SECTION 2—CIRCUIT APPLICATIONS

2-1 PURPOSE AND SCOPE

The purpose of this section is to describe the applications of basic circuits discussed in the Electronic Circuits volume of the EIMB, NAVSHIPS 0967-000-0120. The discussion shows these circuits combined into circuit groups to perform specific functions related to communications equipment and explains the overall circuit operation. Practical subcircuits, unique electronic concepts, and frequently used techniques applicable to this equipment-oriented handbook are discussed. For simplicity and ease of understanding, a block diagram type of presentation is used throughout, and only input and output signals and related circuit functions are considered. Where necessary for a better understanding of circuit operation, however, a more detailed circuit analysis is given.

The scope of this section covers those functions and concepts concerned with the transmission, reception, control, and display of signals used in communication systems. New concepts and functional applications will be included in future changes to the Handbook, as the need rises. No classified information is contained in this section of the Handbook.

2-2 ANTENNA OVERLOAD CIRCUIT

APPLICATION

The antenna overload circuit automatically turns off the transmitter plate current when a predetermined overload point is reached, to prevent damage to the transmitter.

CIRCUIT ANALYSIS

General. Several types of overload circuits or devices are used in transmitters. In older equipment, fuses were connected in the primary power supply, secondary supply fuses were inserted in critical circuits, or resettable circuit breakers were used in the final transmitter stage. Modern transmitters use an antenna overload circuit, which depends upon excessive RF output current or voltage to activate the overload device.

By using a rectifier to produce a DC voltage proportional to the antenna output voltage, a circuit breaker can be made to trip when the RF output voltage (or current) exceeds a predetermined value. It is necessary of course, to permit a higher-than-normal plate current flow without tripping of the circuit breaker, to provide for tune-up variations.

Under normal ship conditions where a number of different antennas are used, a perfect or even close match is usually not obtainable. Thus the VSWR changes considerably when the transmitter operates on different frequencies using different antennas. Since a reflectometer is designed to use only a few watts of RF power from the power output stage, it is suitable for operation of an overload control. Use of the reflectometer output to initiate tripping of the circuit breaker at a predetermined VSWR offers a simple automatic method of antenna overload protection, and yet allows for normal VSWR variations within the safe limits of operations. Variations in VSWR are caused not only by tuning but also by leakage, changes in antenna lead dielectric, and changes in the capacitive reactance offered by the antenna as it swings during high winds or during ship's roll. Hence, with the automatic overload control located in the antenna output line, overload protection is more effective.

Circuit Operation. The accompanying block diagram shows a typical antenna overload device which utilizes the change of VSWR to operate it. As shown in the illustration, the output of the transmitter is applied to an RF monitor unit which contains an indicator (usually a meter) calibrated to indicate output power and/or VSWR. The monitor includes a reflectometer connected in series with the antenna. The reflectometer operates directionally. That is, the output in a forward direction provides an indication which is adjusted to a set value on the SWR indicator output meter. When the indicator direction switch is reversed, the current flowing in the reverse direction (away from the antenna) is indicated. In a perfectly tuned and matched antenna when the forward current is at a maximum value, the reverse current is almost zero. Thus for a 1.1 to 1 VSWR ratio, if the meter indicated a maximum of 100 in the forward direction, it would indicate only about 5 in the reverse direction. However, if the VSWR ratio were 4 to 1, the reverse reading for the same forward indication would be about 60 since the indications are not linear but vary logarithmically.

During normal operation, the RF monitor rectifies the antenna voltage and, through a bias amplifier, places the grid of the control amplifier at cut-off bias. When the antenna circuit is operating within the normal VSWR setting, the relay which controls circuit breaker operation remains inoperable. If the VSWR changes, however, the bias on the control tube and the output current of the control tube also change until, at the tripping value, sufficient current is drawn through the control relay to energize it, and trip the circuit breaker. The final amplifier power input is thus removed, and transmitter overload is prevented automatically by the changed VSWR in the antenna circuit.

Some overload devices also have an alarm circuit which is actuated when the breaker trips, and either visually (by lamp) or audibly (by buzzer) warn the operator to check and readjust the tuning or to look for the trouble.

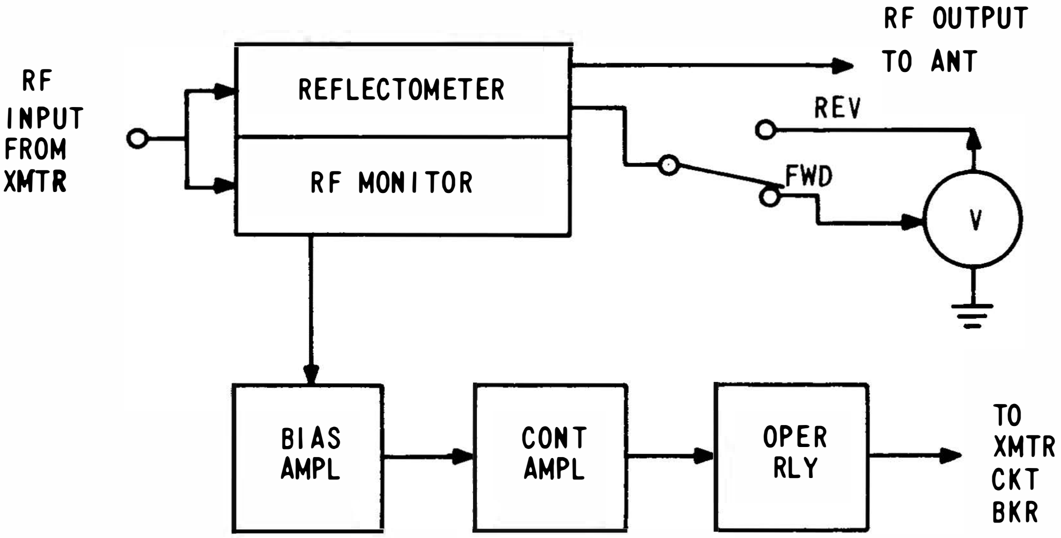
2-3 PRESELECTOR-MIXER CIRCUIT

APPLICATION

The preselector selects the signal, while the mixer beats this signal against an oscillator signal to provide the IF signal.

CIRCUIT ANALYSIS

General. The preselector-mixer circuit can be divided into two separate stages, one stage operating as an RF amplifier and preselector, and the other



Typical Antenna Overload Circuit

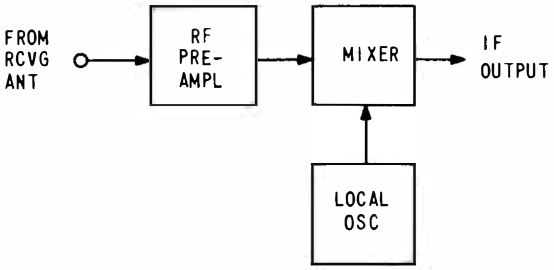
operating as an untuned frequency converter or first mixer. On the other hand, both circuits can be combined into one stage, using a tuned input circuit to provide the preselection, and another circuit to beat the output of the local oscillator signal against the input signal to produce the IF output signal. With the combined stage, the receiver is more susceptible to interference from image signals because of reduced selectivity. This was the first drawback to acceptance of the superheterodyne circuit, since most stations came in at two or more places over the receiver tuning band, and it was difficult to select a station, particularly when the image coincided with another signal and interfered with it. Use of a separate preselector stage increased the image suppression ratio on the lower frequencies. To further reduce receiver image interference, the frequencies of the IF stages were also changed from low frequencies such as 50, 75, or 200 kHz to 455 kHz or higher. Since the image frequency is removed twice the value of the IF from the input signal, the use of a 455-kHz IF causes the image to be 910 kHz higher than the original received frequency. This produces less image interference and fewer repeat spots over the tuning range of the receiver.

As higher-frequency work became more popular, double-conversion and triple-conversion operation also became popular in superheterodyne receivers, so that 3500-kHz and 1600 kHz IF stages were used to feed a final 455-kHz stage. To gain the extreme selectivity available with the high-Q circuits possible at low frequencies, some triple-conversion units used a final IF of 50 kHz to provide extremely sharp selectivity.

In most cases the gain produced in the frequency-conversion or mixer stage is low, and the major action is to convert the frequency to one which can more easily be amplified. Therefore, both RF and IF amplifiers are necessary.

Circuit Operation. The accompanying figure shows a block diagram of a simple preselector-mixer stage combination.

The RF preamplifier operates as the preselector stage, producing both radio-frequency selection and amplification. If amplifies the RF signal at the original signal frequency. In some receivers two stages of RF preamplification are used, but improved techniques in tubes and transistors have achieved high-gain RF preselectors and amplifiers, which make only one RF stage really necessary. Amplification at the RF input frequency increases the signal-to-noise ratio and helps raise the input signal above the noise level, making the receiver more sensitive to weak signals.



Preamplifier-Mixer Circuit

When the preselected RF signal is applied to the mixer stage, it is beat against a local oscillator signal applied to the mixer. The RF difference signal between the received signal and the local oscillator frequency is the IF. In earlier receivers, the oscillator frequency was lower than the received-signal frequency. In most receivers now, the oscillator frequency is higher than the received-signal frequency, so that the combined difference places any image signals at a higher frequency, which is twice the IF from the original signal. Thus, image reception is made much weaker because the image signal is either completely out of the tuning range or so far from the tuned input frequency that the image amplitude is considerably reduced, if not eliminated. Usually, the receiver cannot be tuned to the image unless the receiver is aligned improperly.

The increased signal-to-noise ratio offered by the preselector stage, plus any gain obtained in the mixer or converter stage, usually provides a good IF signal, and only one high-gain IF stage is needed for normal reception. Where high selectivity is demanded, many more tuned circuits are used in the IF to provide the desired bandwidth; in microwave receivers where the initial IF input is low, 3 to 8 stages of IF are commonly employed.

2-4 IF AMPLIFIER AND DETECTOR CIRCUIT

APPLICATION

The IF amplifier provides the desired selectivity and amplification of the converted input signal, and the detector rectifies the IF output to provide an audio frequency output.

CIRCUIT ANALYSIS

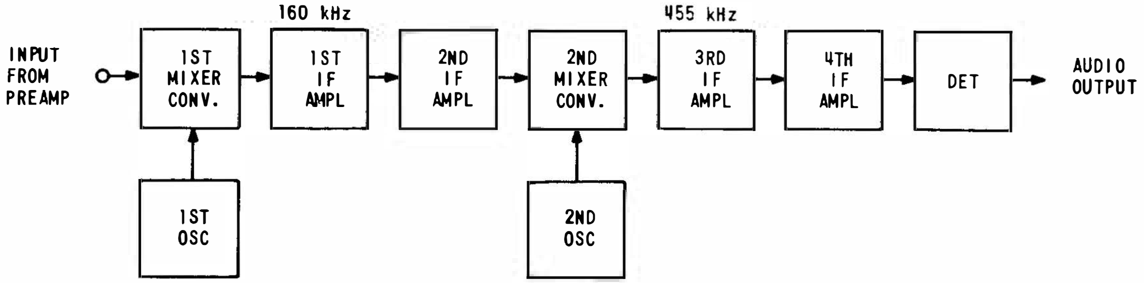
General. In a superheterodyne receiver, the received input signal is converted to the IF amplifier frequency for amplification and bandwidth determination. By using a series of IF amplifiers in cascade, the IF signal amplitude is increased. The numerous tuned circuits in the IF transformer stages control the signal pass band. The more selective the tuned stages, the narrower the bandwidth. For example, a single-stage amplifier may have a pass band of 10 kHz or more at the half-power points, while a series of 3 or 4 stages may have a pass band of 1 kHz or less. Usually, a large number of cascaded stages (each with low gain) provides a sharp filtering effect, although this is affected somewhat by the frequency selected for the IF stages. The lower-frequency IF will have the smallest pass band because the effective IF transformer Q can be made higher. Thus, in a triple-conversion receiver, the first group of IF stages provides a relatively wide pass band, the second group provides a narrower pass band, and the third group provides the narrowest pass band.

In a receiver, the RF preamplifier and mixer provide the first limitation on bandwidth for tuning and signal selection, while the IF stages either maintain this bandwidth or reduce it. Close coupling in the IF transformers broadens the bandwidth and increases the overall gain, while loose coupling reduces the bandwidth and decreases the overall gain. By using a sufficient number of adjustable stages, almost any desired signal pass band may be achieved. Thus an IF input signal of a few microvolts may be built up to hundreds of millivolts or even volts at the detector so that, after detection, not much audio amplification is needed.

Any type of detector may be used, such as AM, FM, or SSB product detectors, depending upon the type of modulation to be detected. The detector must be capable of handling the IF output signal without producing distorition caused by overdrive, saturation, or flat-topping. In most receivers a diode-rectifier type of detector is used, followed by an audio amplifier to provide sufficient audio output.

Circuit Operation. The accompanying figure shows a typical double-conversion IF-detector stage arrangement. The first-conversion IF signal results from beating the first-conversion oscillator output against the original RF input signal in the first mixer. This IF signal is a replica of the original input signal to the receiver and contains all the modulation components, but now its frequency is lower. In the special case where a superheterodyne circuit is designed to receive low-frequency RF signals, the opposite technique is used. That is, the RF signal is converted to a higher frequency to avoid repeat spots over the tuning range of the receiver and to eliminate any blank spots caused by local oscillator harmonics.

The local oscillator signal is usually higher in frequency than the input signal. Thus to convert an



Dual Conversion IF Amplifier and Detector Circuit incoming 1000-kHz signal to a 455-kHz difference IF output, the oscillator frequency is 1455 kHz. In this case, the image signal is twice the IF, or 910 kHz above the original frequency, and usually out of the receiver tuning range. In the double-conversion receiver, the first IF is on the order of 1600 kHz, and the second IF is 455 kHz. The selection of local oscillator and IF frequencies is determined by the design of the receiver.

The IF signal produced by the second-conversion process is also a replica of the input signal, containing the original modulation. It is further amplified by the second-conversion IF stages, and a large amplitude output is supplied to the detector. Usually, the rectified output of the detector provides sufficient voltage to operate headphones. In most cases a stage of audio amplification is added to bring the detector output level up high enough to drive a loud speaker. Usually an output of 1 to 2 watts is provided to supply adequate volume with low distortion. Since a 500-milliwatt output is sufficient to drive headphones, the audio output transformer in some receivers is provided with a separate winding and a jack switch to disconnect the speaker when headphones are used.

2-5 COMPARATOR TYPE AFC CIRCUIT

APPLICATION

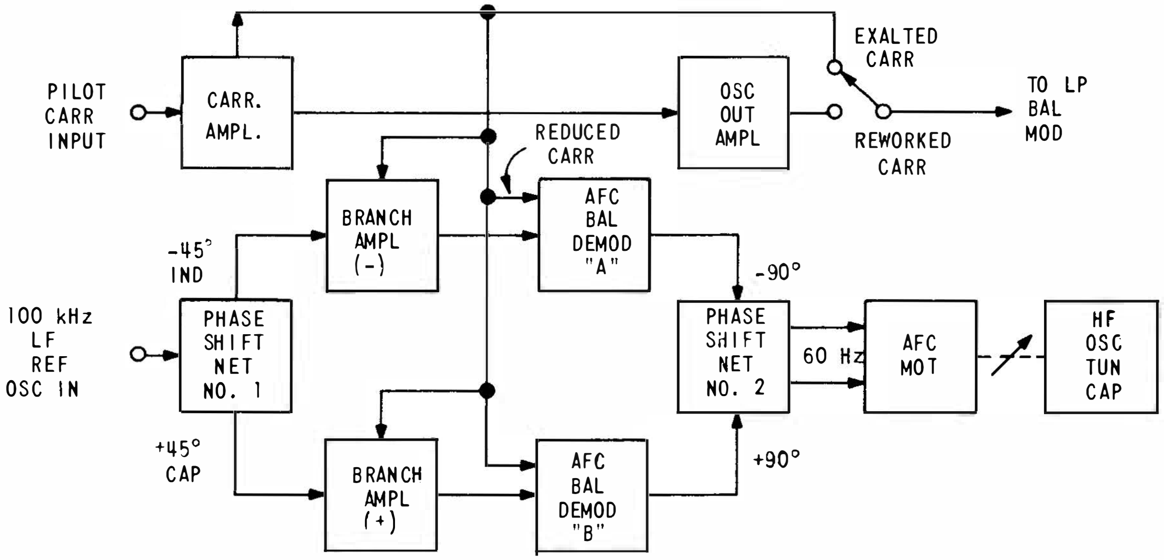
The comparator type of automatic frequency control (AFC) circuit is used to keep the reference oscillator frequency of a single sideband receiver constant.

CIRCUIT ANALYSIS

General. There are two basic types of AFC in general use for communication equipment, the comparator type and the phase discriminator type. The latter type will be explained separately. The comparator type gets its name from its functional application. Usually a pilot carrier (in the partially suppressed carrier type SSB system) is compared with a master (reference) oscillator frequency (or the IF carrier) to produce a constant frequency to act as the reinserted transmitter carrier input. This is important because any difference in frequency between the original carrier (whether or not it is transmitted) and the inserted carrier must be kept within approximately 10 hertz to retain intelligibility. Distortion in the audio output occurs for frequency differences over 10 hertz, and the signal is usually completely distorted and unusable for communication when the difference frequency approaches 50 hertz or more.

When completely suppressed carrier transmission is employed, it is necessary for the audio modulation (or some other system) to be used to generate a reference carrier; in this case, the phase discriminator type of AFC is usually used, since it is more easily controlled. If an AFC circuit is not used, the operator must make slight tuning adjustments, from time to time, to retain clear reception even though stabilized master oscillators and crystal-controlled transmitter and receiver frequencies are used. The main difference between single sideband (SSB) AFC and AFC used for other purposes is that the received bandwidth for SSB is very narrow and the transmitter and receiver frequencies must be more accurately kept than in other types of transmission.

Circuit Operation. The accompanying block diagram illustrates a typical comparator AFC arrangement. Two basic inputs are applied to the AFC circuit. One input is the transmitter pilot carrier, which is amplified in the exalted carrier amplifier stage and is applied through a switch to serve directly



Comparator Type AFC Arrangement

as the demodulator carrier, or through the oscillator output amplifier to the low-frequency carrier reinsertion reference oscillator. In either case, the signal supplied is amplified sufficiently to provide a carrier reinsertion signal amplitude which is about 5 times that of the sideband RF input signal to be detected. Such amplitude difference is necessary for proper production of an output signal from the balanced modulators in the detector circuit. At the same time, a reduced value pilot carrier input is applied to both of the branch amplifiers and fed to the upper and lower balanced modulators (A and B) used for AFC control.

The second input is the low-frequency reference oscillator input, which is applied eventually to the balanced modulators in the AFC output stages through a 45-degree split-phase shifting network and branch amplifiers. The inductive shift provides a negative output signal, and the capacitive shift in the phase network provides a positive output. Thus, minus and plus phase shifts, respectively, are applied through the branch amplifiers to AFC balanced modulators A and B, and the low-frequency signal is 90 degrees out of phase in the modulator outputs. The inserted (pilot) carrier fed in parallel from the exalted carrier stage is in-phase. The in-phase inputs to the balanced modulators in the AFC circuit produce no output, and are cancelled in the push-pull output circuits of modulators A and B. The 90-degree phase difference between the low-frequency oscillator inputs, however, produces an out-of-phase output voltage from the AFC balanced modulators. Arrangement is such as to produce a 60-Hz AC output voltage, to drive a split-phase AFC motor. The AFC motor is mechanically linked to a capacitor connected across the tuned circuit of the high-frequency carrier reinsertion oscillator, so that the output frequency can be increased or decreased by rotation of the AFC motor in the proper direction. Thus, when the difference frequency between the pilot carrier or low-frequency reference oscillator changes, the AFC motor moves in a direction to compensate for this difference. Since the two voltages are constantly compared, a constant difference is produced to keep the AFC action in synchronism with the changes in either the pilot carrier or the reference oscillator. As the oscillator frequency is corrected, the voltage output to the motor will decrease in frequency until zero frequency is reached and the motor stops. The oscillator is thereby tracked to the carrier frequency or vice versa.

The fixed phase shift of the low-frequency reference oscillator signal might seem to indicate only one direction of rotation. This would be true if only the oscillator signal were the driving signal. It must be remembered, however, that it is the difference frequency which is applied to the AFC motor, and that the phases of the two outputs of the modulators reverse as the frequency goes through zero, that is, as the carrier goes through the frequency of the oscillator. Although the reference oscillator used is highly stable, a condition could exist where it may be operating at a higher or lower frequency than the nominal 100-kHz reference oscillator frequency. It makes no difference whether this is the case, or whether the HF or MF oscillator or the received carrier has shifted in frequency, as long as the proper relationship is maintained between the reinserted carrier and the received sideband signal at the demodulator.

If the reference oscillator were low in frequency by 10 hertz, the AFC would correct the HF oscillator frequency so that the 100-kHz carrier and the sideband would also be 10 hertz low in frequency. Thus, the high-frequency input signal which acts as the reinserted carrier for the receiver or transmitter balanced modulators remains effectively at an absolute frequency, so that the proper audio output can be obtained automatically, instead of requiring the operator to constantly retune the receiver to track with the transmitter.

2-6 PHASE DISCRIMINATOR TYPE OF AFC CIRCUIT

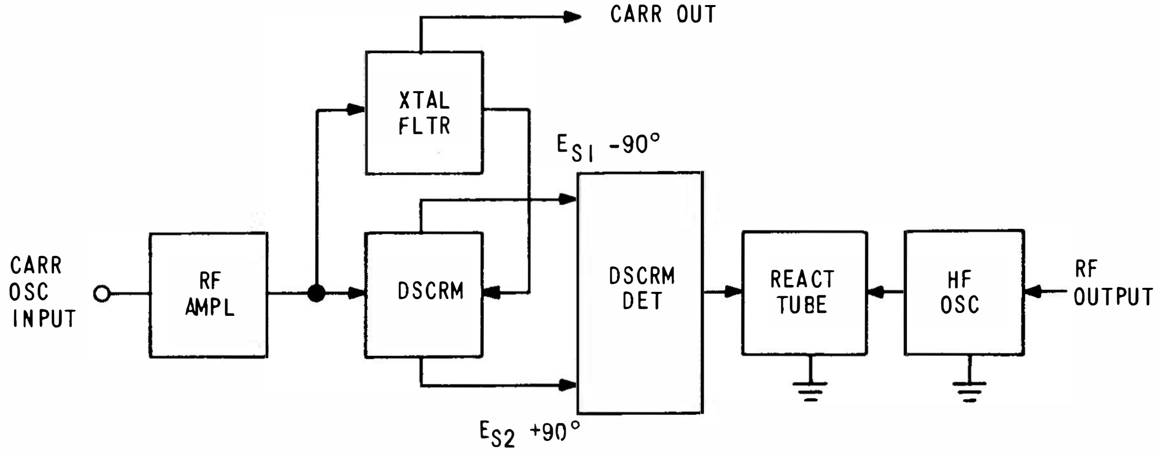
APPLICATION

The phase discriminator type of automatic frequency control (AFC) circuit is used to keep the reference oscillator frequency of a single sideband receiver constant.

CIRCUIT ANALYSIS

General. The comparator type AFC circuit, described previously, is usually used with an unsuppressed or partially suppressed carrier type of receiver. Whereas the phase discriminator type AFC is mostly used for suppressed carrier type receivers. Since there is no carrier or pilot carrier to compare frequencies, a phase discriminator is employed to produce a reference output which can be used to control the AFC circuit. An RF reference oscillator input is applied to represent the carrier, and a reactance tube control circuit is used to provide AFC control of a high-frequency oscillator.

Circuit Operation. The accompanying illustration shows the arrangement of the discriminator type AFC circuit. The output of the low-frequency reference oscillator is applied to an amplifier, the output of which is applied to a conventional frequency discriminator. A crystal filter ground to the selected reference carrier insertion frequency is connected between the primary and secondary of the discriminator. A neutralizing arrangement is usually used to minimize the effect of crystal holder capacity on circuit action. Since the crystal is series connected, the unit acts as a filter, and an exact reference carrier output is supplied from the crystal. Any difference signal between the reference carrier frequency caused by the input frequency appearing either higher or lower in frequency is converted into either a negative or positive voltage, by discriminator bandpass action. The opposite ends of the discriminator produce voltages which are 90 degrees out-of-phase with the carrier and 180 degrees out-of-phase with each other. The reactance tube circuit is connected to the discriminator output load resistor, across which the difference voltage appears, as the discriminator output varies above or below the center frequency. At the center frequency no output exists. Either above or below the center frequency the output voltage varies the grid voltage of a reactance tube modulator (or the base of a transistor). Since the reactance tube (or transistor) is connected across



Phase Discriminator AFC Arrangement

the tank circuit of the high-frequency RF oscillator, any change in discriminator output voltage varies the reactance of the tube or transistor which shunts the tuned circuit. Thus, the high-frequency oscillator output frequency is made to vary exactly as if a capacitor were placed across the oscillator tank and was tuned back and forth.

When the AFC circuit is holding on the desired zero center reference frequency, no change occurs in the high-frequency oscillator since no output voltage appears. Otherwise, the oscillator tracks in accordance with the output voltage excursions of the discriminator output stage. The range of operation depends upon the design of the discriminator. When the low-frequency oscillator changes towards a lower frequency, the output of the discriminator causes the HF oscillator to change a corresponding amount in a higher-frequency direction, and viceversa. Thus, changes above and below the center frequency produce a compensating action to provide the proper reference carrier frequency for SSB demodulation.

2-7 AUTOMATIC GAIN CONTROL

APPLICATION

Automatic gain control (AGC), sometimes called automatic sensitivity control (ASC) or automatic volume control (AVC), operates to keep a relatively constant receiver gain.

CIRCUIT ANALYSIS

General. In AM communications receivers where a carrier is received, the AGC system uses the rectified carrier to produce a stable negative bias which varies in accordance with carrier signal strength. The bias, in turn, is used to keep the output signal at a relatively constant value. In any automatic gain or volume control circuit, some portion of the received signal is rectified and applied as a varying negative DC voltage to control the gain of one or more amplifiers in the receiver. The gain of RF and IF stages is usually controlled. AGC circuitry is found in most AM receivers; however, some variations are often incorporated in SSB receivers. One of the differences, where a pilot carrier is supplied, is that the filtered carrier is usually separated from the sidebands, and used for AGC purposes. This provides a better reference of signal level because the carrier normally has a constant amplitude regardless of modulation. When a carrier is supplied, the carrier is always separately filtered and amplified for reinsertion at the detector. This filtered and amplified carrier is rectified to provide the AGC bias voltage.

In suppressed carrier systems, the carrier is not transmitted and some other form of AGC provision must be used. In this case the audio or sidebands may be rectified by circuitry practically identical to that used for carrier AGC. Use of audio sideband AGC is often more effective than carrier AGC in the reception of code, telegraph, or data transmission signals. Sometimes during multiplex operation a continuous tone is transmitted on one of the channels and is used for control of both AVC and automatic frequency control, after being filtered from the detected audio or output signal.

When suppressed carrier reception is used, the modulation envelope is relied upon, since speech exists in the form of groups of modulated signals with spaces between the peaks. Thus, peak rectification can be used to supply a control signal which will vary somewhat with the modulation. In this case, the time constant in the circuit must be of the socalled fast attack and slow discharge type. For example, it may take as long as 8 seconds to discharge such a network. This type of design holds the AGC at a relatively steady level since extremely large gaps in voice groups are necessary to permit sufficient discharge time to lower the developed AGC bias appreciably.

Circuit Operation. The accompanying illustration shows a simple AGC arrangement, in block diagram form, which is found in most receivers.

Since the last group of IF stages used in a suppressed carrier SSB receiver has an inserted carrier signal applied to convert the RF sideband signals back into audio frequencies for detection, the IF carrier can be used to represent the normal carrier value. The incoming modulation is beat against this carrier to provide the correct frequency components for the applied audio. Since it is desired to use the audio components to provide an AGC signal which varies in accordance with the peak level of the modulation, an AGC amplifier stage is provided to build up the IF signal amplitude so the rectified AGC is sufficient to control the input. By using long time constants, (slow attack time constant circuit) only a fraction of the bias developed in the AGC rectifier is lost during the pauses between syllables and words of the speech. Since these audio signals can also fade and change value, or be affected by flutter from reflections, choices of time constants are usually provided, so that a long, medium, or a short value may be selected by the operator. If fluctuations in volume are encountered, the most appropriate time constant value is selected by the operator to produce the best possible AGC action. By using a controlled diode gate, the AGC may be increased to cutoff value when transmitting, to protect any receiving circuits from overload. By utilizing two or three different values of AGC produced by voltage division, various stages of the receiver may be controlled for best overall performance. Use of speech-developed bias permits net operation on a single frequency, with the changes in level between weak and strong reception controlled automatically, preventing the operator from having to manipulate a manual volume control as each station transmits.

2-8 PHASE-SHIFT DETECTION

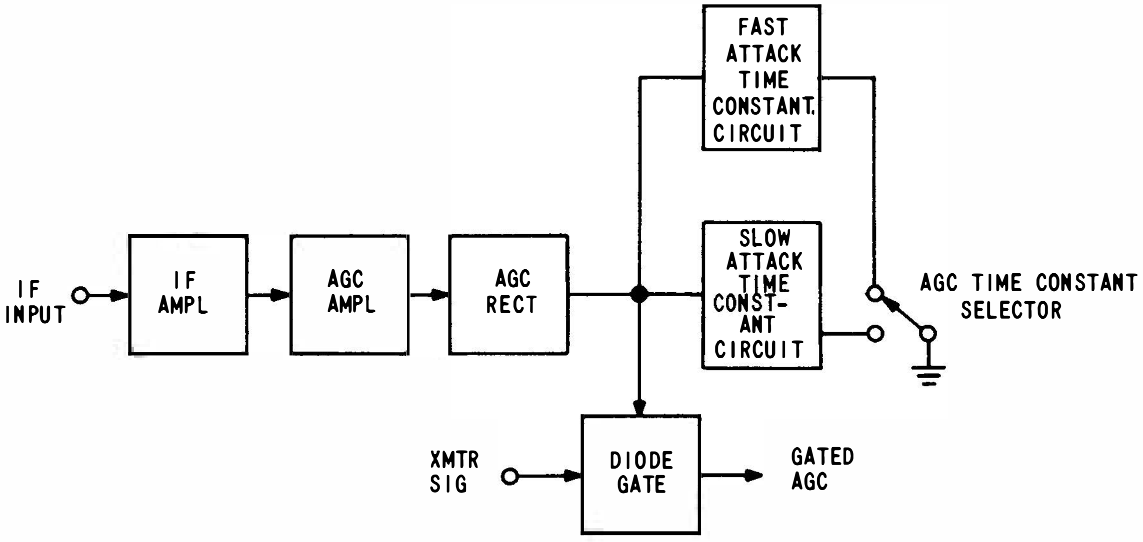
APPLICATION

The phase-shift method of detection provides a means of canceling noise output on one sideband thereby improving reception.

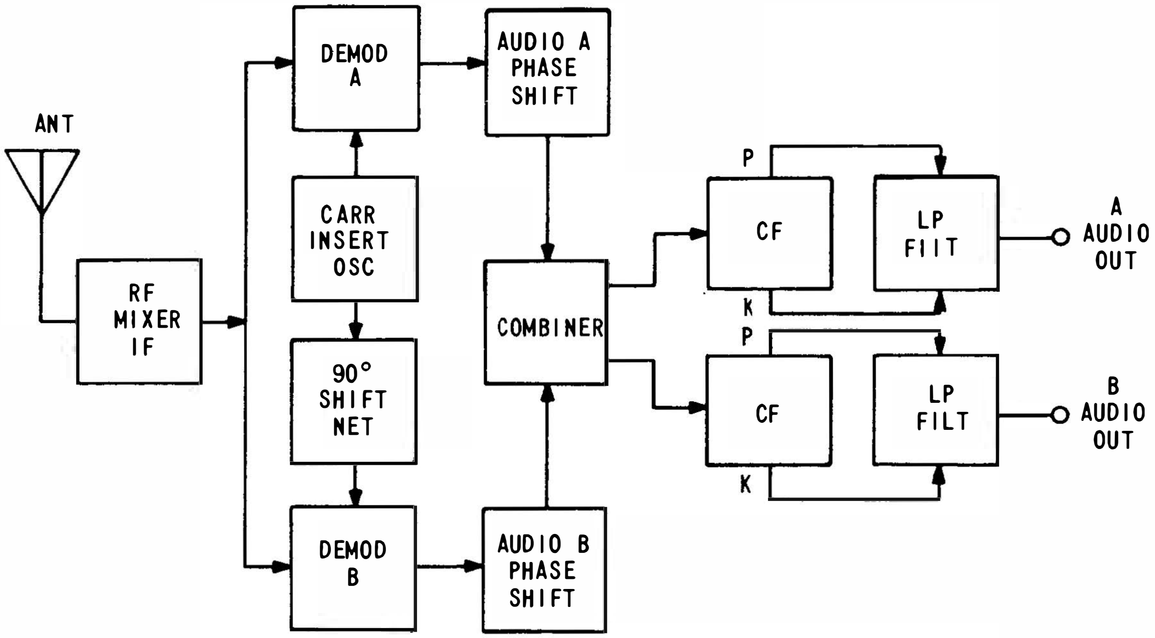
CIRCUIT ANALYSIS

General. When the phase-shift method of detection is used for either SSB or DSB reception, it eliminates the need for sideband filters, allows the use of conventional AM circuitry ahead of the detector, and is particularly suitable for receiving phase-shift modulated SSB transmissions.

Circuit Operation. The block diagram of a typical phase-shift detection circuit is shown in the accompanying illustration. The input signal is received in the conventional AM fashion using RF amplifier, mixer, and IF stages. Two balanced modulators (connected in parallel) are used for demodulation, and the common inserted carrier signal is shifted 90 degrees in phase before being applied to one of the demodulators. Thus, the outputs of the demodulators are in a quadrature relationship. The audio outputs of the two demodulators are applied to separate



Automatic Volume Control Arrangement



Phase-Shift Detection Circuit

audio phase-shift networks which shift the phase several hundred degrees over the audio bandpass of the receiver (from 100 to 3000 hertz), but the two networks still remain 90 degrees apart in phase because of the quadrature input relationship. The outputs of the audio phase-shift networks contain both in-phase and out-of-phase components of the audio derived from either or both sidebands. As can be seen in the illustration, these outputs are applied to a combining network. Sideband selection from the combining network is determined by the connection of the combining network to the outputs of audio phase-shift networks. When both ends of the combining network are connected to cathode followers, the components of one of the sidebands add vectorially in the network, and the components of the other sideband cancel. Which sideband cancels depends upon the polarity of the carrier phase shift, the demodulator in which the shift is applied to, and the polarity of the audio phase shifts in relation to their inputs and with regard to each other. Selection of either sideband is accomplished by reversing any one of the phase shifts, or by switching the audio output from the plate circuits of the cathode followers. The 180-degree phase shift between the cathode and plate circuit is added to the total phase shift appearing at the output.

Complete cancellation occurs when one sideband or a component of a sideband (or some unwanted signal) appears in the output of the B-channel with the same amplitude as in the output of the A-channel, but exactly 180 degrees out-of-phase. This occurs, for example, when the opposite ends of a resistive combining network have the same polarity signal, since the circuit arrangement is push-pull.

This detection method may also be used for dual-channel SSB detection by arranging the combining network so that outputs can be taken from both the plate and cathode circuits of one of the audio networks and applied to a divided-combining, or sum and difference network.

When this system is used with double sideband reception, the carrier insertion oscillator is operated in a phase-locked (synchronous) condition. Thus, both sidebands add and combine, but noise or unwanted signals appear either out-of-phase, or only in one sideband and cancel. Proper switching arrangements permit selection of the sideband in which the noise will be cancelled. Although low-pass filters are used in the audio output circuits to enhance selectivity, they are not needed when accurate balance and a steady 90-degree phase shift is maintained in the carrier-to-detector circuit.

2-9 SPACE DIVERSITY RECEPTION

APPLICATION

Space diversity reception uses two or more receivers or channels, with separately located antennas, to provide an output signal relatively unaffected by fading and other adverse atmospheric conditions.

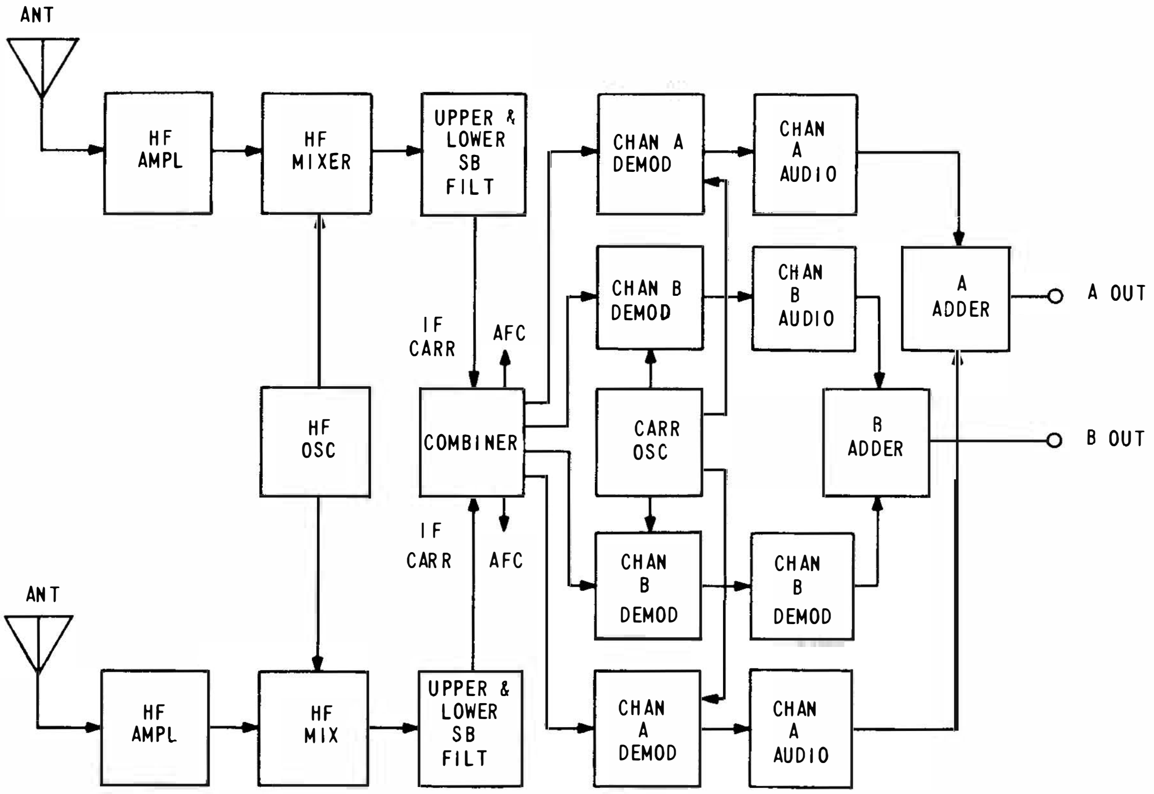
CIRCUIT ANALYSIS

General. In long range communication, fading becomes a serious problem because of the effects of multipath antenna transmission. So-called ground waves are effective at the most for a few hundred miles, while sky waves are bounced off various atmospheric and ionospheric layers for long distances. Thus, sky-wave reception from one antenna receives signals over a multitude of paths from different directions which may cancel or add together. If two or more antennas and receiving systems are used, the signal at one location may be very weak or unusable, while at another location, from 1 to 10 wavelengths away, the signal is much stronger and usable. Thus, when used with a combining network, space diversity reception can be employed to select the best signal or add them. Either separate receivers or a combination of separate receiver channels with common circuits may be used.

Space diversity reception is ideally suited to SSB receivers, since they usually provide for reception of both sidebands simultaneously. Since SSB receivers may use exalted carrier, DSB, and AM, the signals may also be processed with the same equipment. With the addition of a carrier phasing network, phase-modulated signals may also be received and detected.

There are a number of types of combining networks used, but basically they fit into three categories. One is a common load resistor across which all the receiver outputs are added. Another form uses a gating circuit to automatically select the output of the strongest received signal. The third type is used for telegraph and frequency-shift keying (FSK) and may appear in a variety of forms. Combiners for data transmission are included in this third category.

Circuit Operation. The accompanying block diagram illustrates a typical combined space diversity receiver. The AVC, AFC, and control blocks are not shown for simplification. As can be seen from the illustration, the circuit includes practically two dual-channel receivers with a common oscillator and control circuits. The common high-frequency oscillator output is applied to both high-frequency RF mixers (for dual conversion a similar common medium-frequency oscillator-mixer arrangement is also used, but is not shown for simplicity). The individual upper and lower sideband components are applied to separate filters, amplifiers, and demodulators in each receiver channel. The demodulated outputs are applied to separate audio amplifiers. The outputs of both upper sideband A-channels of the two receivers are added, or otherwise combined in a separate combiner unit. Likewise, the outputs of both lower sideband B-channels of the two receivers are also combined in a separate adder circuit. Thus, dual-channel SSB operation (with different information on opposite sidebands)



Space Diversity Receiver Circuit

may be received, or choice of sidebands is provided. A common low-frequency reference (carrier) oscillator operating at about 100 kHz is usually included, and its output is applied to the common AFC circuit, which is of the comparator type. The output of this oscillator is also selected through switching for use in demodulation as the inserted carrier. Either balanced modulators or product detectors may be used.

RF carriers converted into IF carriers from both receiver sections are applied to the combining network, and the output of the network is filtered, amplified, and applied to the AFC circuit. Reconditioned or exalted carrier may be selected by switching circuits for demodulation of the sidebands in lieu of the carrier reference oscillator. In dual-conversion systems, the AFC may be applied to the medium-frequency oscillator, or to the high-frequency oscillator in triple-conversion or other systems. In either case, the oscillator may also operate without AFC, being crystal-controlled or slaved to the carrier.

The AVC may operate from the combined rectified carrier, or switching may be used to permit operation from the combined outputs of all sideband channels (aggregate AVC), or the rectified audio from either output of the combiner may be used. Aggregate AVC is usually used for telegraph reception, and either aggregate or audio-controlled AFC is useful in the absence of (or loss of) a carrier under adverse conditions, or during noisy carrier reception. In some cases, a noise-operated squelch system is used in the combiner circuits or carrier conditioner, to disable the carrier-operated circuits (AFC and AVC) in the event of excessive noise, interference, or jamming of the carrier.

This type of receiving equipment is usually rack-mounted and incorporates the utmost flexibility to allow use of all types of reception. At low frequencies the wide spacing of the antennas requires large installation spaces. In the VHF and UHF range of frequencies, while spacing of antennas a wavelength apart does not present much of a problem spacewise, the same fading conditions that make space diversity reception most desirable at the low- and medium-frequency ranges are usually not present. Usually a tropospheric scatter arrangement is used to cover longer than line-of-sight distances in UHF.

2-10 DIVERSITY NOISE SAMPLING CIRCUIT

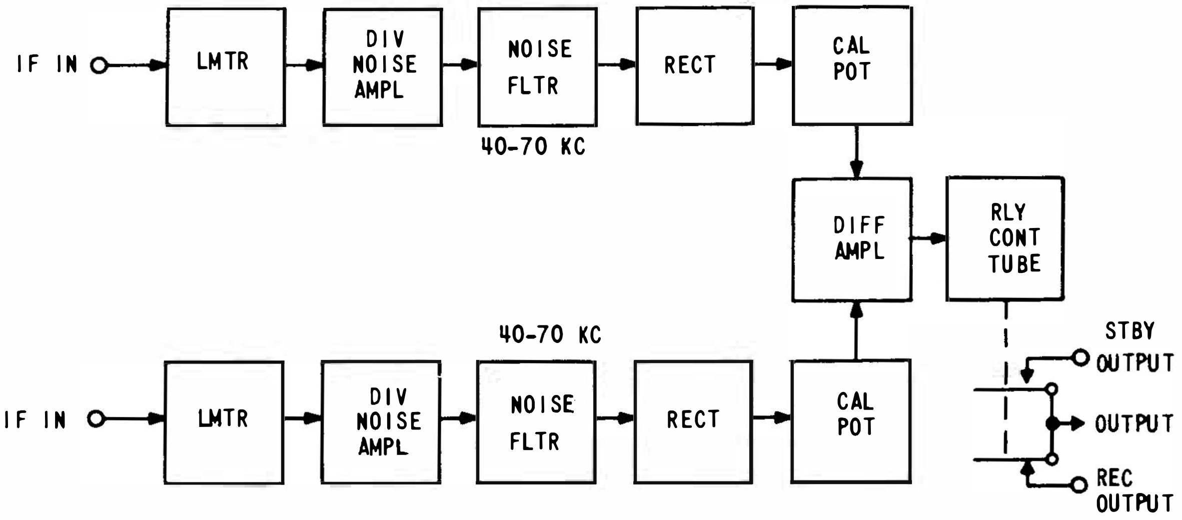
APPLICATION

The diversity noise sampling circuit automatically selects the channel output with the least noise for clearer reception.

CIRCUIT ANALYSIS

General. In a diversity receiving system, one channel may be receiving a signal with less noise than the other channel. By sampling and comparing the noise from two channels, it is possible to use a relay to automatically switch the output connections to the channel with the least noise.

Circuit Operation. The accompanying block diagram shows a typical noise sampling circuit used in diversity reception to select the channel output with the least noise. As shown in the illustration, the sampling circuit contains dual input channels supplying a signal to a differential amplifier for comparison. The differential amplifier inputs control operation of a relay which selects the output of the channel containing the least noise. To determine the amount of noise and develop a control signal, the IF outputs of each channel are applied through limiting stages to a noise amplifier. Selectivity of the limiter is such that only a 200-kHz bandwidth is passed. The amplified and clipped output of the noise amplifier is



Diversity Noise Sampling Circuit

applied to a noise filter which passes only a 40- to 70-kHz pass band. The noise in this pass band is rectified and applied to a calibration potentiometer which acts as the detector load. The potentiometer may be manually adjusted to suit the operator's preference. Normally, with the potentiometers set for the same output voltage calibration with no noise inputs, a larger signal will be applied to the differential amplifier from the channel containing the most noise. When the inputs to the differential amplifier are identical, no output (or only a small output) is produced and the relay will not pull-in. Thus, the normal receiving channel remains connected to the output. However, when the standby channel provides a stronger noise output, the differential amplifier energizes the relay. The relay disconnects the output of the normal receiving channel and connects the standby channel output in its place, or vice versa.

If equal noise signals appear in both channels, they will effectively cancel each other, so that the stronger received signal will control. Where the noise signals in one channel are greater than in the other, the noise plus signal will produce a larger output.

2-11 FREQUENCY SYNTHESIZER

APPLICATION

A frequency synthesizer is used to supply a single frequency output from a group of crystal-controlled frequencies beating together to furnish fixed frequencies for tuning.

CIRCUIT ANALYSIS

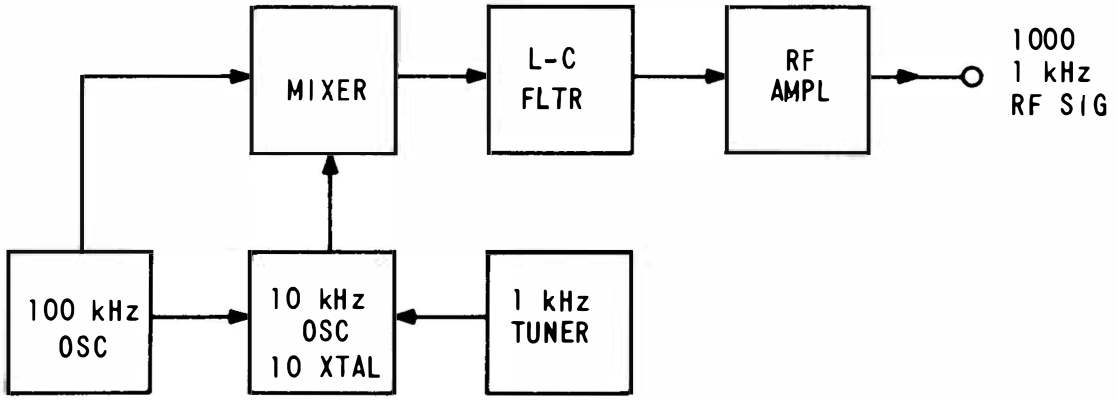
General. In ordinary operation, a variable-frequency self-excited oscillator is usually sufficiently stable to serve as a local oscillator for tuning. To supply the accuracy of an oscillator used for carrier insertion in reception, or for transmission of SSB, it is usually necessary to employ crystal control. This provides a relatively steady frequency which must be beat against another crystal or oscillator frequency to provide the desired output frequency. The frequency synthesizer merely supplies a number of frequencies (from 100 to 1000 or more frequencies separated by small increments, such as 1 kHz). Thus, commercial and military receivers and transmitters can be set to precisely the same frequency, so that the frequency variation does not exceed more than a 10-hertz drift, which is the limit for intelligible SSB transmissions.

There are a number of circuit arrangements which can accomplish frequency synthesis, some even as close as 45 hertz, so that many operating channels may be obtained.

Circuit Operation. The block diagram of a basic frequency synthesizer is shown in the following illustration. As is shown in the illustration, the output frequency of a fixed crystal oscillator such as a 100-kHz standard is applied to a mixer. Another input to the mixer is supplied from another crystal which may also be fixed in frequency, but usually is variable in that it can be pulled frequencywise over a small range of approximately 10 kHz. The initial beating of the two frequencies against each other creates the 10-kHz difference frequency. Meanwhile, the tuning circuit of the oscillator pulls the second crystal from approximately 1 kHz to a maximum of 9 kHz, so that the original frequency may be brought to a difference of 1 kHz. The output of the mixer is applied to a filter to eliminate the low-frequency harmonic components, and finally is amplified before application to the insertion oscillator or carrier oscillator.

In this basic example, the frequencies of 10 fixed crystals are beat against the frequencies of 10 so-called variable crystals to cover a 1000-kHz range in increments of 1 kHz. If the crystals are capable of being pulled the entire 10 kHz, a relatively smoothly tuned crystal-controlled VFO results.

In other models, the original 100-kHz signal is divided down to 20 kHz and then divided by 5 and by 4 to produce a 1-kHz signal. This 1-kHz signal then operates a blocking oscillator which beats against the



Frequency Synthesizer Circuit

input from a harmonic generator. Thus, each of the 1-kHz frequencies is converted to another IF, oscillator frequency, or carrier frequency, which bears a suitable frequency relationship with the transmitting and receiving control oscillators. When such a synthesizer arrangement is corrected for temperature drift (all drifts in the same direction), and AFC is used as a feedback control, it is possible to obtain a stability much greater than the minimum necessary for SSB communication, even on high frequencies.

2-12 STABILIZED MASTER OSCILLATOR

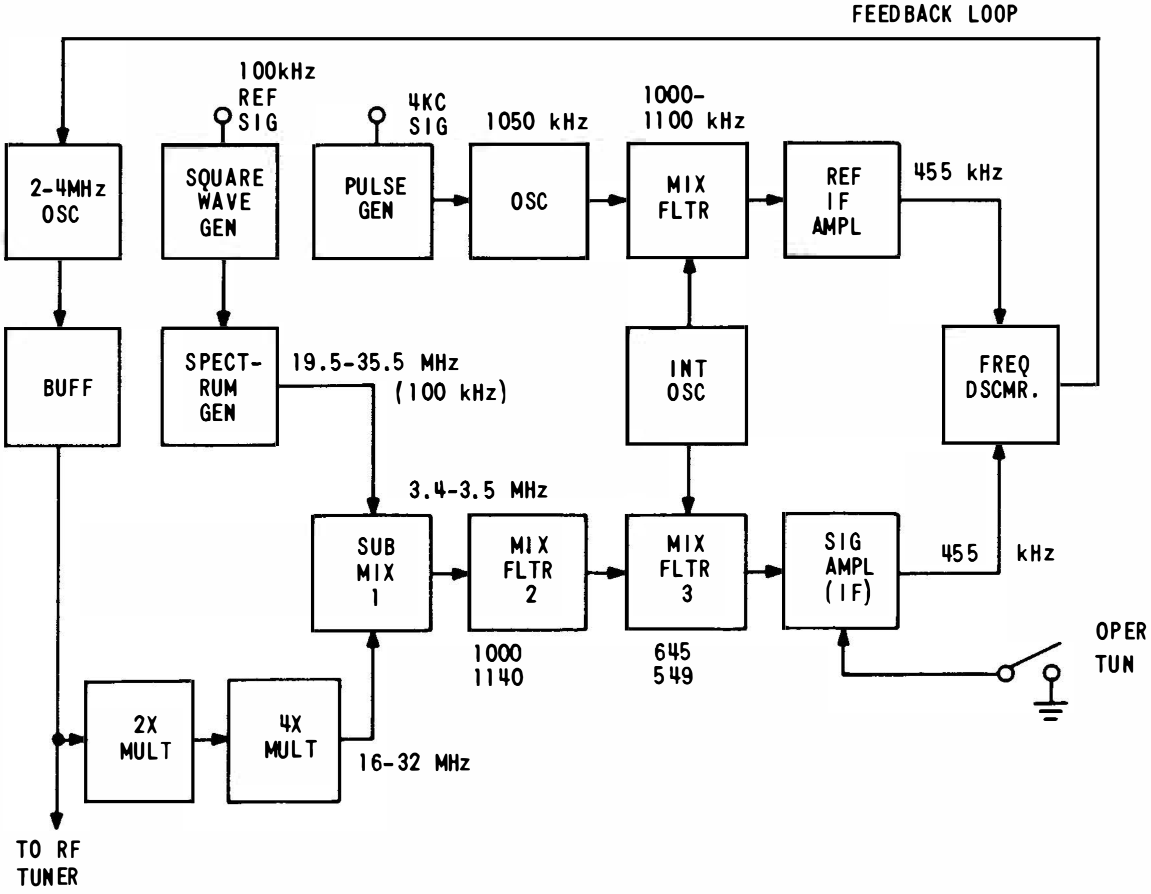
APPLICATION

The stabilized master oscillator (SMO) provides the master frequency for establishing the proper carrier insertion frequency or the initial transmitter frequency in SSB receiver-transmitters.

CIRCUIT ANALYSIS

General. The stabilized master oscillator (SMO) is generally more complicated but similar in arrangement to the stabilized local oscillator (STALO). It usually uses a master oscillator, stabilized by comparison with a reference oscillator and controlled by a feedback loop which locks-in, or stabilizes, its output frequency. It usually is the oscillator which controls the receiver carrier insertion frequency, and acts as the transmitter drive frequency. The proper IF and RF outputs are developed by frequency-conversion stages or mixers in the receiver or transmitter portions of the equipment, for each different type of equipment as required.

Circuit Operation. A block diagram of a typical SMO is shown in the following illustration. As shown in the illustration, the basic master oscillator tunes from 2 to 4 MHz in 1/8-kHz steps. The mechanical position of the tuner determines the exact frequency output, which is multiplied 8 times by the 2X and 4X multipliers, and applied to the first mixer. This first mixer also receives a 100-kHz reference sine wave input after being squared off by a square wave generator and gated by the spectrum generator to produce a 16-MHz band over which 100-kHz spectrums are generated. The first mixer thus receives the 16 to 32-MHz RF output range obtained from the master oscillator multipliers which beats against the 19.5 to 35.5-MHz band received from the reference oscillator



Stabilized Master Oscillator Diagram

via the spectrum generator. The difference is then converted by the subtraction circuit to produce a 3400 to 3500-MHz output.

Application of a 2397 to 2400-kHz reference oscillator signal to the second mixer produces a 1000 to 1140-kHz subtraction output, which is again beat against an interpolation oscillator operating over a range from 645 to 549 kHz in 4-kHz steps. The output of the third mixer, then, produces a 455-kHz signal which is amplified and applied to a winding on the phase discriminator. Each of the mixers is followed by a filter stage which passes only the desired range of frequencies.

The 4-kHz RF input operates on a 1050-kHz oscillator to produce an output of 1000 to 1100 kHz with 4-kHz spectrums, and when beat against the interpolation oscillator input to the reference signal mixer produces a 455-kHz output, which is amplified in the reference signal IF amplifier and applied to one winding of the phase discriminator. The difference in output from the phase and frequency discriminator produced between the reference IF signal and IF signal inputs produces an electrical feedback correction voltage which is applied to keep the master oscillator frequency at its normal frequency. Thus, the master oscillator tracks the reference oscillator, resulting in a stability equal to the reference frequency stability.

Each of the inputs or outputs to the mixers is supplied from, or to, a particular receiver or transmitter stage which requires this frequency. As a result it appears as though an unnecessary number of mixers and conversion signals are ordinarily required. By using each of these frequencies to control the master oscillator, the drifts in each of the different conversion stages are all kept within the same limits. Thus, the SMO effectively controls all associated frequencies.

To further ensure stabilization, the tank tuning circuits of the master oscillator stage are usually contained in a thermostatically controlled oven. This keeps the tank at a constant temperature, to prevent drift caused by ambient temperature change.

2-13 REFERENCE FREQUENCY STANDARD

APPLICATION

A reference frequency standard supplies an accurately controlled RF output of fixed frequency, usually accurate to one part in ten million or better.

CIRCUIT APPLICATION

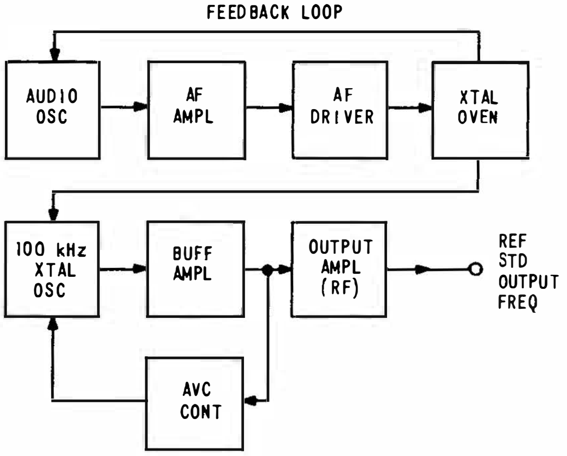
General. The reference frequency standard can be of a fixed rack type or a battery-operated portable type. It may be either vacuum tube or solid state. The standard always contains an oven for heating and maintaining a quartz crystal at a standard temperature. This enclosure usually includes the tuned tank circuit or the entire operating circuit as well. The standard is kept operating at a temperature which is normally higher than that encountered in free space, and the oven is constructed and insulated so that a minimum of heat loss is obtained. To provide better heat control, an audio oscillator is usually used so that line fluctuations do not produce problems in temperature control. The higher than line frequency of the oscillator can be regulated.

The quartz crystals used in standards have special low-temperature coefficient cuts, which lower the temperature regulating requirements of the oven by producing less of a frequency change with temperature than for ordinary crystals. Hermetically sealed crystal and tuning units make them relatively foolproof. They usually have some kind of a trimmer adjustment, however, which allows them to be zero beat against signals produced by atomic clocks or cesium resonators, and to allow correction for errors in propagation medium or other effects. The National Bureau of Standards (NBS) uses an elaborate system of various types of standards to check against each other and to produce a master standard, which is corrected daily and monthly for propagation changes, and approximately every 4 hours for atomic variations. The international frequency standards are indirectly controlled by these clocks. Thus when speaking of Reference Frequency Standards, it depends upon what type of accuracy is meant. The NBS system is essentially a primary frequency standard. Other standards somewhat less complex in nature but calibrated from this primary system are considered secondary standards. A reference standard is normally considered somewhat less accurate than the secondary standard or not more than the equivalent thereof. Today's primary broadcasts have an accuracy of 10^{-12} or 10^{-13}. In some cases, received broadcasts may have an accuracy as high as 10^{-9} and as low as 10^{-6}. Portable reference standards used by the fleet, such as the AN/UQN-9 and the AN/UQN-10 (the transistor version), have daily accuracies of 10^{-9}, and over a 60-day period of 10^{-8}, thus providing better accuracy than can be afforded by signals received from NBS stations. Such standards may even be used as master generators to supply signals throughout the ship for the checking or the control of various equipment.

Circuit Operation. The block diagram of a typical reference standard is shown in the following illustration. As shown in the illustration, the standard crystal operating at 100 kHz is hermetically sealed in an oven which uses a resistance bridge heater. The bridge is connected across a 3 to 4-stage audio amplifier, and causes audio feedback and oscillation until the bridge becomes balanced. It is balanced when it reaches the proper operating temperature. The amplifier and driver stages are used to develop enough power to drive the heater.

The 100-kHz standard output of the crystal oscillator drives a buffer amplifier to isolate it from the output, and furnish sufficient amplification for good AVC. The AVC stage is used to feed back a bias to the crystal oscillator to provide an essentially constant output amplitude. This protects the crystal from being overdriven and drifting because of internal heating of the crystal, which would have a deleterious effect on its use as a standard, even though so-called zero-coefficient temperature cuts are employed. The output amplifier merely increases the level of the standard output to the desired value without loading the standard.

With the increasing frequency accuracy required for good performance of single sideband equipments,



Reference Frequency Standard Circuit

most military equipment uses a similar oscillator arrangement to provide a stable operating and receiving frequency, in combination with a frequency synthesizer, to supply a number of stable channels.

2-14 VARIABLE-FREQUENCY OSCILLATOR

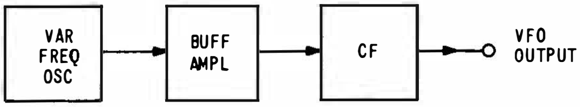
APPLICATION

The variable-frequency oscillator (VFO) circuit supplies the initial transmitter frequency from a selected range of frequencies over which it is tunable.

CIRCUIT ANALYSIS

General. The variable-frequency oscillator offers a relatively stable means of providing transmissions over a large range of frequencies. These ranges are divided into bands selected by a switch, and the oscillator is made tunable over the entire frequency range of each band. Thus, the transmitter need not be supplied with a number of crystals to operate on different net frequencies, and can easily be tuned slightly below or above interfering stations, or zero-beat with a net station to occupy less space in the spectrum. An electron-coupled type of oscillator is usually used to minimize drift and provide reasonable stability. The VFO usually is used for CW and AM transmitters that do not require as much stability as is needed for single sideband (SSB) equipment.

Circuit Operation. The following illustration shows a simple block diagram of a basic VFO circuit. The oscillator stage may be any type of stable oscillator circuit usable over the frequency range covered by the VFO. Normally, separate tank tuning circuits are switched for each band or frequency range covered. To provide sufficient RF drive voltage, vacuum tube oscillators are usually used, although transistors may also be used. The transistor usually requires temperature compensation and unilateralization (or neutralization in the following stages). Assuming a triode-pentode electron-coupled oscillator is used, the tube triode portion operates as the oscillator, and the screen is used to isolate the oscillator from the plate, forming a loosely coupled stable circuit which is lightly loaded. Consequently, in addition to low drift due to operating at light loads and temperatures, pulling effects of tuning through resonance are avoided or minimized. Sufficient output is taken to drive an RF buffer amplifier (the pentode section), which amplifies the tunable oscillations to a desirable driving amplitude and isolates the oscillator from the driver amplifier stages, or the power amplifier stage itself, in small units. By terminating the output in a cathode follower stage, the output can be arranged either as a cathode or plate follower, and be made to properly match the driving impedance of the next stage. At the same time the follower stage also offers an additional isolating effect, which, together with the buffer, provides extremely light loading on the VFO. Hence with the use of zero or negative drift coefficient capacitors, the tank circuit can be stabilized for temperature drift variations, and a stable RF output almost equivalent to crystal control is obtained.



Variable-Frequency Oscillator Circuit

2-15 CRYSTAL-CONTROLLED TRANSMITTER OSCILLATOR CIRCUIT

APPLICATION

The crystal-controlled transmitting oscillator circuit is used to supply a stable fixed frequency for determining the transmitter output frequency.

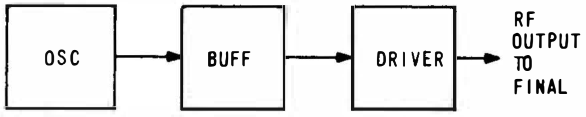
CIRCUIT ANALYSIS

General. The crystal-controlled transmitter oscillator uses a quartz crystal, ground to a particular thickness to determine the frequency, and at an axis which provides the desired frequency-temperature compensation. Ideally, the transmitter frequency should not drift because of temperature. Thus, depending upon the ambient temperatures to be encountered, crystals are gound with different temperature coefficients, both positive and negative, or with a so-called zero coefficient. Each cut is designated by a letter such as X, Y, AT, BT, etc. In most cases, the crystal and the tuning circuit for the oscillator are mounted within an oven and hermetically sealed. Either an external adjustment is provided or a small capacitor is placed across the crystal, to allow setting it to zero beat with a standard frequency generator. Normally, the crystal holder capacitance is balanced out with a neutralizing circuit, and the oven usually uses an audio frequency to energize the oven heater. Some ovens use line frequency AC or thermostatically controlled DC. The oven is normally kept at a temperature above the ambient temperature so that only heat-loss effects need be considered.

There are many basic types of crystal-controlled oscillator circuits. The most commonly used are the Colpitts and Hartley circuits for low frequencies, and the Pierce circuit for HF, VHF, and UHF. Crystals may operate on the fundamental frequency of vibration or on harmonics. On the higher frequencies, most crystals operate on odd harmonics called "overtones" (3rd, 5th, 7th, and 9th overtone operation is common). Fundamental crystal frequency operation usually does not exceed 20 MHz, since the crystal wafers become too thin for cutting and grinding for most cuts above this frequency.

Crystal-controlled oscillators are subject to temperature effects, voltage variations, loading, and shock and vibration; however, variation in frequency due to these effects is minimal in comparison with that of a self-excited oscillator. Circuit construction similar to that in a stable self-excited oscillator, including loose coupling, light loading, and only sufficient drive to produce a stable output capable of driving a buffer stage. Operation on a number of frequencies is accomplished by using a frequency selector switch to select different crystals, by using a frequency synthesizer arrangement, or by using a VFO to heterodyne with the crystal oscillator. For CW, AM, or teletype operation, the standard transmitter crystal-controlled oscillator using an oven to control crystal temperature has sufficient stability. In the older types of equipment (where stability requirements are not as rigorous), the crystal is used without the oven. For single sideband (SSB) operation, simple crystal oscillator operation is inadequate, and more complicated types of circuits and temperature compensation are used.

Circuit Operation. The following block diagram shows a typical crystal-controlled oscillator arrangement for use in a basic transmitter. As can be seen in the illustration, the circuit is very similar to that of a VFO or a frequency standard. It consists of the oscillator, a buffer amplifier for isolation, and a driver amplifier to supply the RF drive power. The buffer isolates the crystal oscillator from any changes in load caused by tuning; at the same time it permits loose coupling and light loading to the driver. Thus, heating of the crystal by grid current drawn through the crystal itself is eliminated. Class A bias is usually used, and is supplied by a cathode bias circuit to prevent excessive plate-current or grid-current drain in event the crystal stops oscillating or is overdriven.



Crystal-controlled
Transmitting Oscillator Arrangement

The buffer stage supplies sufficient drive power for the driver-amplifier stage. For higher-frequency operation, multiplier stages are added to multiply the frequency to the proper value, and then the driver stage, working at the operating frequency, provides the driving power required for the grid of the final output stage. Use of a lightly loaded buffer amplifier effectively isolates the crystal oscillator from load, reactance, or tuning changes, and voltage regulation ensures stable plate voltage and lack of frequency change due to line voltage variations.

For semiconductor operation, a few more stages are required to develop sufficient power to drive the final stage. Also, special transistor compensation circuits are needed to avoid temperature effects, and neutralization, or unilateralization, to prevent feedback effects, is usually needed particularly where a number of circuits operate on the same frequency. Semiconductor operation, however, is similar to tube operation, with the added advantage that smaller crystals may be used, since semiconductors operate at much lower power levels than tubes.

For a given oscillator application, actual operating service requirements determine whether a complicated compensated crystal oscillator is required, or whether a simple one-or-two-stage oscillator buffer circuit is adequate.

2-16 FREQUENCY MULTIPLIER-CONVERTER CIRCUIT

APPLICATION

The frequency multiplier-converter circuit is used in single sideband transmitters and AM transmitters to multiply and convert a lower frequency of the master oscillator to the desired higher frequency of the transmitter.

CIRCUIT ANALYSIS

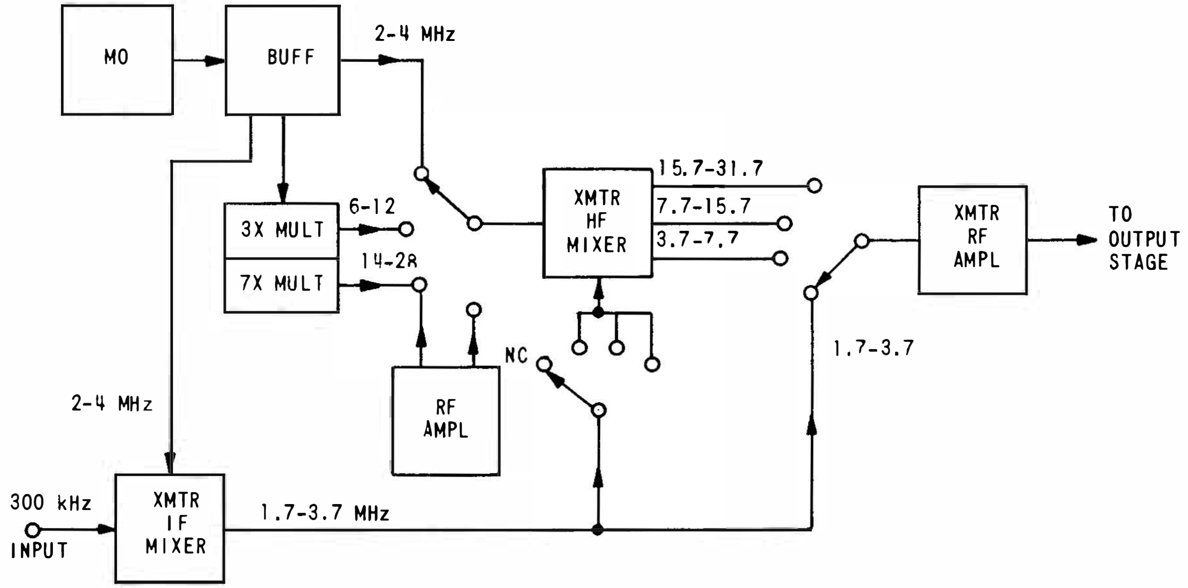
General. Transmitters which do not operate on the fundamental master oscillator frequency alone, but cover a large range of frequencies by tuning over a number of frequency bands, require circuitry to change the original frequency to the desired output frequency. This frequency conversion is accomplished rather simply by the use of multiplier stages and mixer stages. Basically, the conversion process consists of heterodyning two signals and using the beat between them (the sum or the difference frequency) as the output frequency. This type of conversion permits the use of an extremely stable low-frequency oscillator to control the output frequency, and provide a high-frequency signal with the equivalent stability of the original low-frequency signal. Thus, frequency drift is reduced to one or two hertz or, in some cases, to a fraction of a hertz for continuous operation over long periods of time. With such a high degree of frequency stability, either or both upper and lower sideband channels may be used, and numerous multiplex channels can be operated on each sideband. The resultant saving in spectrum space allows more room for both military and commercial users, and many stations can operate on specified frequencies without interference.

Circuit Operation. The following block diagram shows a typical frequency multiplier and converter circuit arrangement, as employed in a modern single sideband transmitter. Note that the conversion frequencies given in the diagram are not standard, but vary from transmitter to transmitter depending upon design. The input frequency to the multiplier-converter circuit is usually supplied from a master oscillator buffer-amplifier, and consists of either a continuously tunable RF signal or a number of discrete frequencies separated by about 1 kHz over a range covering about 2 MHz. In this discussion, the basic range is considered to be 2 to 4 MHz.

The buffer output is applied to a switch which permits the output to be fed to the transmitter high-frequency mixer for direct operation over the low-frequency range of the transmitter. The buffer output is also applied separately to the transmitter IF mixer, to develop the proper difference frequency between it and the reference 300-kHz signal. This 300-kHz signal consists of the 3rd harmonic of a stabilized reference oscillator operating at 100 kHz. Subtraction of the 300-kHz signal from the 2 to 4 MHz signal produces an IF output signal over a range of 1.7 to 3.7 MHz for application to the transmitter high-frequency mixer. For operation on the low-frequency range, a by-pass switch allows the 1.7 to 3.7 MHz signal to be applied directly to the RF driver amplifier by shunting the signal around the mixer.

To convert the low-frequency range to a higher-frequency range, the buffer output is applied in cascade first to a 3X multiplier stage and then to a 7X multiplier stage. Tuned output circuits allow the proper harmonic and multiplication factor to be selected. A switch at the input of the high-frequency mixer allows each multiplier output to be selected separately. Thus, ranges of 6 to 12 MHz and 14 to 28 MHz are available. If desired, the 14 to 28 MHz range can be passed through an RF amplifier to increase the amplitude of the high-frequency range; use of this amplifier makes it possible to compensate for the weaker signals obtained on the higher harmonics.

Final frequency conversion occurs in the transmitter high-frequency mixer stage, where the 2 to 4-MHz, 6 to 12-MHz, or 14 to 28-MHz multiplied outputs from the master oscillator are heterodyned with the 300-kHz IF output of 1.7 to 3.7 MHz. The difference frequency beat is again used to drive the RF driver amplifier. Adding the 1.7 to 3.7-MHz IF signal to the 2 to 4-MHz, 6 to 12-MHz, and 14 to 28-MHz ranges provided by the multipliers and master oscillator, produces final outputs of 1.7 to 3.7 MHz, 3.7 to 7.7 MHz, 7.7 to 15.7 MHz, and 15.7 to 31.7 MHz. Thus by simple multiplication and heterodyning action, it is possible to tune the transmitter over a complete range of 1.7 to 31.7 MHz, either continuously or in 1-kHz increments. The output signal appears only when an audio signal is applied to drive the balanced modulators, or when a carrier is inserted to produce an AM output. The frequency stability is equivalent to that of the reference frequency oscillator or an external standard (which may be used separately in place of the internal oscillator).



Frequency Multiplier-Converter Arrangement

2-17 RF GENERATOR

APPLICATION

An RF generator may be used as a signal generator for testing, or as a driving stage to produce the desired RF output frequency from a transmitter or receiver.

CIRCUIT ANALYSIS

General. An RF generator is usually considered to be an equipment capable of producing appreciable RF power, as contrasted with a signal generator, which generates a relatively weak RF signal. A typical RF generator consists of all those circuits previously discussed individually in connection with RF oscillation, stability, frequency multiplication, frequency conversion, and frequency control, and also includes a driver amplifier. With a final amplifier added, the RF generator can be used as a transmitter.

Circuit Operation. A typical block diagram of a simple RF generator, which may be of either the vacuum-tube or solid-state type, is shown in the accompanying illustration. As can be seen in the illustration, a standard frequency generator or oscillator (temperature-compensated and frequency-controlled by an AFC circuit) is employed to provide a controlled phase lock with the master oscillator. Thus, the master oscillator is stabilized over its range of operation. A buffer amplifier isolates the master oscillator and provides sufficient driving output. The MO output is frequency-multiplied, using doublers, triplers, etc, as necessary, to reach the desired transmitting frequency. (For wide-range frequency conversion, the RF generator may use heterodyne conversion, rather than frequency multiplication.) The final output frequency is applied to a driver amplifier for amplification to a higher power level. For low-power applications, this amplifier may be used as the final output; however, an external linear power amplifier is usually employed to supply additional RF output power.

RF generators can usually be operated over a number of frequency ranges by means of channel switching. The switching circuits vary from generator to generator in accordance with the basic design and purpose of the equipment.

2-18 AUDIO MODULATOR-DRIVER CIRCUIT

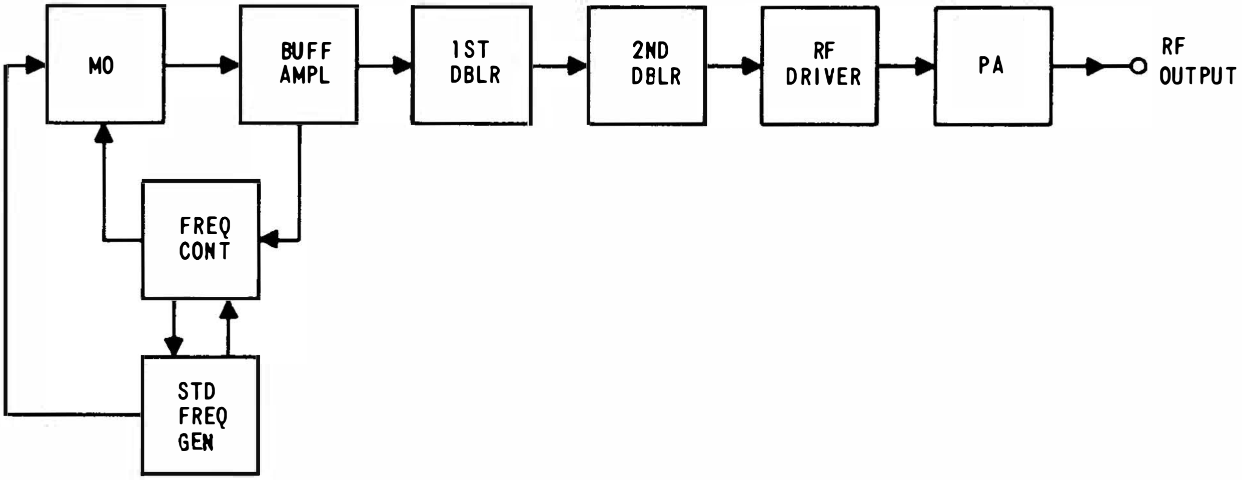
APPLICATION

The audio modulator-driver circuit amplifies the microphone output, or audio input signal, to the voltage and power level necessary to drive the modulator stage.

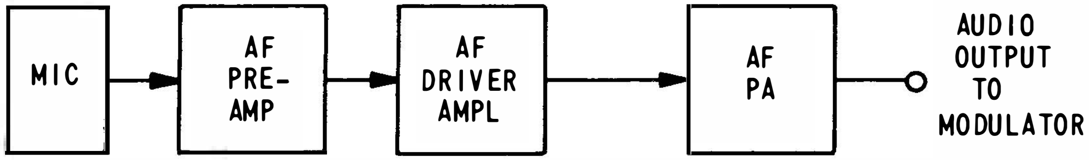
CIRCUIT ANALYSIS

General. The audio modulator-driver circuit is used in both AM and SSB transmitters. In fact, any modulation system requires some type of audio driving power since the microphone output power and voltage are very low. An AM modulator requires higher driving power than an SSB modulator because the AM modulator must be capable of handling a 50-percent increase in carrier power to produce 100-percent modulation. In SSB equipment, audio voltage drive at a relatively low power level is sufficient to drive the balanced modulators, and produce an RF output frequency for each modulation frequency. Final amplification is provided by an SSB linear RF power amplifier at radio frequencies.

Circuit Operation. The following block diagram illustrates a typical stage-by-stage arrangement for an AM modulator-driver unit capable of amplitude modulation of a carrier. The audio output of the microphone is amplified by a preamplifier stage to bring it up to a level sufficient to drive a voltage amplifier, which may be either single-ended or push-pull. The voltage amplifier output is applied to a



RF Generator Arrangement



Audio Modulator-Driver Circuit

higher-powered amplifier stage, which functions as the final driver. This stage must be capable of supplying both voltage drive and grid current to the power amplifier, since the power amplifier usually operates Class B. In some instances, Class AB' operation (AB_1 or AB_2) is used to provide less distortion. The drive voltage and power requirements depend upon the design, which is more or less fixed by the types of tubes employed. In the latest audio modulator-driver design, transistors are used throughout, including power transistors for the final stage. For either tube or transistor circuits, the same overall function is required. That is, the modulator-driver stages must supply an audio voltage at sufficient power to drive the type of modulator in use.

2-19 SSB DRIVER-TRANSMITTER CIRCUIT

APPLICATION

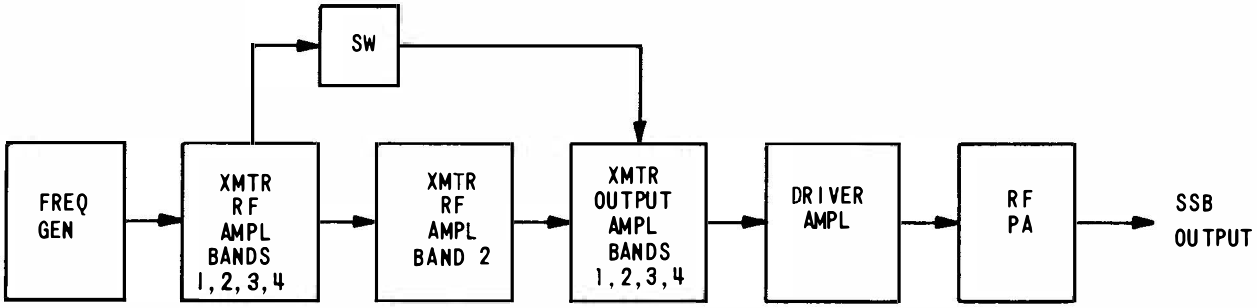
The SSB driver-transmitter circuit supplies RF drive power to operate the SSB transmitter as its rated peak output.

CIRCUIT ANALYSIS

General. In a single sideband transmitter, the modulated audio input is converted into specific frequencies covering a spectrum of approximately 300 to 3000 hertz above and below the transmitter frequency. After the modulator produces the sideband frequencies, the carrier is balanced out or suppressed, and only the sideband frequencies are transmitted. Transmission may be made on either the upper or lower sideband, and both sidebands may be treated independently as separate channels for different modulation inputs, if desired. After the sidebands have been generated, the various frequencies are heterodyned against a fixed frequency to convert them to the desired band; a variable-frequency oscillator (VFO) is usually used to set the exact transmitting frequency on each band. Frequency coverage over the range of 2 to 30 MHz is normally achieved in four bands. Once the frequency is converted to the proper output frequency, the sideband frequencies are amplified in linear RF amplifiers to the rated power output. It is necessary to use a Class B or AB amplifier to amplify the sidebands, since it is the only known efficient RF amplifier which is linear. For economy, Class AB_1 or AB_2 operation is normally used, since the Class B amplifier requires excessive driving power and extreme plate voltage regulation for best results. Class C operation provides a distorted output, and Class A operation is too inefficient.

The driver-transmitter circuit consists of that portion of the transmitter after modulation, and after the sidebands have been generated and converted to the desired output frequency.

Circuit Operation. The following illustration shows a block diagram arrangement of a representative RF driver-transmitter circuit. Since different transmitters generally employ slightly different basic



SSB Driver-Transmitter Circuit Arrangement frequencies for heterodyning and conversion and may cover bands other than those shown, the frequency conversions discussed in the following explanation are to be considered as typical. Also, there may be more or fewer amplifier stages than are indicated in the illustration.

As shown in the illustration, the basic frequency conversions are developed by the frequency generator, which is assumed to provide the proper sideband frequencies for the band in use. In the typical transmitter being considered, there are four bands, covering 1.7 to 3.7 MHz, 3.7 to 7.7 MHz, 9.7 to 15.7 MHz, and 15.7 to 31.7 MHz. These bands are continuously tunable, and either or both the upper and lower sidebands may be used. In addition, a carrier may be inserted so that either one sideband or both sidebands with suppressed carrier may be used, or double sideband AM (at reduced power) may be generated.

The first RF amplifier amplifies all bands. The second RF amplifier amplifies only band 2 (there is a switching arrangement which shunts the signal around this stage on bands 1, 3, and 4). A separate amplifier is necessary on band 2 to select the proper output frequencies and to eliminate undesirable harmonics and beats which do not appear on the other bands. The third RF amplifier is an output stage which amplifies all bands and supplies sufficient amplitude to excite the RF driver amplifier, which in turn supplies sufficient power to drive the transmitter power amplifier. The RF driver is required because, even though Class AB operation is used, some grid current is usually drawn in the transmitter power amplifier, and this grid power must be supplied by the driver.

Summarizing, the first three RF amplifiers are basically RF voltage amplifiers used to increase the amplitude of the input frequencies to the level required for the RF driver amplifier. The transmitter power amplifier is a linear amplifier capable of supplying the rated peak output power, when driven sufficiently by the preceding driver stage.

In some cases automatic level control (ALC) is used to control the amplitude of the signal from the frequency generator, to ensure that the linear range of the power amplifier is not exceeded by overdriving. Exceeding the linear range would produce distortion, causing spurious output frequencies which could interfere with other transmitters in the same band or at harmonically related frequencies. In the particular transmitter arrangement just described, the ALC is called transmitter gain control (TGC). It produces an automatic negative feedback voltage when the final stage draws grid current. This negative voltage reduces the input frequency amplitude until grid current stops. Thus, maximum output is obtained without distortion.

2-20 CARRIER FREQUENCY SHIFT TELETYPE CIRCUIT

APPLICATION

The carrier frequency shift (CFS) teletypewriter (TTY) circuit is generally used for long range fleet communications.

CIRCUIT ANALYSIS

General. There are two general teletype systems, the carrier frequency shift type and the tone frequency shift type. This article discusses the carrier frequency shift type; the tone frequency shift type will be explained later in this section of the handbook.

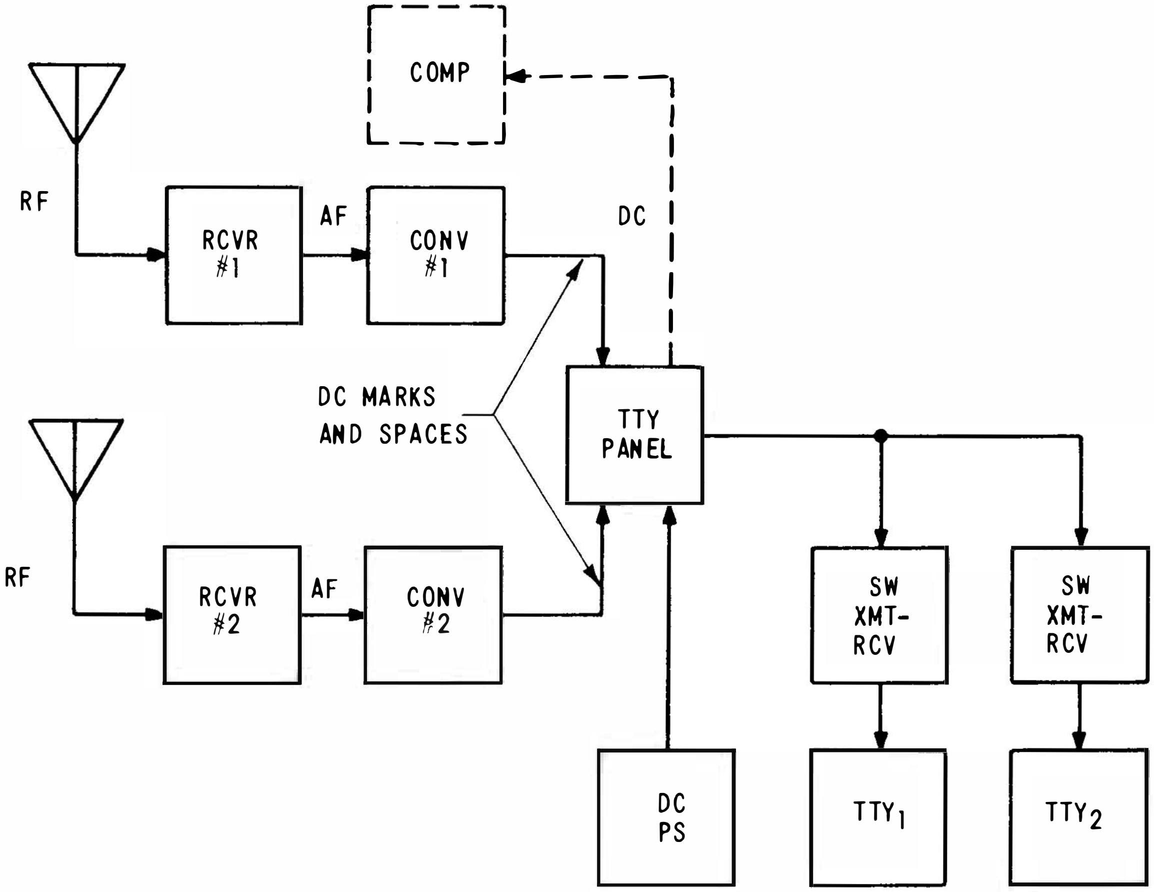
The carrier frequency shift type of transmission shifts the carrier frequency to a higher or lower value. As a general rule, the carrier frequency shift system increases the carrier frequency for a mark signal and decreases the carrier frequency for a space signal. Otherwise, the necessary DC looping current furnished by the teletypewriter panel, power supply, switching control, and teletypewriter are the same as those used in the tone frequency shift system.

The advantage of the CFS system is that, by using two different receivers and transmitters, a frequency diversity receiving system can be arranged to take care of fading and atmospheric reception conditions, which might ordinarily interfere with a single-frequency arrangement. Thus, long distance teletype is best served by the CFS system, and the Navy teletype system is set up for CFS use. In addition, under good reception conditions two messages can be received and transmitted simultaneously with the frequency diversity setup, so that its use provides additional communications circuits.

Circuit Operation. The following illustration shows a block diagram arrangement of the carrier frequency shift system. As shown in the illustration, two receivers, two converters, and the remaining equipment are connected for frequency diversity use. Both receiver-converter channels operate in the same manner, but on a different carrier frequency.

The received input signal consists of an RF carrier whose frequency is shifted by mark and space signals at the teletypewriter transmitter. The receiver detects the frequency-shifted signal and provides an audio output to the converter. The converter receives two different audio frequencies, one for mark and one for space. With the power supply furnishing DC loop power to the TTY panel, the converter produces direct-current mark and space signals by converting the audio frequency from the receiver into DC keying signals. These mark and space signals operate a selector magnet in the teleprinter machine, which changes the electrical impulses into printed characters to form a printed message.

As shown in the illustration, two separate radioteletype (RTTY) circuits will produce two simultaneous messages from transmissions on two separate frequencies. If a comparator unit (shown dotted in the illustration) is connected to the TTY panel and through it to the two converters, frequency diversity operation is obtained. With frequency diversity operation, the stronger signal determines which receiver will operate. Thus the two units can be switched back and forth automatically and instantaneously to take full advantage of the better reception conditions in the two paths. The versatile converter-comparator group and teletype panel provide the operational flexibility and controls to accommodate almost any combination of conditions arising in long-range radioteletype operations.



Carrier Frequency Shift Teletype Arrangement

2-21 AUDIO-FREQUENCY TONE SHIFT TELETYPE CIRCUIT

APPLICATION

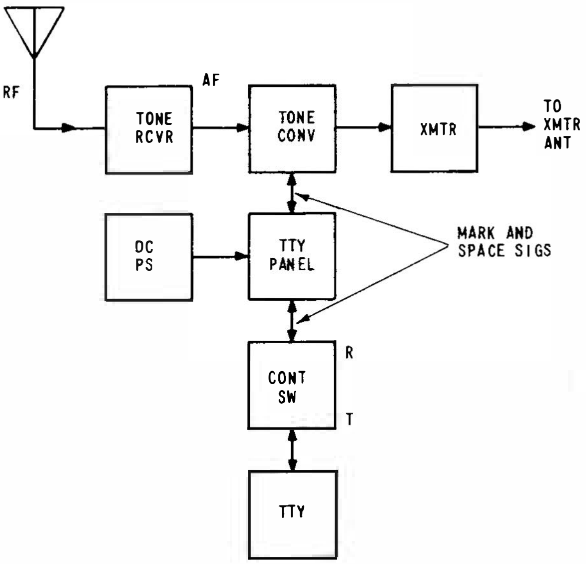
The audio-frequency tone shift teletype (TT) circuit produces different audio tones on the same carrier frequency to generate mark and space signals which operate the radioteletypewriter.

CIRCUIT ANALYSIS

General. The tone shift teletypewriter system is used by the Navy on UHF for short range fleet communications. DC mark and space signals produced by a teletypewriter pass through a switching control unit and the teletype panel to the transmit side of a tone converter unit. There the direct-current pulses are changed to corresponding audio-frequency tones by a two-tone oscillator in the transmit relay unit. Usually the two tones are separated by about 800 hertz. The audio tones are applied from the converter to the transmitter, where they tone-modulate the transmitter carrier frequency. In reception, this process is reversed to produce DC mark and space signals from the AM RF transmission.

Circuit Operation. The following block diagram illustrates a typical audio-frequency tone shift teletype system. The tone shift system is similar to standard AM radio. It can be used with any voice transmitter and any voice receiver. The tone converter is the heart of the tone shift radioteletype system. It is used for both transmitting and receiving. Consequently, the switching control unit associated with the teleprinter has a single "transmit-receive" position for tone shift operation. A start impulse from the local teleprinter instantly and automatically switches the tone converter to the transmit condition. While the tone converter is in the transmit condition, signals from the receiver are blocked. The system cannot transmit and receive simultaneously.

When the transmission stops, there is a slight delay before the converter automatically reverts to the standby receive condition. The equipment then remains ready for reception until local transmission is resumed. The two basic circuits in the tone shift



Audio-Frequency Tone Shift Teletype Arrangement

radioteletype system are the transmit and the receive systems. A circuit common to both systems is the direct current power supply to the teletype panel that furnishes the local "looping" current.

When an incoming tone-modulated signal is received, it is detected and a sequence of audio tones is applied to the tone converter. The converter, which by now has been automatically switched to the receive condition, converts the sequence of audio tones into corresponding direct-current marks and spaces. The mark and space signals pass through the teletype panel and the switching control, and operate a polarized relay in the teleprinter. The teleprinter prints out the received message in accordance with the coded mark and space signals.

2-22 FM MODULATOR CIRCUIT

APPLICATION

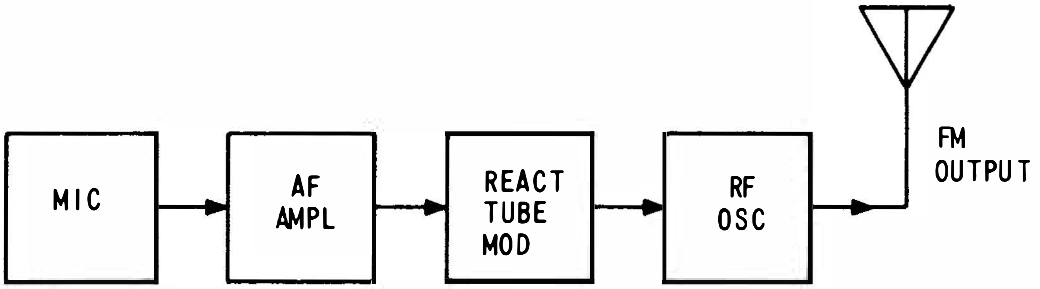
The FM modulator circuit produces a frequency-modulated output signal from an amplitude-modulated input signal.

CIRCUIT ANALYSIS

General. In amplitude modulation (AM), the carrier frequency remains steady and the modulation varies at audio frequencies, causing the carrier amplitude to rise and fall in accordance with the audio variations. With no input, only the carrier exists. At full modulation the carrier amplitude increases 50 percent. In frequency modulation (FM), the amplitude of the output RF never changes, but the basic frequency varies above and below the center, or nominal, carrier frequency. However, no actual carrier exists: the carrier is actually the center frequency to which modulation occurs. Each modulation component is a separate frequency which either adds to, or subtracts from, the center frequency to which the oscillator is fundamentally tuned.

For transmission of a same type signal, an FM transmission occupies a larger range of the spectrum than an AM transmission. For example, an FM broadcast occupies a band of at least 75 kHz, and FM voice communication occupies about 15kHz, while the corresponding AM transmissions occupy bands of 10 kHz and 3 kHz, respectively. In a special form of FM called narrowband FM, the voice bandwidth can be reduced to a minimum of about 5 kHz. A great advantage of FM is that noise is more easily eliminated. Noise amplitude-modulates the signal and the FM detector is relatively insensitive to amplitude variations present in a signal as a result of limiting. The incoming signal is limited to produce a steady unchanging amplitude, before the signal is applied to the detector. In spite of this advantage, however, the Navy uses FM only in line-of-sight mobile communications and in a few special low-powered applications, because of the extra bandwidth required.

Circuit Operation. The following block diagram shows a simple FM modulator circuit arrangement. Phase modulation can also be used, but is somewhat



FM Modulator Circuit

more complicated. As can be seen in the illustration, the input to the modulator is produced by a conventional microphone. In most cases a microphone amplifier stage is necessary to raise the signal level to the proper value to drive the modulator. The modulator, which is of the reactance-tube typed, is essentially an electron tube with its plate and cathode shunted across the tuned circuit of an FM oscillator. Normally, a relatively stable oscillator is used so that the idling or center (carrier) frequency will not be subject to drift. With the modulator tube connected across the tank circuit of the oscillator, the modulator tube acts as if it were a variable capacitor. As the input grid voltage varies with speech modulation, the reactance or impedance of the tube changes accordingly. Hence, the FM oscillator output frequency varies above and below the center frequency in accordance with the impressed audio frequency. The greater the drive, the greater is the frequency shift. Usually a small, low-powered oscillator is used to develop the FM signal, and the oscillator output frequency is multiplied for operation at high frequencies, with the final stage being capable of supplying the desired power output. The reactance-tube modulator requires essentially no extra power to drive it, and, unlike an AM modulator, it does not supply any additional power to the output.

2-23 AUTOMATIC LEVEL CONTROL (PEAK POWER)

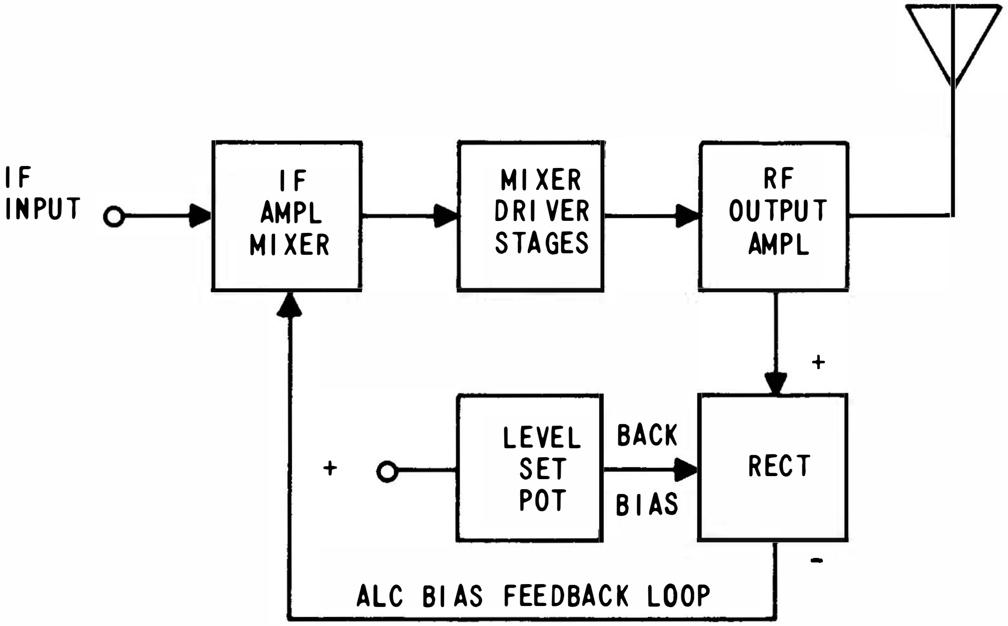
APPLICATION

The peak power type of automatic level control (ALC) is used to control the peak output power of single sideband (SSB) transmitters.

CIRCUIT ANALYSIS

General. To prevent modulation peaks from exceeding the linear range of operation of a linear amplifier, a form of delayed ALC is used in SSB transmitters. The ALC circuit takes a control voltage from the output of the linear amplifier, produced only near the peaks of operation, and uses it to control the gain of the driving stage. Thus ALC is similar to automatic gain control (AGC) where the detected output is rectified and fed back to control the gain of preceding stages. By using ALC, the SSB transmitter cannot be overdriven to produce flat topping and peak clipping. Prevention of this kind of distortion is essential, because a heavily driven, flat-topping linear RF amplifier can produce extraneous frequencies (splattering) which will interfere with reception at local stations. If sufficiently strong, these interfering frequencies may be radiated and cause interference to services operating on frequencies quite remote from the basic transmitting frequency. ALC permits adequate driving for full undistorted output from an SSB transmitter, but prevents over driving. When used for average power control, ALC is useful for double sideband transmitters; this application is discussed later in this section of the handbook.

Circuit Operation. The block diagram of a typical peak power ALC circuit arrangement is shown in the following illustration. As can be seen from the illustration, a sample of the RF output is taken from the amplifier (usually from the plate) and is applied to a back-biased diode. The back-bias for the diode is obtained from the level-setting potentiometer, which selects a positive voltage of a value near the peak amplitude to keep the rectifier cut off until the peak RF



Peak Power ALC Circuit

voltage reaches this level (this is the effective delay portion of the circuit). When the peak voltage at the output exceeds the reverse bias from the potentiometer, the diode conducts and produces a negative control voltage. This negative voltage constitutes the ALC voltage and is fed back to an earlier stage, either the sideband IF amplifier or a mixer stage in the low-frequency portion of the sideband unit. Since the IF amplifier or mixer supplies the input to the mixer-driver stages, its gain determines the level to which the output amplifier is driven. The bias is adjusted manually by the operator to produce a peak output just below the point of clipping, which is the maximum limit of linear operation. Hence, whenever a high-level input tends to overdrive the sideband transmitter into peak clipping, the ALC negative feedback loop increases the bias on the controlled stage, to reduce the output level to the allowable maximum undistorted peak output.

In some equipments a meter or other type of indicator is provided for the operator's use in adjusting the ALC circuit to indicate the voltage level at which ALC operation commences. Below the operating level, the diode remains cut off and there is no feedback and no change in bias, so the RF peaks are passed with no ALC action.

2-24 AUTOMATIC LEVEL CONTROL (AVERAGE POWER)

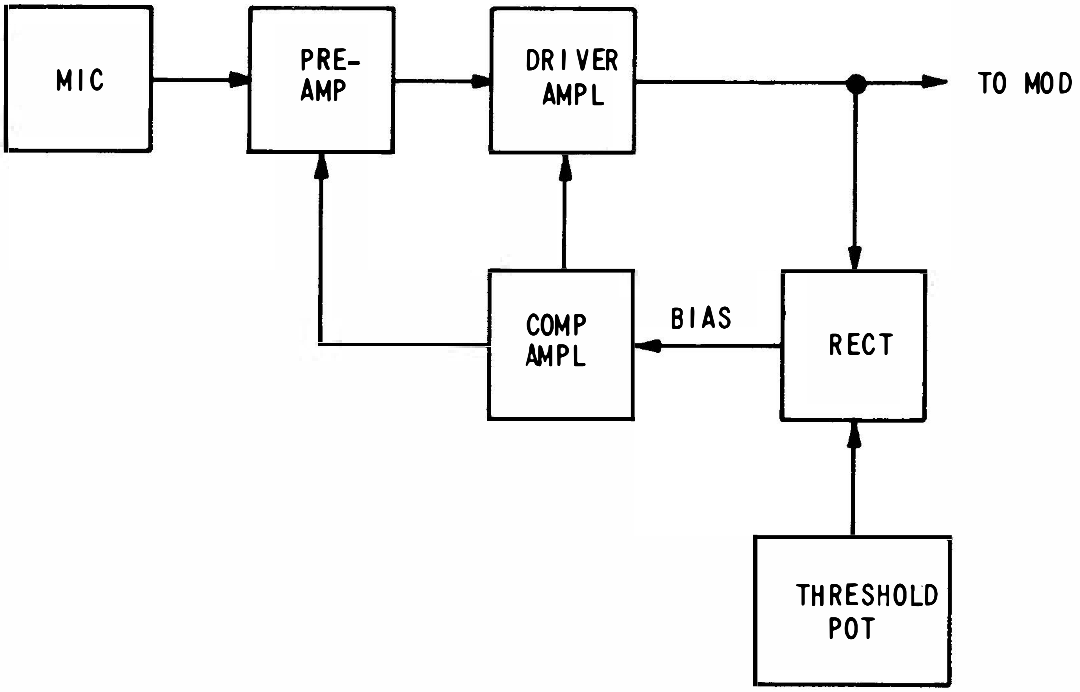
APPLICATION

The average power type of automatic level control (ALC) is used to control the average output power of double sideband transmitters.

CIRCUIT ANALYSIS

General. The average power ALC functions as a voice compression type of gain control to maintain an essentially constant audio output for driving the modulator in a double sideband transmitter. The end result is to keep the average power output of the transmitter at a uniformly high level for more efficient operation.

Circuit Operation. The following illustration shows the block diagram arrangement of a typical average power ALC circuit. As can be seen in the illustration, an output from the audio driver stage is applied to a rectifier. This rectifier is backbiased by a threshold control so that it will not operate at too high a level. The control allows the circuit to be adjusted so that the background level is steady between words and syllables. Otherwise, there would be an objectionable rise in noise because of the highly



Average Power ALC Circuit

increased amplification with no input. When the threshold level is exceeded, the rectifier conducts, producing a DC control voltage. After amplification to a satisfactory level, this voltage is fed to the preamplifier audio stages or to the microphone input stage. This feedback voltage controls the bias, and hence the gain, of the stages to which it is applied. Normally the control voltage is negative, and its magnitude decreases when the microphone input is low, and increases when the microphone input is high. Thus, high-level signals are essentially reduced in amplitude, while low-level signals are increased in amplitude. The increased gain for low-level signals and the decreased gain for high-level signals produces a compression effect. Hence, the overall power level is increased so that a greater average output is automatically obtained. This type of circuit is also used with coupling components that reduce the amplification of frequencies between 100 and 500 hertz (which contain the highest energy of the speech components). As a result, the medium frequencies are amplified more than the lower frequencies, there is less chance of hum modulation, and more power is available to increase the average level without exceeding the power supply capability.

2-25 VOICE-CONTROLLED OPERATION

APPLICATION

Voice-controlled operation (VOX) circuits permit break-in type of radio telephone operation. The transmitter is automatically controlled by the speech input to the microphone.

CIRCUIT ANALYSIS

General. Since the operation of electronic circuits is practically instantaneous, it is possible to trigger a control circuit which turns the transmitter on automatically by voice input. Only one or two syllables of the speech input are lost during the time it takes to operate the turn-on device; therefore, intelligibility is not seriously affected. With break-in operation, conversation by radiotelephone is similar to that by ordinary telephone. Once radio communication has been established between stations on the desired frequencies, the VOX unit can be used to extend telephone service into a long distance landwire and radio circuit to contact remote places served only by radio.

VOX circuits may be electron-tube or solid-state devices. By means of phone patching, the output of a telephone may be connected to supply the voice input, using a hybrid transformer arrangement, so that speech on a remote telephone line can operate the transmitter.

The VOX circuit is designed to automatically hold for a predetermined time after speech ceases before opening and turning off the transmitter, and connecting the receiver output circuits. This delay feature is incorporated so that slight pauses between words will not let the VOX relay open. Thus, partial clipping of each word is prevented, and the difference between fast and slow speaking operators can be accommodated. The use of VOX operation eliminates the normal push-to-talk operation, which requires the pushing of a button or the turning of a switch each time it is desired to speak over the air, and thereby speeds up voice communication.

Circuit Operation. The accompanying figure shows the basic circuits involved in a typical VOX circuit. The unit may be built into the transmitter or supplied as a separate outboard connected and operated device.

To control the speech volume necessary to operate the VOX circuit, the VOX speech amplifier is usually connected to the microphone speech amplifier through an input control, usually called the "sensitivity" control. Adjustment of the sensitivity control determines the peak voice amplitude required to develop a voltage in the VOX detector sufficiently large to drive the relay control circuit by overcoming the normal bias and allowing relay operation. The rectified speech input is stored and filtered by an LC filter to develop the proper amount of DC bias to operate the control stage. The control circuit consists of an amplifier whose plate current is used to energize the off-on-relay. When sufficient plate current flows, the relay closes and turns on the transmitter or the transmitter keying circuit.

When a common transmitting and receiving antenna is used, other relay contacts simultaneously turn on the transmitter antenna relay, which disconnects the receiver input from the antenna, to avoid overloading the front-end. In addition, the voice coil speaker contacts are either grounded or opened, and are shunted by a resistor of the same impedance as the voice coil to provide the proper output load. This prevents any audio feedback from the receiver speaker from overriding the VOX input and causing feedback howl.

In normal reception, an output from the receiver voice coil is applied to the VOX anti-trip amplifier. This stage amplifies the normal received signal or noise, and converts it to a bias voltage to hold the control stage in a cut off condition. Thus, extraneous signals will not trigger the VOX system into operation at undesired times. Usually an anti-trip control is provided for proper adjustment, but if the VOX sensitivity control is set too high it is possible for an extremely loud output to override the anti-trip circuit. With proper adjustment of the VOX sensitivity control, the VOX will operate only when the operator speaks into the microphone at the proper level.

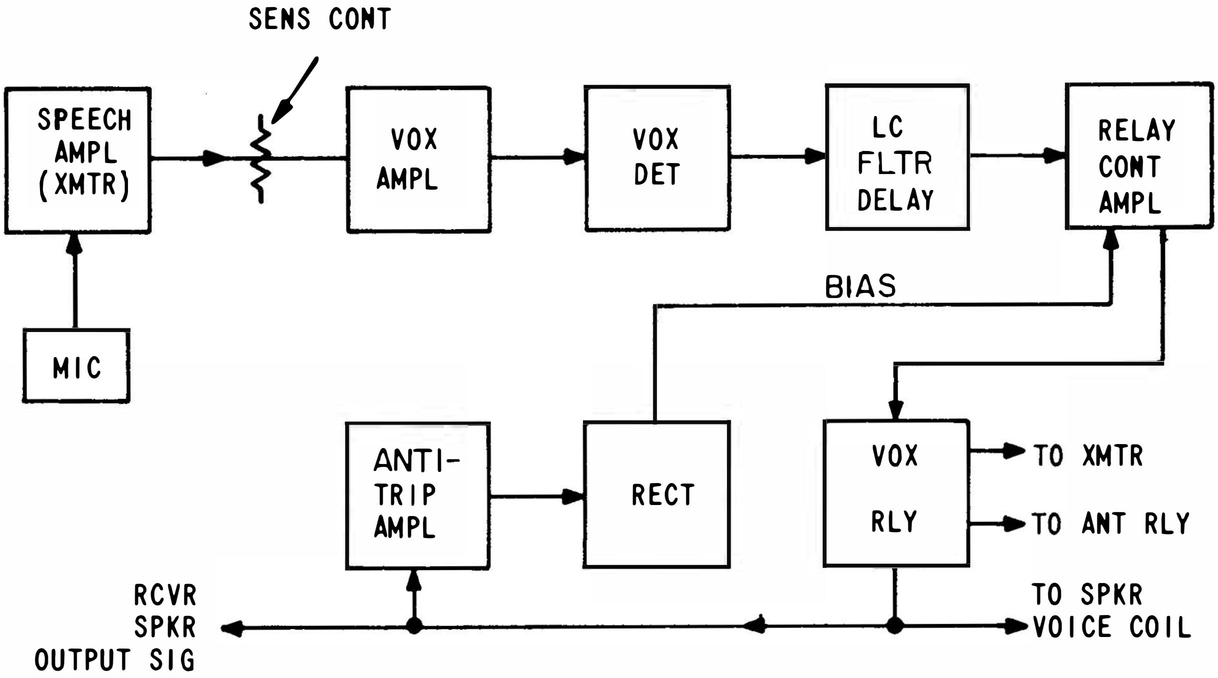
2-26 KEYING CIRCUIT

APPLICATION

The keying circuit is used to key a transmitter indirectly to avoid the possibility of shock, and to improve the CW signal.

CIRCUIT ANALYSIS

General. There are a number of methods of keying transmitters, such as directly grounding the cathode, breaking the negative lead, and reducing the buffer or power amplifier grid bias. Using the direct keying connection creates a shock hazard in that the operator may touch the "hot" part of the key. Also, key contacts may burn or arc and cause a garbled signal. Straight grid keying may cause such abrupt on and off operation as to produce key clicks, which can cause receiver interference to other nearby ships



Voice-Controlled Operation Arrangement

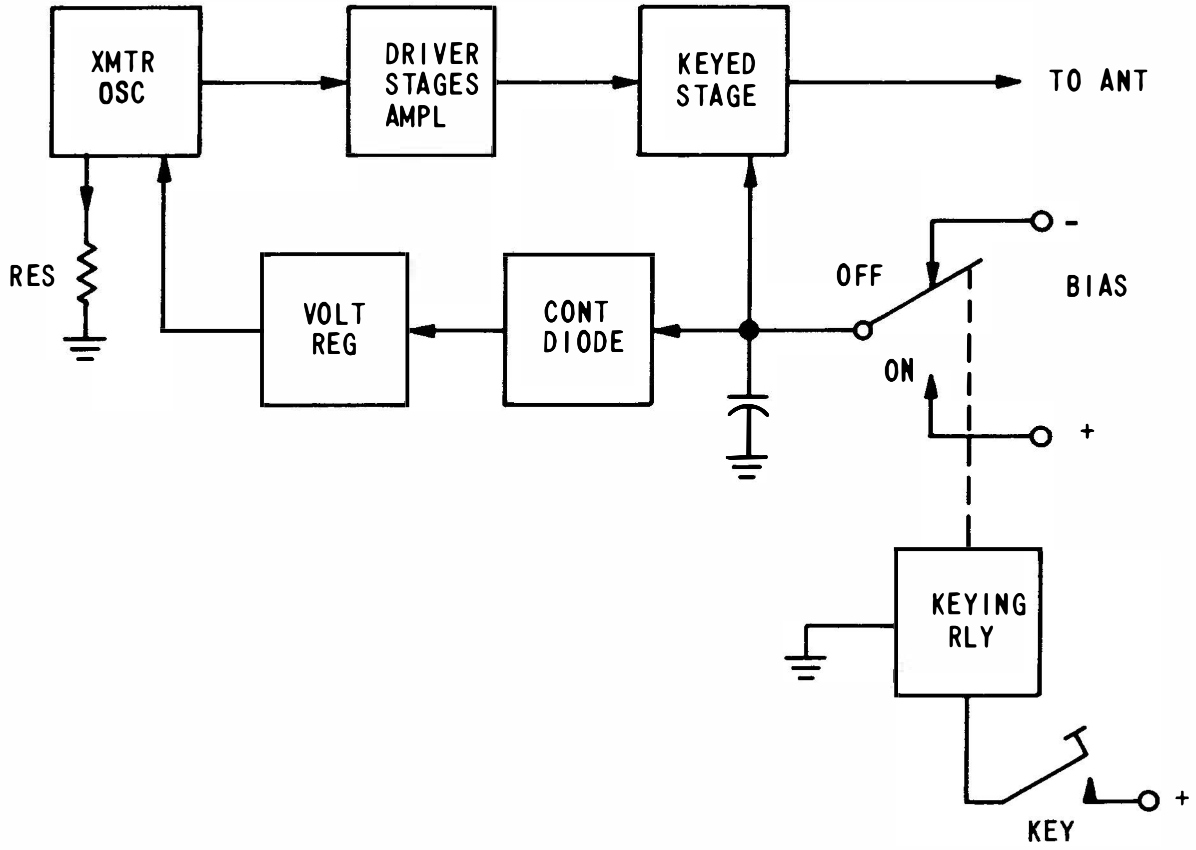
or stations across the receiving band. In high-power amplifiers, screen grid keying may also cause an objectional back wave. However, a combined arrangement using negative screen bias to hold the plate current at zero with the key up and an automatic turn-off and turn-on oscillator switching circuit will result in satisfactory sharp keying without undesirable key clicks, if the correct circuit constants are used. An alternate but less preferred arrangement is to use a tube in series with the cathode of the keyed stage. The tube is negatively biased with the key up and positively biased with the key down. A single tube or several tubes in parallel can be set up to carry the necessary tube current, and the slight delay in operation will cause a softer make and break operation so that key clicks are reduced. In high-speed machine keying, a flip-flop may be used to key the keying control tube and produce better keying.

Circuit Operation. The block diagram of the figure shows a typical vacuum tube keyer to key both the oscillator and final amplifier. Solid-state devices may also be used in a similar arrangement.

The oscillator is biased negatively through a voltage regulator tube and control diode from a negative voltage source. With the key up, the oscillator is biased off by the negative voltage applied through the diode, voltage regulator, and resistor to ground. With the regulator and diode conducting, the drop across the resistor is applied as cutoff bias to the oscillator. Meanwhile, the same negative supply is applied to the screen grid of the output tube. This holds the output tube in a cutoff condition with zero plate current. Therefore, no signal from the driver stages can pass through the tube interelectrode capacitance and be radiated as a back wave. Simultaneously, the capacitor charges negatively.

When the key is held down, a positive voltage from another power supply is applied to the screen of the output tube to permit conduction. At the same time the positive cathode voltage stops the diode from conducting, the voltage regulator tube stops conduction, and cutoff bias is removed from the oscillator, allowing the tube to oscillate. The oscillator then produces an output through the driving stages and keyed output amplifier. Note that in this case the oscillator starts slightly after the transmitter is ready to operate and stops after the keyed stage has cut off. The effect is indirect keying of the oscillator. As long as the oscillator frequency is not changed by changes in voltage or current, a chirp will not be produced. The tendency will be for the oscillator waveform to have slightly rounded leading and trailing edges, which eliminate any possibility of key clicks. This method of operation is usually known as differential keying. By having the oscillator off when the key is up, the operator can listen between dots and dashes (break-in operation) for a stop signal from the receiving station.

Most military transmitters use grid bias keying for low-power operation and differential keying for high-power operation. For machine operation, a flip-flop is substituted for the diode and VR combination,



Keying Circuit

and sharply shaped pulses are used to key the transmitter. Keying is usually accomplished through a control tube and relay. In some equipments, a shaping circuit may be used to provide the desired sharp waveform and the oscillator may be turned on and off by conduction of the control tube.

It should be remembered that any form of keying involves on or off operation and that either the oscillator alone, a number of driver stages, or the final stage alone may be keyed; or any combination of these methods may be used simultaneously. If the oscillator voltage is changed considerably by tuning and the loading and is not well regulated, the keyed signal will normally be chirpy because of the frequency change caused by the "pulling" effects of this changing voltage.

2-27 SPEECH COMPRESSION AND CLIPPING TECHNIQUES

APPLICATION

Since natural speech waveforms contain peaks greatly varying in amplitude, the techniques of compression and clipping are used to average the individual amplitudes.

CIRCUIT ANALYSIS

General. Speech is a syllabic variation which changes instantaneously from a very low amplitude to a large peak amplitude and varies from word to word. It is evident from looking at any speech waveform on an oscilloscope that there is a great variation in average to peak audio values. The general ratio of speech peaks to noise is about 28 to 1. By compressing the speech, we increase the peak level of the low-level peaks and reduce the peaks of the high-level peaks. Thus, we obtain a more nearly constant peak level which produces a higher average power gain. An effective output of 15 to 20 dB or more can be realized, provided that the transmitter output tubes are capable of handling the increased power and the additional heat generated as the average output is increased. This compression, of course, tends to change the quality of the speech and the shape of waveform so that it is different from the original. However, if the distortion created is not excessive, it will not really interfere with the understanding of the speech. In fact, the increase in speech power in practice makes the voice signal stronger and pushes it through any noise or interference so that it usually is much more clearly distinguishable. Where an unprocessed signal may just be readable and intelligible, a processed signal, in effect, booms out clear and loud. Since the distortion involved consists of frequency distortion due to the change in waveform, the amount of spurious frequencies inserted by the compression process determine whether the output bandwidth is adversely affected; that is, whether the signal covers a greater spectrum or whether certain objectionable harmonics may interfere with adjacent channels. With the correct amount of compression, the distortion can be minimized so that it causes no real objectionable increase in bandwidth.

In a similar manner, clipping can be used to reduce or cut off the higher peaks and essentially square off the waveform. If we clip the peaks 20 percent, we can increase the drive that much more to obtain the maximum peak value to retain 100 percent modulation in AM, or to retain the maximum peak-to-peak ratio in single sideband applications. The results in both cases are similar. That is, the smaller peaks do not reach the clipping level but are amplified more, while the larger peaks are cut off. This causes frequency distortion too, but it also increases the average to peak power so that greater power output is obtained. When the average level is increased, the effective RF output is increased. When the clipping is kept to a level which minimizes the distortion and maximizes the increased power output, an effective gain results.

By combining both speech compression and clipping the most useful results are obtained, with compression as high as 40 dB producing a transmitter gain of 8 to 12 dB. To reduce the distortion produced by clipping, it is necessary to use a filter to minimize the effects of the harmonic frequencies introduced by the clipping action. If the clipping is done at audio frequencies alone, over a band of from 300 to about 3000 hertz, the peak limiting is about 25 dB and an increase in peak envelope power (pep) of about 10 dB can be obtained. With syllabic audio compression, peak limiting generally is restricted to about 20 to 40 dB with a 10 dB increase in output. With RF clipping, about 18 to 20 dB of limiting is obtained and an output gain of about 11 dB is obtained. This type of processing generally keeps the RF output peak level relatively constant over a large range of modulation values.

In comparing the different types of speech processing, it has been determined that with 40 dB of peak compression the threshold for constant level speech will be increased about 6 dB, as contrasted with an approximate 8.5 dB improvement with 20 percent RF clipping followed by filtering. The important difference, however, is that compression produces less distortion and better speech quality. The reason for this is that the compressed signal has about 6 dB less third harmonic distortion and 12 dB less fifth harmonic distortion than the RF clipped signal. Since RF compressors generate harmonic distortion at frequencies that are multiples of the RF filter frequency, the harmonic distortion is rejected, and only odd order products falling within the filter passband appear in the output. Therefore, signals passed through RF sound processors generally sound better than those passed through audio processors. Because speech processing changes the character of the sound, breathing sounds and background noise assume greater significance, and use of a noise canceling microphone helps produce a significant reduction in the ambient background noise.

The current trend is to incorporate separately built solid-state speech processors outboard from the transmitter. Proper adjustment for minimum distortion and maximum increase of average-to-peak output levels produce an effective increase in speech level at the receiver, which provides better communication than a ten-time increase in power level without speech processing. When speech processing circuits are built into the transmitting equipment, only a slight change in physical size is made and the results of a much more powerful transmitter are obtained.

Circuit Operation. A block diagram of a typical speech processor utilizing compression and clipping is shown in the figure. Since various forms of compression and clipping are used, only a basic device is shown.

The audio input is applied to a preamplifier which drives a push-pull compressor amplifier, controlled by AGC bias. The AGC bias is obtained from the input preamplifier through an AGC amplifier and rectifier, and is applied to the compressor to control the gain. The overall result is a practically constant output from the compressor which is applied to a voltage amplifier and thence to a diode clipper for audio frequency clipping. From the clipper, the compressed and clipped signal is applied to a low-pass filter, which removes all frequencies above 3000 hertz. The filtered output is applied to either AM or SSB modulators to produce the output.

2-28 TRANSMITTER POWER SUPPLY

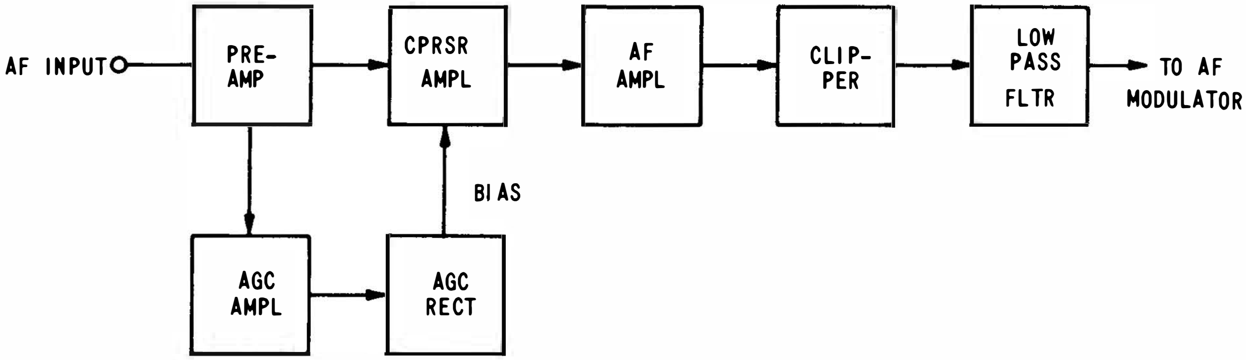
APPLICATION

The transmitter power supply provides the high voltage and current required for the transmitter power output circuit.

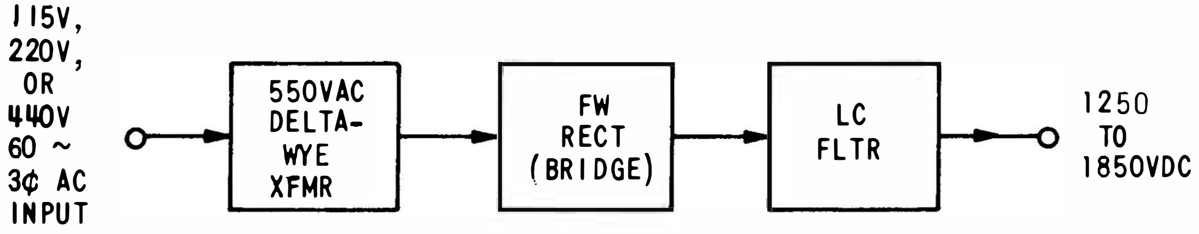
CIRCUIT ANALYSIS

General. In some equipments, all power is provided by a single power supply, which furnishes the various low and high output voltages needed. However, the transmitter power supply for AM, single sideband, and FM transmitters usually consists of two different sources, a low-voltage source and a high-voltage source. Usually the low-voltage source is considered a portion of, or is taken from, the receiver's low-voltage supply, and is used for the preliminary RF driving and RF oscillator-mixer-multiplier stages of the transmitter. The transmitter supply described in this discussion is the high-voltage supply used to supply power for the final or both the final and its driver stage.

Circuit Operation. The following illustration shows a block diagram of a basic SSB high-voltage transmitter power supply. Three single-phase transformers are used in a delta-wye hookup so that they may be operated from the ship's 115V, 220V, or **440V**, 3-phase, 60-hertz primary supply. The lower-power



Typical Speech Compressor and Clipper



Transmitter Power Supply Arrangement

transmitter output uses the wye connection to supply a lower output voltage, while the high-power transmitter output uses the delta connection to supply a higher output voltage. Typical output voltages are 1250 volts for low power and 1850 volts for high power.

The transformers feed a conventional 3-phase bridge rectifier circuit, which uses a choke-capacitor type of output filter. The use of three phases has the effect of reducing the ripple in the output, so that the output is easier to filter than that of a single-phase power supply. Since there are no real requirements for regulation, no complex voltage regulator is used; the simple L-C filter is able to supply all the peak or average power required at a relatively steady DC output voltage.