The TH Radio Microwave Carrier Supply System

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The TH microwave carrier supply system furnishes all of the carrier frequencies required at a radio repeater station. All the frequencies are harmonically derived from a common, highly stable, 14.82593-mc crystal oscillator, to avoid interference problems. Total reliance on a common generator of carriers for an entire station calls for a highly reliable and adequately protected carrier supply. To this end, a complete standby supply is arranged with fast automatic switching to replace the regular supply when needed. Special emphasis is placed on conservative circuit design, careful selection of components, adequate monitoring and trouble detection facilities, and provisions for routine maintenance.

I. INTRODUCTION

As described briefly in a preceding paper,[1] the common microwave carrier supply system supplies all the carrier frequencies (often called beat oscillator, or BO, frequencies) needed for a fully equipped repeater station. The major portion of the system is in three sliding-rack bays[2] which house regular and standby frequency generators, together with switching and control circuits. This equipment supplies four harmonically related frequencies (29.7 mc, 59.3 mc, 6301 mc and 6049 mc). Other parts of the carrier supply system are the carrier distribution networks which carry these frequencies as needed to the various transmitters and receivers, where carrier supply modulators[3] produce the specific frequencies desired.

Frequency stability and over-all reliability are prime objectives for the microwave carrier supply. Frequency stability is given by a crystal-controlled, thermistor-compensated oscillator with a long term stability of better than 10 ppm over operating temperatures of 40°F to 140°F. Reliability is obtained by the regular-standby arrangement. This requires various detectors, control circuits, and switches of a reliable nature to identify a failure quickly and replace the failed regular carrier supply with the operative standby supply. A failed regular supply is replaced by the working standby supply in about five milliseconds. Failures of the standby supply are alarmed; no switching results for this case. Various manually controlled switches are provided for maintenance work.

All of the power connections and test points are independent to prevent simultaneous failure of the regular and the standby supplies. Also, to the extent possible, the equipment layout is arranged to minimize accidental contact by maintenance personnel with a carrier supply which is actively connected to the distribution circuit.

II. BLOCK DIAGRAM

A simplified block diagram of the microwave carrier supply is shown in Fig. 1. The 14.8-mc signal from either the regular or the standby crystal oscillator feeds both the regular and the standby frequency generators through the low-frequency switching circuit. Both generators are supplied by the same oscillator to prevent beats which might be caused by a minute frequency difference between the two oscillators. This eases

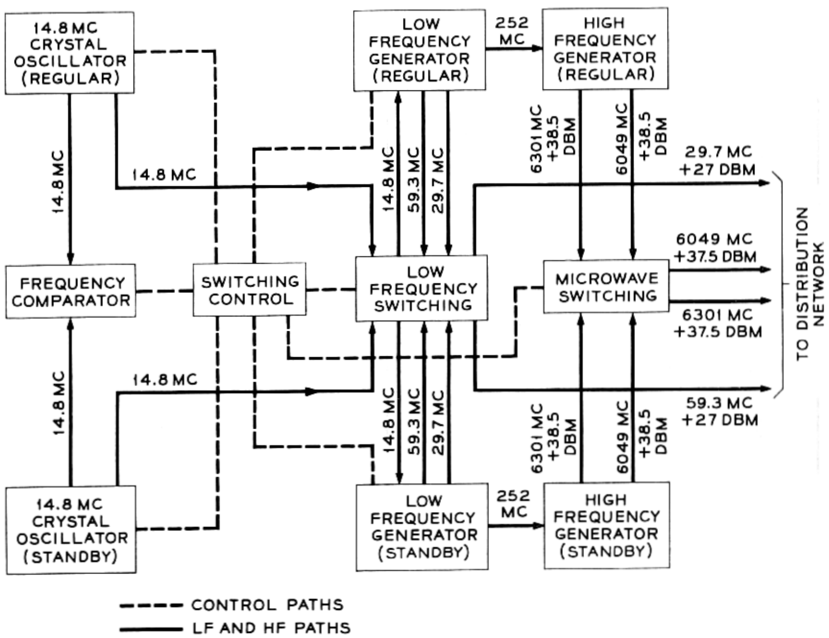

Fig. 1 — Simplified block diagram of the microwave carrier supply.

the isolation requirements on all the switches except those associated with the 14.8 mc. The low-frequency generator supplies the second harmonic (29.7 mc) and the fourth harmonic (59.3 mc) of 14.8 mc by successive frequency doubler circuits. A third output is the 17th harmonic (252 mc) which is supplied to the high-frequency generator. Here it is multiplied 24 times in three doublers and a tripler (cavity type multipliers). The resulting microwave frequency is the 408th harmonic (6049 mc). This in turn is added to the 17th harmonic to obtain the 425th harmonic (6301 mc) of the crystal oscillator frequency. Amplifiers are provided to obtain the required output powers of +27 dbm at 29.7 mc and 59.3 mc and of +37.5 dbm at 6049 mc and 6301 mc. The switching system normally connects the outputs of the regular frequency generators to the distribution system; if a failure or serious degradation of the regular equipment is detected, an automatic switch transfers operation completely to the standby equipment.

Of the three sliding-rack bays, the bay on the left contains the regular frequency generators and an identical bay on the right contains the standby generators. The middle bay contains the regular and standby 14.8-mc oscillators, the low-frequency switching circuits, and the switching control circuits. The microwave switching equipment is mounted across the top of the three bays. Regular and standby equipments are fed from independent ac power sources. Solid-state rectifiers are mounted on the racks to obtain the dc voltages for the individual circuits on that sliding rack.

2.1 *Distribution*

The carriers at 29.7 mc and 59.3 mc are each connected through coaxial cable to a narrow band-pass filter which suppresses other harmonics of 14.8 mc and then to a hybrid transformer tree. Each signal is divided four times to provide a total of 16 equal outputs at 29.7 mc and 12 equal outputs at 59.3 mc. These 28 outputs are connected through coaxial cable to the various broadband transmitters and receivers and to the auxiliary channel receiver circuits. The four auxiliary channel transmitters do not use either the 29.7-mc or the 59.3-mc carrier.[4] With a nominal input power of +27 dbm, the nominal power at the outputs is +13 dbm. This assumes 0.5-db insertion loss for each transformer and the 3-db loss due to equal power division in each transformer.

The carriers at 6049 mc and 6301 mc are subdivided by trees of waveguide power splitting junctions, as shown in Fig. 2. These junctions provide an equal division of power between the two output ports 2 and 3, when a signal is connected to the input port, 1. Each microwave signal is divided to provide a total of 8 equal outputs for broadband transmitter bays, 4 equal outputs for broadband receiver bays, and 8 equal outputs for the auxiliary channel transmitters and receivers. The outputs to the broadband channels are further split locally, once on the transmitter bays and twice on the receiver bays, to furnish a total of 32 equal outputs for the broadband transmitters and receivers. Connection to the broadband channel bays is made through waveguide and to the auxiliary channel bays through coaxial cable. Alternate stations on a TH route interchange 6301 mc and 6049 mc between transmitters and receivers as shown by the X and Y alternatives of Fig. 2.

With a nominal input power to the distribution system at 6049 mc and 6301 mc of +37.5 dbm, the nominal output power delivered to a

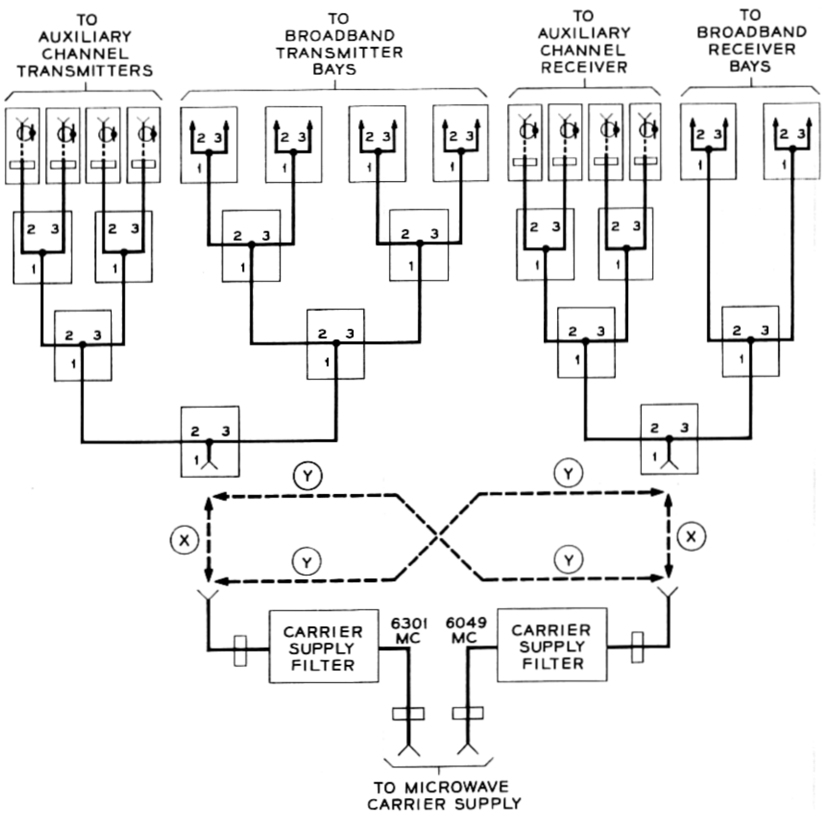

Fig. 2 — Block diagram of distribution circuits for the high-frequency microwave carrier supply.

broadband transmitter or receiver is +20 dbm and the nominal output power for the auxiliary channel equipment is +26.3 dbm. This assumes 0.2-db insertion loss for the junctions, 1.5-db insertion loss for the band-pass filters, and 0.1-db insertion loss for the transducers plus the 3-db loss due to the equal power division of the junctions.

III. 14.8-MC OSCILLATOR

This circuit, shown in block form in Fig. 3, uses two 404A pentodes, the first as a crystal-controlled oscillator and the second as a buffer amplifier. The modified Pierce oscillator circuit operates the crystal on its third overtone. Temperature compensation of the crystal may be provided, depending on temperature testing of the individual crystal. This compensation keeps the operating frequency within limits of ±148 cycles over a temperature range of 10° to 60°C. A variable inductor in the plate circuit is used as a vernier frequency adjustment to set the output within a few cycles of a standard frequency source of 14.82593

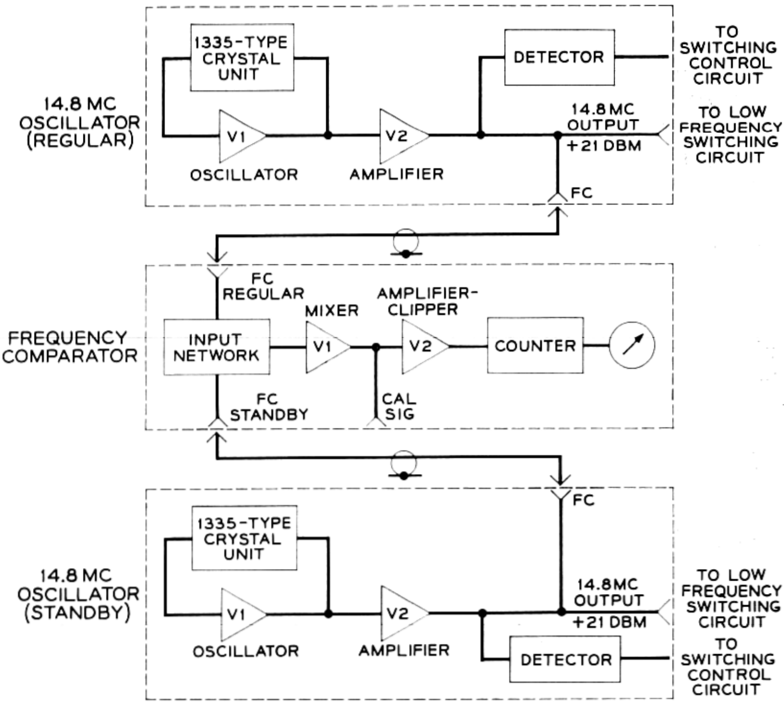

Fig. 3 — Block diagram of the 14.8-mc supply circuit.

mc. This inductor also prevents the crystal from oscillating at its fundamental frequency.

The second stage (v2) is a class B amplifier with its output circuit tuned by a variable capacitor to the input frequency. The output coupling network is essentially a pi-type matching network between the plate circuit of v2 and a 75-ohm output jack. Portions of the output are capacitively coupled to the frequency comparator and to a peak detector circuit. The latter furnishes a dc control signal to the switching control circuit. The coupling capacitor associated with the detector circuit is variable to allow the dc output of the detector to be set at the required level.

The output signal power is adjustable over a range of approximately 9 db by means of a potentiometer in the cathode circuit of the amplifier stage. Nominal output is adjusted to +21 dbm.

IV. FREQUENCY COMPARATOR CIRCUIT*

The two 14.8-mc oscillators are in continuous operation, and by comparing these two frequencies, relative changes in frequency can be detected. The frequency comparator does this and also provides a means of comparing either oscillator to a standard frequency. Both aural and visual monitors of the difference frequency are provided, and an alarm is issued if the difference exceeds 150 cps.

The building blocks of the frequency comparator are the input network, mixer, amplifier-clipper, and counter circuit as shown in Fig. 3. A simplified schematic is shown in Fig. 4.

The position of the frequency comparator is literally between the two 14.8-mc oscillators in both the mechanical and electrical sense. Thus, it could provide a cross coupling path between the two oscillators. To obtain the required coupling loss, a hybrid transformer is used which provides 40 db of isolation, and a 20-db pad is in series with each input signal. This provides a total of approximately 80-db loss between the oscillators.

The two input signals are combined in the hybrid transformer and are applied to the grid of v1, a 404A pentode, producing the sum and difference frequencies in its plate circuit. The plate load of v1 has a low-pass filter characteristic so that only the difference frequency appears at the input of v2-A. This is half of a 396A dual triode operating as a class A voltage amplifier. The amplified sinusoidal signal is coupled to v2-B, where it is converted into a rectangular wave by combined grid-

* This section was written by A. F. Perks.

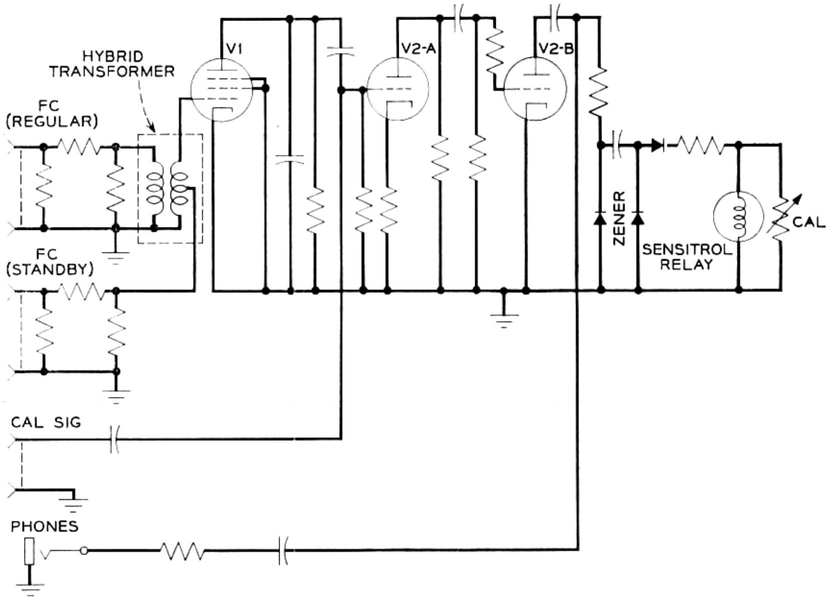

Fig. 4 — Simplified schematic of the frequency comparator.

circuit and plate current cutoff clipping. A voltage reference diode in the plate circuit of V2-B gives additional clipping and reduces any variations in voltage level due to tube aging.

The counter circuit converts the rectangular signal from V2-B into a train of rectified current pulses whose shape is independent of the frequency as long as the time constant of the counter circuit is much smaller than the period of the signal. The pulse train is used to deflect a 50-microampere Sensitrol relay. The average current through the winding, therefore, increases linearly with the repetition rate of the incoming rectangular signal.

The counter circuit is calibrated by inserting a 60-cps signal at CAL SIG and adjusting the potentiometer for a meter reading of 20 μa. A change of 1 μa in the meter reading will then correspond to a change of 3 cps in the difference frequency. Thus, for a difference frequency of 150 cps, the current will be 50 μa, at which time the Sensitrol relay contacts will make and an alarm will be initiated.

V. LOW-FREQUENCY GENERATOR

A block diagram of this circuit is shown in Fig. 5. With the exception of the last three stages, V8-V10, it uses 404A pentodes. The 14.8-mc in-

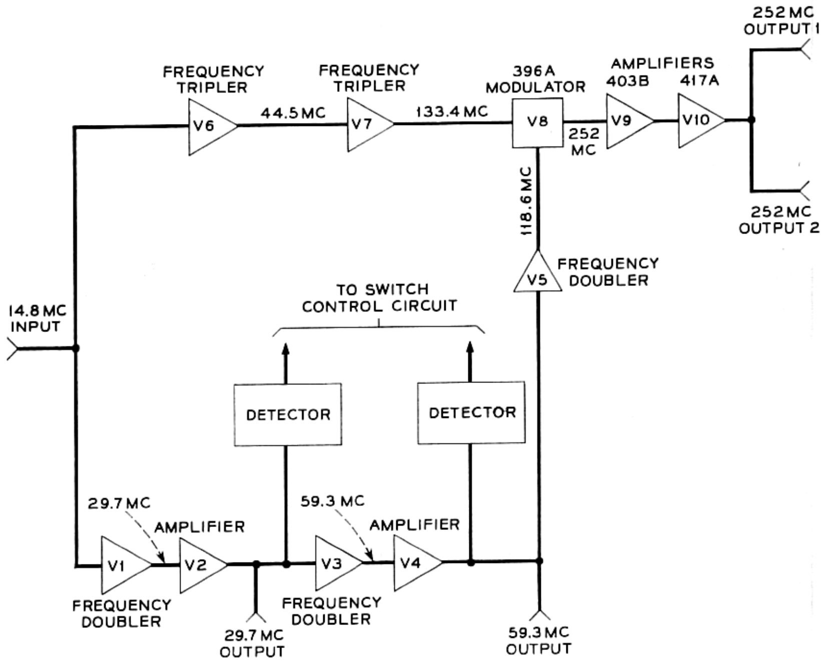

Fig. 5 — Block diagram of the low-frequency generator.

put signal at approximately +17 dbm is connected to two circuits, one a chain of three frequency doublers and two amplifier stages, and the other a chain of two frequency tripler stages. The outputs of the first and second doublers are amplified to provide the signals at 29.7 mc and 59.3 mc. The outputs of the third doubler and second tripler are fed to a balanced modulator whose output is tuned to 252 mc. The 252-mc signal is further amplified to provide the third output signal of the low-frequency generator.

For the most part, the circuits are fairly conventional. The power amplifiers, v2 and v4, provide a maximum output into a 75-ohm load of +31 dbm. Input signals for these stages are coupled from the preceding doublers through diode limiters, which maintain a constant input level and hence a constant output power for relatively large variations in signal level at the plate of the preceding stage. The output power is adjustable over a range of approximately 8 db with a nominal value of +28.5 dbm. A portion of the output is capacitively coupled to a peak detector circuit which furnishes a dc control signal to the switching control circuit. The coupling capacitor is variable to allow the dc output of the detector to be set at the required level.

The modulator stage (V8) uses a 396A twin-triode in a balanced modulator type circuit. The balanced secondary of the input transformer is tuned by a variable split-stator capacitor to the output frequency of V5 (118.6 mc). An analysis of the modulator, assuming a square-law characteristic, shows that the output circuit contains only sum and difference products. Even harmonics of both input signals tend to be cancelled by about 20 db, depending on the degree of balance of the two sections of the tube and on the balance in the input and output transformers. Both the balanced primary and the secondary of the output transformer are tuned to the sum frequency (252 mc). The difference frequency is far enough removed that no special filtering is needed. The secondary is capacitively coupled to the grid of the following stage.

A 403B pentode (V9) is used as an amplifier between the modulator stage and the final amplifier. Most of the tube bias voltage is developed across the grid resistor. A small cathode resistance provides the remainder of the bias and limits the plate current under zero signal condition to a safe value. This method of obtaining tube bias provides an output signal that is relatively independent of variations in the input signal level over a moderate range.

The final amplifier (V10) uses a 417A triode in a grounded-grid circuit. Signal from V9 is capacitively coupled to the cathode circuit. The output, nominally +22 dbm into 75 ohms, supplies the 252-mc shift modulator in the HF generator. A portion of this output is capacitively coupled to a 50-ohm coaxial line, to feed the high-frequency multiplier chain. Both outputs are controlled by a variable resistor in the cathode circuit of V10. The output at the 50-ohm jack may be adjusted independently over a limited range by a variable capacitor.

VI. HIGH-FREQUENCY GENERATOR

A block diagram is shown in Fig. 6. The 252-mc input passes through a narrow band (about 500 kc wide) cavity-type filter to a chain of harmonic generators, HG1 to HG4. Fig. 7 is a photograph of these. All harmonic generators are frequency multipliers using a 416-type planar triode mounted in a grounded-grid circuit.

The input of HG1 is fixed tuned. The output is a coaxial section of fixed length and is tuned by an adjustable screw plunger which acts as a variable capacitance between the plate of V1 and ground.

The coaxial output of HG1 is connected to the input of HG2, which is fixed tuned. The coaxial output section is tuned to 1512 mc by a movable quarterwave coaxial transformer. The combination of this section and two fixed quarter-wave sections provides an impedance transformation between the plate of V2 and the coaxial output cable.

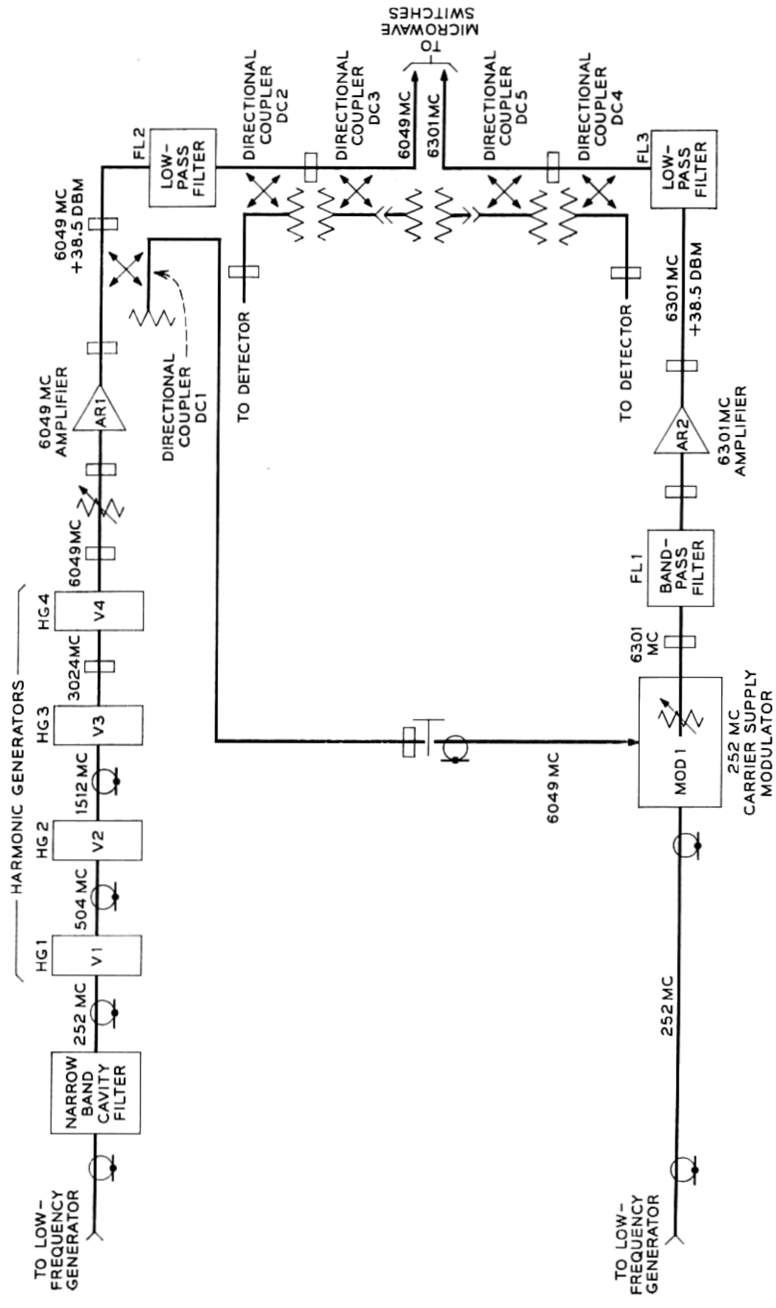

Fig. 6 — Block diagram of the high-frequency generator.

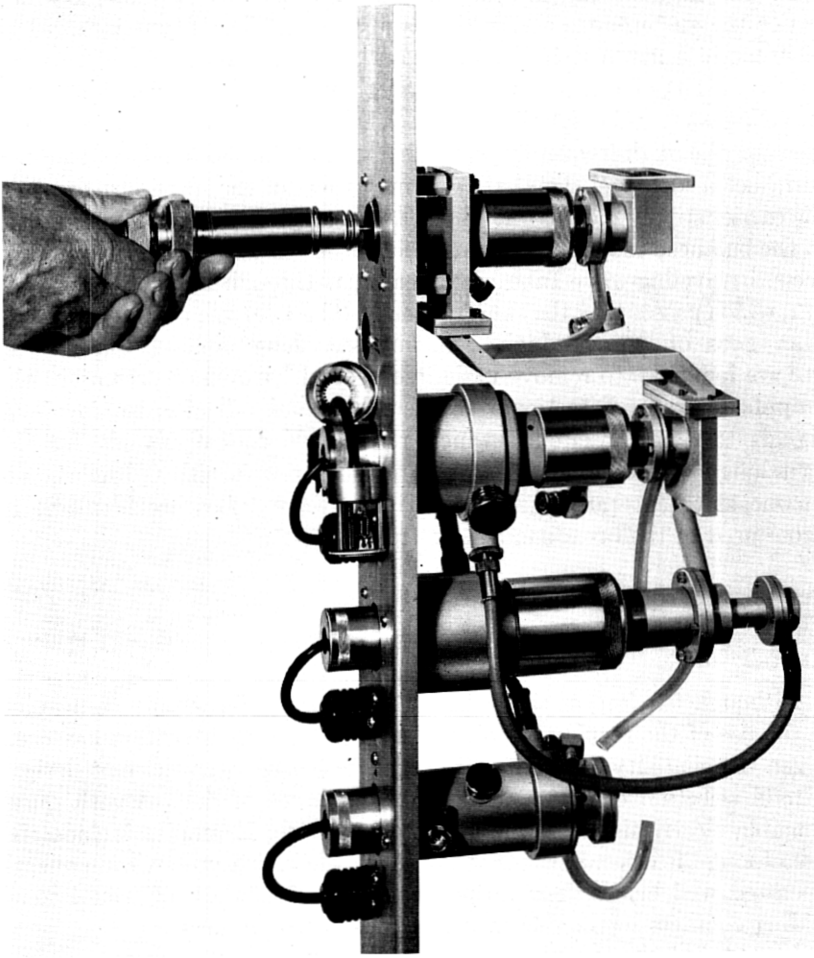

Fig. 7 — Chain of harmonic generators used in the high-frequency generator.

The coaxial input of HG3 is tuned to 1512 mc by an adjustable screw plunger which acts as a variable capacitance between the inner and outer conductors of the coaxial input section. The output section is coaxially tuned as in HG2 to 3024 mc. However, the output is waveguide-coupled to the last harmonic generator (HG4) through a coaxial-to-waveguide transducer, which is an integral part of the cavity structure.

The input signal to HG4 at 3024 mc is coupled to the cathode by an iris and a cylindrical cavity which surrounds the grid and cathode terminals. The input circuit is tuned by an adjustable screw plunger which varies the susceptance across the cavity walls. The output is tuned to 6049 mc in a manner similar to the output tuning for HG2.

The output of HG4 is coupled through waveguide to the input of a traveling-wave tube amplifier, AR1. The main output at +38.5 dbm goes to the high-frequency switching circuit. Directional coupler DC1 furnishes a low-level signal at 6049 mc as one of the inputs to the 252-mc carrier supply modulator. The 6049-mc and 252-mc signals are mixed in the balanced modulator, and the output is connected to the input of a second traveling-wave tube amplifier, AR2, through a band-pass filter, FL1, which passes only the sum frequency. The 6301 mc output at +38.5 dbm goes on to the high-frequency switching circuit. Filters FL2, FL3 are low pass, to remove undesired second harmonics present in the amplified signal. Directional couplers, DC2 and DC4, furnish low-level signals to detector circuits which provide dc control signals for the switching control circuit. Couplers DC3 and DC5 furnish 0-dbm signals for measurement purposes. The traveling-wave tubes are identical to those used in the broadband radio transmitter.[3]

VII. SWITCHING AND CONTROL

7.1 *Reliability*

Although the largest single factor assuring carrier supply continuity is the use of the regular-standby arrangement, great attention has been given to reliability in the detail design, by conservative circuit design, careful selection of components, and avoidance of devices with questionable electrical and mechanical performance. Examples include the use of long-life electron tubes at low levels of driving power, components operated well below their ratings, and the elimination of troublesome sliding contacts in tunable microwave cavity structures.

In addition, diode limiters are used to reduce changes in output amplitude level during normal tube aging. Routine maintenance will normally detect aged tubes before any resulting degradation is noted. All of the active circuits in the carrier supply are in tandem. A sudden failure of any one of these circuits along the frequency multiplier chains is detected at the 6301-mc output and initiates a fast switch. Additional detectors are located along the chains, as noted in the previous paragraphs, to assure that slow-level degradations will be detected and that appropriate switching action will result. These detectors control slow-acting Sensitrol relays.

Most of the components in the switching circuits themselves are reliable passive devices to insure low failure rates in the common output circuitry. The control circuits that operate the switches are also designed with long-life components which function at conservative operating limits. Manual switching controls permit routine maintenance without permanent loss of carrier. The switching circuits and their control circuits can also be maintained without loss of carrier.

7.2 *Low-Frequency Switching*

The low-frequency switching circuit is shown in much simplified form in Fig. 8. Terminations, crosstalk suppression paths, test points and monitor circuits are not shown. All leads are coaxial. The coaxial switches (223 type), controlled by the switching control circuit, are either all in the energized state when furnishing signals from the regular oscillator and low-frequency generator, or all in the de-energized state when furnishing signals from the standby equipment. The 29.7-mc and 59.3-mc outputs of the switching circuit are monitored to provide alarm information only. The transformer-switch arrangement shown allows a switch removal without totally disabling that carrier supply output. Test points are included on the transformers for in-service continuity testing.

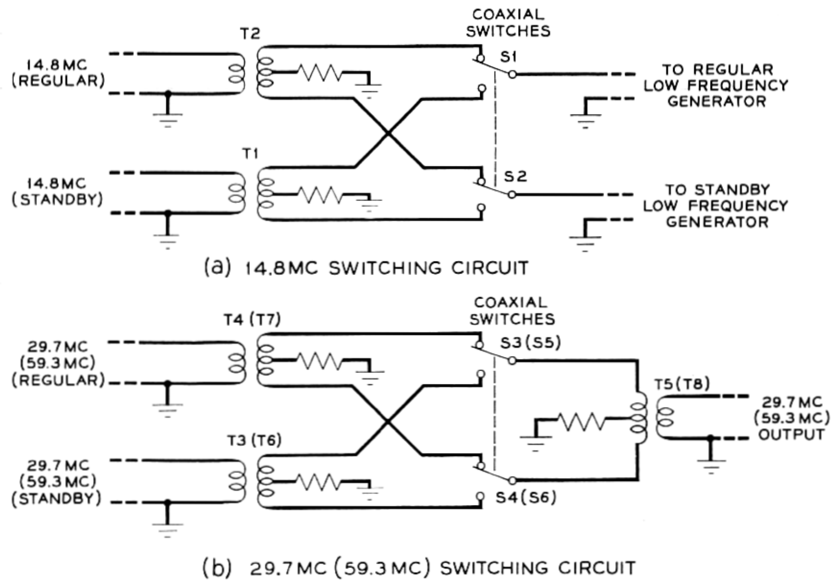

Fig. 8 — Simplified schematic of the low-frequency switching circuit.

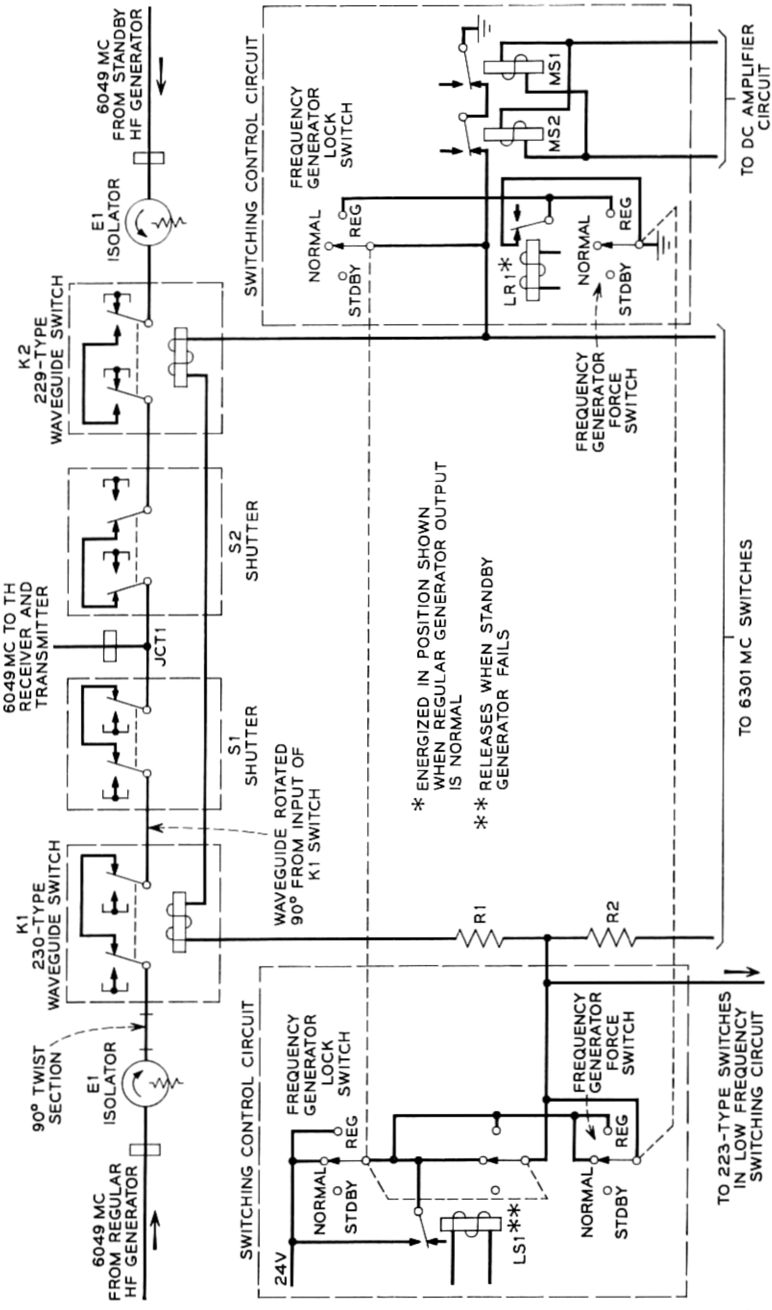

Fig. 9 — Simplified schematic for the high-frequency microwave switching circuit.

7.3 *Microwave Switching*

A simplified schematic of the microwave switching circuit is shown in Fig. 9. The microwave outputs of 6049 mc and 6301 mc are connected to the distribution circuit through ferrite-loaded microwave switches. Fig. 10 shows the polarization of the 6049-mc or the 6301-mc wave for the magnetized and unmagnetized conditions of one type of ferrite waveguide switch. The input and output rectangular waveguides are orientated to accept the polarization of the wave when the magnetic field is ON and to reflect the wave when the magnetic field is OFF. Another type of switch is identical except that the input and output waveguides are orientated to transmit the wave when the magnetic field is OFF and to reflect the wave when the magnetic field is ON.

The switches that transmit the signal when magnetized are connected to the 6049-mc and 6301-mc outputs of the regular high-frequency generator. The switches that reflect the signal when magnetized are connected to the outputs of the standby generator. The ferrite switch outputs are connected through a junction to the distribution network.

To provide fail-safe operation, the switch coils are connected in series as shown in Fig. 9 and are normally in the energized state. For this condition the regular generator supplies the distribution system, and the switches connected to the standby generator reflect the energy for

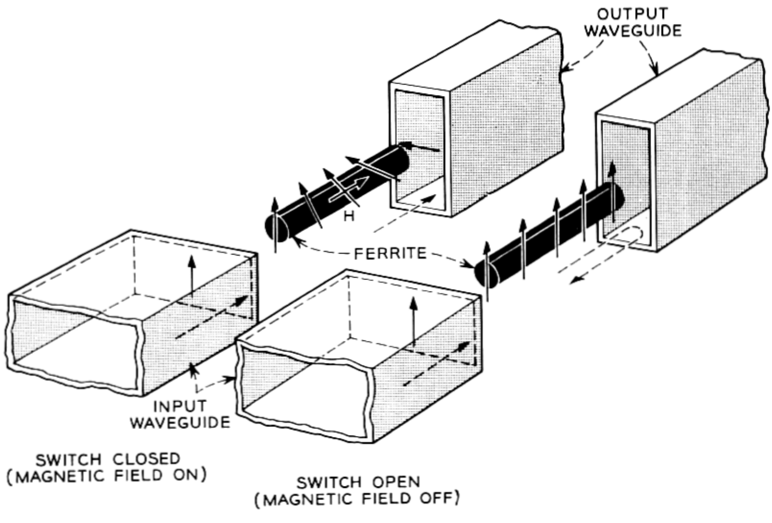

Fig. 10 — Diagram of a normally reflecting ferrite waveguide switch, showing polarization for the magnetized and unmagnetized conditions.

dissipation in isolators. For standby operation the coils of the switches are de-energized and the roles of the regular and standby switches are interchanged.

Manually operated shorting gates (shutters) are provided between the ferrite switches and the junction. Manual control switches (not shown on Fig. 9) which by-pass the coils of the normally transmitting ferrite switches are provided to facilitate removal of a ferrite switch under operating conditions. Automatic and manual control of the high-frequency switching circuit is performed by the switching control circuit.

7.4 *Switching Control*

A functional diagram of the switching control is shown in Fig. 11. Sudden equipment failures of the regular supply are detected at the 6301-mc output of the regular high-frequency generator. When this signal level drops approximately 4.5 db below the nominal value, the dc amplifier releases the 291-type buffer relays, which in turn release the coaxial relays in the low-frequency switching circuit and the microwave switches in the high-frequency switching circuit. The distribution circuit is now connected to the standby supply. Release of any one of the

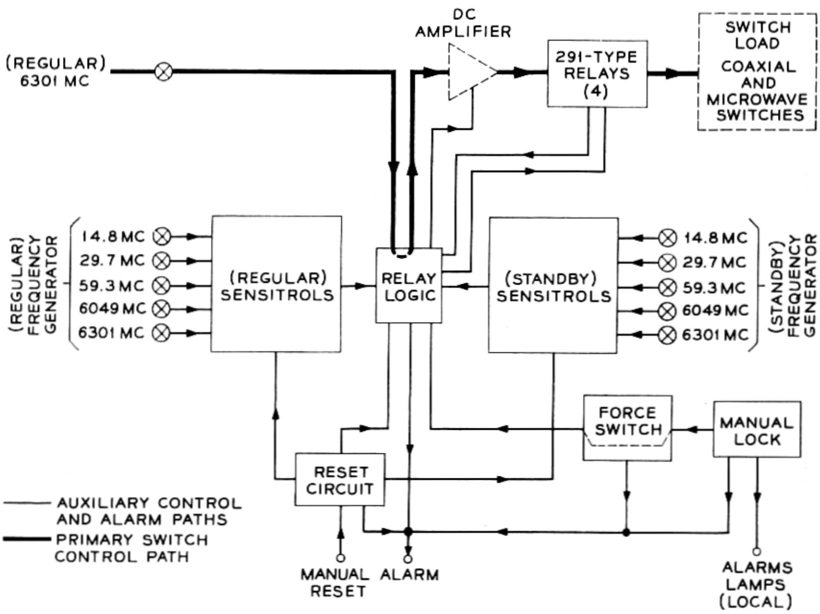

Fig. 11 — Functional diagram of the switching control.

Sensitrol relays connected to detectors at other points in the regular generator chain operates a relay which opens the dc amplifier input, causing a switch to the standby supply as before.

A magnetic amplifier, operating as a bistable switch, is the principal component of the dc amplifier. Its power source operates at approximately 20 kc to provide the required response time. The magnetic amplifier transfer characteristic is shown in Fig. 12. The power supply for the magnetic amplifier is a transistor inverter circuit consisting of a multiwinding transformer and two transistors. Failures of the magnetic amplifier, the inverter, or the power supplies associated with the dc amplifier result in a switch to the standby carrier supply.

The control circuits and switches are operated in a "fail-safe" manner; that is, failure in the control circuits or switches or loss of power to these devices will result in a switch to the standby supply.

The control circuit also energizes alarms and inhibits the operation of a manual switch to a failed supply. A forced switch is provided in the event a switch must be made to the "failed" supply. To prevent accidental forced switches, the forced switch operation involves the manual closure of two keys.

A lock-out circuit is provided to prevent the switching circuits from nigh-speed hunting when the switch is initiated by the 6301-mc monitor. The lock-out circuit short circuits the dc amplifier input once the dc amplifier has switched OFF, establishing a permanent switch to the

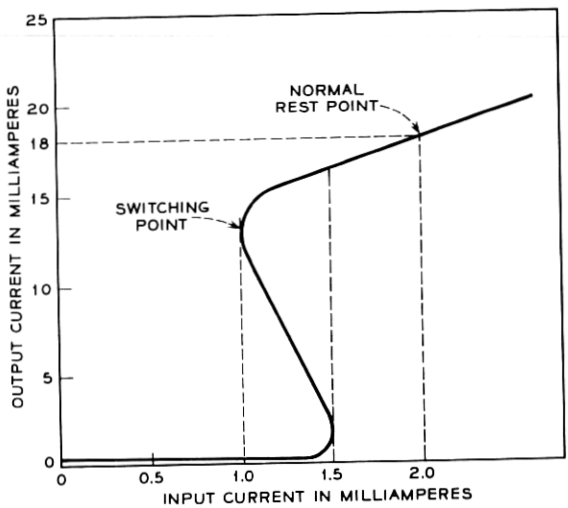

Fig. 12 — Typical transfer characteristic of the magnetic amplifier

standby generator. The lock-out is removed only after successful reset of the Sensitrol relays associated with the regular generator.

A reset operation is required to restore the regular supply connections to the distribution network. The reset may be accomplished manually or by remote control over the auxiliary channel facilities. The reset circuit consists of gas-tube timers and relays to reset the Sensitrol relays and to verify that the regular supply is operative before the switches are reset. The decision to permit a reset is based on information from the level detectors that connect to the regular Sensitrol relays, not by the ON switching point of the dc amplifier.

Detectors along the standby multiplier chain connect to the standby Sensitrol relays, which operate at level drops of approximately 4.5 db below nominal power output. Operation of a standby Sensitrol relay initiates alarms and prevents a manual lock to the standby generator. Manual locks can be performed only if the generator to which the lock is to be made is operative. However, once a successful lock is performed, the microwave carrier supply remains connected to that generator until the manual switch is cleared, regardless of the condition of that generator.

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