Auxiliary Radio Channels for the TH Radio Relay System

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The operation and maintenance of the TH and TD-2 radio relay systems require communication facilities along the route which can be used for the transmission of voice, protection switching and alarm signals. Special narrow-band microwave facilities, referred to as the auxiliary radio channels, which have been developed as an integral part of the TH system to supply this need, are described in this paper.

I. INTRODUCTION

The operation and maintenance of the TH and TD-2 radio systems require communication facilities along the route which can be used for the transmission of voice, protection switching and alarm signals. In the TD-2 radio system such facilities are typically provided by wire lines running approximately parallel to the radio route, but often separated by several miles. Where such separations exist, additional wire-line facilities are required to connect the individual radio stations with the parallel wire-line route. The desirability of providing narrow-band microwave channels for the transmission of these signals within the frequency allocation of the TH system was recognized early in the TH development. Narrow-band channels which have been designed for this purpose are described in this paper. These channels, called auxiliary channels, serve both the TD-2 and the TH systems where there is a combined installation.

Before proceeding with a detailed discussion of the auxiliary channel system, its associated systems and signals will be briefly described.

1.1 *The C1 Alarm and Control System*

The C1 alarm and control system as it was originally developed for use with the TD-2 system has been described in a paper on that system.[1]

Its purpose is to allow an attendant at an alarm center to monitor the operation of a number of unattended radio stations. An expanded but otherwise similar version now exists which can handle a combined installation of TD-2 and TH. A maximum of twelve unattended radio stations can be associated with a single alarm center. These are usually arranged so that not more than six stations are located on either side of the alarm center. A one-way voice-frequency circuit (known as the alarm line) is provided from each group of six stations to the alarm center. Over this circuit each station transmits a continuous and distinctive tone at one of the six frequencies (1100, 1300, 1500, 1700, 1900, and 2100 cycles) which are available for this use. These tones are detected in separate frequency selective circuits at the alarm center. The interruption of a tone for approximately ten seconds registers an audible and visual alarm. Because each station is assigned a different frequency, the station whose tone is interrupted is easily identified.

The removal of one of the station alarm tones described above indicates that a particular unattended station is in trouble, but it does not identify its nature. To get this detailed information, the attendant at the alarm center sends an order over another one-way voice circuit* (known as the order circuit) which connects to the group of six stations. The orders consist of a 1600-cycle carrier modulated in sequence by selected combinations of twelve modulating frequencies available in 16-cycle steps from 277.5 to 442.5 cycles. By choosing a particular combination, one of several possible orders can be sent to a particular station. Typical orders might be to start the gas engine alternator or, as in this case, to scan certain alarm indications. As these alarm indications are scanned in the station in response to an order, a series of 900-cycle pulses are transmitted at a 5-cycle rate over the two-wire alarm line back to the alarm center. Whenever an alarm condition is encountered, a 700-cycle pulse is transmitted simultaneously with the 900-cycle pulse. The presence of a 700-cycle pulse causes the appropriate lamp to be lighted on a lamp display in the alarm center.

1.2 *Voice Circuits*

A second two-way, four-wire voice circuit is used for telephone conversations which are required in connection with system maintenance. It connects all the stations along a section of the radio route with the associated alarm center. Known as the "radio order circuit," this circuit is essentially a party line which permits an individual in one station

* This one-way circuit is opposite in direction to the alarm circuit. Thus, the other half of a four-wire, two-way telephone channel can be used for this purpose.

to talk with an individual at any of the other stations in the section. Means for signaling from one station to another are provided as a part of the C1 system.

Additional voice circuits, called "express radio order circuits," are provided over much longer sections of the radio route, but only selected stations are connected. Normally, these "express circuits" will not be provided over the auxiliary channels.

1.3 *TD-2 Protection Switching*

The TD-2 protection switching system has been described in an earlier paper.[2] Two one-way voice channels are required; each permits transmission from the receiving end to the transmitting end of a TD-2 switching section, a distance which normally consists of from five to fifteen radio hops. When all of the regular radio channels in the section are working properly, a 700-cycle guard tone is transmitted over this facility. This guard tone prevents the operation of TD-2 protection switches on extraneous signals, such as noise in the voice channel, and provides an indication that the voice-frequency facility has not been impaired. If detectors at the receiving end indicate that transmission on one of the regular TD-2 radio channels is impaired, and if the protection channel is available, the 700-cycle guard tone is removed and another tone, depending on the channel in trouble, is transmitted. Tones at 900, 1100, 1300, 1500 and 1700 cycles are used for the five regular channels. When the tone corresponding to a particular channel is received at the transmitting end of the section, the signal on the regular channel is transferred to the spare channel. When transmission on the regular channel returns to normal, the procedure is reversed: the tone representing the regular channel is removed and the 700-cycle guard tone is restored.

1.4 *TH Protection Switching*

The TH protection switching system described in a companion paper[3] requires transmission facilities for a total of sixteen tones in each direction along the radio route. These tones are located at 1-kc intervals in the band from 20.5 kc to 35.5 kc. Of the sixteen tones transmitted in one direction, eight alternate tones starting at 21.5 kc are status tones for the eight broadband channels being transmitted in the opposite direction. The other eight (actually two groups of four) are order tones for the eight channels being transmitted in the same direction as the tones. A two-out-of-four code is used for each group of order tones.

Thus, for the eight channels in a given direction there are eight possible order tones in the same direction and eight status tones in the opposite direction.

Tone-reporter circuits are provided in each radio station which can selectively attenuate any of the eight status tones. If the transmission on a particular broadband channel is impaired, the corresponding status tone is attenuated. This action is detected at the transmitting end of the protection switching section, and a switching action will be initiated there. The order tones, in the other direction, are then used to signal for the corresponding switch at the receiving end.

II. DESIGN FEATURES

To compete with wire-line facilities, the auxiliary channels must provide a less expensive and more reliable medium for transmitting the signals described in the preceding sections. As a result, the auxiliary channels share the antenna system and common microwave carrier supply of the broadband channels. In addition, the auxiliary channels employ double-sideband amplitude modulation, operate without radio frequency amplification in the transmitter, and use components designed for the broadband channels wherever practical.

The required reliability is achieved by providing two narrow-band radio channels for each direction of transmission. At each radio station, the baseband inputs and outputs of the two channels are connected in parallel. In addition, the automatic gain control circuits of the receivers operating in the same direction are connected in parallel. This interconnection of baseband circuits and automatic gain control circuits provides protection against fades in the transmission path and equipment failures without the necessity of automatic switching circuits and results in a nearly optimum signal-to-noise ratio. This equipment diversity has the further advantage of permitting in-service removal of units for maintenance.

At each station, it is necessary to recover the baseband signal so that specific components, as described in the preceding sections, can be added or removed. For a ten-hop route — the maximum length of a TH protection switching section — a total of ten amplitude modulators and demodulators are thus connected in tandem. To reduce the linearity required in these circuits, a baseband frequency allocation is used in which second-order modulation products fall outside the signal bands. This leads to the baseband signal spectrum shown in Fig. 1. Some further advantage in over-all linearity is achieved by modulating the two channels in a given direction with baseband signals which are 180° out

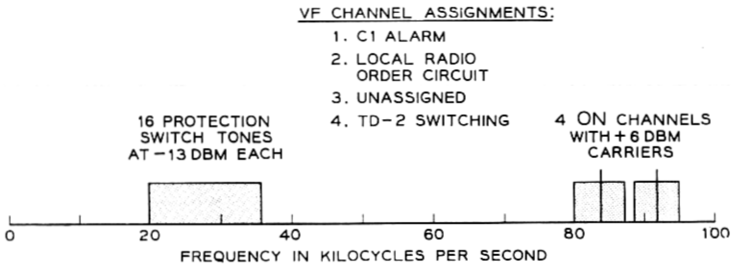

Fig. 1 — Baseband signal spectrum for auxiliary radio channels.

of phase so that even-order modulation products tend to cancel when the baseband signals are recombined at each station.

III. DESCRIPTION

3.1 *General*

A simplified block diagram of a typical auxiliary channel installation is shown in Fig. 2. In the west-east (W-E) circuit shown at the top, amplitude modulated microwave signals are received on channels 10 and 19.* Radio receivers with interconnected AGC circuits (which will be discussed in greater detail in Section 3.3) recover the baseband signals, which are then combined in a hybrid. This combined baseband signal is then fed to a transmitting hybrid where the signal is again split and applied in parallel to the two radio transmitters on channels 20 and 29. The receiving portion of the ON carrier terminal is bridged across the baseband circuit. This permits any of the four telephone signals on the W-E circuit to be received at the respective voice-frequency terminals of the ON equipment. In addition, a tone-reporter circuit (Section 1.4 above) is bridged across the baseband connection between receivers and transmitters. Signals from the transmitter portion of the other ON carrier terminal are added to the baseband signal by means of the connection shown to the right of the tone reporter. The lower half of Fig. 2 shows a duplication of these facilities for the other direction of transmission.

In the arrangement described above, the baseband signals, including the four ON channels in the 80–96 kc band, are connected directly from the radio receivers to the radio transmitters. In this way signals being

* The frequency allocation of the auxiliary channels is described in detail in Ref. 4.

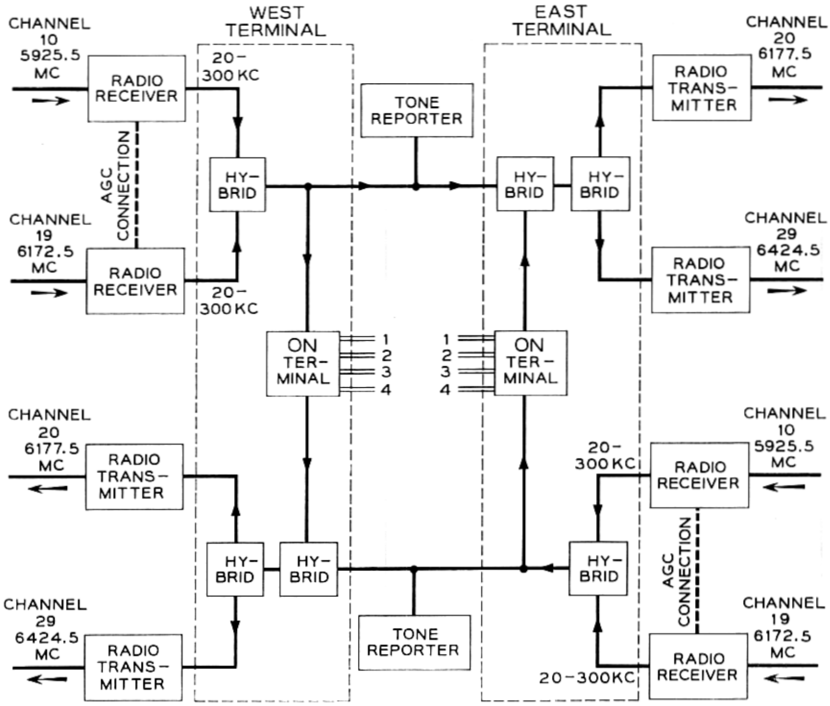

Fig. 2 — Simplified block diagram of typical auxiliary channel repeater installation.

transmitted through a given station are not impaired by repeated demodulation to voice frequency and by the subsequent modulation back to baseband frequency. However, the ON terminals are connected in such a way that signals can be received and transmitted on any of the voice channels in either direction. This arrangement provides certain advantages. Transmission impairments for ten ON terminal pairs in tandem are avoided. This is particularly desirable for the compandored circuits. Furthermore, only those voice circuits required at a given station need be equipped. On the other hand, this method of operation requires the twin channel carriers at 84 kc and 92 kc in the ON terminal to be suppressed at all except the first station in a section. At all other stations, twin-channel sidebands are added in the baseband signal adjacent to the twin-channel carriers which originate in the first station. Therefore voice-frequency signals originating at other than the first station are subject to a slight frequency shift equal to the difference between the twin-channel carrier at the first station and that of the station where the signal originates.

3.2 *Radio Transmitter*

A block diagram of the radio transmitter is shown in Fig. 3. The baseband signal is combined with a microwave carrier in the first modulator — the transmitter modulator — to produce a double-sideband, amplitude modulated signal. This microwave signal, in turn, is shifted to the assigned channel by combining it with the output of a crystal-controlled oscillator in a second modulator. The output of this second modulator — the frequency shift modulator — contains amplitude modulated carriers corresponding to both the sum and the difference of the two input frequencies. The bandpass filter selects the desired signal. The isolator following the bandpass filter provides good terminations for both the filter and the channel-separation network through which the transmitter is connected to the antenna system.

3.2.1 *Transmitter Modulator*

The transmitter modulator, shown in Fig. 4, consists of a dual isolator, a short-slot directional coupler, a diode mount, and a baseband coupling network. It is closely related to the broadband transmitter modulator, described in a previous article,[5] with adaptations for amplitude modulation use. The waveguide attenuator and the cross-guide directional coupler are used to measure and adjust the microwave input power. Fig. 5 is a simplified schematic of the transmitter modulator.

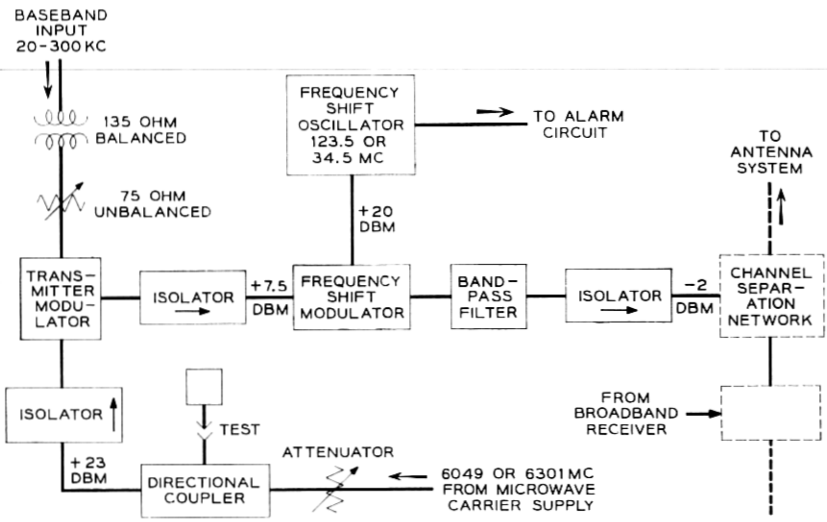

Fig. 3 — Block diagram of auxiliary channel transmitter.

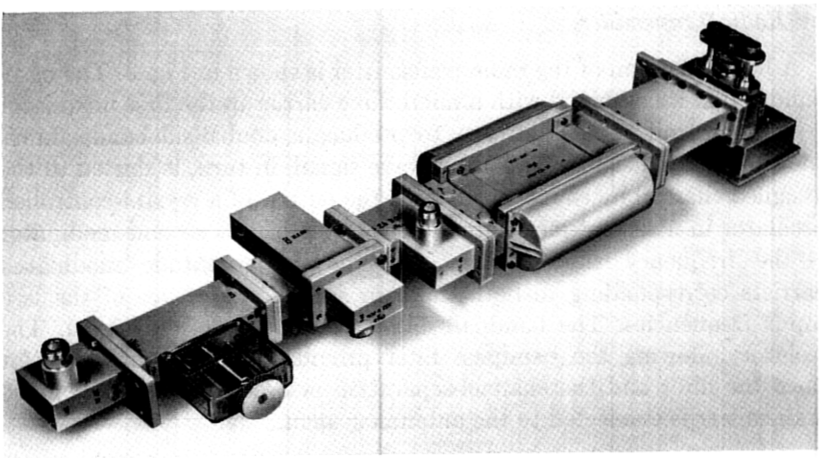

Fig. 4 — Modulator of auxiliary channel transmitter.

The short-slot directional coupler divides the incoming microwave carrier equally between the two diodes CR1 and CR2. Each diode absorbs a fraction of the incident carrier and reflects the remainder. The directional coupler divides each reflected signal equally between the IN and OUT ports. However, the phase characteristics of the directional coupler cause these reflected signals to add at the OUT port and to cancel at the IN port. As a result, the signal at the OUT port is proportional to the sum of the complex reflection coefficients of the diodes, and the signal at the IN port is proportional to their difference. The reflection coefficients are determined by the microwave tuning adjustments (RF TUNERS 1 and 2) and the diode biases. When these tuning adjustments are properly set, the magnitude of the reflection coefficient varies with the diode bias, and its angle remains constant. For a given carrier power there is a value of diode bias about which the magnitude of the reflection coefficient varies linearly with the diode bias. If the low-frequency baseband signals are superimposed on this dc bias, the reflection coefficients and, in turn, the signal at the OUT port are amplitude modulated. The dc bias determines the carrier power and the amplitude of the superimposed baseband signals determines the per cent modulation. Variations of the microwave carrier input produce variations in both the microwave carrier output and the per cent modulation. To minimize these variations, the diodes are operated with a combination of self- and fixed-bias. Rectified currents flowing through R1A and R1B produce the self-bias; the fixed-bias is developed across R2. Inductors L1 and L2

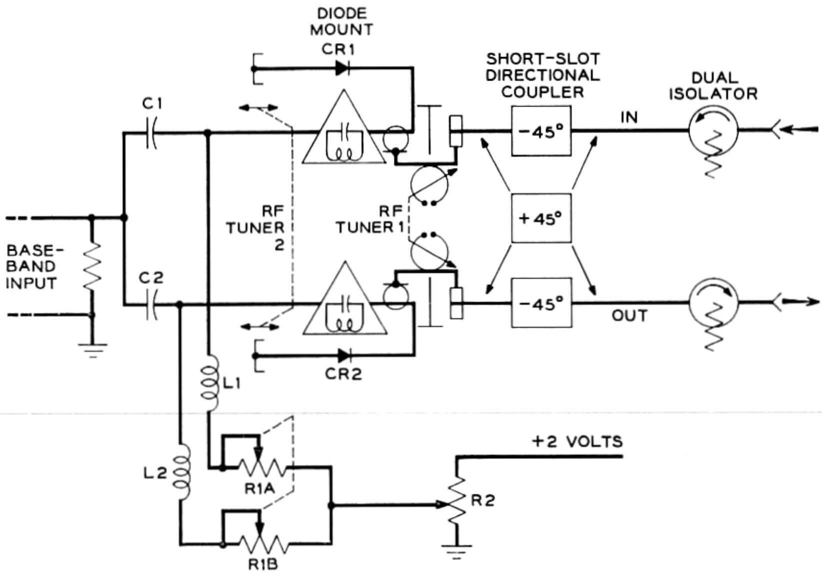

Fig. 5 — Simplified schematic of the transmitter modulator.

and capacitors C1 and C2 separate the baseband circuits and the bias circuits.

The frequency shift modulator is similar in appearance and operation to the carrier supply modulator described in a companion paper.[5] The powers shown in Fig. 3 indicate the performance of this modulator.

3.2.2 *Frequency Shift Oscillator*

The frequency shift oscillator is a conventional oscillator-buffer amplifier combination. The frequency determining element in the oscillator stage is a series-resonant overtone crystal. Normally, the frequency is 123.5 mc. However, when only one antenna is provided for each direction of transmission,[4] the channel 20 transmitter is temporarily assigned to channel 23, and the frequency of the associated oscillator is changed to 34.5 mc. Rectified current from a diode power monitor in the output circuit of the buffer amplifier operates a sensitive meter-type relay. A reduction in the output power of the buffer amplifier causes the relay to operate and, in turn, to initiate an alarm. Since the microwave carrier supply contains low-output alarms for the 6049-mc and 6301-mc carriers connected to the transmitter modulator, the inclusion of a similar alarm in the frequency shift oscillator insures, in effect, that any significant reduction in the output of the auxiliary channel transmitter will initiate an alarm.

3.3 *Radio Receiver*

A block schematic of the radio receiver is shown in Fig. 6. The incoming microwave signal, which has been selected by the channel separation network, is connected to the receiver modulator through a band-pass filter. The receiver modulator shifts the microwave signal to an IF of 64.2 mc by combining the incoming signal with a beat-oscillator frequency obtained from the common microwave carrier supply system, exactly as in the broadband radio receiver.[5] The shift frequency of 59.3 mc is normally used with the carrier supply modulator; 29.65 mc is used when the channel 20 receiver is temporarily assigned to the channel 23 slot. This temporary assignment occurs at those stations equipped with only one antenna for each direction of transmission.

The 64.2-mc output of the receiver modulator is amplified in a three-stage preamplifier and is connected to the IF amplifier through an IF attenuator. This fixed pad is used to adjust the input power to the IF amplifier and to compensate for differing free-space path losses between repeater stations (e.g., short hops). The first three stages of the IF amplifier are controlled by a separate automatic gain control (AGC)

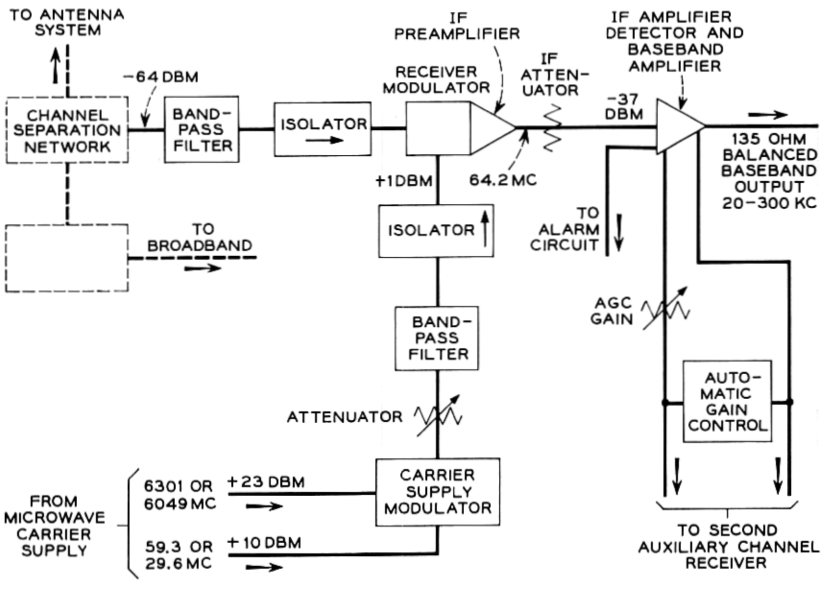

Fig. 6 — Block diagram of the auxiliary channel receiver.

unit; the fourth stage operates at fixed gain. The output of the fixed-gain stage is applied to an averaging detector which recovers the original baseband signal and also provides a voltage proportional to the applied IF signal. The baseband output of the detector is amplified in a two-stage feedback amplifier and then connected to the terminal equipment, where it is combined with the baseband output of the parallel radio receiver. The dc output of the detector is connected to the AGC circuits.

In normal operation (paralleled radio channels) the two AGC units are operated in parallel. Fig. 7 shows the interconnection. The internal impedance of each detector loads the other so that the actual voltage applied to the AGC units is one-half the sum of the open-circuit voltages of the two detectors. The outputs of the AGC amplifiers, Fig. 7, are also combined. The diodes permit the AGC unit with the more negative output voltage to control both IF amplifiers. The action of this interconnection is to maintain the sum of the receiver baseband outputs practically constant. The AGC GAIN adjustments compensate for differences between the individual loop gains.

The switches shown in Fig. 7 are arranged so that one receiver may

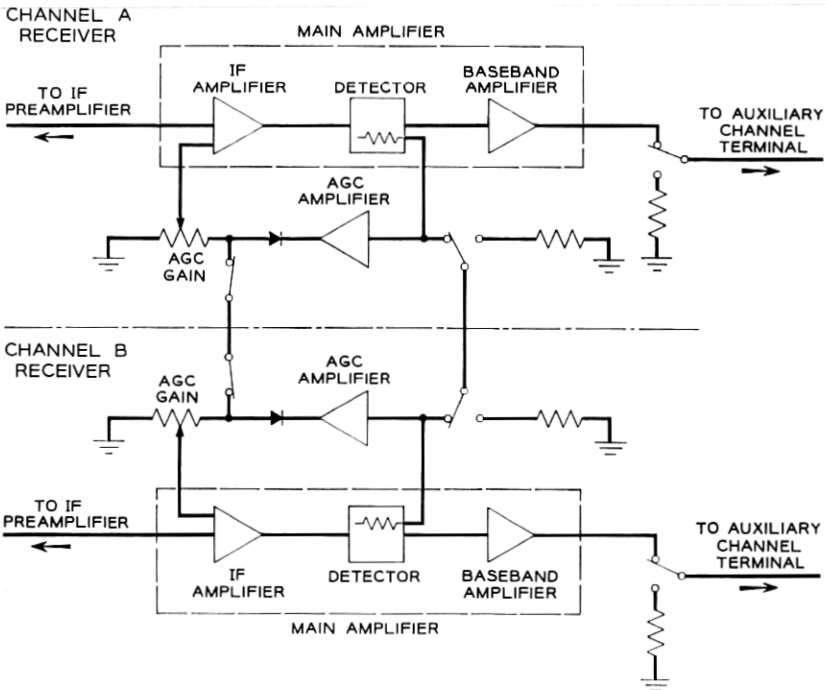

Fig. 7 — Block diagram showing interconnection of AGC circuits.

be disconnected without affecting the baseband signal level in the terminal equipment When the switches associated with one receiver are operated, the interconnections are broken, and the detector of the operating receiver is terminated. With only one detector contributing to the input of the remaining AGC unit, the gain of the corresponding IF amplifier increases 6 db to maintain that dc output constant. The baseband output of the operating receiver also increases 6 db and, as a result, the sum of the two receiver outputs remains constant.

The receiver modulator in the auxiliary channel receiver is identical to the modulator used in the broadband receiver, but the preamplifier is slightly different. The auxiliary channel preamplifier utilizes two 417A triodes in a modified cascode circuit followed by a 404A pentode as an output stage. The net gain of the receiver modulator-IF preamplifier is 37 db, and the overall noise figure is typically less than 10 db.

3.3.1 *IF Amplifier-Detector and Baseband Amplifier*

The three gain-controlled stages of the IF amplifier employ 404A pentodes and the fixed-gain stage, a 418A pentode. Each variable-gain stage has a cathode compensation network to stabilize the gain-frequency characteristic as the bias on the stage is varied. The detector employs two 427A gold-bonded germanium diodes connected in a voltage doubler configuration. The gain of the IF amplifier is sufficient to maintain a 2.5-volt dc detector output when the input signal is between -35 dbm and -60 dbm. The transmission characteristic is flat over a 2-mc band centered on 64.2 mc.

The two-stage baseband amplifier which follows the detector employs a 404A as a voltage amplifier and a triode-connected 418A as an output stage. With feedback, the transmission characteristic of the baseband amplifier is flat to ± 0.1 db from 20 kc to 200 kc. The transformer-coupled output stage is capable of delivering $+21$ dbm to a 135-ohm balanced load with negligible distortion.

As a means of indicating multipath fades and equipment failures, the 84-kc twin-channel carrier of the ON multiplex equipment is sampled by a narrow-band filter bridged across the output of the baseband amplifier. The output of the filter is amplified and detected, and the rectified current operates a sensitive meter-type relay. If, as a result of a fade or equipment failure, the 84-kc twin-channel carrier drops 20 db or more, an alarm is initiated.

3.4 *Terminal Circuits*

The terminal circuits at a typical repeater installation have been discussed in Section 3.1 with reference to Fig. 2. Although this represents the most common case, other arrangements are required at the ends of a TH protection switching section and at intermediate points where one or more of the voice circuits are terminated. The latter may occur at alarm centers or the ends of TD-2 protection switching sections. These special interconnecting arrangements are shown in Fig. 8.

Standard ON terminals, described in Ref. 6, are used in all cases. In some respects, however, the method of operation differs from conventional ON practice. Most significant is the previously described suppression of the twin-channel carriers at intermediate stations. This is easily accomplished since balanced modulators are used in which the carriers are suppressed. The carriers are later inserted under control of a potentiometer, which can be set for zero carrier. Another change consists of disabling the signaling circuits, which are not now required because signaling is done over the C1 alarm system.

Several types of channel units are available for use in the ON terminals. Channel units with compandors are used for the voice circuit in order to improve the noise performance. Special service channel units are used on the circuits for C1 alarm and TD-2 protection switching.

At the ends of TH protection switching sections, the east terminal

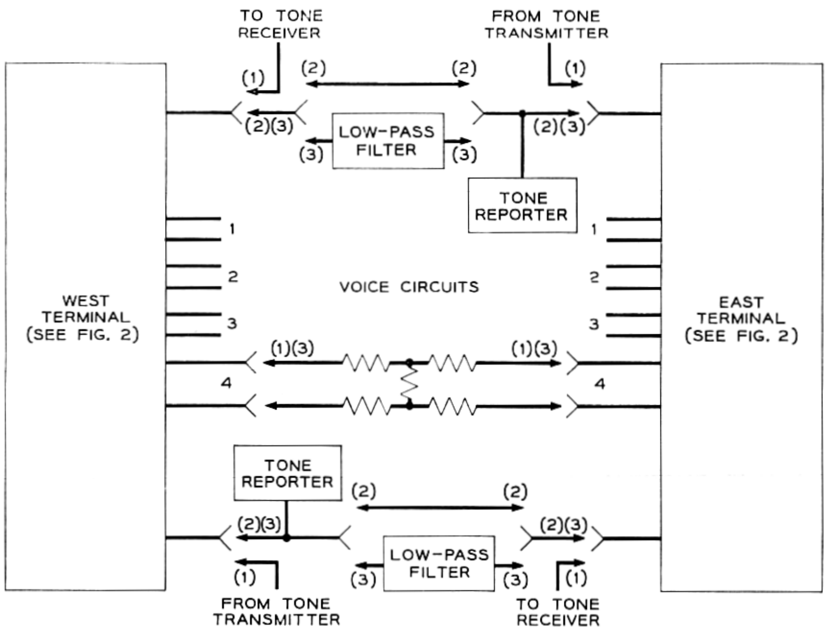

Fig. 8 — Simplified block diagram showing special terminal interconnections.

and the west terminal are separately connected to the appropriate tone transmitters and receivers in the TH protection switching system. In this arrangement, shown as option 1 in Fig. 8, there is no baseband connection between the two terminal circuits. The east and west sides of the stations are served by separate auxiliary channel systems. When it is necessary to provide continuity in a voice channel through such a station, the appropriate connections are made at voice frequency, as shown for voice circuit No. 4. In such stations the ON twin-channel carriers at 84 kc and 92 kc are supplied to the baseband circuit by the ON carrier terminals. At the end of a TH route a similar arrangement is used except that only one of the two terminal circuits needs to be provided.

At typical intermediate stations in a TH protection switching section, the arrangement shown as option 2 is used. This is identical with Fig. 2, already discussed. At such stations the ON twin-channel carriers are suppressed.

Still another arrangement is used, shown as option 3, at intermediate stations in a TH protection switching section where one or more of the voice circuits must be terminated. Such a situation can exist at the ends of C1 alarm sections or at the ends of TD-2 switching sections. In this case, a low-pass filter is provided in the baseband circuit which blocks the four ON channels but allows TH protection switching signals to pass through. The ON carriers must be provided at such stations, and all voice circuits which require continuity through the station require voice-frequency connections.

Fig. 9 shows a photograph of the auxiliary channel terminal bay. A photograph of the radio transmitter-receiver units and a more complete description of the equipment design are given in Ref. 7.

IV. PERFORMANCE

The performance data discussed in the following paragraphs are based on field measurements of an eight-hop loop and on laboratory measurements of several prototype units.

4.1 *Transmission Gain*

Transmission gain, measured from the common input of two paralleled radio transmitters to the combined output of the corresponding receivers, is essentially constant between 20 kc and 200 kc. Field measurements showed the following results: 20 kc, -0.2 db; 50 kc, 0.0 db; 200 kc, -0.3 db.

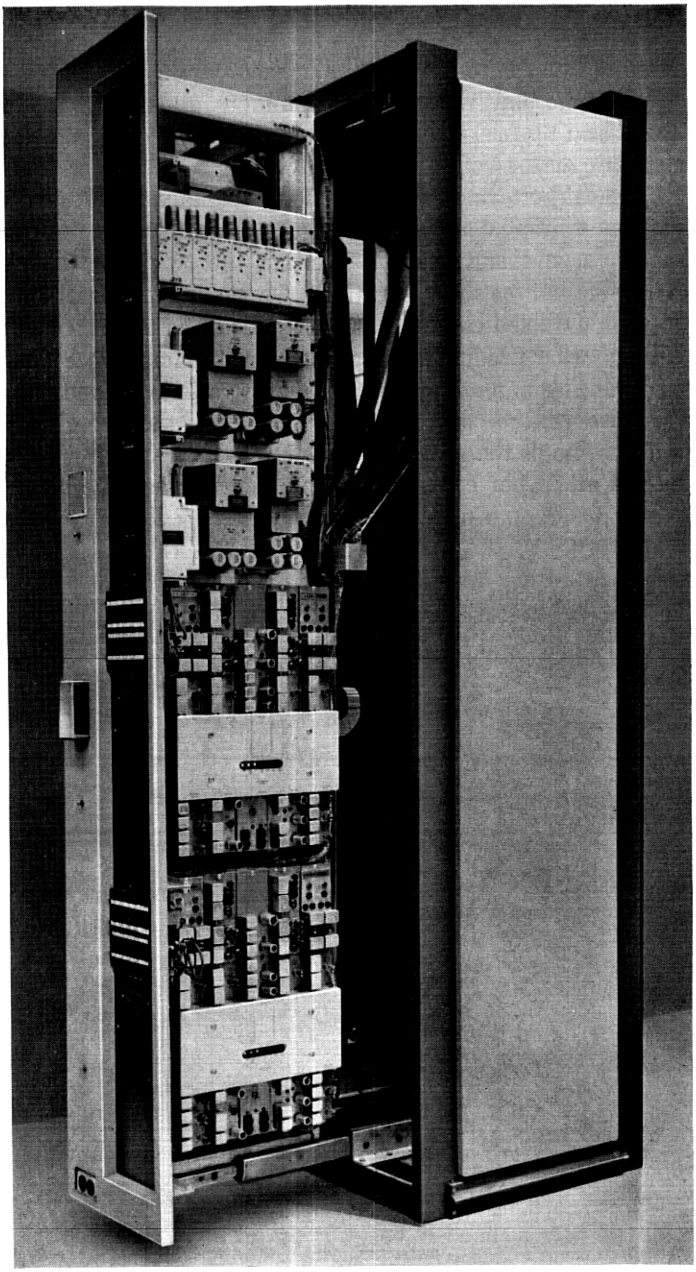

Fig. 9 — The auxiliary channel terminal bay.

4.2 *Modulation*

The modulation performance was measured in the laboratory by applying a 100-kc sine wave at the common input to two paralleled transmitters and by measuring the fundamental, second harmonic, and third harmonic at the combined output of the corresponding receivers. A plot of typical performance obtained in this manner is shown in Fig. 10. Of particular interest are the curves of second harmonic performance. The dashed curve corresponds to exciting the two radio channels in phase. The solid curves show the effect of reversing the baseband phase of one of the paralleled channels at both ends so as to get some cancellation of even-order products. As can be seen, the improvement is quite pronounced during nonfading periods. During a fade on one of the two channels, however, the baseband contributions of the two channels are unequal and some of the advantage is lost.

Field tests at 70 per cent modulation showed that the second har-

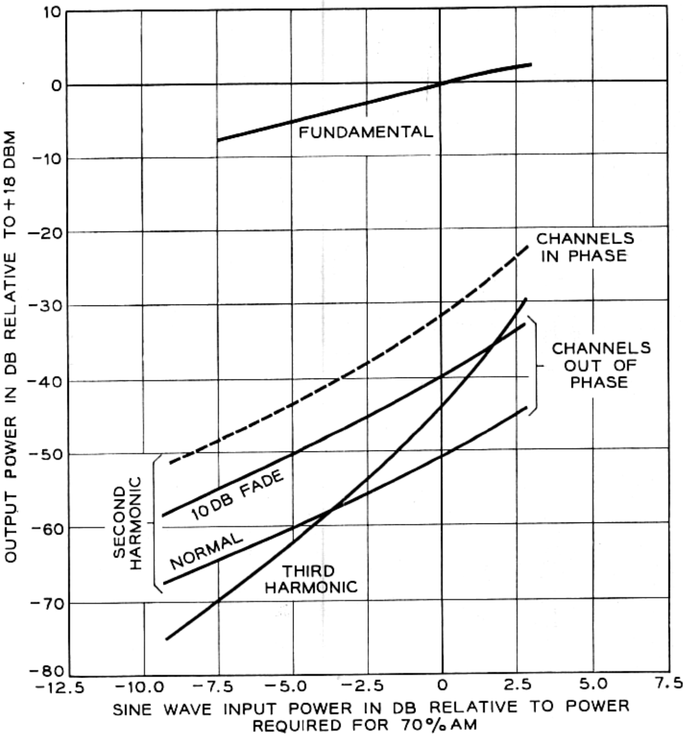

Fig. 10 — Typical modulation performance of a one-hop system.

monic power at the end of the eight-hop loop was 42 db below the fundamental and that the third harmonic was 34 db below the fundamental. The ratio of second harmonic to fundamental is well within system objectives; the objective for the ratio of third harmonic is 22 db.

4.3 *Fluctuation Noise*

Fluctuation noise in the baseband output depends on a number of factors, the most significant of which are transmitted power, receiver noise figure, and the radio path loss. The nominal transmitted power is −2 dbm, the receiver noise figure is 10 db, and the nominal loss from the transmitter output to the receiver input is 62 db. The fluctuation noise in a 3-kc band at combined output of the radio receivers is expected to be −44 dbm. Since this is a −2 db transmission level (TL) point, the noise would be −42 dbm or 40 dba at a 0-db TL point. At the end of 10 repeaters the noise would be 10 db greater or 50 dba. Thus, in the compandored voice circuits which have a subjective noise improvement of approximately 23 db, the apparent noise will be 27 dba at 0-db TL during nonfading periods.

The field data for the 8 hops gave noise power as −50 dbm in a 500-cps band at −8 db TL. This is −34 dbm in a 3-kc band at 0 db TL and agrees well with the expected value.

The bandwidth of the selective filters for the protection switching tones is approximately 400 cps. At 0-db TL the expected noise in this band is −41 dbm at the end of 10 repeaters. Since the tones have a power of −13 dbm at this point, the nominal signal-to-noise ratio for a protection switching tone is 28 db.

A statistical study based on fading and failure data which have been accumulated for the TD-2 system indicates that for the worst fading periods the performance will be somewhat poorer. However, for 90 per cent of the time during the midnight to 6 A.M. period during the worst three fading months, the expected performance will be degraded less than 4 db. For 99 per cent of the time during the same period the expected degradation is less than 7 db.

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