PROJECT ECHO

960-mc, 10-kw Transmitter

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The 10-kw transmitter operating at 960 to 961 mc which was used at the eastern terminus of Project Echo is described. This transmitter is located on Crawford Hill near Holmdel, New Jersey. The 10-kw output feeds into a waveguide line leading to a 60-foot dish antenna. Exciter-driver units are available to drive the power amplifier with various modulations, such as wide-deviation FM, low-index phase modulation, single-sideband or double-sideband modulation with or without carrier, 960.05 or 961.05 mc constant-frequency cw and radar on-off pulses at 961.05 mc. The main output amplifier consists primarily of a four-stage, externally-tuned-cavity, water-cooled klystron operating at a beam voltage of 16 to 18 kv.

The transmitter has been operated during many Moonbounce, tropospheric scatter, and Echo I tests with very satisfactory results.

I. GENERAL INTRODUCTION

This paper describes the 960 mc, 10-kw output radio transmitter used in Project Echo.* The main transmitter unit and its input stage driver unit are standard commercial equipments supplied by the Federal Telecommunication Laboratory.† These units were selected from a number of those available, since they came closest to our particular requirements for wideband FM transmission.

These general requirements were that the transmitter could (a) deliver 10 kw of RF power into a 50-ohm load at a frequency of about 960 ± 2 mc; (b) be frequency-modulated over the audio frequency band with deviations of ±200 to 300 kc; and (c) be used with other types of modulation such as single-sideband (SSB), double-sideband (DSB), interrup-

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* Although this equipment was designed by the Bell System as part of its research and development program, it was operated in connection with Project Echo under Contract NASW-110 for the National Aeronautics and Space Administration.

† Division of International Telephone and Telegraph Corporation.

ted continuous wave (ICW), etc. The transmitter has performed satisfactorily for all required tests.

The main radio amplifier consists of a four-stage klystron (Eimac 4K-50,000 LQ) having external tunable cavities and operates at beam voltages of 16 to 18 kv. The necessary power supplies, cooling system, and control units are also incorporated as part of the transmitter.

The driving stage amplifier is capable of delivering up to 10 watts, but for normal 10-kw klystron output less than one-half watt is required; i.e., the klystron has a power gain of 40 to 50 db.

The modulating units have an output of about one watt at a frequency of 70 mc and feed into a mixer which is also driven by an 890.05-mc cw signal of the proper level. This latter frequency originates in a crystal controlled oscillator at 49+ mc and is stepped up to the desired value by an 18-times frequency multiplier. The final output frequency is the sum of the 890.05 and the 70-mc modulated frequencies, or 960.05 mc.

The transmitter with all the necessary controls, power supplies, cooling system, driver units, measuring equipment, and recorders is housed in a metal building that has 16 by 26 feet of floor space and a 10-foot ceiling. This building is located at the base of the 60-foot-diameter Kennedy dish antenna (see Fig. 1). A control panel for manual operation and orientation of the dish antenna is also included in this building.

II. THE POWER AMPLIFIER

The 10-kw power amplifier, as previously mentioned, consists primarily of the water- and air-cooled klystron. With its control circuits and power supplies it is contained in a three-compartment metal cabinet 152 inches long, 37 inches deep, and 85 inches tall. The heat exchanger, used for klystron cooling, is about the same height and depth and is 56 inches long; this is placed along the rear wall of the building and not in line with the transmitter proper. Figs. 2 and 3 show the general arrangement of equipment.

A liquid-cooled dummy load consisting of a 6-foot length of $3\frac{1}{8}$-inch 50-ohm coaxial line is provided for output power calibration and measurement. The RF power is dissipated directly in the coolant liquid, and by calorimetric measurement of temperature rise and flow rate, the power may be calculated. The coolant liquid used is a 50 per cent water and ethylene-glycol mixture for protection from freezing when the transmitter is not in use. The same coolant liquid and heat exchanger is used for both the dummy load and klystron closed circulation system.

The power amplifier output terminates in a $3\frac{1}{8}$-inch coaxial line, coupled to the fourth-stage cavity of the klystron. The klystron output

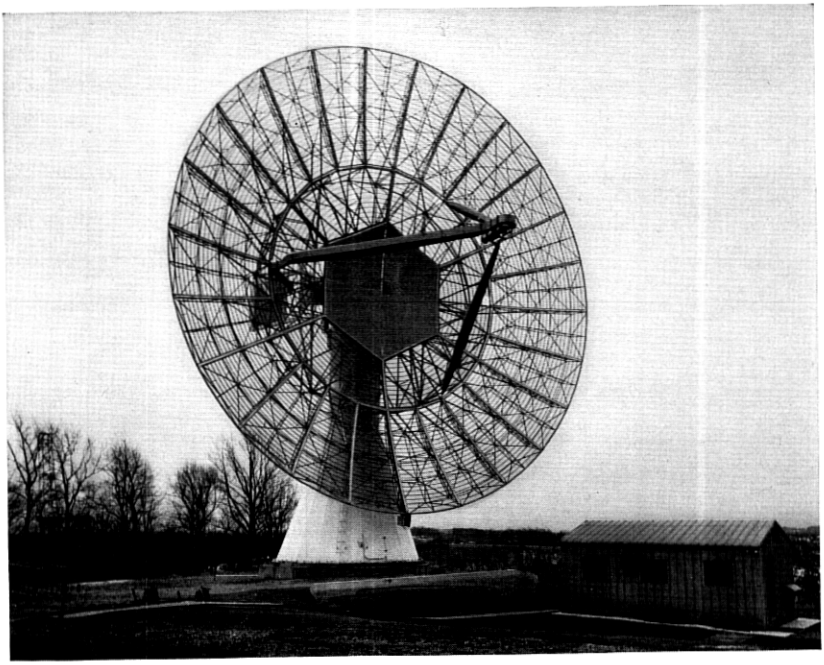

Fig. 1 — Transmitter building and Kennedy dish antenna at Crawford Hill.

may be connected either to the dummy load or to the line feeding the antenna. A coaxial-to-waveguide transducer with pressure seal is used to convert from the coaxial output to the $4\frac{7}{8}$- by $9\frac{3}{4}$-inch rectangular waveguide going to the 60-foot dish antenna. The waveguide line is kept under about one-half pound pressure of dry nitrogen to prevent moisture leakage.

Circuits and meters are provided for continuously monitoring the incident and reflected RF power at both input and output of the power amplifier. The actual transmitted power is continuously recorded with an Esterline-Angus pen recorder.

The high-power klystron is capable of dissipating the total beam power in its collector (about 35 kw), and can therefore be safely operated without RF power drive. This makes it feasible to gate the driver stage, as is done for radar pulse or SSB transmission. Two high-voltage rectifiers are provided. One supplies 2000 volts at 0.7 ampere for the klystron bombarder and the other supplies 18 kv at 2.0 amperes for the klystron beam circuit. The beam voltage may be continuously varied from 12 to 18 kv. The primary power requirement of the transmitter, including

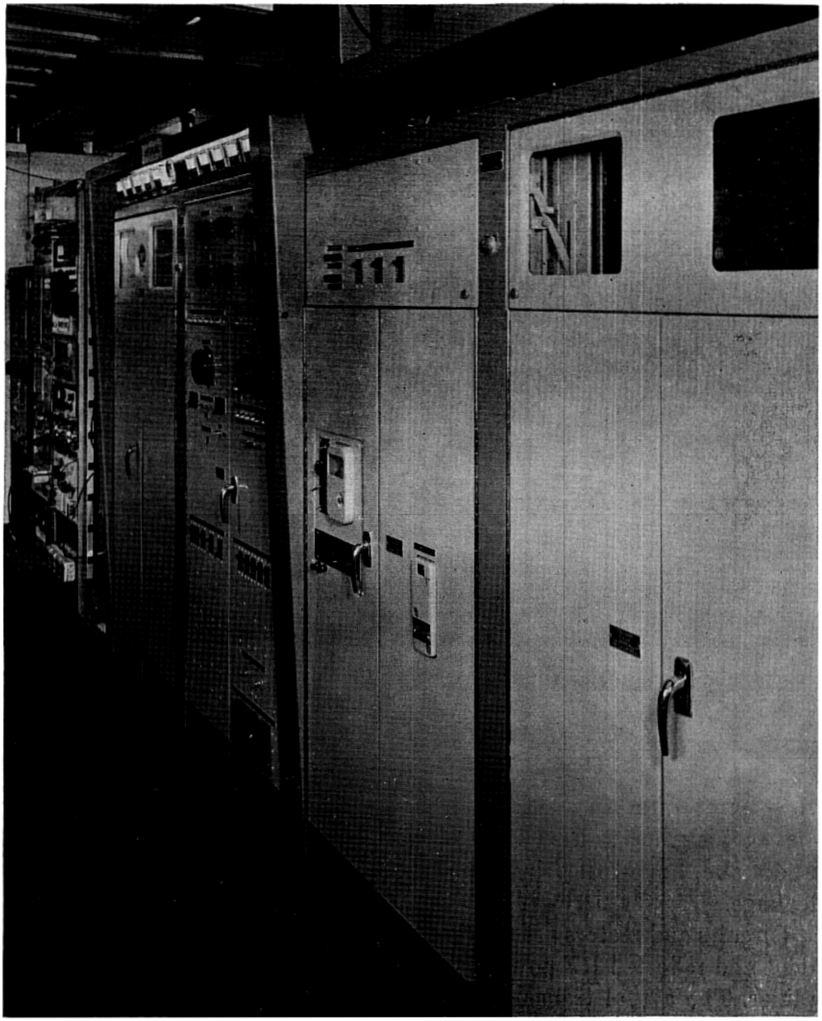

Fig. 2 — Front view of complete transmitter, showing FM driver unit, control and monitor panel, measuring equipment, and antenna manual control.

the heat exchanger, is about 50 kw maximum, three-phase, four-wire, 208 volts.

III. DRIVER MODULATION UNITS

Various types of exciter-modulator units have been provided to drive the power amplifier, as is shown in Fig. 4. They all generate a signal at

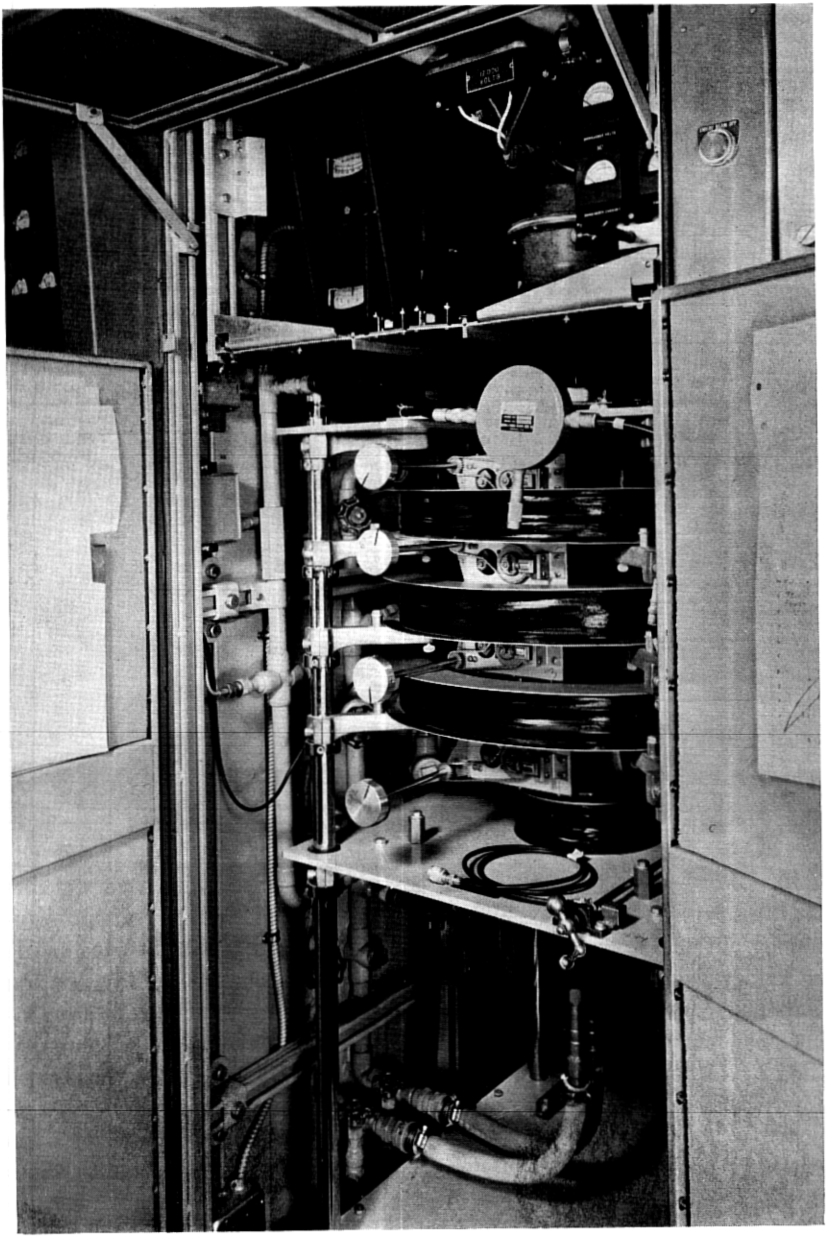

Fig. 3 — 10-kw klystron in cabinet.

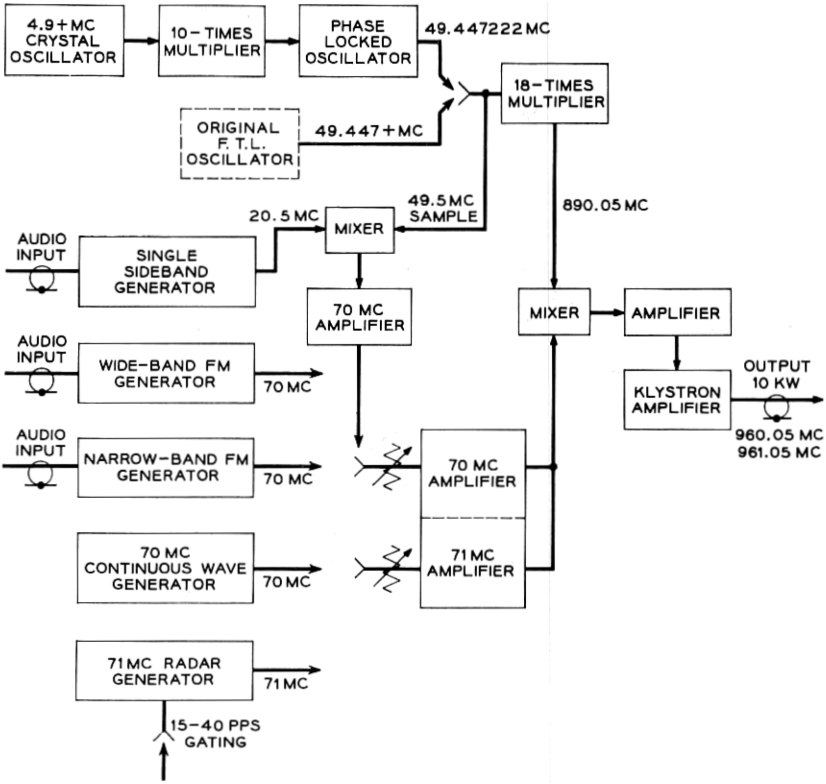

Fig. 4 — Over-all block diagram of transmitter.

about 70 mc, either cw or modulated, which is mixed with a very stable and accurate frequency of 890.05 mc to produce the final output frequency of 960.05 mc (961.05 for radar). Fig. 5 is a block diagram of the frequency generation and mixer-amplifier arrangement; it may be seen that the frequency stability of the output frequency is primarily dependent upon the crystal supplying the 49.44+ mc output, which is multiplied by 18 to give the 890.05-mc mixer signal. The crystal and oven in the original equipment did not meet our requirement, and they were replaced by a high-stability Western Electric crystal oscillator and oven assembly operating at 4.944+ mc. This was followed by a ten-times multiplier arrangement to give the desired 49.44+ mc frequency. In order to remove residual FM noise from the oscillator-multiplier output frequency, a phase-lock oscillator was interposed between the ten-times multiplier and the driving point of the three-times multiplier. W. W.

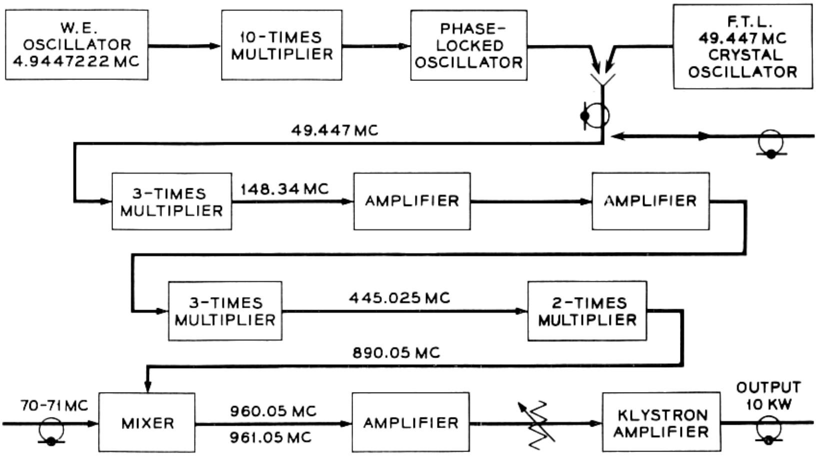

Fig. 5 — Block diagram of crystal generator and multiplier, showing mixer-amplifier arrangement.

Rigrod and A. J. Rustako of Bell Laboratories were responsible for the design and procurement of the improved crystal control system as well as for the addition of the SSB exciter equipment described below. The 890.05 mc frequency is now stable to about two parts in 10^9. This new arrangement is an integral part of the driver circuit for all types of modulation, which are all added to the mixer at the 70-mc frequency level.

3.1 *Wide-Deviation FM Modulator*

This is an FM modulator-exciter provided by Federal Telecommunication Laboratory (Model NUS 3315.3) and is the basic one for the Echo tests. This unit is capable of producing an FM driving signal with deviations of ±300 kc, for baseband frequencies from zero to 500 kc. Fig. 6 is a block diagram showing the arrangement of the FM generator circuits.

The wide-deviation FM exciter has operated satisfactorily in conjunction with the FM with feedback (FMFB) method of reception during the Echo tests. The actual deviation used was ±30 kc, as was determined by quality overload tests with the FMFB receiver,[1] using audio and voice frequency modulation.

3.2 *SSB Exciter*

This is also a commercial unit, Technical Materiel Corporation, Model SBE-3, referred to previously. Fig. 7 is a block diagram showing the

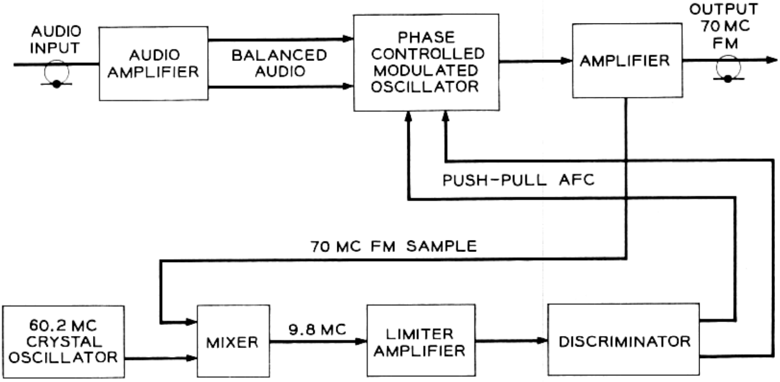

Fig. 6 — Block diagram of wide-deviation FM modulator.

general method of signal generation, and Fig. 8 is a photograph of the equipment. This unit can produce single- or double-sideband modulation with controlled amounts of carrier and has an audio bandwidth of 350 to 7500 cycles. Its output at a frequency of 20.55+ mc is mixed with a sample of the 49.447+ mc crystal-controlled output to give the 70 mc desired for introduction to the F.T.L. driver.

3.3 *Low-Index Phase Modulator*

This unit was built to use during comparison tests of various types of transmission and replaced one that was furnished for the original Moonbounce tests by the Jet Propulsion Laboratories. This new unit is much smaller and more compact than the JPL unit and, like all the driver units, has an output frequency of 70 mc. It is capable of producing phase modulation of at least one-half radian over the audio frequency voice band. It is crystal-controlled with a 35-mc crystal, and this frequency is doubled and phase-modulated in a buffer stage. Fig. 9 gives the principal circuit details.

3.4 *70- and 71-mc CW Units*

The crystal-controlled oscillators for these units were made by Bulova Watch Company. A buffer stage and amplifier were added to each oscillator output and provision made for controlling the pulse-gating of the 71-mc unit. These units were provided to produce a very stable frequency with a minimum of residual FM modulation, when used to drive the F.T.L. mixer, again producing 960.05 or 961.05 mc antenna power. The former frequency is used for constant frequency transmission during

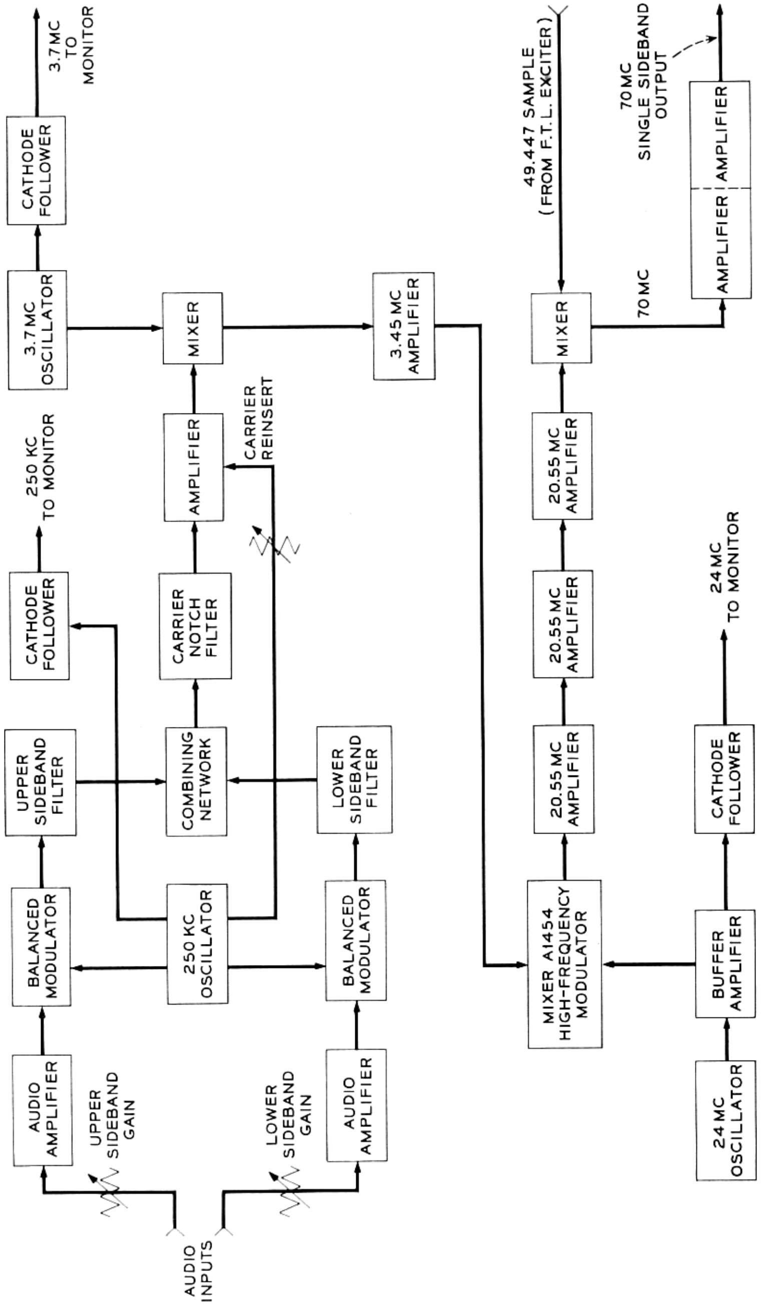

Fig. 7 — Block diagram of single-sideband modulator.

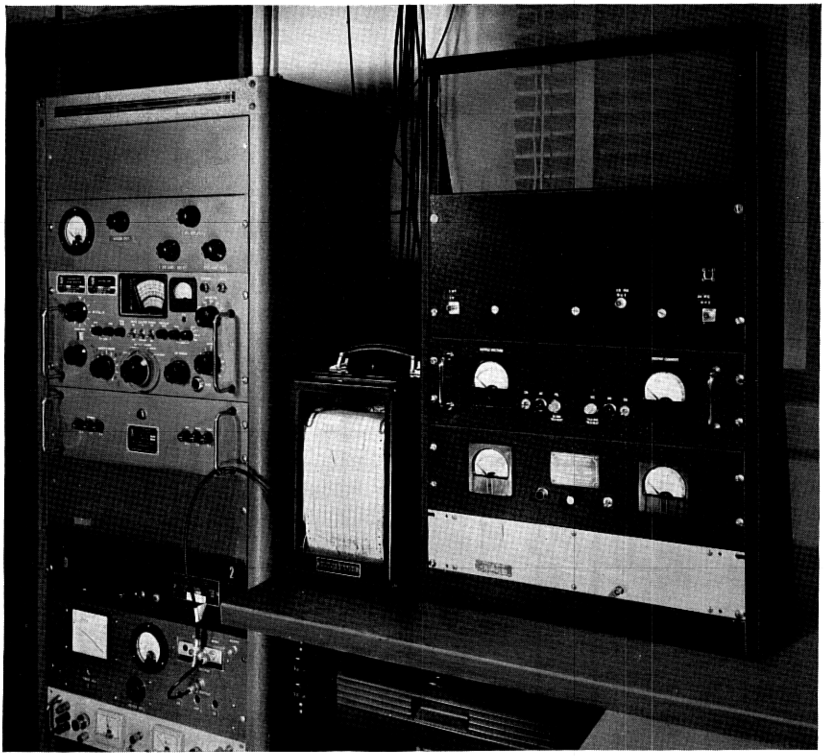

Fig. 8 — Left, single-sideband generator and monitor; center, RF power-level recorder; right, double-sideband generator.

doppler measurements and the latter for radar pulse tests. Fig. 10 is a block diagram of these exciters.

3.5 *Radar 71-mc Unit*

A separate 71-mc crystal-controlled oscillator was built to replace the Bulova unit described in Section 3.4 because of some difficulties encountered when the latter was pulse gated for radar transmission. The principal trouble was that the duty cycle of the on-and-off pulses changed as much as 3 to 1 when the keying frequency was changed from 15 to 45 cycles. This has been corrected in the new unit. Fig. 11 shows a block diagram of the present arrangement.

A twin 70- and 71-mc amplifier is provided so that the transmitter can be excited with either or both a 70-mc modulated signal (for FM, PM, SSB, etc.) and the on-off 71-mc radar pulses. The two signals are

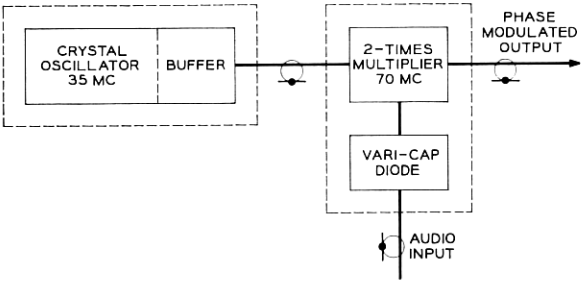

Fig. 9 — Block diagram of low-index phase modulator.

fed in separately through attenuator controls so that any desired level is introduced (see Fig. 4). The combined sum of the two signals then drives the regular F.T.L. mixer. The total output antenna peak power is kept to 10 kw.

The radar gating is done by a relay controlled from the radar receiver location and is described in more detail in a companion paper.[2]

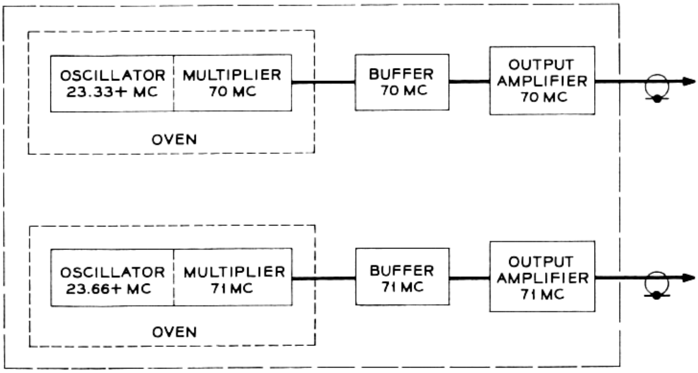

Fig. 10 — Block diagram of 70- and 71-mc crystal oscillators and amplifiers.

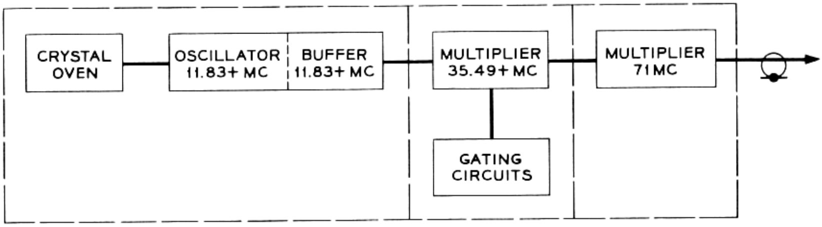

Fig. 11 — Block diagram of 71-mc radar oscillator.

IV. MONITORING EQUIPMENT AND CONTROL PANELS

During normal operations it is necessary to monitor or record such characteristics of the transmitter as (a) transmitted frequency, (b) transmitted power, (c) modulation quality, and (d) time.

Since there are many different modes and conditions of transmission the monitoring apparatus becomes relatively complex, as is shown by the block diagram, Fig. 12, and the photograph, Fig. 13. If the functions are examined according to the four categories listed above, operation should be readily understood.

4.1 *Transmitted Frequency*

Frequency counters to operate at 960.05 mc were not available, so a sample of the transmitted signal (obtained from a probe in the output

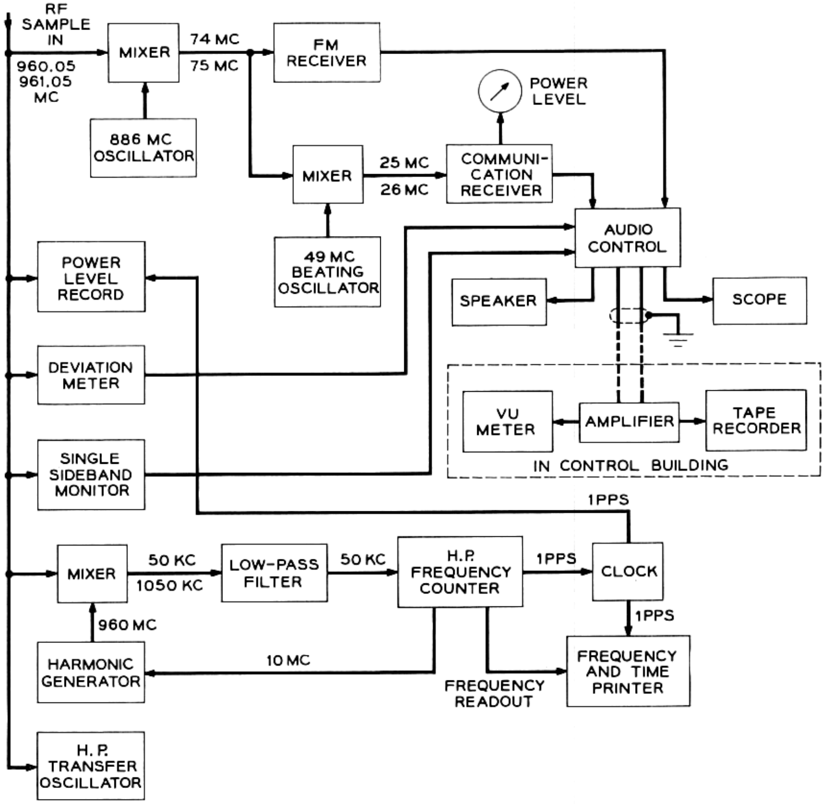

Fig. 12 — Block diagram of RF monitoring equipment.

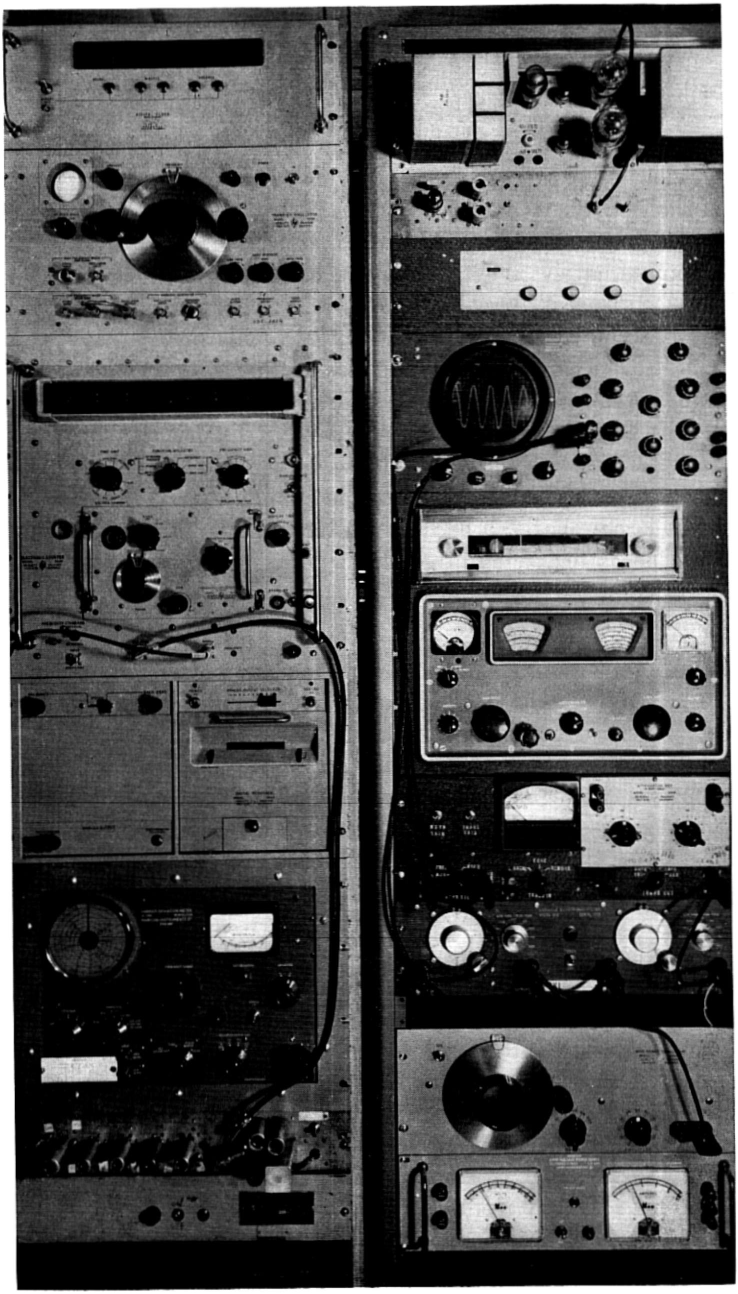

Fig. 13 — Monitoring and measuring equipment.

coaxial line and fed to all monitoring equipment) is mixed with a 960.00-mc signal, and the difference frequency of 50 kc is read by a Hewlett-Packard 524C frequency counter and also printed out on a paper tape by a Dymec 560A digital recorder. A 10-mc signal available from the frequency counter is multiplied by the harmonic generator to 960 mc and provides a beating oscillator with a stability and accuracy equal to that of the frequency control crystal oscillator in the counter. The manufacturer's specifications indicate a short term stability of three parts in 10^8 or approximately 30 cycles at 960 mc. The counter cannot determine whether the signal is above or below 960 mc, but this is done by means of a Hewlett-Packard type 540B transfer oscillator.

When both radar and communication channels are being transmitted, there are two frequencies, of approximately 50 kc and 1050 kc, out of the mixer. The frequency counter is unable to distinguish between these two, so a low-pass filter with a cut off frequency of 80 kc is inserted between the mixer and counter in order to eliminate the 1050 kc and measure the 50 kc. Similarly, a high-pass filter could be used to eliminate the 50 kc and measure the high frequency.

4.2 *Transmitted Power*

Two different methods of monitoring output power are employed. In the first, a probe in the output coaxial line powers a diode rectifier. The crystal current drives an Esterline-Angus strip recorder and provides a continuous ink record of the average power output. A second probe and diode powers the regular output power meter. When only one carrier is transmitted this is quite satisfactory. However, when more than one carrier is being transmitted (especially when one of them is a pulsed carrier) the indicated powers are meaningless. Measurement under these conditions requires a selective system which will accept one carrier frequency and reject all others.

In the second method of monitoring power, a sample is taken from the RF monitoring line and heterodyned to 74 mc. (This frequency is also used for the FM monitoring to be described later.) A second converter reduces the frequency to 26 mc. A Hammarlund HQ 110 communications receiver is then used as a variable-frequency IF amplifier with a bandwidth adjustable between about 3 kc and 500 cycles. An additional detector was installed to drive a microammeter which has been calibrated to read directly from 0 to 12 kw.

With this system it is possible to adjust and monitor each carrier to a specific power level, including each sideband of double-sideband transmission.

4.3 *Modulation Quality*

Three different methods are employed in the measurement and monitoring of wide-band frequency modulation, narrow-band FM or phase modulation, and amplitude modulation.

For wide-band FM a sample of the signal is heterodyned to 74 mc (as discussed previously) and received on a Sherwood S-30000 II FM tuner whose input circuits were modified to cover a range of 70 to 80 mc. The detected output is amplified in the audio control unit to be described later, and may be monitored visually on an oscilloscope or audibly on a loudspeaker. Spurious noise and hum are measurable down to about −70 db below the normal signal deviation of ±30 kc. Frequency deviation is measured by a Marconi TF-791D deviation monitor. The actual signal-to-noise ratio for normal FM operation is about 45 to 50 db.

Deviation of narrow-band FM or phase modulation is also measured by the Marconi deviation meter. Audio output available from this instrument is monitored through the audio control.

Amplitude-modulated signals are received on the same communications receiver and detector described under power monitoring. Audible and visible presentations are available through the audio control.

The single-sideband monitor, which was also designed and engineered by W. W. Rigrod and A. J. Rustako, is shown in block form in Fig. 14. Its operation, in brief, is as follows: A sample of the 960.05 mc SSB output signal is mixed with a sample of the 890-mc exciter drive to produce a

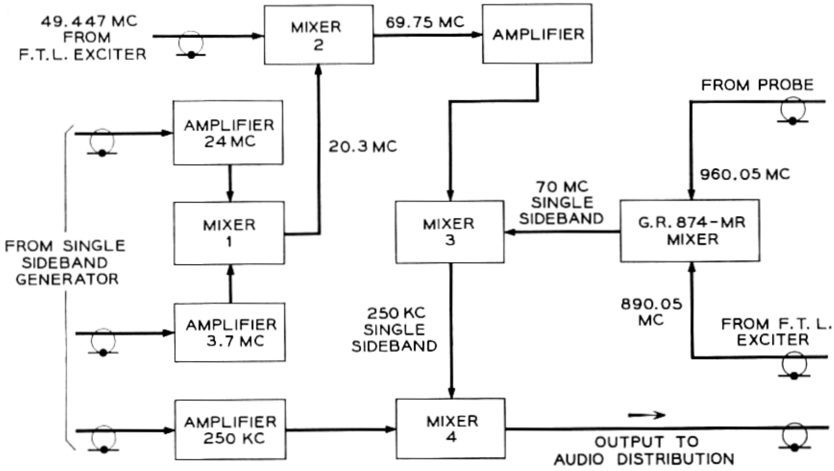

Fig. 14 — Block diagram of single-sideband monitor.

modulated 70-mc output in a General Radio 874-MR mixer. Frequencies of 3.7 and 24 mc, available from the SSB generator, are combined to produce 20.3 mc in mixer 1. In mixer 2 this frequency is added to a sample of the 49.45 mc driving the F.T.L. exciter to produce 69.75 mc, which is subtracted from the 70 mc out of the G.R. mixer to produce a modulated 250-kc signal in mixer 3. By beating this with a sample of the 250-kc oscillator in the SSB generator, audio output is recovered in mixer 4 and routed to the audio distribution control. By utilizing the same oscillators for both transmitting and monitoring, small frequency variations are cancelled out and complete synchronization is assured.

4.4 *Time*

Comparison of frequency or signal-level recordings of a received reflected signal with the corresponding frequency and power-output recordings at the transmitter requires that there must be a time reference permanently impressed on each recording.

The Hewlett-Packard frequency counter will furnish highly accurate one-per-second pulses. These trigger a Dymec DY 2508A clock which indicates hours, minutes, and seconds on a Nixie tube readout, and can also furnish time data to a Dymec 560A digital recorder. Frequency count data from the 524C counter are also fed into the printer, and the result is a paper tape printed record containing the last five digits of the frequency and six digits indicating time. Rate of printout may be varied from one each 20 seconds to five per second.

The Esterline-Angus power-level recorder charts are printed with a time scale of three inches per hour, and this is generally of sufficient accuracy. When a short transmission with a higher resolution is required the tape may be speeded up to three inches per minute and a second recording pen, driven by the one-per-second pulses from the digital clock, will record one-second intervals along the chart. Thus, by accurately setting the digital clock to a known time standard such as WWV or CHU, both the frequency and power recordings are accurately indexed in time. Samples of the frequency counter printout and the high-speed operation of the E-A power level recorder are shown in Fig. 15.*

V. AUDIO DISTRIBUTION

All audio circuits required for transmission or monitoring are routed to an audio control panel, shown in block form in Fig. 16.

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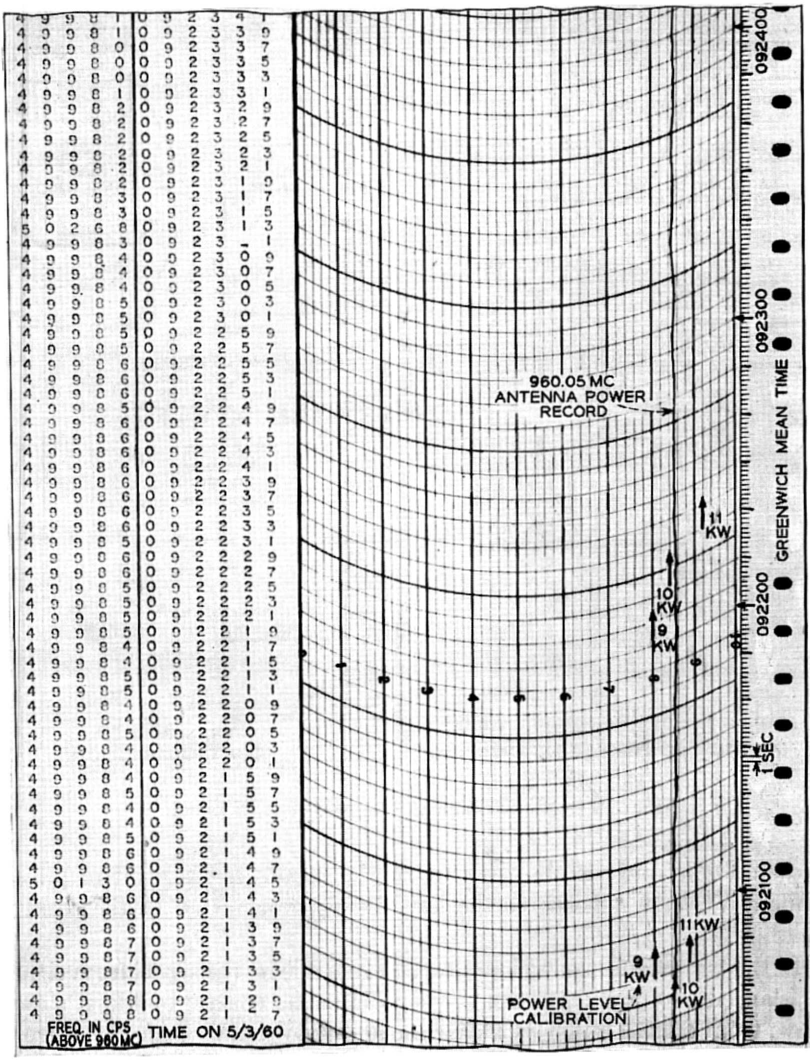
* Data records shown in Figs. 15, 18, and 19 were taken in connection with National Aeronautics and Space Administration Contract NASW-110.



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4 9 9 8 1 | 0 9 2 3 4 1
4 9 9 8 1 | 0 9 2 3 3 9
4 9 9 8 0 | 0 9 2 3 3 7
4 9 9 8 0 | 0 9 2 3 3 5
4 9 9 8 0 | 0 9 2 3 3 3
4 9 9 8 1 | 0 9 2 3 3 1
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4 9 9 8 4 | 0 9 2 3 0 5
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4 9 9 8 5 | 0 9 2 2 3 1
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4 9 9 8 6 | 0 9 2 2 2 7
4 9 9 8 5 | 0 9 2 2 2 5
4 9 9 8 5 | 0 9 2 2 2 3
4 9 9 8 5 | 0 9 2 2 2 1
4 9 9 8 5 | 0 9 2 2 1 9
4 9 9 8 4 | 0 9 2 2 1 7
4 9 9 8 4 | 0 9 2 2 1 5
4 9 9 8 5 | 0 9 2 2 1 3
4 9 9 8 5 | 0 9 2 2 1 1
4 9 9 8 4 | 0 9 2 2 0 9
4 9 9 8 4 | 0 9 2 2 0 7
4 9 9 8 5 | 0 9 2 2 0 5
4 9 9 8 4 | 0 9 2 2 0 3
4 9 9 8 4 | 0 9 2 2 0 1
4 9 9 8 4 | 0 9 2 1 5 9
4 9 9 8 5 | 0 9 2 1 5 7
4 9 9 8 4 | 0 9 2 1 5 5
4 9 9 8 4 | 0 9 2 1 5 3
4 9 9 8 5 | 0 9 2 1 5 1
4 9 9 8 6 | 0 9 2 1 4 9
4 9 9 8 6 | 0 9 2 1 4 7
5 0 1 3 0 | 0 9 2 1 4 5
4 9 9 8 6 | 0 9 2 1 4 3
4 9 9 8 6 | 0 9 2 1 4 1
4 9 9 8 6 | 0 9 2 1 3 9
4 9 9 8 7 | 0 9 2 1 3 7
4 9 9 8 7 | 0 9 2 1 3 5
4 9 9 8 7 | 0 9 2 1 3 3
4 9 9 8 7 | 0 9 2 1 3 1
4 9 9 8 8 | 0 9 2 1 2 9
4 9 9 8 8   0 9 2 1 2 7
FREQ. IN CPS
(ABOVE 960MC)     TIME ON 5/3/60
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Fig. 15 — Typical frequency counter printout (left) and high-speed RF power-level recording (for Tiros pass of May 3, 1960).

In the monitor control section, outputs from the various detectors are selected and amplified by a one-stage amplifier having a 600-ohm output impedance and variable gain. A balanced 600-ohm line transmits the signal to the main console in the station control building. An oscilloscope and high-impedance input audio amplifier driving a monitor loudspeaker

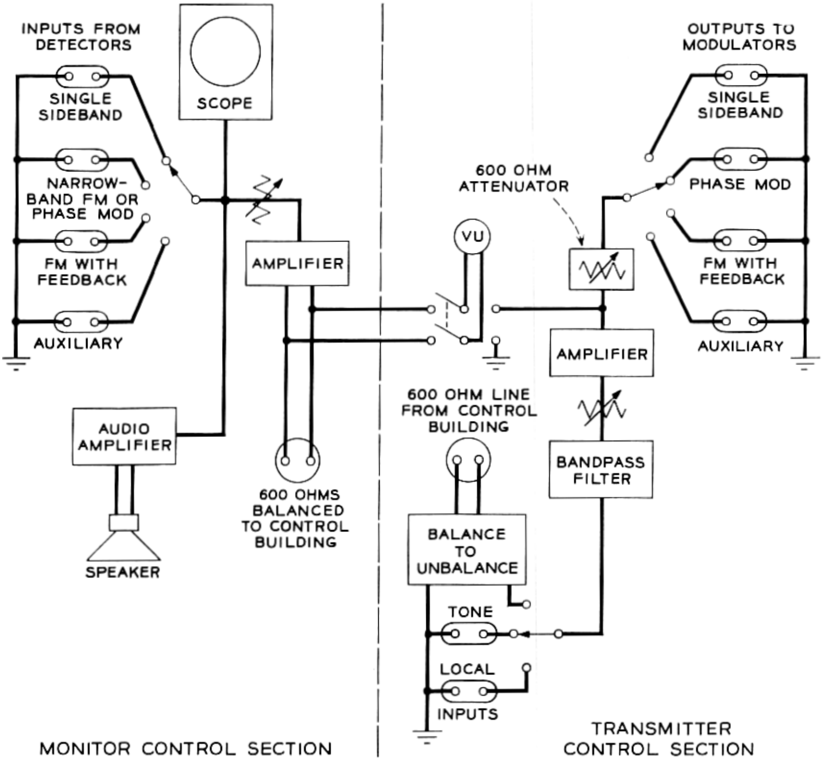

Fig. 16 — Block diagram of audio control panel.

allow audible and visible checking of the inputs to the control panel, while a VU-meter measures the level being transmitted to the control building.

In the transmitter control section a switch selects the signal from either a balanced 600-ohm line from the console in the control building, a sine wave from a local audio oscillator, or an audio signal of any type from a local source. An amplifier similar to the one in the monitor section amplifies the selected signal and transforms it to 600 ohms unbalanced. A second switch routes this output to the desired modulator. A VU-meter and a Hewlett-Packard 350A attenuator allow the measurement and adjustment of level into the modulator.

The frequency response of the audio distribution system is ±1 db from 30 to 12,000 cps, and it is linear up to 1.8 volts rms into 600 ohms. However, any desired restricted audio bandwidth at the transmitter input may be provided by means of a Spencer-Kennedy 302 variable electronic filter. This versatile unit consists of two filters, each of which is adjustable for cut-off frequencies from 20 cps to 200 kc, and may function as either a high-pass or low-pass unit, or as a combination band-pass. Rate of cut-off is 18 db per octave, and the two sections may be operated in series to provide a slope of 36 db per octave.

VI. MEASUREMENTS AND CHARACTERISTICS

A number of the over-all transmission characteristics of the transmitter are of interest. One of particular concern for various types of transmission is the input-output overload characteristic, in terms of 70-mc drive to the F.T.L. mixer and the 960-mc (or 961-mc) power in the antenna. For straight FM modulation, the linearity of this characteristic is not important; this is, of course, the type of transmission for which the set was designed. However, for SSB or any type of amplitude modulation, particularly when radar transmission is added, a departure from linearity will introduce some distortion, and this makes difficult the determination of the division between the 960- and 961-mc power output.

Most of the non-linearity occurs in the power klystron. The higher the beam voltage used, the straighter the characteristic and the lower the distortion. Fig. 17 shows some typical characteristics of the relationship between the 70-mc input and the 960-mc output. It will be seen that there is no departure from linearity for the low-power driver stage over the range required to drive the klystron to full power (one-half watt). The klystron characteristic at 17 kv shows a curvature above about 3 or 4 kw output and is about 3 kw down from the ideal at 10 kw. The characteristic at 18 kv is somewhat better than the one at 17 kv, and this is the one used during tests when linearity is of any importance (18 kv is the maximum voltage available with the present equipment). These load characteristics have also been checked at 961 mc and are essentially identical with those at 960 mc.

The over-all frequency characteristic of the transmitter is determined by various parameters, such as the tuning and adjustment of the mixer-amplifier of the exciter, the tuning of the klystron cavities, and the coupling adjustments to the load. The band can be adjusted to about 4 mc at the 3 db points and 2 mc at the 0.5 db points. For the particular application in which it is being used for Echo tests in which only relatively narrow frequency bands are used, the main concern is that nearly equal outputs at 960 and 961 mc are obtained for equal 70- and 71-mc drive amplitudes. This is easy to accomplish.

The transmitter output circuit operates into a fairly well matched load

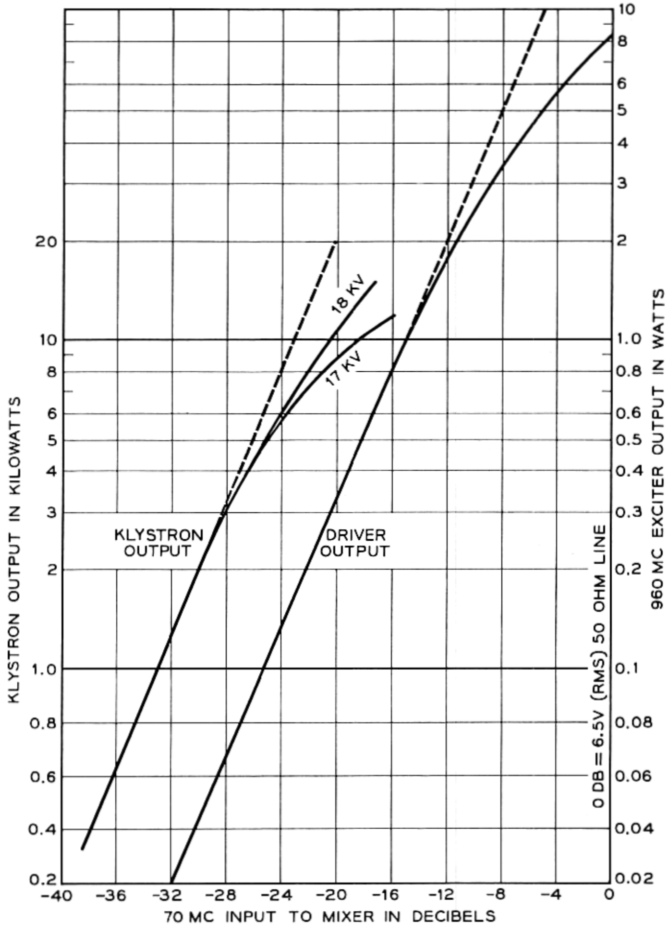

Fig. 17 — Input-output characteristics of 960-mc driver and 10-kw klystron amplifier.

with either the dummy water load or the 60-foot dish antenna. The actual reflected power with 10 kw output is about 100 watts for the antenna and about 30 watts with the dummy load, corresponding to return losses of 20 and 25 db respectively.

The calibration of the antenna output power meter is checked occasionally by transferring the transmitter output to the dummy load, where coolant flow and temperature measurements give a measure of actual power. From these readings a calibration curve for the power meter is obtained. This meter is a special dc milliammeter calibrated in kilowatts, which is coupled to the output RF line through a crystal diode. A similar arrangement is used to obtain a direct current to operate the Esterline-Angus recorder that gives a continuous record of output power when the transmitter is in operation. Figs. 18 and 19 are sample recordings showing the variations in power with time for various types of emission.

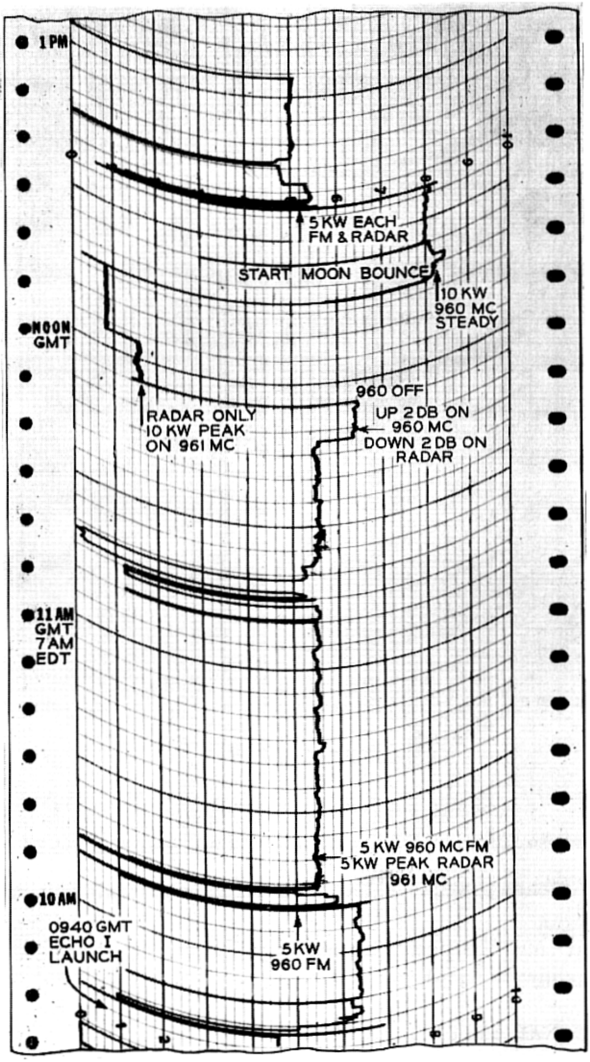

Fig. 18 — Antenna power-level recording for Echo pass 1 (August 12, 1960).

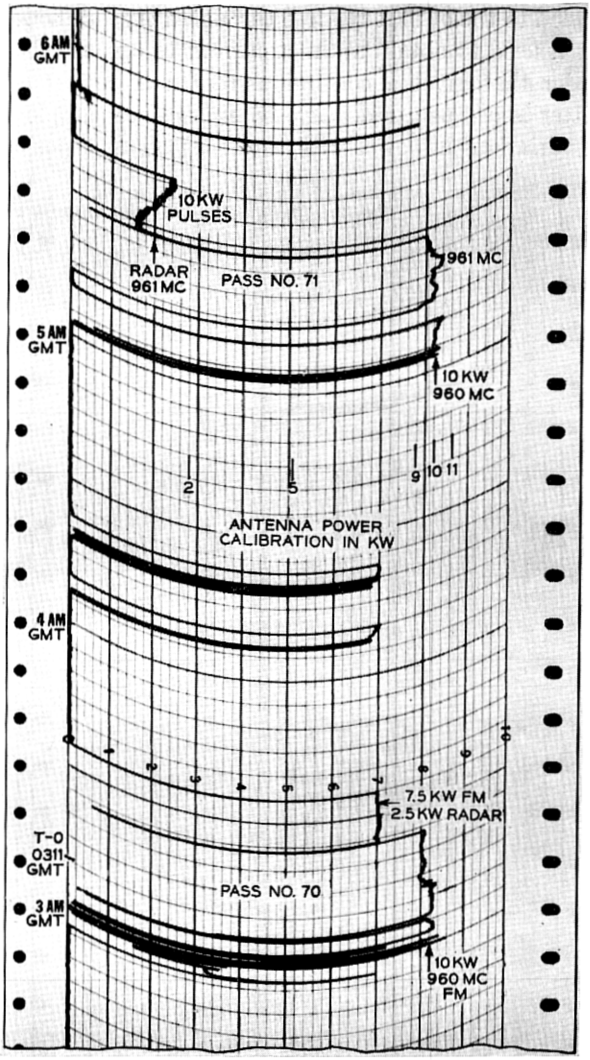

Fig. 19 — Antenna power-level recordings for Echo passes 70 (August 18, 1960).

It is believed that the power as read by the meter or registered on the recorder is accurate to about ±0.1 db.

VII. OPERATIONAL RESULTS AND CONCLUSIONS

The operation of the 10-kw transmitter has been very satisfactory since it was placed in service in July 1959. There have been a few minor equipment failures during this time, but fortunately they occurred at other than scheduled pass times. One interruption causing lost time in one of the early Moonbounce tests was due to arcing in some loose contacts near the rotary joints of the coaxial feed line to the dish antenna. This was corrected and no further trouble has been encountered from this source.

One annoying type of trouble which required considerable time to run down was what were termed "momentary interruptions." These would occur without regard to beam voltage or load and would only last for a second or two, which is the recycling time of the main high-voltage circuit breaker. Sometimes several interruptions would occur within a few minutes, and at other times they would be spaced several hours or days. These interruptions were finally traced to faulty vibration-sensitive relays in the beam current and body current overload circuit and to a faulty air-flow switch in the heat exchanger. They vibrated enough at certain times to open the relay contacts, which in turn opened the holding coil of the main circuit breaker. This breaker would reclose automatically and power would be reapplied without giving a positive indication or warning light. Since these relays and the air switch have been replaced, the momentary interruptions have apparently been eliminated.

There have been many long and extended transmission periods at full 10-kw output power with beam voltages up to 18 kv during Moonbounce, tropospheric scatter, Shotput, and Echo test transmissions. After the successful launching of Echo I there were transmissions during 124 different passes of the balloon from pass 1 on August 12, 1960, to pass 2407 on February 24, 1961. These tests are continuing.

Many different types of modulation have been used, such as wide-deviation FM, low-index phase modulation, constant-frequency cw, single-sideband and double-sideband with varying amounts of carrier, and on-off radar pulses.

Radar pulse signals are employed to aid in tracking the balloon and therefore are transmitted simultaneously with the communication channel modulated frequency. This requires a division of transmitted power between the two frequencies, the total not to exceed 10 kw. The power can be divided as desired, depending on the conditions of the particular test. Sometimes it is desirable to favor either the communication signal or the tracking radar. A nominal division frequently used has been 7.5 kw communication and 2.5 kw radar peak power.

The radar pulses are keyed at a low-frequency rate of 15 to 45 cycles, with a duty cycle nearly equal to 50 per cent time on and off. Due to compression nonlinearity of the high-power klystron input-output characteristic, it is difficult to control the division of power between the two frequencies. If they are set separately to a given amount and then applied together, each signal and the sum will be lower than desired. They must therefore be adjusted when both are operating. The value of the power at each frequency is obtained by the use of the narrow-band frequency-selective amplitude-measuring receiver described in Section IV. There is a certain amount of amplitude modulation introduced into the communication channel by reason of the klystron compression when the radar pulses are added, but this has not caused any trouble or added any appreciable noise in the monitoring FM receiver output. There is some low-level pulse noise in the SSB receiver output, but this has not been considered harmful to good speech quality. Low-frequency high-pass filters help to eliminate the interference due to radar keying.

VIII. ACKNOWLEDGMENTS

The authors wish to recognize the helpful suggestions and cooperation of many people working on Project Echo, particularly O. E. DeLange, for his part in selecting the transmitter equipment and his close cooperation in the engineering necessary to provide radar pulse modulation; G. S. Axeling, F. E. Guilfoyle, and A. J. Rustako for operating assistance during some of the long night tests and for their parts, along with that of J. T. Ruscio, in building and providing necessary auxiliary equipment; L. R. Lowry, for his supervision in furnishing adequate housing, power and grounds facilities at the transmitter building; and, of course, to W. C. Jakes, Jr., for his general advice and encouragement as Project Echo engineer.

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