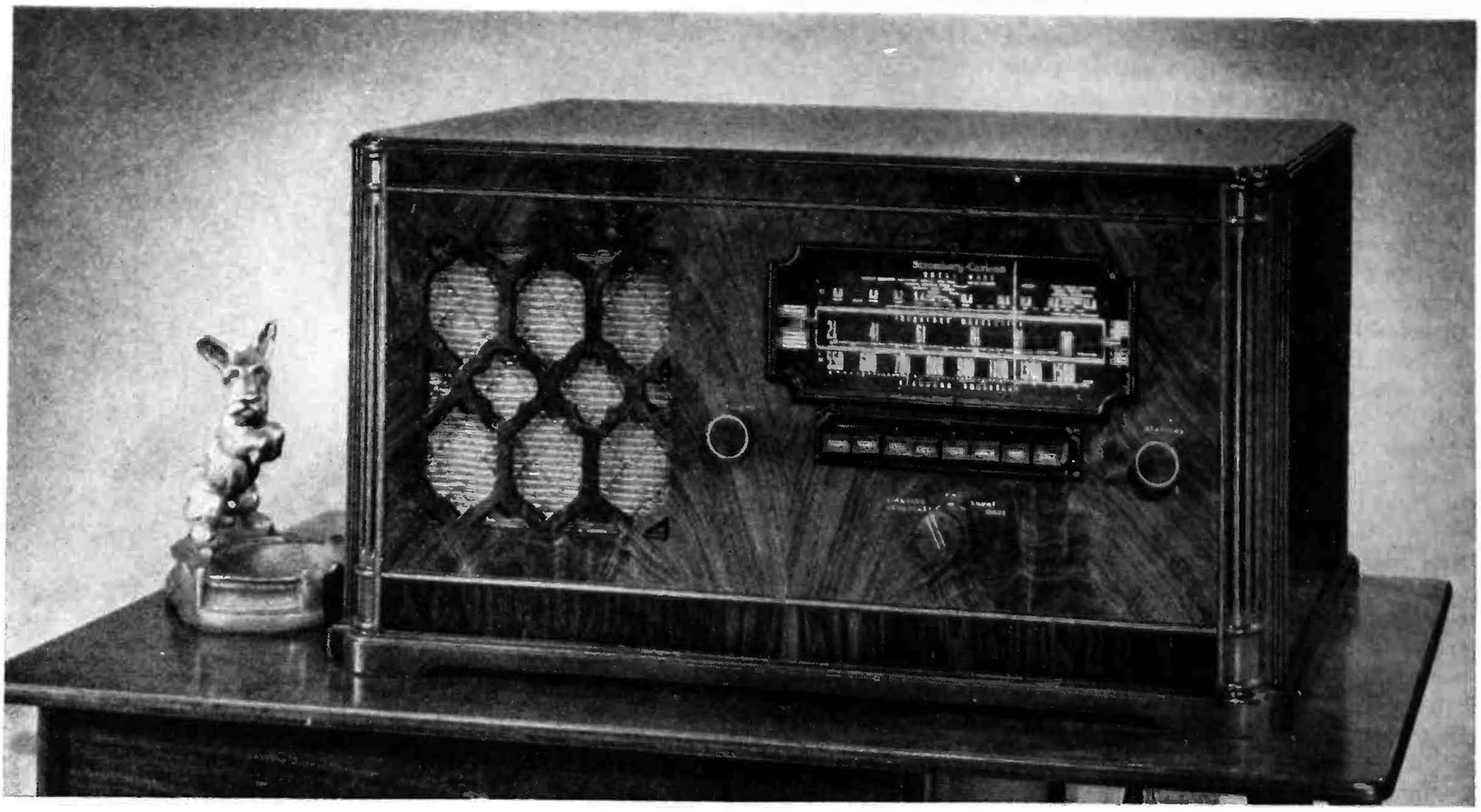


Combination AM-FM-Short Wave radio receiver.

FM RECEIVER DESIGN CONSIDERATIONS

By V. G. MARTIN
Design Engr., Stromberg-Carlson Co.

Some factors which must be taken into consideration in the design of quality FM receivers.

THE construction of broadcasting stations for the transmission of programs through the medium of frequency modulation (FM), and the introduction of radio receivers designed to receive these programs constituted one of the important phases of the radio broadcast art in the period immediately prior to the war. All indications point to a large increase in the number of such transmitting stations after the war with the consequent demand for radio receivers in a wider market. Because these transmissions are radiated at frequencies heretofore not commonly used for broadcast purposes (42-50 mc.) and because the design requirements of apparatus used to receive these transmissions are peculiar to a new art, this discussion is presented.

Standards of Design

To take full advantage of frequency modulation principles, there are a number of fundamental considerations[1] confined to FM reception in addition to other considerations common to reception by either FM or amplitude modulation (AM) that must be heeded. At the outset, this discussion will be on the basis that transmission is by wide band FM under present-day regulations of the Federal Communications Commission.

Quiet reception by FM through reduction of electrical noise and interference is made possible in large part by the use of a limiting tube and circuit which acts to remove disturbing AM components in the received and amplified wave and leave undisturbed the desired FM components. The characteristic of this device is shown in Fig. 3 where it is observed that beyond a certain value of input voltage the changes in amplitude due to noise or other amplitude effects give rise to little change in output, thus cancelling largely their disturbing effects. Changes in frequency introduced as a result of FM are passed through the limiter with no change in form.

From Fig. 3, however, it will be noticed that a relatively large value of radio frequency (r.f.) voltage (as the radio receiver engineer views it) is required to bring about this limiting action. This is a restriction common to vacuum tubes presently available. In order to arrive at the desired degree of noise reduction through limiter action, it is necessary, therefore, to provide r.f. amplification sufficient to raise the value of voltage intercepted by the antenna to an amount sufficient to cause limiter operation. Since the amount of amplification is confined to the limitations of vacuum tubes and associated circuits, it may be concluded that effective reception to an exceedingly low value of intercepted antenna voltage is possible with pres-

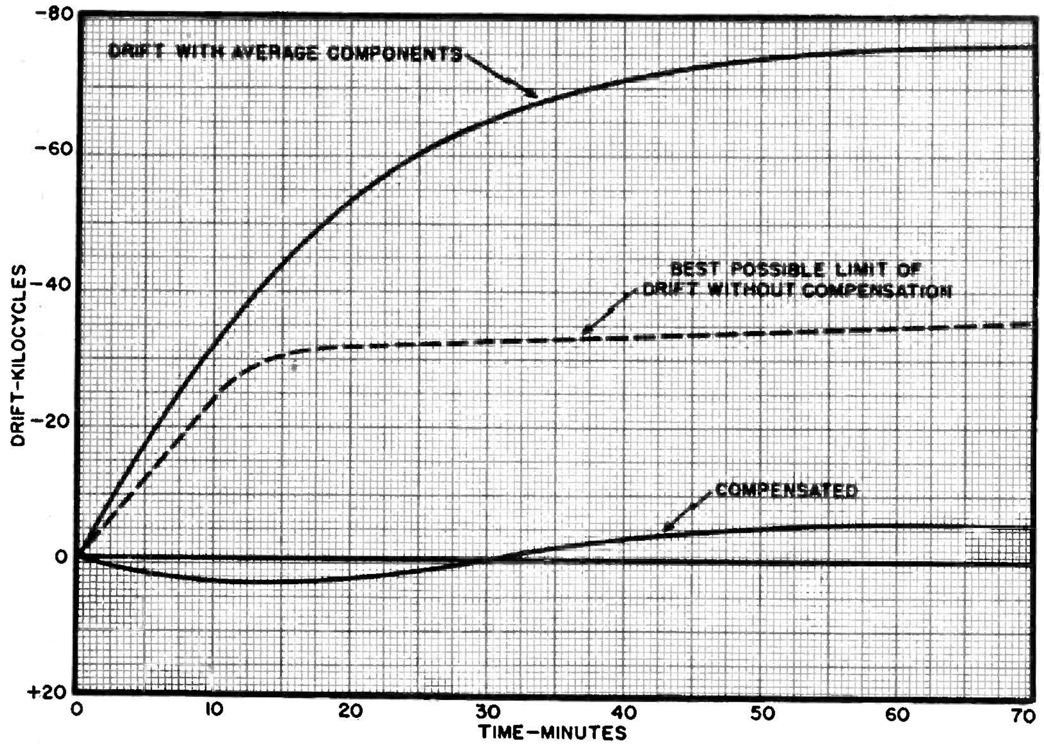


Fig. 1. Frequency drift in uncompensated and compensated oscillators.

ent-day components and to a degree far in excess of that realized in conventional AM design. This is, indeed, one of the very valuable properties of this system of FM transmission. Fig. 5 illustrates the voltage gain distribution in a well-designed type of broadcast receiver for the FM band. The term "sensitivity" serves to define the overall voltage amplification provided.

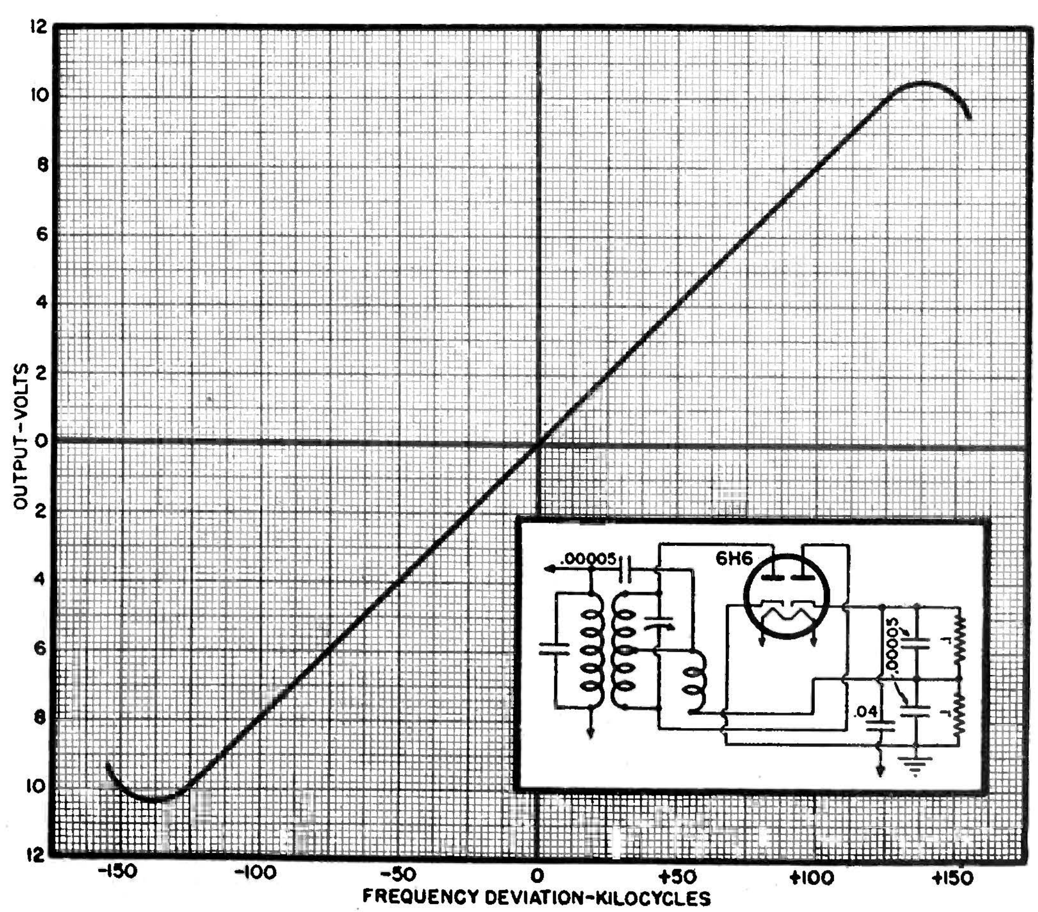
Having provided limiting action for noise reduction and sufficient sensitivity for adequate limiting and quiet reception, it is now necessary to introduce means whereby the desired station may be received and the undesired stations eliminated as a source of interference. The regulations of the FCC, previously referred to, restrict each station to a band of frequencies plus and minus 100 kc from an assigned carrier frequency and require that modulation effects be confined to a band plus and minus 75 kc from the assigned frequency. This regulation automatically defines the selectivity characteristic of the radio receiver, requiring it to pass a band of frequencies 150 kc. wide and attenuate rapidly thereafter so as to be unaffected by the presence of stations in the adjoining channels. Figure 6 shows the ideal selectivity characteristic as well as a practical characteristic realized in well designed broadcast receivers.

The output of the limiter is the desired FM signal substantially free of disturbing impulses. It is now necessary to derive the a.f. components from the frequency modulated wave. This is done by means of an FM detector termed a discriminator in which frequency changes at the input of the device result in direct current changes at the output which are directly proportional to the a.f. modulation at the source.[2] A typical discriminator characteristic is shown in Figure 2. Here it will be observed that its characteristic fulfills the band-pass requirements in that a linear relation of input frequency change and output current change is realized to a value beyond plus and minus 75 kc. from the carrier. This insures distortion-free detection.

The fidelity of reproduction in a well-designed frequency modulating receiver is limited only by the capabilities of the audio amplifier and acoustic system associated with the receiver. The phenomenon of high audio frequency attenuation by r.f. selective circuits as commonly experienced in receivers designed for AM is not present in any degree in FM receivers. This is due, of course, to the fact that frequencies at the extremes of the band represent those caused by high modulation levels at the transmitter and may be of any value in the a.f. spectrum. Attenuation of these frequencies by excessive r.f. selection will give rise to phase shifts through the r.f. amplifier with consequent distortion. Experience has indicated that attenuations at the extremes of the band to a value of 6 db may be tolerated as the consequent distortion is not appreciable to the careful listener. It is the practice, therefore, to design so as to allow reproduction of a.f. to an upper limit of 10,000 cycles per second. This is the limit of reproduction in conventional loud speaker systems. Using specially designed loud speaker systems, an overall reproduction of a.f. to a limit of 15,000 cycles per second has been attained. Suffice to say that high fidelity reproduction is a normal by-product of reception by FM.

The high sensitivity customarily designed into FM receivers will result, in the absence of a received carrier, in an excess of noise caused by fluctuation effects in tubes and associated circuits as well as by the antenna pickup of electrical disturbances usually present. These effects are observed when tuning between stations and are

Fig. 2. Typical discriminator circuit (insert) and characteristic.



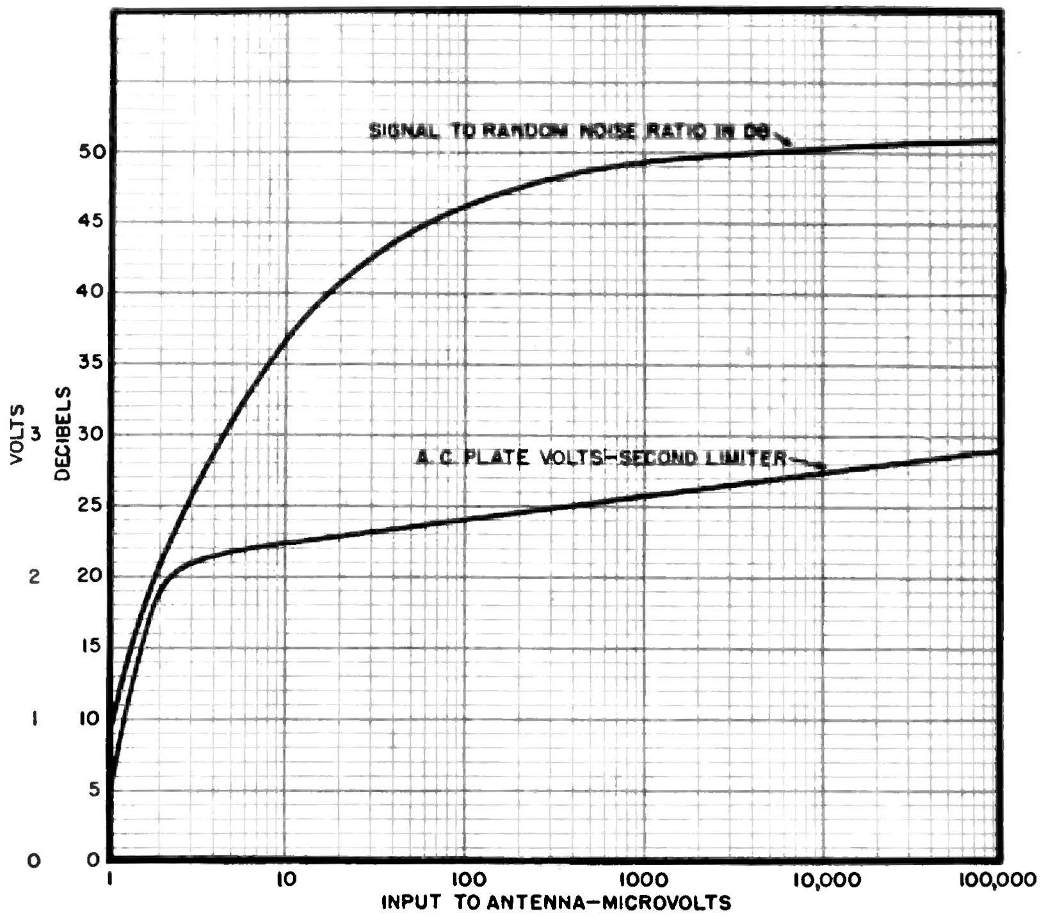


Fig. 3. Limiter characteristic, showing variation in limiter output with antenna input.

annoying to the user of the receiver. It is good practice to design means in the receiver whereby these disturbing effects are nullified. Details of several possible methods are given later in the article.

The ability of an FM receiver to retain an adjustment to a broadcast station, once this adjustment is properly made by the user, is an important characteristic in design. The deviation or drift of the receiver from exact tune results in distortion similar to that previously described for excessive selectivity. In this instance, the transmission characteristic of the receiver is no longer symmetrical about the desired carrier wave. Distortion is, therefore, a function of the deviation of the receiver from exact tune.

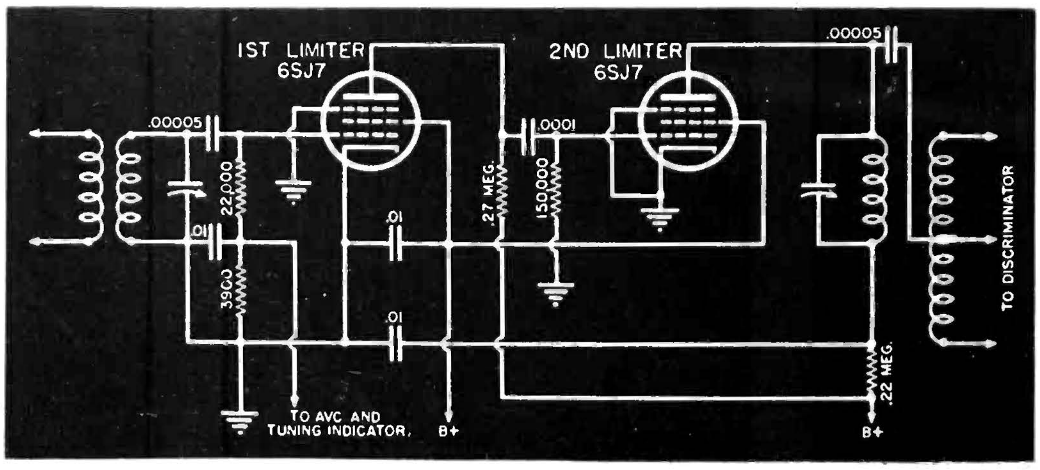
The introduction of an FM band incorporating the characteristics outlined above should not compromise any of the accepted standards of performance of the AM band. The required voltage gain of about 2,000,000 times between antenna and limiter on FM, coupled with low gain per stage caused by high operating frequencies, and broad i.f. transformer design, necessitates many high mutual conductance tubes in cascade. Having designed for best FM performance, it is a difficult matter to eliminate distortion on the standard broadcast band using conventional high mutual conductance tubes. As is the case in many designs, the engineer is faced with the problems of making the best possible compromise.

The sensitivity of the receiver to FM signals should be made as high as possible in order to make the greatest use of the broadcasting station coverage. An antenna sensitivity of one microvolt is readily obtained in a single-band FM receiver with generous use of high mutual conductance tubes, but is not as simply obtained in a combination AM-FM receiver. High mutual conductance tubes operating at best efficiency are characteristically sharp cut-off which makes for poor automatic volume control action on the standard broadcast band which in turn causes r.f. distortion at the high antenna voltages experienced in the vicinity of powerful broadcasting stations. The use of one remote plate current cut-off tube or the operation of one or two high mutual conductance tubes with series screen resistors to extend the cut-off point is possible with consequent reduction in gain. It was experimentally determined that a type 6SK7 tube (remote cut-off and average gain) used in the first i.f. stage, actually resulted in more stage gain with its lower grid-plate capacity at 4.3 mc. i.f. than a type 6AB7 or type 6AC7 with a series screen resistor to extend cut-off. A 6SG7 or 6SH7 tube with appropriate circuit constants would give further improvement. Loss in long leads to the switch used for changing from AM to FM also reduces gain. Therefore, in order to attain FM sensitivity of the order of 1 or 2 microvolts, in a combination AM-FM receiver, special emphasis must be given to the design of r.f. and i.f. transformers and to the disposition of circuit components to obtain the greatest efficiency.

If the FM band is extended to include 42 to 56 mc. the intermediate frequency will undoubtedly be increased to 8:25 mc. in order to keep the image outside the band. An increase in frequency represents a potential loss in gain per stage because of (1) lower inductances in the coupling transformer resulting in lower tube loading impedances, (2) increased coupling through the plate-grid capacitance, and (3) low circuit efficiency because of increased r.f. resistance. To keep the inductances as high as possible, a lower value of tuning capacitor may be chosen, but it should not be made so small as to permit tube and other incidental shunt capacitance to be a large part of the total capacitance. Too small a trimmer capacity would allow mis-tuning with tube temperature changes and tube replacement.

Instability is always a limiting factor in stage gain. If all stray circuit paths are eliminated, the theoretical stage gain cannot be realized, particularly at high frequencies, but must be held to a value where feedback through the tube plate-grid capacitance does not seriously affect the symmetry of the selectivity curve. The best amplifier tube for FM would

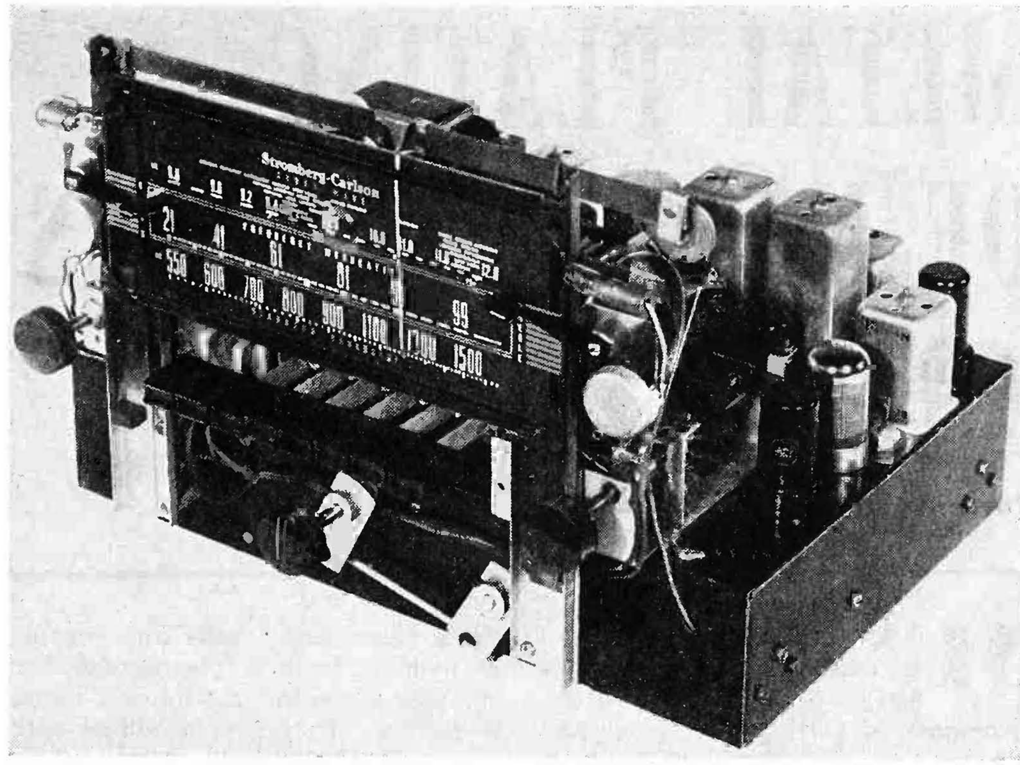
Fig. 4. Schematic diagram of a typical double limiter circuit.



be one with the highest mutual conductance and the lowest grid-plate capacitance with consideration given to its AVC characteristic on the AM bands.

Selectivity describes the ability of a receiver to provide a desired signal free of interference from other signals. The number and quality of the tuned circuits and the choice of the intermediate frequency determine the degree of selectivity. One type of interference is minimized by making the i.f. a value slightly more than half the range of the FM band so that the image falls outside the band. The i.f. tuned circuits, more than the r.f. or pre-selection tuned circuits, determine adjacent channel selectivity because of the larger number of tuned circuits in the i.f. amplifier. While interference between stations on adjacent channels does not usually exist with good receivers, the increase in the number and power of FM stations may require better selectivity. An increase in i.f. from 4.3 mc. to 8:25 mc. for the proposed extension of the FM band presents a problem in obtaining adequate selectivity because the higher frequency reacts in several ways. First, the circuit Q, or efficiency, would be less. Second, doubling the frequency would double the width of the pass band, even if the Q remained the same, since for a given Q the ratio of pass-band to center frequency is a constant. And third, feedback through the plate-grid capacitance, which is regenerative on one side of resonance and degenerative on the other, would have a greater effect on symmetry of the selectivity characteristic. The desired selectivity characteristic is one which passes all frequencies equally well within a range of 75 kc either side of resonance (the maximum FM swing) yet gives as much attenuation as possible beyond.

As stated before, the tuned circuits of the r.f., or pre-selection stages, contribute little to adjacent channel rejection, their main function being the rejection of spurious responses. When a station is heard at more than one setting of the dial, the additional points are called spurious responses. A spurious response is created by a combination of harmonics of the signal and oscillator frequencies in the modulator to produce a resultant frequency equal to the receiver i.f. The response nearest in frequency to the resonance point of the receiver is the strongest. Whether or not the degree of rejection attained at present will be adequate with the anticipated increase in number and power of stations is difficult to determine, but some indication could be obtained by surveys in the vicinity of existing high power FM broadcast stations.



Chassis of combination AM-FM-Short Wave receiver.

To show, for example, how a 45.1 mc. signal would appear at 47.25 mc. on the dial with a 4.3 mc. i.f., it may be assumed that the oscillator is tracking on the low frequency side of the signal or at a frequency of 42.95 mc. The second harmonic of the undesired signal (90.2 mc.) minus the second harmonic of the oscillator (85.9 mc.) produces 4.3 mc. or the intermediate frequency. Other spurious responses are determined by similar combinations. The proposed 8.25 mc. i.f. would double the frequency separation between responses and the resonant frequency, and hence would improve the rejection.

Improved oscillator stability is a subject which should receive attention. During the period of an hour after a receiver is turned on, the oscillator progresses to a lower frequency and if this "drift" is large, the station to which the receiver was originally tuned may be well out of tune in a few minutes. The causes of drift and the measures for its correction are

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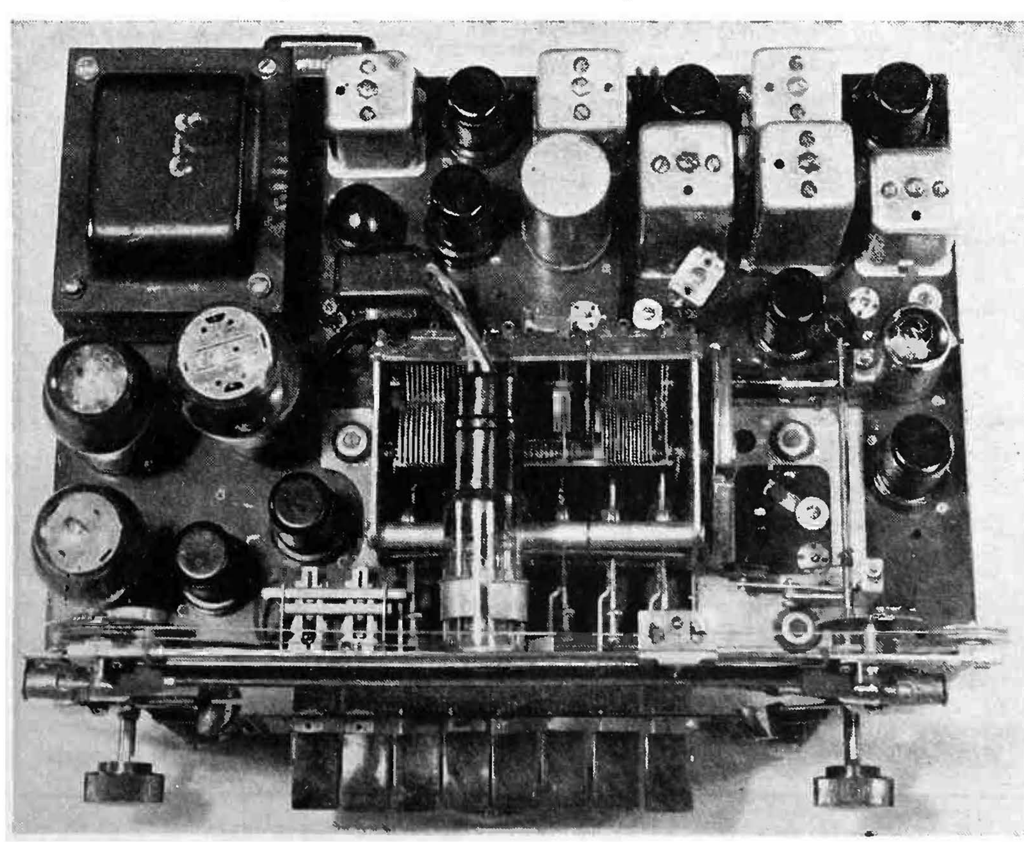
Top view of chassis of receiver pictured above.



Personals

R. J. BIELE has been appointed assistant engineer of the Receiver Division of the General Electric Company's Electronics Dept. He will be located at the company's Bridgeport plant. Mr. Biele joined General Electric in 1935 after graduating from the University of Utah with an electrical engineering degree. His work had been in the receiver division exclusively. He is an associate member of the A.I.E.E. and I.R.E.

JOHN F. DRYER, JR. has joined the staff of Amperex Electronic Products as an electronics engineer. He will devote himself to the development of power and control tubes for use in industrial applications. Mr. Dryer's most recent position was with Fairchild Engine and Airplane Company where he helped to develop a high frequency heating unit used in fabricating wooden parts and for thermosetting of glues.

G. KEITH FUNSTON, former director of purchases at Sylvania Electric Products Co., was elected president of Trinity College in Hartford, Conn. This 33-year-old business man has been granted a leave of absence from the college to serve as a Lt. Cmdr. in the Navy. He graduated from Trinity College in 1932 where he was a Phi Beta Kappa, and from Harvard Business School. He is now on duty in Washington, D. C.

WALTER F. KEAN will be in charge of the new field engineering and allocation service now being offered to the FM and Standard Broadcasting industry by Andrew Company of Chicago. Mr. Kean comes to Andrew from the Western Electric Company where he was in charge of testing radio and radar projects. He is an associate member of the A.I.E.E. and I.R.E. Broadcast executives are welcome to use his services.

RICARDO MUNIZ has joined the Espey Mfg. Co. as director of engineering. Until recently Mr. Muniz was chief engineer of Radio Navigational Instrument Corporation. He has authored several technical books as well as numerous articles on radio and television circuits. He taught radar and directed classes in radio design and development at Hunter College, New York. Mr. Muniz speaks Spanish and French fluently.

DR. ELLIS R. OTT has resigned as associate professor of mathematics at the University of Buffalo to accept the position of assistant to the Director of Engineering of the National Union Radio Corporation. Dr. Ott will devote his time to statistical quality control problems at National. He is the author of several mathematical texts as well as numerous articles which have appeared in leading technical journals.

Receiver Design

(Continued from page 21)

well known. Any component in the oscillator circuit whose capacitive, inductive, or resistive characteristic changes even slightly with heat or humidity, contributes to drift. When all normal precautions, including use of air dielectric trimmer capacitors, are taken, the principal remaining causes of drift are the oscillator tube itself and the oscillator coil. Materials having the least dimensional change with temperature or humidity must be chosen for the coil. The tube will contribute the most drift in a good oscillator circuit. The drift will amount to about 0.05% in frequency or about 23 kc at an initial frequency of 45 Mc. A shunt capacitor with negative temperature coefficient is used to offset the normal drift. Figure 1 shows an example of rather considerable drift which is adequately corrected with a 32 $\mu\mu$f thermal compensating capacitor.

The next consideration is the limiter and discriminator stages. An FM receiver is essentially similar to an AM receiver through the r.f. and i.f. stages. Not only is the desired FM signal amplified but all electrical disturbances of an AM character as well. Nearly all the amplitude variations which appear as noise may be removed by addition of a limiter stage which will pass frequency variations but present a "saturated" condition to voltage amplitude changes. This condition is obtained with a sharp cut-off pentode in a grid bias circuit with the plate and screen voltages approximately 2 and 20 volts respectively. Under these conditions an FM signal of 2 or more volts applied to the grid will cause plate current saturation and hence be relatively unresponsive to the grid voltage variations. When the applied FM voltage is less than the limiting value, the limiter acts as an amplifier for AM, and the noise will likely be greater than the signal.

A single limiter cannot suppress noise of the random or sinusoidal type and impulse or shock noise with equal effectiveness owing to the great difference in wave shape. If the time-constant of the grid capacitor and grid leak combination is correct for the average random noise, it is too high to follow pulses of short duration. The grid capacitor must charge and discharge with the rise and fall of noise voltage, in order not to alter the steady-state condition of the plate current. The choice of a low time-constant for a single limiter not only is unsatisfactory for random noise, but the sensitivity of the stage is reduced because of the low value of series ca-

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in the first limiter can be used to control a positive bias on the second limiter grid by applying the voltage drop across a resistor in the first limiter grid to the grid of an extra tube and applying a portion of the positive plate voltage to the second limiter grid. In operation, a signal of predetermined magnitude will bias the "squelch" tube to plate current cut-off, thereby removing the disabling positive voltage from the grid of the second limiter.

A simple and effective method of inter-station noise suppression is applicable to a single as well as a double limiter, and no extra parts or circuits are required. It consists only in operating the limiter screen grid at a higher voltage than is customary. The best constants are a no-signal screen voltage of about 51 volts from a well regulated source such as a tap on the bleeder resistor, and 2.2 volts on the plate through a dropping resistor. With these conditions the limiter is entirely unresponsive to voltages under 0.75 volts applied to the grid. This value is just above that created by inherent receiver noise and hence entirely quiet operation between stations is attained. The sensitivity of the receiver, rated on the basis of a 20 db signal to noise ratio, and a 2 volt limiter grid signal, is not impaired. With a signal grid voltage of 1 volt or more, the limiter functions normally. The action is much like a trigger and the effect is demonstrated when tuning in a station. While a normal limiter would permit an appreciable interval of noise rise as resonance is approached, the interval is extremely short with the limiter described here because of the narrowed range of noise voltage response.

A tuning indicator, or "eye," is essential for satisfactory operation of an FM receiver, because three peaks of audio response are heard when tuning, only the center one being free of noise and distortion. This is characteristic of a discriminator, hence the need for accurately locating the center point with visual means. Exact

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adjustment to the midpoint of the discriminator is desirable to insure undistorted response and to balance out ignition and other noise types not entirely removed by the limiter. Several accurate methods of indication con-

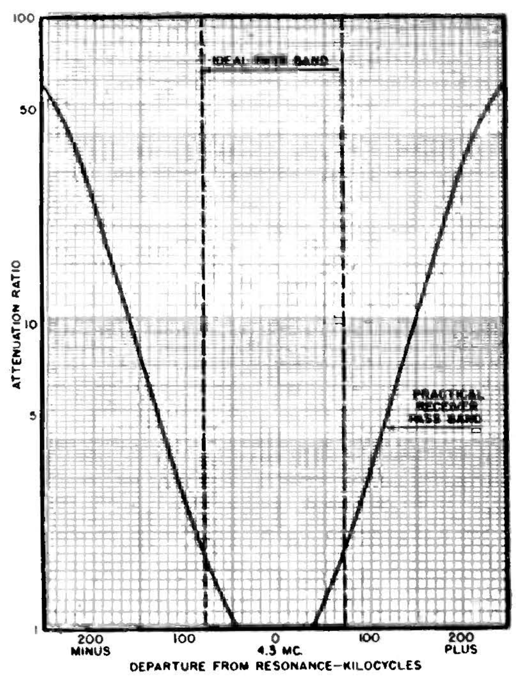

Fig. 6. Ideal and practical selectivity characteristics for FM broadcast receivers.

trolled by the discriminator are available [3] but the simplest type, controlled by limiter grid current, proves adequate on carefully aligned receivers. This is a 6U5 type indicator tube which responds to the amplitude of the received signal. A small amount of AVC in the i.f. amplifier is required to insure a sharp indication with strong signals.

Extended fidelity or the transmission and reception of the higher audio frequencies and overtones necessary to the full appreciation of good music is one of the outstanding characteristics of FM. Standard broadcast stations on AM are only 10 kc apart in the spectrum and audio modulation frequencies above 5,000 cycles per second give side-bands which extend into the adjacent channel and produce interference. The means for obtaining high fidelity reproduction on the regular broadcast band is a serious design problem, while high fidelity in an FM receiver is simple, limited only by the design of the audio amplifier and speaker system. The pre-emphasis inserted at the transmitter in order to give a more favorable signal-to-noise ratio is compensated with a shunt capacitor of about .002 μf and series resistor of about 68,000 ohms at the output of the discriminator in the receiver.

In conclusion, the following improvements are recommended for post-war receivers:

1. The normal drift of the FM oscillator should be reduced as much as possible.
2. Alignment procedure should be as simple as possible, and should allow peaking by a meter reading rather than by an oscilloscope.
3. A better limiter circuit and a simple combination FM discriminator and detector should be developed.
4. Push buttons should be provided for FM as well as AM.
5. Dial calibration in production receivers should not deviate more than ±¼ channel from exact tune.
6. Inter-station noise should be suppressed.
7. More efficient built-in antennas should be installed.
8. A tuning indicator should be employed.
9. A better selection of components and better quality control in production will insure more uniform performance in the field.

Thus, the improvement of postwar FM receivers and the consequent increase in public acceptance rests squarely on the engineer. His ability to solve some of the more troublesome problems existing today in FM reception is of utmost importance if this improved method of radio reception is to be universally utilized and enjoyed.

REFERENCES

1. *Armstrong, Edwin H., "A Method of Reducing Disturbances in Radio Signaling by a System of Frequency Modulation," Proc. I.R.E., May, 1936.*

2. *Roder, Hans, "Theory of Discriminator Circuit for Automatic Frequency Control," Proc. I.R.E., May, 1938.*

3. *Rogers, J. A., "Tuning Indicators and Circuits for Frequency-Modulation Receivers," Proc. I.R.E., March, 1943.*