1955: Equipment Examples

- BC-348 HF Receiver: 1.5-18 MHz
  - Fitted to USAAF bombers & transports
  - Paired with BC-375, ART-13 transmitters

1945–1955: Equipment Examples

- Collins ART-13 LF/HF Transmitter (AM, CW, MCW*)
  - Fitted to USAAF bombers & transports
  - Autotune - 100W (813 PA) - 0.2-0.5 & 1.5-18.1 MHz

*used mainly on LF range, for compatibility with crystal and TRF receivers

1945–1955: Radios in Kit Form

Heathkit AT-1 CW Transmitter (25W)

Kits were a good, affordable alternative to surplus or costly commercially-built radio gear.

Knight-Kit R-100A Amateur HF Receiver

1955–1965: Transitions

- Techniques
  - Single-sideband (SSB) pulled ahead of AM on HF amateur bands by the 1960's.
    - SSB: 9 dB higher S/N and 50% less bandwidth than AM.
  - Transistors appeared in amateur equipment: power supplies, then audio stages, complete receivers and finally low power (QRP) transmitters.
    - Tubes still dominant in amateur equipment until late 1970's.
    - Solid-state/hybrid gear drove mobile operation.
  - Success of FM in land-mobile led to its large-scale adoption on 144 and 440 MHz, and also on 50 MHz in some areas.

1955–1965 (continued)

- Techniques
  - First VHF TEP (trans-equatorial propagation) contacts in 1957-58, at peak of sunspot cycle 19. Several amateurs in Southern Africa among TEP pioneers.
    - Cycle 19 coincided with International Geophysical Year (IGY).
  - 1960: First 1296 MHz moonbounce (EME) contacts, using special military-surplus UHF tubes.
  - 1961: OSCAR 1 (orbital satellite carrying amateur radio) launched. This pioneered a series of multi-national ham radio satellite programs.
    - OSCAR 1 started a tradition of ham radio in space, continuing with hams aboard MIR, Shuttle, and ISS.
      - Astronaut hams communicate regularly with terrestrial groups (e.g. schools).

1955–1965 (continued)

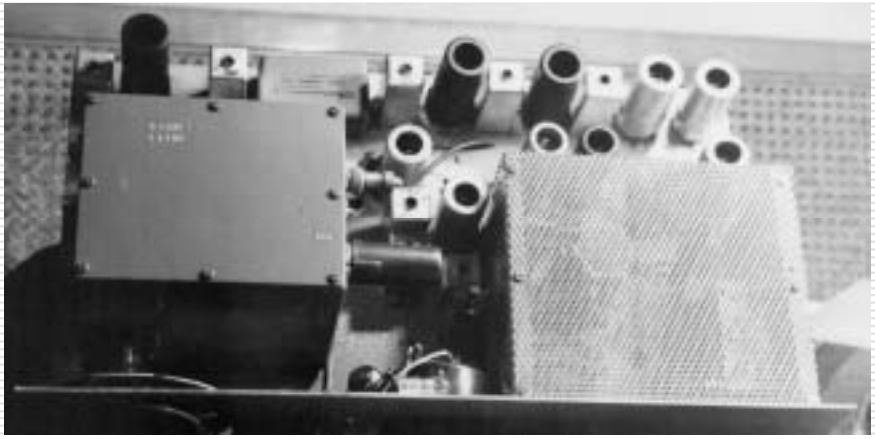
- Equipment
  - HF-SSB transceivers revolutionized amateur station design, displacing separate receiver and transmitter.
    - Transceivers share many common circuits between receiver and transmitter sections.
    - Transceivers were very large factor in eclipse of AM by SSB.
      - Examples: Collins KWM-2, 1964 DIY 14 MHz transceiver.
  - Land-mobile regulatory changes released huge quantities of VHF/UHF radios to surplus market.
    - Hams converted base, mobile and portable units.
      - This drove rapid growth of FM repeater networks, which flourish to this day and provide emergency comms.

1955–1965: Equipment Examples

- Collins KWM-2 (1959)
  - 3.4 – 30 MHz, 100W (SSB & CW)

1955–1965: Equipment Examples

- DIY 14 MHz SSB/CW Transceiver
  - 65W, built by author in 1964. 11 tubes, 40 transistors
  - 7360 mixer tube as receiver front end and transmitter modulator: 4.5 dB NF, 94 dB cross-mod rejection



1965–1975: Consolidation

- Techniques
  - HF-SSB advances:
    - First HF-SSB transmitters used phasing (PSN) modulation; improved crystal filters led to predominance of filter method. “Third Method” (by Weaver) used in some commercial/military HF systems and DIY amateur transmitters.
    - Need for higher frequency stability in SSB led to dual-conversion architecture with crystal-controlled 1st local oscillator and highly-stable tunable 2nd oscillator.
    - Early frequency synthesizers used TTL IC’s, but were not as spectrally pure as classical LC or crystal oscillators.
    - Development of reliable HF power transistors (f_T > 100 MHz) led to first 100% solid-state commercial (1966) and amateur (1978) HF transceivers.

1965–1975 (continued)

- Techniques
  - Antennas:
    - Multi-band dipole developed by Louis Varney G5RV (1958). Brian Austin ZS6BKW (now G0GSF) refined this design further. W3DZZ developed trap dipole for space-limited sites.
    - Cubical Quad, patented by C. Moore W9LZX (1951), became popular amongst hams – lighter and less costly than Yagi.
  - VHF/UHF advances:
    - Ultra-low-noise UHF amplifier tubes e.g. planar triodes drove long-haul terrestrial VHF/UHF, moonbounce (EME) and tropospheric/meteor scatter communications.
    - Networking of repeaters via point-to-point UHF links led to extensive mobile ham radio networks in Western US.
      - Many repeaters offered telephone interconnect (autopatch).
      - Some repeaters included remote-controlled base stations, allowing access to other VHF repeaters or even to HF.

1965–1975 (continued)

- Equipment (HF)
  - Japanese suppliers Trio-Kenwood *(later Kenwood)* and Yaesu Musen began competing with US incumbents (Collins, Drake, Hallicrafters, National, Hammarlund etc.)
  - By 1975, Japanese were dominant; US firms had left the sector or ceased to exist.
    - Drake hung on until 1984; Rockwell-Collins is today a major player in mil/gov and avionics.
    - Ten-Tec and Elecraft (both US) are doing well today by creating a niche market.
  - Japanese HF transceivers were hybrid; solid-state w/3 tubes in PA stage. Many comparable US radios were still 100% tube.
    - Typical HF systems: Collins S/Line & KWM-2, Drake “3” & “4” lines, Kenwood TS-520S, Yaesu FT-101, Heathkit SB-100 series.
    - British “KW Electronics” amateur HF gear was popular in the UK and Commonwealth countries.

1965–1975 (continued)

- Equipment (VHF/UHF)
  - Japanese synthesized FM mobile and handheld radios began displacing converted land-mobile gear.
  - Synthesis offered unprecedented frequency agility.
  - Surplus conversions still dominated repeater construction.
  - Japanese VHF/UHF all-mode transceivers began displacing DIY transmitter/down-converter/receiver combinations.
  - Transverters (transmit up-converter with PA + receive down-converter) expanded HF transceiver coverage to bands above 30 MHz.
  - Low-noise solid-state VHF/UHF receive preamplifiers became cost-effective, displacing costly special tubes.

1965–1975: Equipment Examples

- Trio-Kenwood TS-520 HF Transceiver (1972)
  - 3.5, 7, 14, 21, 28 MHz, 100W. Hybrid, 3 tubes in PA section.

1965–1975: Equipment Examples

- Kenwood TR7400 (1976): 144-148 MHz FM, 25W

1975–1985: New Tech, New Bands

- Techniques
  - HF-SSB now entrenched, with solid-state transceiver as its main exponent.
    - Direct digital synthesis (DDS), originally developed for military, now became cost-effective in amateur equipment.
    - DDS greatly reduced synthesizer phase noise, improving receiver dynamic performance and transmitter spectral purity.
    - Up-converting architecture (1st IF above highest signal frequency) offered continuous frequency coverage. This drove improvements in preselectors, synthesizers, mixers, IF filters and RF/IF amplifiers.
  - WARC*'79 allocated 3 new ham bands: 10, 18 and 24 MHz.
    - All manufacturers offered new HF models, and modifications to some existing radios.

**ITU World Administrative Radio Conference*

1975–1985 (continued)

- Techniques
  - Digital Signal Processing (DSP), another military spin-off, first appeared in the ham shack.
    - Baseband DSP accessories providing tunable audio filters, heuristic noise reduction and suppression of unwanted single or multiple tones.
  - Amateur Packet Radio began in 1978 (Montreal).
    - Current AX.25 protocol grew from discussions in October 1981.
    - VHF packet network grew as switching nodes were added.
    - DX Packet Cluster began announcing rare foreign HF stations.
    - On HF, AMTOR (a subset of ITU SITOR*) merged with packet, evolving into PACTOR. This became a popular HF digital mode.

**Simplex Teleprinter over Radio*

1975–1985 (continued)

- Equipment (HF)
  - Solid-state ham gear came of age, eclipsing earlier all-tube & hybrid designs.
    - "No-tune" 50Ω output replaced tunable π-output network.
    - Many HF transceivers now incorporated automatic antenna tuners.
  - Icom took its place alongside Kenwood & Yaesu, with…
    - Solid-state HF, VHF all-mode and VHF/UHF FM transceivers.
  - Solid-state 500W HF auto-tune amplifiers from Icom, Yaesu and Ten-Tec broke tube-amplifier monopoly.
  - HF mobile operation revolutionized by compact transceivers (e.g. Kenwood TS-50) & remote-mounted automatic antenna couplers.
    - Antennas and couplers from SGC and Japanese firms.
  - R.L. Drake released TR-7 and TR-5 solid-state HF transceivers, R-7 HF receiver & TR-6 50 MHz transceiver.
    - Unable to compete with Japanese; left amateur sector in 1984.

1975–1985 (continued)

- Equipment (VHF/UHF)
  - The GaAsFET made cost-effective ultra-low-noise RF amplifiers and mixers available to radio amateurs.
  - Compact synthesized FM mobiles and handhelds became the norm, displacing land-mobile surplus conversions.
  - Commercially-manufactured amateur repeaters came into use, with sophisticated repeater controllers providing telephone interconnect, remote control and other features.
  - Almost all this new equipment was Japanese.
    - There were a few US products, such as the rather costly – and short-lived – Drake UV-3 tri-band FM transceiver.

1975–1985: Equipment Examples

- Icom IC-2KL HF Amplifier System (500W, 3.5 – 30 MHz)
  - AT-500 Auto-Tuner, PSU, IC-2KL Amplifier

1975–1985: Equipment Examples

- Icom IC-32E 5W 144/440 MHz Handheld

Motorola “Micor” VHF FM Repeater

1985–1995: Change! PC and DSP

- Techniques: PC
  - Affordable personal computers (PC) had a major impact on many aspects of amateur radio.
    - Regulatory changes permitting IA5 transmission on ham bands (in addition to IA2) drove adoption of new transmission protocols, often subsets of methods used in other services.
      - Examples: AMTOR and SITOR, AX.25 and X.25.
    - Hams developed software and radio/PC interfaces for these protocols. Many of these programs also supported:
      - Computer control of transceiver, amplifier, antenna rotator etc.
      - Logging of stations contacted by time, frequency, callsign etc.
      - Keyboard and automatic sending and decoding of Morse, RTTY and other radio datacomm modes.
    - The PC completely eclipsed the electromechanical teleprinter in the ham shack.

1985–1995 (continued)

- Techniques: DSP
  - Towards the end of the decade, several revolutionary new HF transceivers incorporated integral IF-level DSP, encompassing:
    - IF selectivity (bandpass and bandstop/notch filtering).
    - IF passband shifting (“Passband Tuning”).
    - Noise reduction by correlation discrimination.
    - AGC derivation and impulse-noise suppression.
    - Baseband management and speech compression.
    - Modulation/demodulation for all modes.
  - Operators now had the ability to adjust IF bandwidth and shape factors at will, without the need for costly analogue IF filters. Passband Tuning and notching aided interference suppression.
    - These facilities were all inside the AGC loop.
  - The old phasing method of SSB generation now reappeared in a highly-refined form as an IF-DSP function (PSN modulation).

1985–1995 (continued)

- Equipment
  - Early examples of HF transceivers with IF-level DSP:
    - Kenwood TS-870S (Japan, 1995).
    - Kachina 505DSP (USA, 1997).
      - Kachina was unique; it was a “box” with no front panel.
      - Custom software running on a connected PC controlled the transceiver, which was operated from the PC.
      - Features included an integral spectrum scope (panoramic amplitude/frequency display).
  - Icom IC-781 HF transceiver and R9000 wide-range receiver (100 kHz – 2 GHz):
    - Although analogue, these radios featured an integral CRT-based display with spectrum scope.
      - They set the standard for HF equipment of the decade to follow.

1985–1995 (continued)

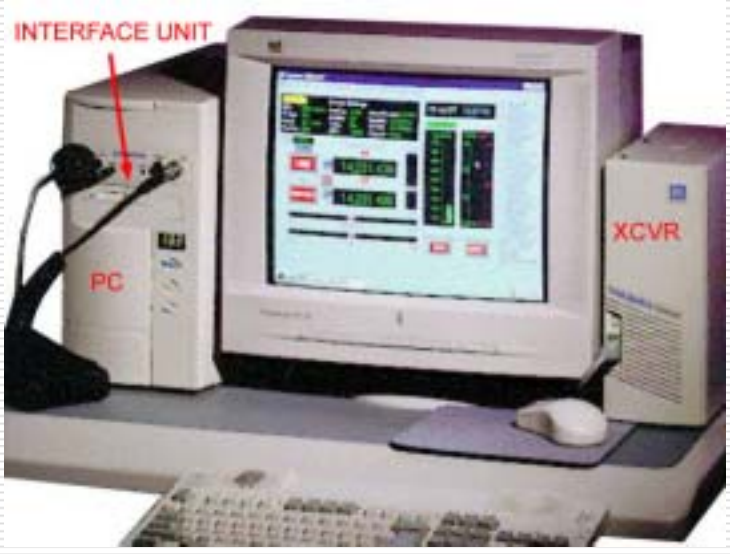
- Equipment
  - Ten-Tec and Kachina were the only US ham radio manufacturers still active.
    - Kachina dropped out in 2001.
    - Elecraft and other custom houses launched low-power (QRP) radios in kit form, replacing Heathkit which had ceased to exist by 1986.
      - Elecraft later introduced a range of fully-featured amateur HF transceivers (K2, K3) and accessories in kit form.
  - Japanese dual- and multi-band (VHF/UHF) amateur FM mobiles and handhelds became very popular…
    - but often had indifferent strong-signal receiver performance due to wide RF bandwidth and insufficient RF preselection.
      - "Purist" hams still favoured land-mobile radio equipment.

1985–1995: Equipment Examples

- Kenwood TS-870S IF-DSP HF Transceiver
  - 100W output; no accessory filters required.

1985–1995: Equipment Examples

- Kachina 505DSP HF Transceiver with PC
  - 1.8 – 30 MHz, 100W.
  - Optional auto-tuner installs in XCVR case.
  - Radio interface unit installs in PC CD drive slot.



1985–1995: Equipment Examples

- Icom IC-781 HF Transceiver
  - 150W output, with CRT display and spectrum scope.

1995–2009: Ham Radio in the Digital Age

- Techniques
  - Major technological, operating & regulatory changes.
    - "Marriage" of ham radio and the Internet.
      - IRLP (Internet Radio Linking Protocol) tied many VHF/UHF repeaters into national and international networks via TCP/IP, VoIP.
      - Remote control of HF stations via Internet: "shack in a PC".
      - Internet-based QSL (contact confirmation) and DX station locators.
    - PC's now perform many different tasks in the station:
      - radio control, logging, datacomm modes, equipment design etc.
    - 2003: ITU abolished mandatory Morse requirement for HF.
    - 2003: ITU recognized official disaster-communications role for amateur radio. Hams provide comms. in 2004 tsunami etc.
      - This has greatly enhanced hams' first-responder status with their respective national authorities.

1995–2009 (continued)

- Techniques
  - Inexpensive DSP, ADC, DAC, FPGA, ASIC and other specialized IC's for the consumer audio and wireless sectors spurred development of sophisticated DSP radio designs and SDR (software-defined radio).
  - AMSAT (Amateur Satellite Corporation) came of age, with multiple orbiting satellites and ham radio aboard ISS and Space Shuttle. All NASA astronauts now licensed hams.
  - "Dotcom bust" placed large quantities of first-class lab test equipment well within many amateurs' reach.
    - Spectrum analyzers, oscilloscopes, signal generators, network analyzers, RF microwattmeters etc. started showing up in ham shacks.
  - Amateur television (ATV), using broadcast TV standards, had seen limited growth due to its bandwidth demands. Pressure from repeater networks moved most ATV from 430 MHz to 1200 MHz.

1995–2009 (continued)

Equipment

- Rapid evolution of DSP/SDR drove development of remarkable new radio equipment and software packages for the sophisticated amateur. Example: the Icom line of HF transceivers with IF-level DSP and TFT screen with spectrum display.
- SDR kits began appearing, followed by commercially-made SDR transceivers with analogue homodyne front end driving PC soundcard (FlexRadio).
- Fast, cost-effective ADC's (16-bit, > 100 Msps) have brought SDR receivers with direct RF sampling (Perseus, RFSpace, HPSDR) to amateur/SWL marketplace. These radios still require USB link to PC, but self-contained transceivers are now under development.
- These exciting new technologies, with modest but steady growth in amateur population, are generating much interest and optimism regarding amateur radio's future.

1995–2009: Equipment Examples

- Icom IC-7600 HF/50 MHz Transceiver
  - 100W output, IF-level DSP, TFT display, spectrum scope

1995–2009: Equipment Examples

- Perseus Direct-Sampling SDR Receiver

Exterior

Interior

Typical Display Screen

Links for further study

- American Radio Relay League
- Radio Society of Great Britain
- Radio Amateurs of Canada
- Amateur Satellite Corporation
- Amateur Radio on Wikipedia
- North Shore Amateur Radio Club