EVOLUTION OF THE COMMUNICATIONS RECEIVER

PART 1. PRE-WAR SETS

A two-part series tracing circuit-design trends of amateur and short-wave communications receivers from the very earliest crystal and regenerative sets up to the present-day sophisticated models.

By MAURICE P. JOHNSON, W3TRR

THE history of radio reception probably began as far back as 1887 with the experiments of Heinrich Hertz in Germany. With a receiver consisting of a wire looped into a circular spark gap, he was able to detect radio signals by watching arcs across the gap. Such a primitive device would hardly inspire the technician of today; yet barely seven years later wireless communications was well on its way. In England, Oliver Lodge had managed to record Morse Code transmissions with a receiver consisting of an antenna, a tuned circuit, and a "coherer" type detector, which was essentially a glass tube filled with iron filings. Once Lodge's methods were revealed, a flurry of interest followed and "experimental wireless" activity began.

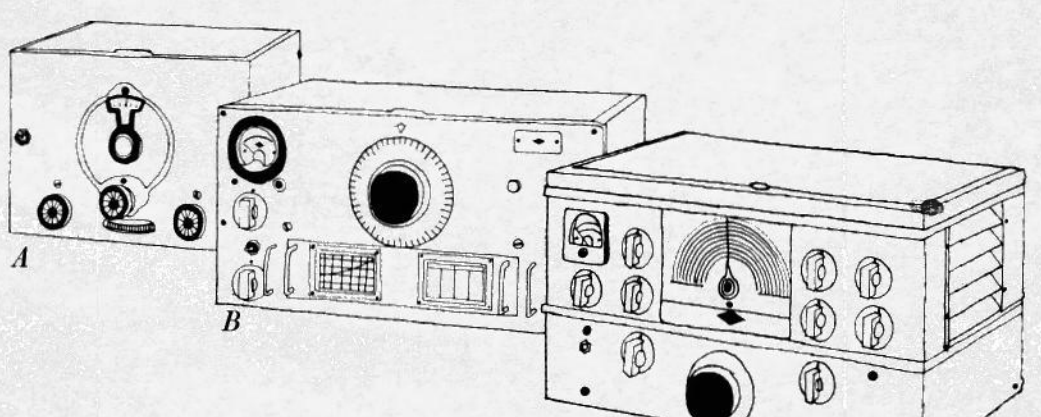
The development of the vacuum tube did much to spur receiver design in the years that followed. The discovery of the Edison effect had led to the diode or "oscillation valve" of Fleming. The Fleming valve could be used to detect r.f. signals and could thus replace the crystal detector. By 1906, de Forest had added the grid to control the current flow within the diode. This gave receiver designers the triode tube, or "audion" as it was called, which was able to amplify as well as to detect radio signals.

In the radio magazines of the early 1900's, some crystal detectors and their circuits (Fig. 1A) were pictured, but there were several allusions to the superiority of the audion circuits. Early tube manufacture was beset with problems, but designers hastened to incorporate the delicate triodes into receivers and many circuits were developed around them.

One of the most popular circuit configurations to evolve was the grid-leak detector (Fig. 1B), which permitted the triode to function as a detector as well as an amplifier. Sensitivity was improved by the gain thus introduced into the receiver, but selectivity was still limited by the single tuned circuit.

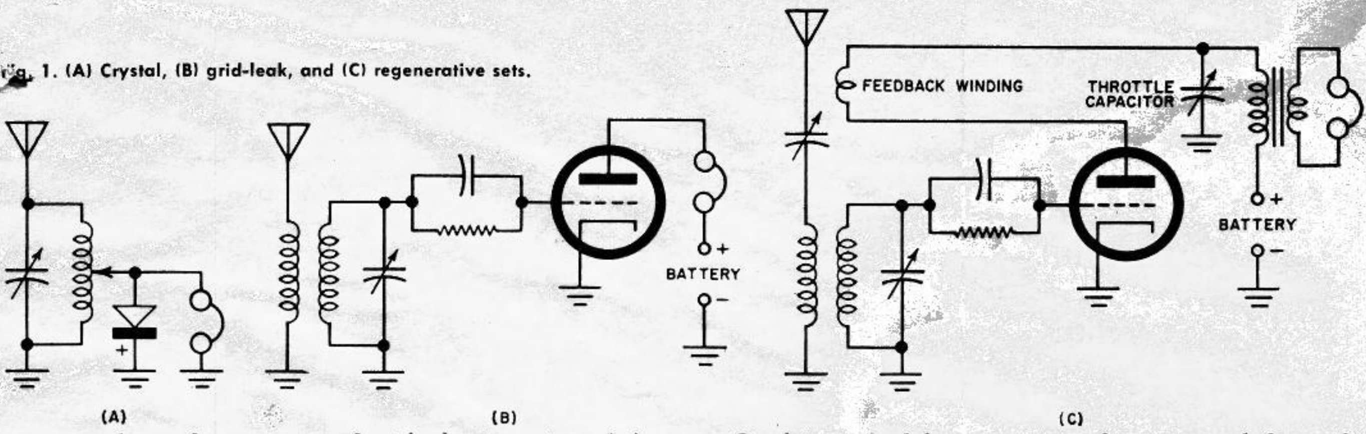
It will be noted that amplification is at audio frequencies since the tube gain follows the detection. Design refinements appeared as improved tube manufacture, antenna matching with an added primary coil, and audio transformers to couple the tube to the headphones. However, selectivity still suffered because of the grid-current loading on the tuned circuit.

Sensitivity continued to receive much attention. A most



National (A) SW-3, (B) HRO, (C) NC-200.

Fig. 1. (A) Crystal, (B) grid-leak, and (C) regenerative sets.



important forward step occurred with the invention of the regenerative circuit by Armstrong in 1914. This introduced positive feedback from the output to the detector input, which served to couple reinforcing energy back into the tuned circuit by means of a feedback or tickler coil. This resulted in tremendously increased sensitivity because of the re-amplification which took place. Control over the feedback energy involved a variable resistance shunting the tickler winding. Another regeneration control consisted of a variable plate bypass capacitor, familiarly known as the "throttle" capacitor. See Fig. 1C.

Sensitivity of the detector had now been amazingly improved but the addition of regeneration added a critical operating control to the receiver. The operating point of maximum sensitivity required careful adjustment of the feedback to a point nearly sufficient to overcome the circuit losses. Any further increase in feedback caused the circuit to "spill over" into self-oscillation. However, the oscillating detector did permit "autodyne" reception of unmodulated code (c.w.) signals.

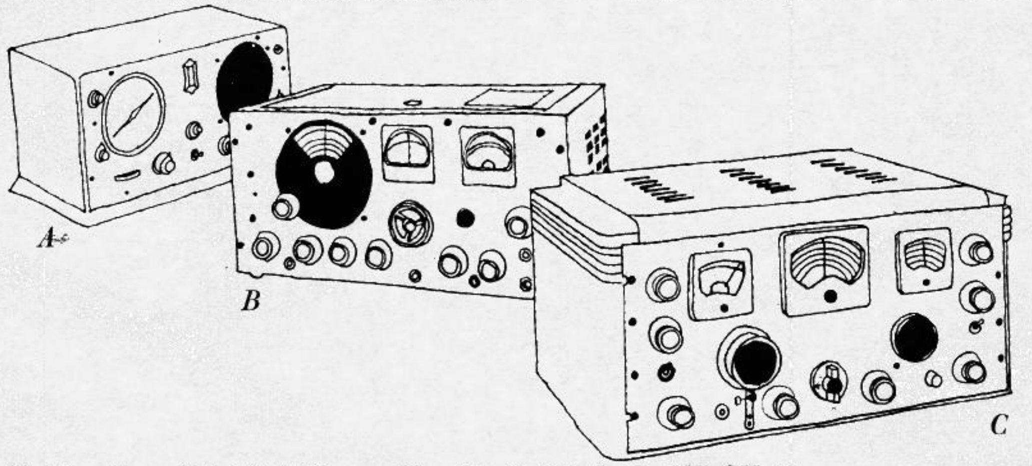
The ordinary grid-leak detector and the non-oscillating regenerative detector produce an audio output only from modulated signals. Audible reception of unmodulated c.w. signals was therefore impractical since no audio output was produced. However, if two r.f. signals are applied simultaneously to a detector, heterodyne or beat products appear in the output. If the separation between the r.f. signals is equal to an audio frequency, the beat is audible. In the oscillating regenerative autodyne detector, one r.f. signal is that being received, while the beating r.f. signal is that developed due to feedback in the detector. The received c.w. signal produces an audio note in the receiver output. Thus the regenerative detector was useful for reception of both modulated signals as well as unmodulated code signals.

Combinations of the regenerative detector coupled to audio amplifiers were developed, but the oscillating detector did have an inherent disadvantage. It acted as a transmitter as well as a receiver, radiating a signal from the antenna that caused interference in other receivers. This led to the name "blooper" for the set.

Radio continued to be of an experimental nature up until World War I when transmissions were forbidden. Until then, in addition to c.w. transmissions, voice modulation had developed as microphones and modulation techniques were perfected. During the war, considerable progress was made in tube production techniques. Following the war, radio broadcasting began and radio started its invasion of the home as an entertainment medium. Although this article is not really concerned with broadcast receivers, certain developments in the receiver art were directly attributed to the demand for broadcast receivers for home use and should be acknowledged.

The improved triodes were introduced as r.f. amplifiers ahead of the detector. The problem of increasing selectivity was attacked by tuning the r.f. stage, and the t.r.f. stage was born. A tuned-plate and tuned-grid load were thereby presented to the r.f. tube, but the triode with high grid-to-plate capacity was always a potential oscillator. To keep this stage from oscillating, several neutralization circuits were devised; one of the best was developed by *Hazeltine* in the "neutrodyne" receiver.

To increase the acceptance of radio in the home and to lift receivers to a level above that of "knob-twister's delights," the tuned r.f. circuits were ganged and tracked, resulting in one-knob tuning. The t.r.f. stage was finally tamed with the appearance of the screen-grid tube with its reduced inter-electrode capacity. This obviated the need for neutralization. The demand for operation from the a.c. outlet in the home



Hallicrafters (A) 1935 "Super Skyrider," (B) S-27, (C) SX-28.

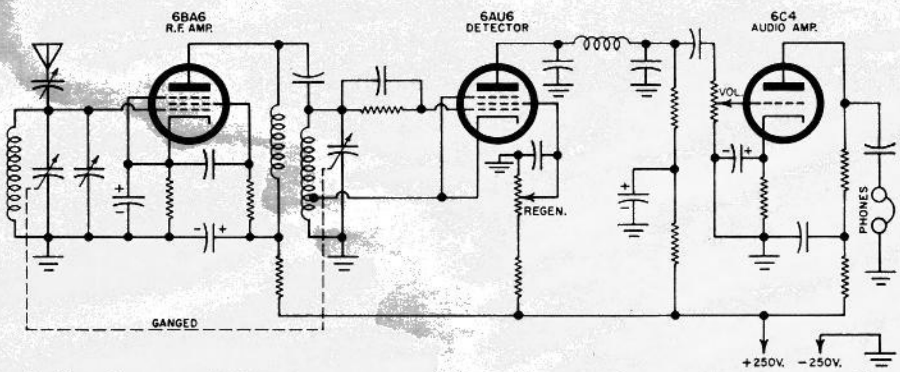


Fig. 2. Typical three-tube regenerative receiver using ganged tuning of the r.f. and detector stages. Trimmers are used for antenna matching and for improved tracking of the r.f. amplifier stage. The regeneration control varies the screen voltage of the grid-leak detector. Another stage of audio amplification was frequently used if a loudspeaker was to be employed. An a.c. rectifier, usually full-wave, completed the set's tube lineup.

resulted in battery eliminators, power packs, and new tube types. When all components were combined with the loudspeaker into furniture-type enclosures and cabinets, home receivers had arrived.

The t.r.f. receiver still suffered from varying sensitivity and selectivity across the tuning range, and this limitation was probably the main reason for its being gradually supplanted by the superheterodyne as *the* broadcast receiver circuit in the years that followed. However, the t.r.f. continued to find favor for short-wave reception for a much longer time.

Regenerative Communications Receivers

The evolution of the regenerative detector and t.r.f. stage has been briefly covered to portray the receiver design picture up to the mid 1920's. Although the superheterodyne had been developed by Armstrong before this time, it was a more complex circuit than the t.r.f. Tubes were comparatively expensive, and factors such as initial cost and current drain made the simpler circuits continue to find application.

Actually, the combination of a t.r.f. stage preceding a regenerative detector and followed by audio amplification proved to be a very practical circuit of such wide short-wave application that it probably deserves to be known as the beginning of the "communications" receiver. Many versions of the circuit continued in popularity in the late twenties, through the thirties, and at least up to World War II. Such receivers appeared in marine, aircraft, and police installations and have been used by amateurs, experimenters, and SWL's right up to the present.

A familiar set of the type in the early 1930's was the *Pilot* "Super-Wasp." This was available in both battery and a.c. versions and tuned 500 to 14 meters with plug-in coils. An article in the January, 1931 issue of "QST" described the *National* SW-5 "Thrill Box" as a new design offering "single control" and "socket power" with "tuned r.f. for the sake of selectivity and sensitivity, a screen-grid detector for the sake of sensitivity," and plug-in coils to cover the bands to 10 meters. Again the emphasis was on selectivity and sensitivity as measures of receiver worth. The circuit used type '24 screen-grid tubes for the t.r.f. and detector stages and '27 tubes in the audio. The r.f. and detector were gang-tuned with a drum dial, while an antenna trimmer and regeneration control completed the panel lineup. A separate a.c. power pack was used.

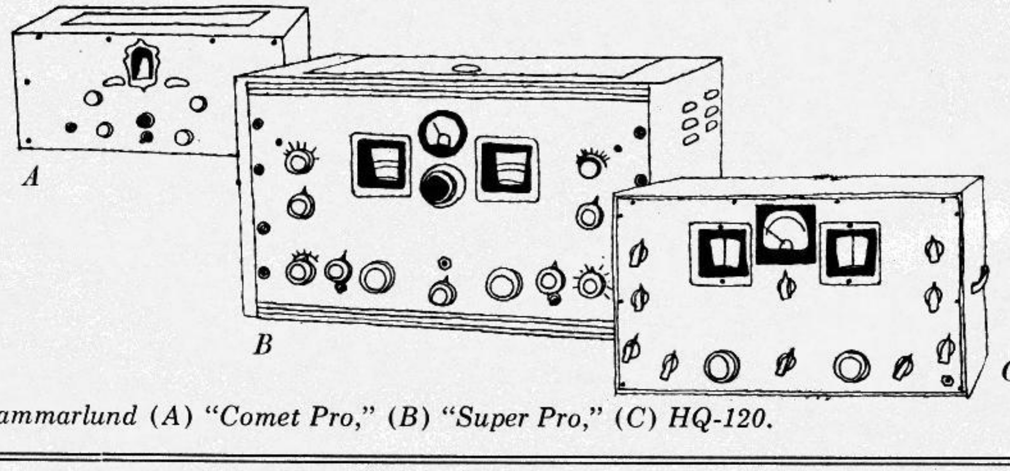
Variable-*mu* and receiving pentodes appeared and, in 1931, James Millen wrote of the application of new tubes to the famous *National* SW-3 receiver. This popular receiver could be used with a.c. power pack or batteries. A '35 variable-*mu* r.f., '35 regenerative detector, and '27 audio stage to power headphones comprised the a.c. lineup. For battery operation, these tubes were replaced with '36's and a '37. The receiver then found application in aircraft, auto, and portable installations.

The three-tube receiver circuit has survived until today and is still useful for experimenters and beginners. For a time, the 30, 33, and 34 tubes were popular for battery sets and the 58, 57, and 56 became a favored lineup for a.c. use. Metal tubes appeared and a pre-World War II *RCA* tube manual featured the circuit with 6SK7's and a 6C5. The circuit is still of interest and a representative version with more modern tubes is given in Fig. 2.

It is interesting to note that the basic circuit remained much the same from 1930 onward, the improvements being limited to utilizing the newer tube types as they appeared.

Superregenerative Receivers

Before passing on to the superhet, a variation of the regenerative detector should be mentioned. This is the superregenerative circuit developed by Armstrong in 1922. In this arrangement, a supplementary "quench" oscillator operating in the range of 20 to 100 kc. is tied to the grid of a regenerative detector (Fig. 3). This quench voltage acts as a varying grid bias which pulls the regenerative detector in and out of oscillation at a supersonic rate. Although the quench frequency is too high to be heard in the output, the



Hammarlund (A) "Comet Pro," (B) "Super Pro," (C) HQ-120.

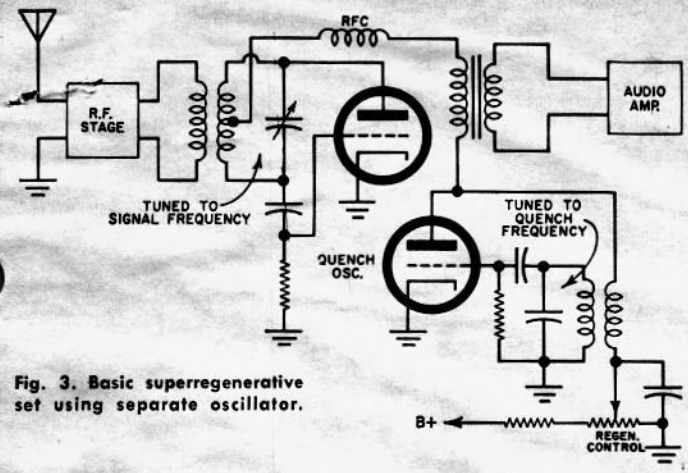


Fig. 3. Basic superregenerative set using separate oscillator.

superregenerative receiver is characterized by "regeneration hiss" because of the extremely high gain under no-signal conditions. Sensitivity of the circuit is greater than the straight regenerative detector, but selectivity is poor due to the grid loading and it tends to radiate strongly. It is seldom used without a preceding r.f. stage to reduce this radiation. Some variations of the circuit use self-quenching arrangements which eliminate the separate oscillator by combining both actions in the superregenerative detector.

The circuit has been useful for the ultra-high frequencies since the straight regenerative circuit is not very successful above 10 meters. The superregen was used extensively on the old 5-meter ham band in pre-World War II days. A typical 1933 circuit used a type 58 tube as t.r.f., a 24-A screen-grid type as regenerative detector with a '27 quench oscillator, and a type 59 audio output. By 1941, a similar t.r.f. superregenerative circuit utilized the 9002 triode in the regeneration stage and the 9001 in the r.f. stage to reduce radiation and antenna loading on the detector. Such circuits were used for the 112-mc., 224-mc., and higher bands.

The *National Company* produced the "One-Ten" receiver, which used a four-tube circuit to cover the range from one to ten meters. This used acorn r.f. tubes, with a 954 t.r.f. stage, a 955 self-quenching superregenerative detector, a 6C5 audio stage, and a 6F6 audio output. The receiver used plug-in coils to cover the tuning range. In the 1950's, superregens were largely supplanted by converters ahead of the usual communications superhets, except for some simple experimental applications.

The recent advent of the Citizens Band has brought renewed activity in superregen designs. Several Citizens Band kits and factory-built receivers use the t.r.f. superregen cir-

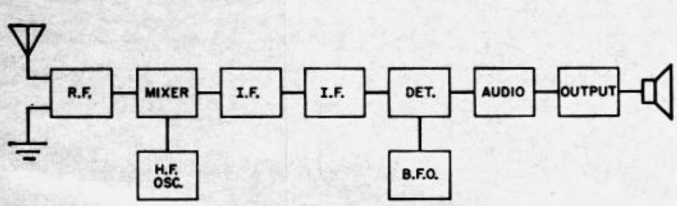


Fig. 4. Block diagram of the basic superheterodyne receiver.

cuit to provide good sensitivity on the 27-mc. band with maximum circuit simplicity. "Walkie-talkie" versions of this circuitry are also popular.

The Superheterodyne

The superheterodyne receiver (Fig. 4), which was to emerge as the most satisfactory circuit approach for communications receivers, was developed during World War I. The heterodyne principle had previously been used to produce audio signals from code transmissions. However, Armstrong's idea was to produce a higher beat frequency, at the so-called intermediate frequency (i.f.), which could then be amplified in a fixed-tuned amplifier. This i.f. amplifier was followed by a detector and audio stages. The important advantage of this circuit was that the major portion of receiver gain was at the i.f. frequency so that sensitivity and selectivity became more or less independent of the received signal frequency. Thus, the remaining disadvantages of the t.r.f. receiver had been overcome, but at the expense of a more complex circuit. While the advantages of the superhet were quickly recognized, in its early days the cost of tubes was an inhibiting factor which limited application of the circuit to only the most expensive sets.

With improvements in tube performance and their reduced cost due to mass production, the superhet soon became the standard circuit for the home broadcast receiver. Some experimentation for suitable i.f. frequencies took place before the standardization at 455 kc. Present-day home receivers, portables, and auto radios are practically stereotyped in circuit, with differences in packaging and styling the major variations. However, adaptation of the superhet circuit to short-wave and communications receivers has been a continuing process that still occupies the time of receiver designers.

Because of cost, some early efforts to introduce the superhet to short-wave reception were directed toward converters for use ahead of broadcast receivers. A 1931 circuit of this type featured type '24 screen-grid tubes for the local oscillator and the high-frequency mixer, or first detector, as it was often called. Plug-in coils were used and much attention was centered on the problems of making the two tuned circuits "track" to permit single-control tuning.

The disadvantage of the converter was that the i.f. response of the broadcast receiver determined the over-all selectivity of the combination. Reception of code signals with the superhet required the action of a supplementary beating oscillator, the b.f.o., to generate an audible signal. This further complicated the converter approach for short-wave receivers since the b.f.o. signal properly should be applied to the second detector.

In the decade preceding World War II, considerable effort was concentrated on the development of superheterodyne communications receivers. Circuit designs evolved that were tailored to the special requirements of short-wave reception. The great importance of good selectivity ahead of the second detector was recognized in terms of improved r.f. and i.f. circuits. The fact that the necessary beat method of c.w. reception produced sidebands on both sides of the carrier was attacked by Lamb in 1932, with the result that "single-signal" reception became the primary receiver feature of the day. This reception technique was made possible by the introduction of a crystal filter in the i.f. amplifier. By tuning the desired sideband into this filter passband, the crystal bridge neutralizing or "phasing" capacitor could be adjusted to null out the undesired sideband, so that c.w. signals became effectively single-sideband at the second detector.

Selectivity continued to merit attention, and improved r.f. amplifiers appeared. The square-law second detector was supplanted by the linear diode detector. Automatic volume control was incorporated into the short-wave receiver. The rectified second-detector output was sampled through a long time-constant filter and was applied as degenerative bias to the variable-gain tubes of the r.f. and i.f. amplifier stages.

In 1934, crystal i.f. filters for single-signal reception and a.v.c. were the latest features of receiver design. Some representative sets at this time were: *McMurdo Silver*'s "5 series Supers," *Patterson*'s "PR-12," *RCA*'s "ARC-136," *RME*'s "9D," *Hammarlund*'s "Comet Pro," and others. The *Hallicrafters* name appeared on the first "Skyrider" at about this date.

Receiver coverage was pushed toward 30 mc. with the surge of interest in the ten-meter band. This increased the image problem, which was approached by increasing r.f.

band, which could be widened by external loading. *Hammarlund* developed one of the more versatile variable-selectivity i.f. crystal filters which found application in the "Super-Pro" and the "HQ-120" series receivers. This used steps of resistance loading to widen the filter bandwidth.

With the burden of selectivity relegated to the i.f. amplifier, the r.f. stages functioned mainly to improve the image rejection. A single r.f. stage was adequate to reduce image response on the lower tuning ranges, but two stages were necessary to even approach satisfactory image rejection on the higher bands. An image ratio of 20:1 was considered to be good at 30 mc. for a receiver with two r.f. stages and a 3-stage 456-kc. i.f.

A few additional comments may be made concerning other features of typical receivers. Separate mixer and h.f. oscillator tubes were used for isolation of the two circuits. Voltage regulation of the oscillator plate supply improved the voltage stability, while ceramic in coil forms, switch decks, and tube sockets, together with temperature-compensating capacitors helped to improve the frequency stability. For c.w. reception, a b.f.o. at the i.f. frequency was injected into the second detector. The a.v.c., applied to variable-*mu* tubes in r.f. and i.f. stages, could be disabled for c.w. signals. An "S" meter indicated received signal strength by measuring the reduction of plate current of an i.f. amplifier when the signal-developed a.v.c. voltage appeared on the grid. The diode second detector was usually followed by a peak-clipping diode audio noise limiter which reduced the effects of impulse-type noise pulses that fed through the audio circuits. A few receivers used the Lamb i.f. type noise silencer. Audio and r.f. gain controls were individually adjustable for optimizing operational gains. Few receivers tuned above ten meters, so that usable signal-to-noise ratios were determined by external noise on the antenna, and receiver noise figures of nearly 10 db were adequate. Mixer noise was not a great problem with one stage of r.f. gain ahead of the converter.

Some of the receivers being manufactured at this time included the "HRO" by *National*, *Hallicrafters*' "SX-28," *Hammarlund*'s "Super-Pro" and "HQ-120-X," the *RME* "69," the "490" by *Howard*, and others. One or two special-purpose receivers had appeared to reach beyond ten meters. Tuning ranges went from 27 to as high as 145 mc. with acorn tubes in capacitively tuned front-ends. Such specialized communications receivers were the *National* "NHU" and the *Hallicrafters* Model "S-27."

This was the state of communications receiver design when the years of World War II began for the United States.

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selectivity, so that one or more tuned r.f. stages ahead of the converter became common. The 2A7 tube arrived as a combined electron-coupled oscillator and detector in one envelope, and was quickly utilized as a first detector as well as a second detector and b.f.o. Tube designs flourished and many receivers re-appeared in modified form to keep up with newer tube lineups. Then metal tubes arrived on the scene, to be quickly incorporated into receivers of advanced design.

Circuit refinements continued in the remaining years of the 1930's. This resulted in the decline of plug-in coils in favor of bandswitching, and communications receivers grew to be twelve- to fifteen-tube affairs with self-contained power supplies. *National* revised the earlier "HRO" and introduced the "NC-100," and "NC-200" receivers. *Hammarlund* had developed the "Super-Pro." *Hallicrafters* had been adding the numbers, advancing to the "Super Skyrider" designs.

Pre-War Circuit Features

Examination of the circuits of good communications receivers of the period just before World War II reveals many features shared by nearly all sets. The frequency coverage was usually all-band, from broadcast to ten meters, with a few versions extended to the lower marine bands, or above 30 mc. Two-knob tuning involved a multi-band calibrated main tuning dial coupled to the ganged tuning capacitor, plus an additional vernier bandspread dial for expanding ham bands or crowded short-wave broadcast regions.

The receiver front-end included bandswitching coil assemblies with one or two tuned r.f. amplifiers, followed by a tuned mixer stage and the high-frequency oscillator, usually tracking higher by the i.f. frequency than the incoming signal. Outstanding similarities of all designs were the use of 456-kc. i.f. channels, single conversion, and tunable h.f. oscillators. Two or three i.f. stages were used, with considerable attention given to control of the i.f. passband, since it determined the over-all selectivity. Variable i.f. bandwidth was usually provided, with the wider bandwidths established by the amount of coupling between i.f. transformer windings.

Sharper selectivity than that afforded by transformers alone was added by including a crystal filter in the i.f. path. The bridge-connected crystal, series-resonant at the i.f. frequency, had a parallel resonant notch which could be moved about in the passband by means of the phasing control. This action was useful in reducing interfering beats or signals. Being inherently high-"Q," the crystal produced a very narrow pass-

EVOLUTION OF THE COMMUNICATIONS RECEIVER / Part 2. Post-War Sets

By MAURICE P. JOHNSON, W3TRR

Circuit design techniques that have led up to the highly sensitive, very selective, and stable radio amateur and short-wave receivers of the present.

WHEN receiver manufacturers returned to the production of commercial products after World War II, evidences of new design efforts began to appear. The multi-purpose communications approach reached a peak of versatility with the impressive "SX-42" produced by *Hallicrafters*. This complex 15-tube package of modern styling attempted, with a large measure of success, to function as a high-fidelity AM and FM broadcast receiver, as an all-band general-coverage set tuning from broadcast to above 108 mc., and also as a bandspread ham receiver with crystal filter, noise limiter, and b.f.o. included for good measure. Despite the necessary compromises in such an encompassing design, the set performed quite well.

Several other receiver designs appeared, invariably using the standard 455-kc. i.f. with crystal filter (Fig. 5), and one or more tuned r.f. stages. Signal-to-noise ratios improved with newer high-gain r.f. tubes, so that high-frequency performance got better. The finer designs lavished attention on reduction of drift in the h.f. tunable local oscillator. Image response continued to be a problem, and was particularly bad at 30 mc.

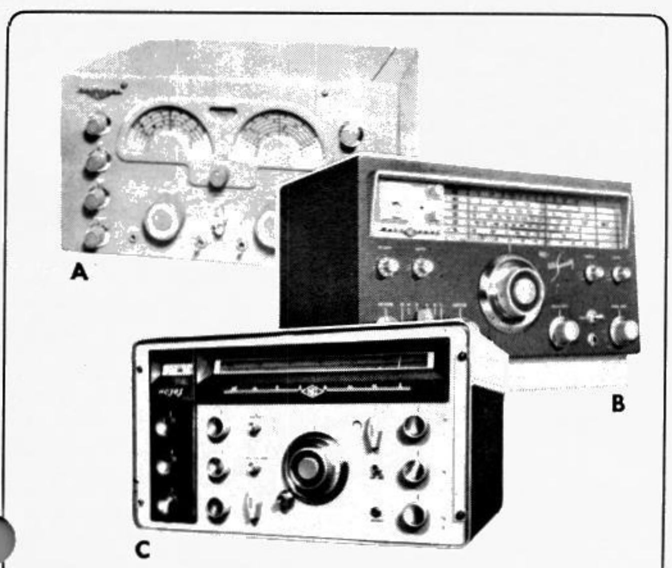
By the late 1940's, some representative receivers on the market were *Hammarlund's* "SP-400," and "HQ-129" and *National's* "HRO-7," "NC-173," and "NC-183." *Hallicrafters'* compact "S-53" hinted at things under development, with the unusually high i.f. frequency of 2.075 mc.

Dual Conversion

The image problem was never completely resolved in single-conversion receivers, even with two tuned r.f. stages. Because of the wide tuning range of most communications receivers (usually from 550 kc. to 30 mc.) and the fact that the i.f. frequency should not appear in the receiver r.f. tuning range, an i.f. near 455 kc. had become standard. Images then appeared at frequencies twice the i.f. removed from a desired signal, or only 910 kc. away. This was very close to a carrier at 30 mc. The net result was double-spot tuning, so familiar on the ten-meter band. The 455-kc. i.f. was satisfactory in terms of image response up to about 10 mc., but higher i.f. frequencies were called for at 14, 28, or 56 mc. The i.f. frequencies of 1.5 to 5 mc. would be suitable for good image rejection at these r.f. ranges, but again percentage bandwidth interferes in the form of poor i.f. skirt selectivity.

The solution to these conflicting problems is the dual-conversion i.f. strip, wherein both high- and low-frequency i.f. amplifiers are combined in cascade. The first high i.f. provides the desired image rejection, while the low i.f. gives the needed selectivity to define the passband. See Fig. 6.

National (A) NC-173, (B) NC-270, (C) NC-303.



Hallicrafters (A) SX-42, (B) SX-100, (C) SX-101A.

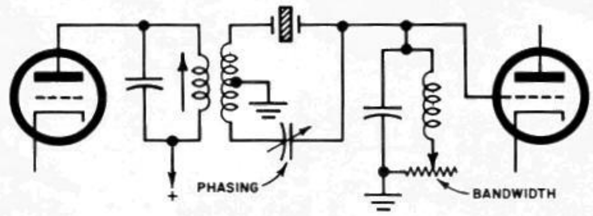
Hallicrafters used this design approach in its Model SX-71, a receiver of about 1950 vintage. This set gave continuous coverage from 550 kc. to 56 mc. The low-frequency i.f. with variable crystal filter operated at 455 kc., but above 7 mc. an additional converter and 2.075-mc. first i.f. were added to the string. The over-all i.f. selectivity was made quite sharp and no attempt was made to provide for wide-band high-fidelity reception. Without the crystal filter, the i.f. bandwidth was 3.5 kc. at 6-db down, and 14 kc. at 60-db down. With this narrow bandwidth, the signal-to-noise ratio was good and the set was quite sensitive. Provision was made for NBFM reception as well. Both high and low i.f. amplifiers and the second conversion oscillator were fixed-tuned, consequently the h.f. first oscillator was tunable. With the improved selectivity, plus extended coverage to the six-meter band, first oscillator stability was a very important factor.

Double conversion appeared in *Hallicrafters'* deluxe ruggedized Model "SX-73" receiver. *National* used double-conversion techniques in the "NC-183D," and up-dated the "HRO-50" to double conversion with the "HRO-60."

With the combination of high and low i.f. frequencies doing a good job of solving the image problem over tuning ranges extending to six meters, the choice of the second i.f. frequency, which had remained near 455 kc. for so long, was re-evaluated. Again the percentage-bandwidth factor—lower i.f. frequencies could be used for narrowing the over-all passband in the dual-conversion system. The increasing popularity of single-sideband signals on the air did much to spur development of increased i.f. passband control.

Hallicrafters introduced the "SX-88," which featured double conversion on all bands from 535 kc. to 33 mc. This receiver had two r.f. stages, tunable first oscillator, and selectable high i.f. channels of either 1.550 or 2.075 mc. The second conversion used crystal-controlled oscillators with a choice of either 1.500 or 2.125 mc. as beating signals. This permitted selection of either the upper or lower sideband output from the second mixer to be passed through a following 50-kc. i.f. strip. The 50-kc. i.f. featured eight tuned circuits in the three stages, with six-step variable selectivity without crystal filtering, the bandwidths ranging from 10 kc. to only 250 cycles on the "nose." An interesting aspect indicative of the selectable single-sideband approach was evident in the fact that bandwidth narrowing was not symmetrical. Instead, the carrier was located at one edge of the i.f. passband, with bandpass narrowing from one side as selectivity increased. See Fig. 7.

Previously, most i.f. strips had been designed to pass both



BASIC I.F. CRYSTAL FILTER

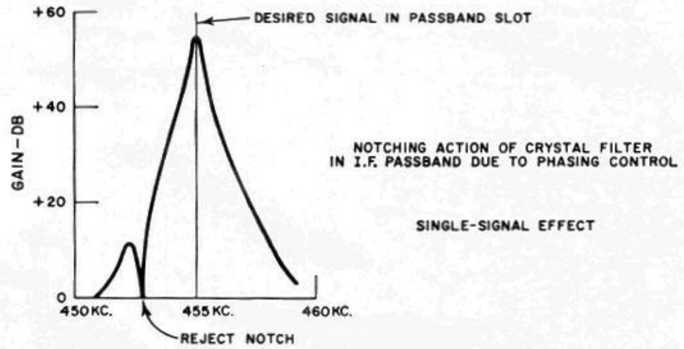


Fig. 5. Typical crystal i.f. filter and passband notching action of the phasing control. Another control is provided in the circuit in order to vary the bandwidth of the amplifier.

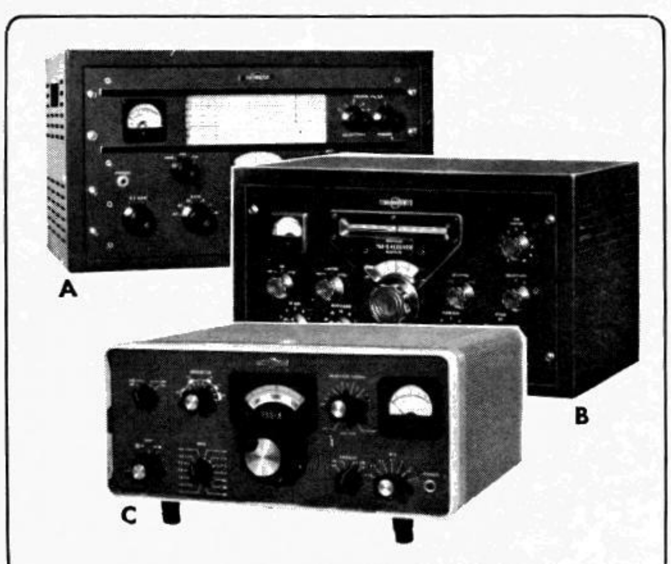
carrier sidebands through a symmetrical passband, with carrier centrally located. Bandwidth control was by means of variable mutual inductance coupling, which served to symmetrically reduce the passband. In the "SX-88," the passband variation was obtained with more complex interstage coupling, by means of capacity and resistance rather than inductive coupling. In addition to the selectable sideband feature, the increased use of single-sideband on the air was recognized in the isolation of second detector, a.v.c. and b.f.o., variable b.f.o. injection level, and attention to the stabilization of the tunable first oscillator.

Specialized-Use Receivers

The development of special-purpose receivers continued as *National* introduced the "NC-300" intended for ham-band operation only. This was a ten-tube double-conversion design of about 1955. Besides coverage of ham bands to ten meters directly, an additional 30- to 35-mc. tuning range was included to act as a tunable i.f., giving triple conversion on the 6-, 2-, and 1¼-meter bands in conjunction with accessory converters. Thus the problem of stability on six meters and

Hammarlund (A) HQ-110A, (B) HQ-180, (C) SP-600.

Collins (A) 75A-1, (B) 75A-3, (C) 75S-3.



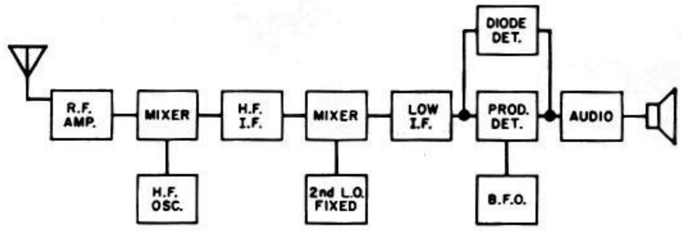


Fig. 6. Block diagram of typical present-day communications receiver employing double-conversion. Note the use of the tunable high-frequency oscillator and the fixed i.f. amplifier.

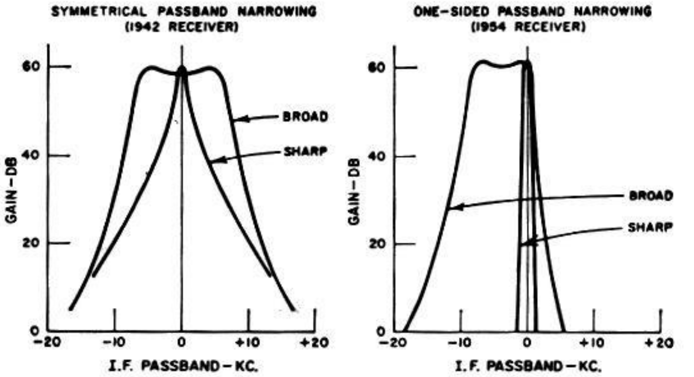


Fig. 7. Comparison between symmetrical and one-sided narrowing.

above was attacked by means of crystal-controlled converters and, effectively, a tunable i.f. amplifier.

This receiver included other features worthy of mention. The type 6BZ6 high-gain pentode, characterized by low cross-modulation or crosstalk, was used for the r.f. amplifier. A 6BA7 and 6AH6 tunable h.f. oscillator handled the first conversion. The high i.f. frequency was 2.215 mc. and here appeared a crystal filter with variable selectivity and rejection notch. The second i.f. was at 80 kc., with variable bandwidth. A choice of diode or a 6BE6 heterodyne product detector was provided, while the selection of upper or lower sideband was governed by b.f.o. frequency.

National then produced the "NC-303" receiver, a revamped and up-dated version of the "NC-300." The crystal filter was

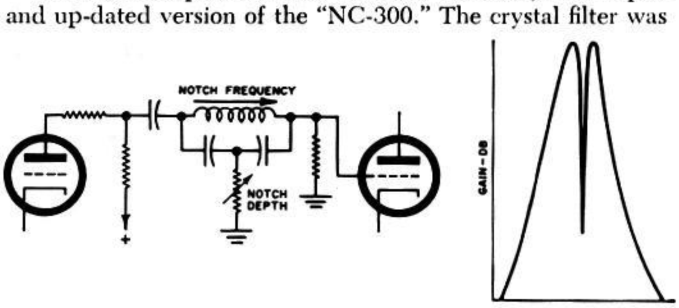


Fig. 8. Typical T-notch i.f. filter and passband notching action. The variable resistor determines the depth of the notch while tuning the coil shifts the position of the notch.

removed from the 2.215-mc. i.f. and a "*Q*"-multiplier added at 80 kc. Second conversion was now crystal-controlled. Both diode and product detectors were continued, with noise limiters for each.

Hallicrafters continued the development of the selectable sideband receiver with the "SX-96" and then the "SX-100." These sets continued the use of dual-conversion on all bands. A 6CB6 r.f. stage, 6AU6 mixer, and 6C4 tunable first oscillator comprised the front end. The first i.f. was 1650 kc., followed by crystal-controlled second conversion oscillators at either 1600 or 1700 kc. The second i.f. was 50 kc., with five selectivity ranges from 5.0 to 0.5 kc. A bridged-T notch filter (Fig. 8) included in the "SX-100" permitted adjustment of notch depth and frequency to help remove an objectionable signal from the passband. A series diode noise limiter was useful on both phone and c.w. signals. The a.v.c. and b.f.o. could be switched in or out individually.

Thus, it is evident in the receiver designs of the 1955 period to the present time that single-sideband reception had influenced design principles. Selectivity and stability continued as the goals of much design effort. Heterodyne product detectors for c.w. and SSB had been paired up with the more conventional diode AM detector. Bandpass shaping methods had become more sophisticated. The b.f.o. and its injection level had been given attention and a.v.c. time constants had been modified for SSB. The sideband selection feature was suited to AM as well as SSB reception. Double-conversion techniques had improved image rejection to a very marked degree. For example, the "SX-71" had an image rejection ratio of 40 db at 30 mc., with one r.f. stage, compared to only 26 db for an earlier single-conversion receiver with two tuned r.f. stages. The "SX-88," in turn, had an image rejection of 60 to 120 db over its tuning range.

Some other receivers of this period, deserving of mention, include the ruggedly built dual-conversion *Hammarlund* "Pro-310" with bandswitching coil turret, reminiscent of a deluxe TV tuner turret; the quality "GPR-90" receiver of *Technical Material Corporation;* and the *RME* "4350" with its very good noise figure of under 6 db.

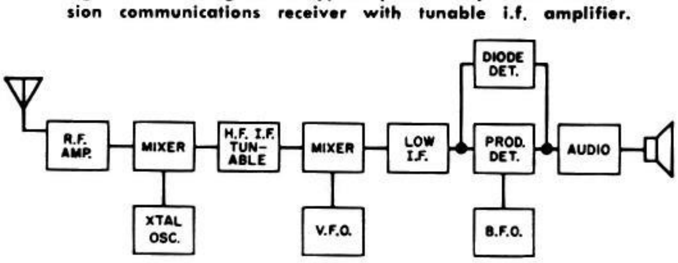
The "SX-101" which appeared in late 1956 was another *Hallicrafters* design, adapting much of the "SX-100" circuitry to a ham-band-only type receiver. With sensitivity and selectivity rather well accounted for in previous sets, this receiver is notable for its emphasis on the third important design criterion: stability. Mechanical ruggedness was apparent in the heavy chassis and solid assembly. Electrical stability was evident in the attention given to the first conversion oscillator, which included ceramic trimmers and coil forms. Crystal control was continued in the second oscillator. Voltage regulation was provided for all oscillators, plus extensive temperature-compensation methods. The use of a small eight-watt heater, connected directly to the power line to run continuously, contributed to stability by preventing buildup of humidity within the chassis confines. The newer "SX-101A" version even keeps heater voltage on the first h.f. oscillator tube by means of an independent filament transformer wired directly to the a.c. line.

Other receivers were indicative of the design efforts being directed toward increased stability. *Heath* produced the "Mohawk," a 15-tube double-conversion ham-band-only receiver in kit form. *Hammarlund* turned out the "HQ-160," which had a tuned r.f. stage, separate mixer and h.f. oscillator, and a 3.035-mc. first i.f. amplifier. This was followed by a crystal-controlled converter to generate the 455-kc. second i.f. Selectivity was controlled by a shunt-type "*Q*"-multiplier and a T-notch filter, replacing the crystal filter that *Hammarlund* had previously developed to a high state of perfection.

The desire for increased selectivity had resulted in new methods of bandpass narrowing. With this reduced i.f. bandwidth, however, the need for stability in the conversion oscillators had become greater than ever. Stability in the second conversion oscillator was relatively easy to obtain, because the frequency was comparatively low and usually

(*Continued on page* 69)

Fig. 9. Block diagram of typical present-day double-conversion communications receiver with tunable i.f. amplifier.



Communications Receivers

(*Continued from page* 56)

fixed. Likewise, the b.f.o., operating at the second i.f. frequency and of narrow tuning range, could be stabilized by means of temperature compensation, voltage regulation, and mechanical rigidity. In both cases, where a very stable design was required, crystal-controlled oscillators could be called into service for these circuits.

The problems of stabilizing the high-frequency oscillator, particularly when tunable over the extremely wide frequency range needed for multi-band coverage, were not so readily solved.

Tunable I.F. Receivers

Rather than attempt to stabilize the h.f. oscillator working into a fixed-frequency i.f. strip, another design approach has become increasingly popular in some very recent receivers. Essentially, this is simply a happy marriage between a low-frequency superhet receiver and a crystal-controlled front-end converter to extend the r.f. tuning ranges. The technique had previously been used to extend the coverage of the usual communications receiver to the six- or two-meter bands. The combination might well be termed the "fixed h.f. oscillator, tunable i.f." receiver (Fig. 9). The present trend is to extend this technique down into the usual coverage range of conventional receivers.

Probably the first advocates of this approach were the designers at *Collins,* who produced the "75A" series receivers. Unusual in concept at the time was the "75A1," which had a crystal-controlled first oscillator, followed by tunable high-frequency i.f. amplifier and transmitter-type v.f.o. as tunable second oscillator. A second i.f. amplifier at 500 kc. with crystal filter was used. This receiver tuned the ham bands only.

Collins continued with the "75A2" and then introduced the mechanical i.f. filter in the "75A3." Next came the "75A4" in continuing revisions of the series. This version used a 6DC6 r.f. tube, 6BA7 mixer, and 12AT7 crystal-controlled first oscillator. The tunable i.f. ranged from 1.5 to 2.5 mc. as the v.f.o. tuned 2.955 to 1.955 mc. A mechanical i.f. filter appeared in the 455-kc. strip which followed, as did a bridged-T "Q"-multiplier. The bridged-T notched the i.f. passband somewhat like the phasing adjustment of earlier crystal filters. The b.f.o. and main tuning were ganged to produce a unique passband tuning, which served to move the signal in the receiver passband without changing the b.f.o. note.

A somewhat similar approach is used in the recent *Drake* "2A" and "2B" receivers. In these sets, crystal control is again used for the h.f. oscillator, which is bandswitched over twelve bands, but is not tunable. Instead, the high i.f. is varied over a 600-kc. increment, from 3.5 to 4.1 mc. This i.f. is mixed against a v.f.o.-type second oscillator covering 3.955 to 4.555 mc., to produce a fixed lower i.f. of 455 kc. Because the v.f.o. operates at fairly low frequency, and over a limited tuning range as well, stability is more easily obtained. A third conversion produces a final i.f. frequency of 50 kc., which then passes through an amplifier with tunable bandpass filter. The main tuning dial drives a ganged capacitor to tune the v.f.o. and tunable i.f. The r.f. stage is independently peaked in grid and plate circuits by means of another ganged capacitor. This preselector covers 3.5 to 30 mc. by bandswitching.

Other Recent Designs

Another recent receiver to use crystal-controlled h.f. oscillator design is the *Hallicrafters* "SX-115" which tunes the ham bands in nine 500-kc. steps. This set uses broadband circuits in the r.f. and mixer stages, with ganged tunable i.f. and v.f.o. The first i.f. ranges from 6.005 to 6.505 mc. as the v.f.o. covers 5 to 5.5 mc. The second i.f. is therefore 1.005 mc., which is amplified and introduced to a third mixer. Here the selectable sideband feature appears; the choice of crystal-controlled oscillator frequencies of 1.055 or 0.955 mc. is available for this conversion. The third i.f. at 50 kc. includes a selectivity control with five steps and a T-notch filter.

This improved design approach has produced receivers with less than 500 cycles drift after warmup. The tunable i.f. technique results in a constant tuning rate, irrespective of the signal frequencies being received. However, it will be noted that this stability has been achieved at the expense of limited tuning range per band, because of the reduced tuning range of the tunable i.f. The usual result is a limited-coverage receiver—ham-bands-only in most designs.

Complete coverage requires a large number of bands and a considerable outlay for first-oscillator crystals. Design is also further complicated by possible spurious problems. However, some highly stable general coverage receivers have been designed using this particular technique.

One such set is the *Eddystone* Model "880" which covers a range of 500 kc. to 30.5 mc. in thirty bands, the tunable i.f. covering one megacycle for each band. The selling price of over $1500 limits the market for this receiver, but it is an example of an extremely stable design. Other designs intended largely for military use feature crystal-controlled synthesizers as local oscillators, sometimes phase-locked, giving precision and stability for rigorous applications. ▲

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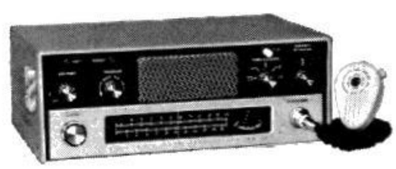

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