RADC-TDR-64-303
Final Report

100 MEGACYCLE VHF RE-ENTRY RADAR FOR STALLION SITE, WHITE SANDS MISSILE RANGE AN/TPQ-20

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Rome Air Development Center
Research and Technology Division
Air Force Systems Command
Griffiss Air Force Base, New York

System 627A

(Prepared under Contract No. AF 30(602)-2824 by J. W. Marchetti, Inc., 12 Mercer Road, Natick, Massachusetts.)

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ABSTRACT

A 100-megacycle, 1-megawatt, variable pulse width (1, 2.5 and 5 microseconds) radar, the AN/TPQ-20, was installed at the Stallion Site, White Sands, New Mexico, for the purpose of viewing and photographically recording A-scope displays of the Athena test vehicles. Vertically polarized signals were transmitted and two receivers used, one for vertically polarized and one for horizontally polarized signals. The vertical and horizontal signals were recorded photographically on a pulse to pulse basis, together with range time. Ancillary data was paper recorded on Brush recorders. The antenna consists of five yagis mounted on an azimuth elevation mount and pointed to the area of interest by slaving the entire mount to an FPS-16 or L/UHF precision radar. This radar is presently controlled and operated by Air Force personnel located at Holloman Air Force Base.

PUBLICATION REVIEW

This report has been reviewed and is approved. For further technical information on this project, contact

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EVALUATION

The VHF radar, AN/TPQ-20, was installed at Stallion Site, White Sands Missile Range, New Mexico to measure re-entry phenomena. Ballistic Systems Division is collecting data from this and other measurement radars as part of the Advanced Ballistic Re-entry System (ABRES) Program.

Because of its location, the VHF radar is in a position to collect data on other vehicles impacting on WSMR when target cross section and range are within the radars capabilities.

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SECTION 1.0

INTRODUCTION

The VHF Radar was installed at the Stallion Site at White Sands, New Mexico, in the latter part of 1962 to provide part of the instrumentation for the Air Force Ballistic Systems Division (BSD), Advanced Ballistic Re-Entry Systems Program (ABRES 627A). It is a crystal controlled, 1 megawatt, 100 megacycle radar which records oscilloscope data on film. A modification of a standard series of re-entry ionization radars, it was primarily designed to measure re-entry phenomena in the Athena portion of the Re-entry Program. The specific purpose of the radar was to view and record A-scope displays of the Athena test vehicles. The radar was modified, fabricated, installed and operated for one year under Contract AF 30(602)-2824 with Rome Air Development Center.

On 10 November 1962 the VHF Radar was first operated as a complete radar, recording data on films. It was used at that time to record the returns at 101 megacycles in some special experiments being conducted on sounding rockets fired from the southern end of the range at White Sands. These sounding rocket tests were conducted under BSD management from time to time during the year following installation. At the present time the equipment is awaiting the initiation of the firing of the Athena test vehicles.

The radar is a standard pulsed radar with special features added that permit accurate calibration of the radar returns from ionization trails. A pre-flight and post-flight calibration procedure is resorted to in order to permit accurate assessment of the ionization echoes to approximately 1 or 2 db error. To this end, transmitter power, receiver sensitivity and antenna gain are measured accurately both before and after a flight. Oscilloscope deflections are calibrated and all the necessary test equipment and special fixtures for such calibrations are provided on site. The data is taken photographically by four six-inch strip film cameras so that pulse to pulse photographs of the A-scope displays are available for post-flight measurement. Three scopes are provided on the indicator display: one for the visual observation of the operator, and two for photographic recording: one on an expanded range basis, and one on a normal range basis. These indicators exist in duplicate, one recording the return on vertical polarization and the other recording the return on horizontal polarization.

Figure 1-1 is a photograph of the site showing the azimuth elevation mount alongside the main radar building and Figure 1-2 shows the radar and calibration antennas. The radar before installation is shown in Figure 1-3 and some of the equipment installed at the site in Figure 1-4.

It was planned that the radar be slaved to one of the FPS-16 precision radars or to the nearby Continental L/UHF radar, also a slaved system, deriving pointing data from a WSMR computer. Most of the tests were so conducted,

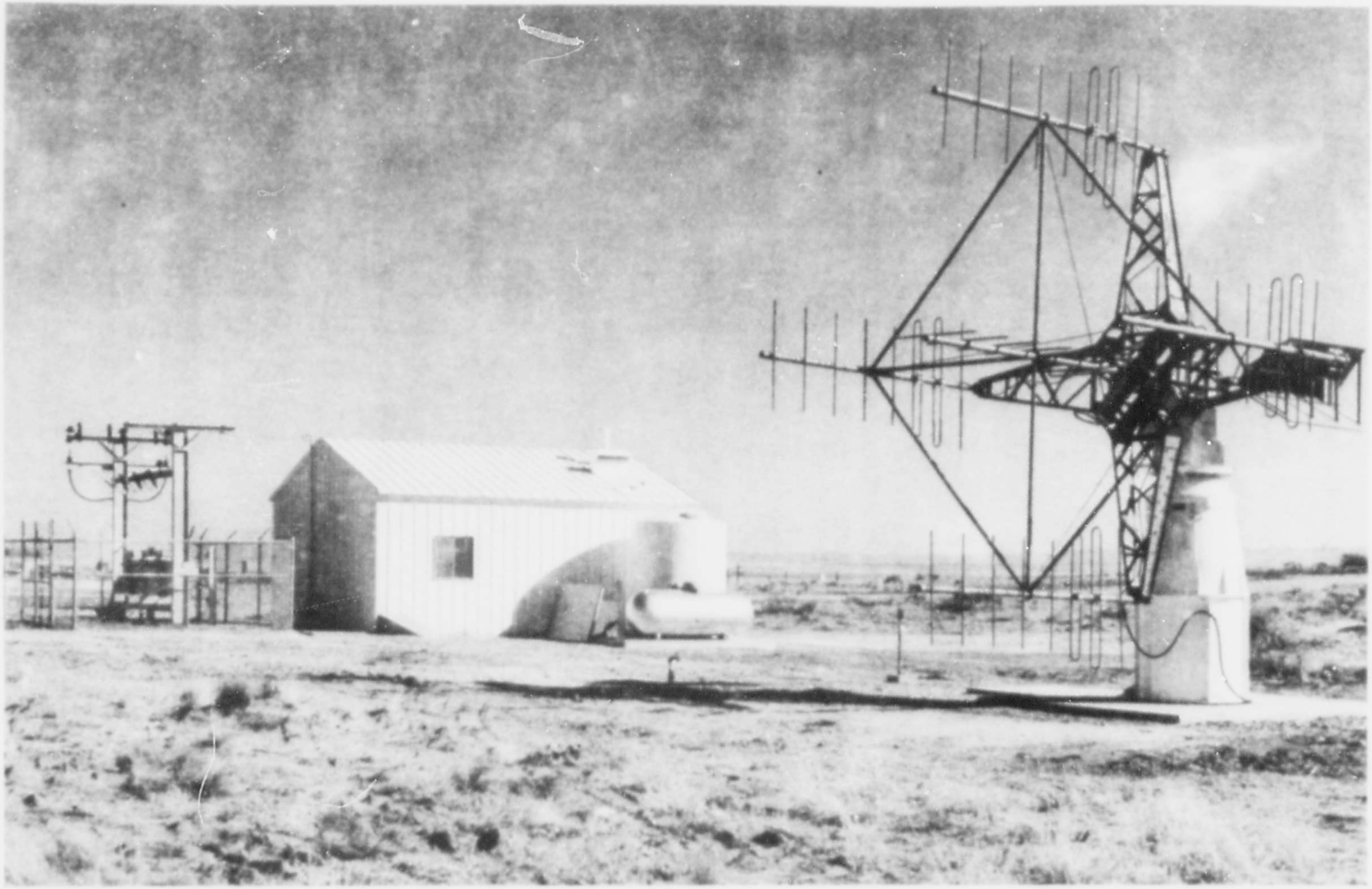


Figure 1-1. VHF Radar at Stallion Site, WSMR

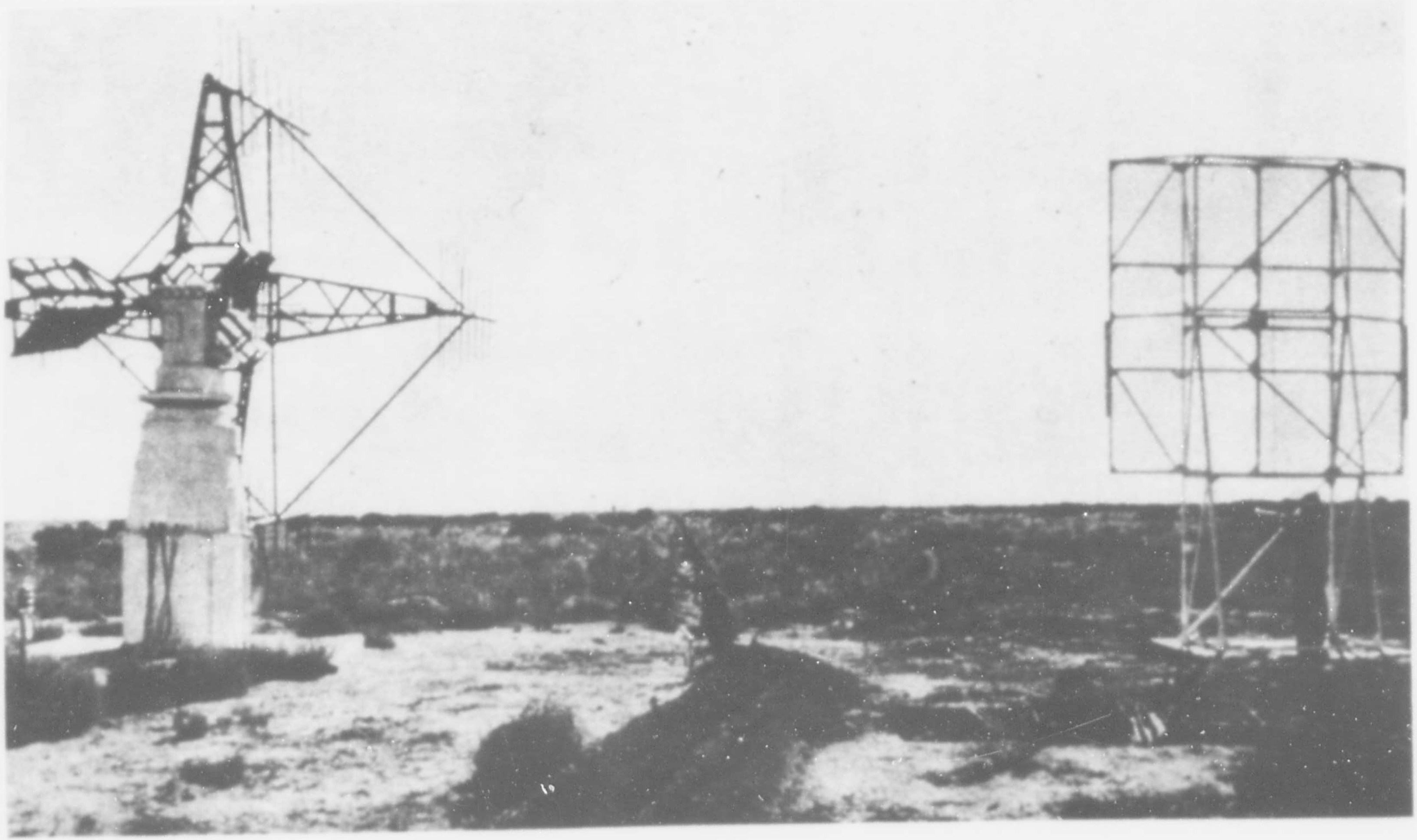


Figure 1-2. Radar and Calibration Antennas, WSMR

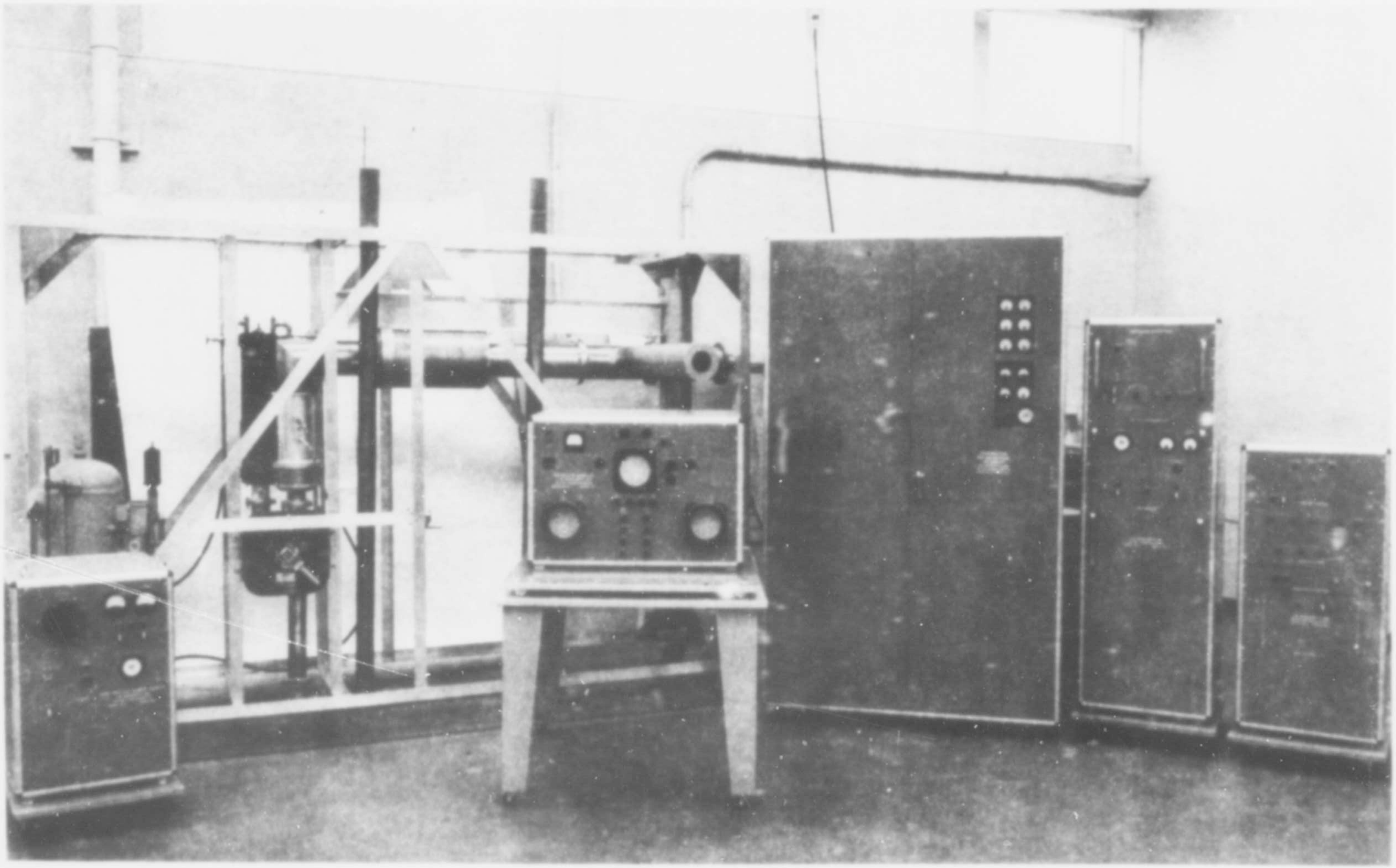


Figure 1-3. Photo of Radar Before Installation

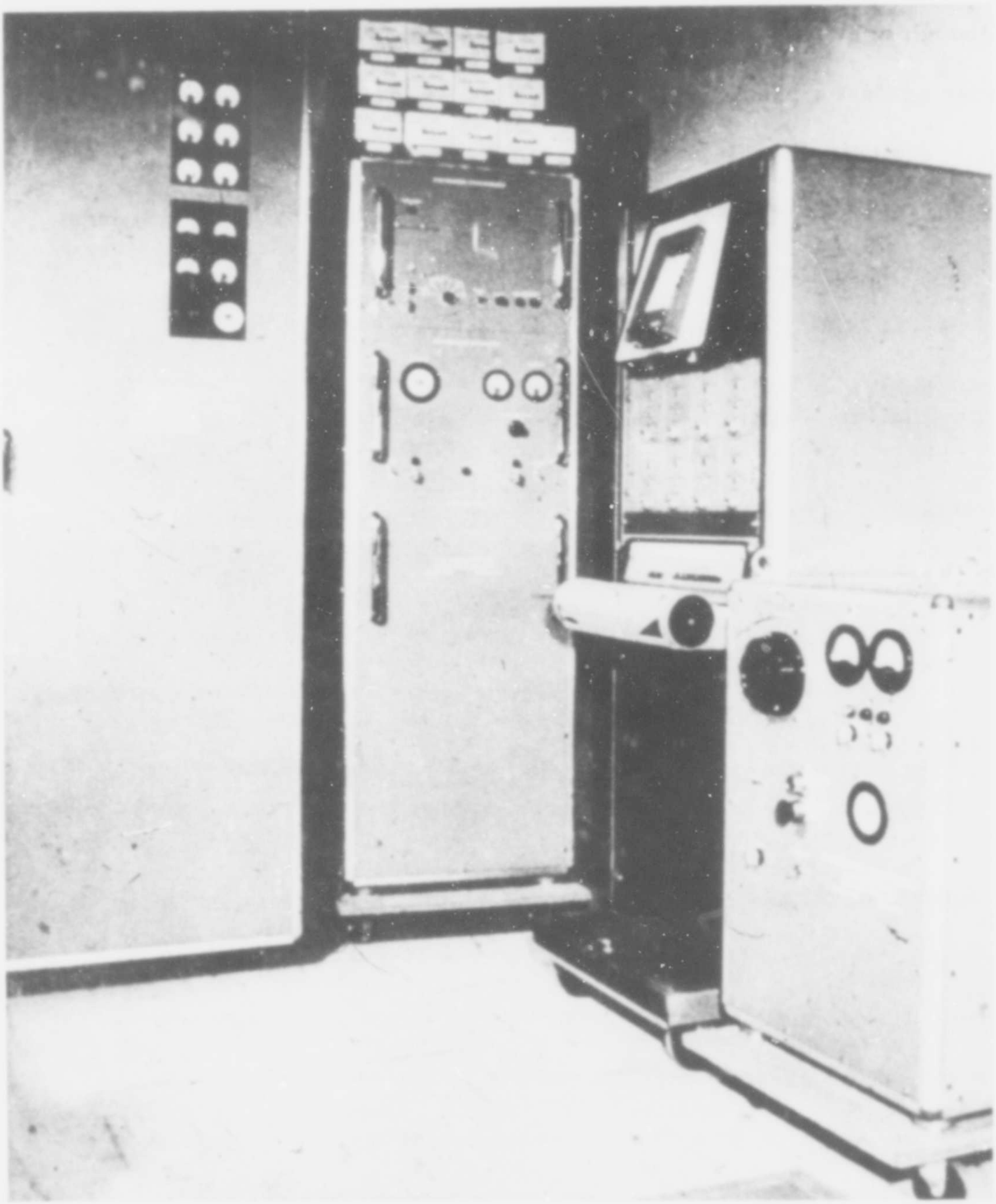


Figure 1-4. Transmitter, Synchronizer, Recorder and HV Power Supply Installed at Site

although in at least two instances it was possible to get data by pointing the radar against a predicted flight path and a known time of firing. During the sounding rocket firings, it was impossible to pick up the rocket at lift-off since the signal was well below the horizon. However, during all tests the trajectory even at low angles was followed as a procedural plan that would permit smooth tracking well ahead of the anticipated echoes. On a few occasions the target was picked up for a short time and in one flight the apparent separation of pay load at a fairly high angle (30°) was clearly detected. These are merely ancillary points, since the main purpose of the radar was to track in a slaved position to the FPS-16 or the L/UHF and detect only the phenomena which occurred during the latter part or high speed end of the trajectory. Several other radars are located at the Stallion Site and will obtain data on the same vehicles at other frequencies.

Several improvements to the basic radar were made during the first year of operation. In particular, a calibration antenna was added, and the photographic recording of range timing was simplified. In addition to its capability for recording amplitude data, the site is provided with (1) analog pen and ink recorders to record such data as antenna position, and (2) a 30 channel event recorder for the recording of operators' settings of the radar switches, such as the receiver attenuation, camera speed, etc. The basic range time, IRIG Format B, is photographed directly on the four data films that take pulse to pulse echo information. Attenuation settings are also recorded on each of the four films. The remaining paper records are coordinated time-wise with the main records with a precision of approximately one second. The photographic data is on a frame-to-frame basis of the radar pulse frequency and is of course a more precise record of time.

Because of the relatively high side lobe levels and wide beam inherent in the yagi array used with this radar, severe ground clutter results at certain pointing angles. Should the echo of interest fall in a range interval that is coincident with the ground return, then the data will of course be lost. The ground return at the Stallion Site is appreciable since Stallion is located on a valley floor between two lines of mountain ranges. At 100 megacycles, these mountain ranges provide returns that have been observed to be 80 to 90 db above system noise, and even the strong echo anticipated from the Athena shots could be lost if the shot is not in the clear. The planning at the present time is predicated on the radar viewing the data in the clear. If the shot is fired as predicted, it will be clear of the mountain echoes by approximately five miles in range at all times.

SECTION 2.0

TECHNICAL DESCRIPTION

2.1 GENERAL

The VHF radar is normally operated in a slave status to a precision FPS-16 radar which operates on a skin track basis or to the nearby Continental Electronics slave radar which derives its tracking data through Kineplex equipment from WSMR. Due to the broad beams of approximately 20^{o} in both coordinates, only nominal accuracy is required in the slave position. The broad antenna beams also compensate for the lesser acceleration performance of the VHF radar mount when slaved directly to the FPS-16. Under high acceleration the VHF mount will lag the FPS-16 somewhat, but the target of interest will nevertheless remain within the beam. Furthermore, these periods of high acceleration never occur during important data taking time. The broad antenna beams also provide a subsidiary advantage which has been used several times in the past year and a half during the sounding rocket tests, namely to operate the radar without any pointing information. This is accomplished by pre-calculating the various azimuth and elevation angles as a function of time prior to the actual firing of a shot. Then, with information on lift-off time only as a parameter, it is possible to follow the trajectory sufficiently well to record useful data.

Figure 2-1 is a block diagram of the VHF Radar, and Table 2-1 lists its principal parameters.

2.2 TRANSMITTER

The transmitter is crystal controlled and presently operates at 101 megacycles but is tuneable over 90-110 megacycles. It provides pulses of 1, 2.5 and 5 microseconds. Working backward from the high power end, the last stage is a coaxial amplifier using an RCA A2581C tetrode. This stage has a nominal gain of 10 db. It is preceded by two identical stages using a somewhat smaller tetrode, the RCA 7214. Each of these two intermediate stages has an approximate gain of 11-12 db. Figure 2-2 gives a clear view of these three stages which are mounted in the main transmitter cabinet. On the left is the final stage which is driven via flexible cable approximately 1 inch in diameter. The output is 6-inch coaxial line as shown in the upper left-hand portion of the photograph.

The two preceding stages have both their input and output r-f connections in flexible cable approximately 1/2 inch in diameter. The design of these three stages is somewhat similar. The construction is obviously entirely coaxial and comprises a plate to screen cavity with a plate blocking condenser of teflon. The screens are grounded directly and all three stages are cathode driven. The grid to screen blocking condenser as well as the cathode to grid blocking condenser are also of the teflon coaxial type. The voltages on the condenser are such that dry wrap of the teflon is

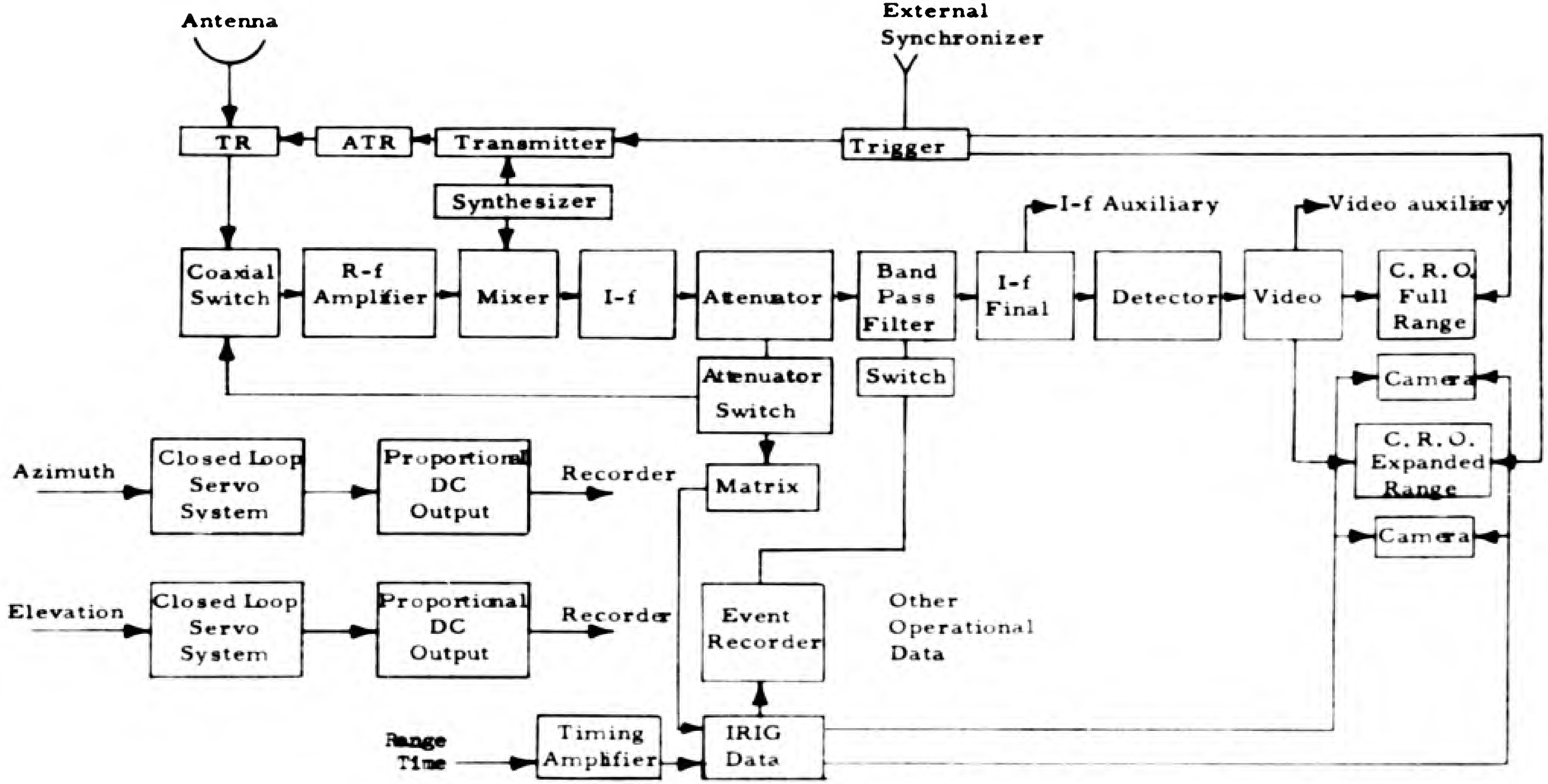


Figure 2-1. VHF Radar Block Diagram

Table 2-1. VHF RADAR PARAMETERS

Power	1 megawatt	
Pulse Width	1, 2.5 and 5 μsec	
Repetition Rate	100, 200 and 400 pulses/sec	
Frequency	101 megacycles, crystal controlled	
Receiver Noise Figure	3 db	
Receiver Dynamic Range Inherent	40 db	
Receiver Dynamic Range With Attenuator	110 db	
Coarse Displayed Ranges	180, 100 and 50 nautical miles	
Fine Displayed Ranges	20, 10 and 5 nautical miles	
Transmit Antenna, Vertical Polarization, 4 Yagis	Nominal Gain Beam Width	18.0 db 20 degrees
Receive Antenna, No. 1 Vertical Polarization, 4 Yagis	Nominal Gain Beam Width	18.0 db 20 degrees
Receive Antenna, No. 2 Horizontal Polarization, 1 Yagi	Nominal Gain Beam Width	10.0 db 45 degrees
Antenna Azimuth Slew Rates	Velocity Acceleration	22.3 degrees/sec 2.8 degrees/sec/sec
Antenna Elevation Slew Rates	Velocity Acceleration	14.6 degrees/sec 1.6 degrees/sec/sec
Azimuth View Angle	0-360 degrees (no rotary joint)	
Elevation View Angle	0-90 degrees (no rotary joint)	
Recording	4 Hathaway Cameras Max Speed 150 inches/sec 8 Channel Brush Recorder of Analog Data 30 Channel Event Recorder	

Table 2-1. VHF RADAR PARAMETERS (cont'd)

Timing Signals	IRIG Format B now recorded serially on film. Capability for parallel recording provided
Main Power	400 cps single phase 120 volt
Power for Antenna, Analog and Event Recorders, Test Equipment, Building	60 cps, single phase 117 volt

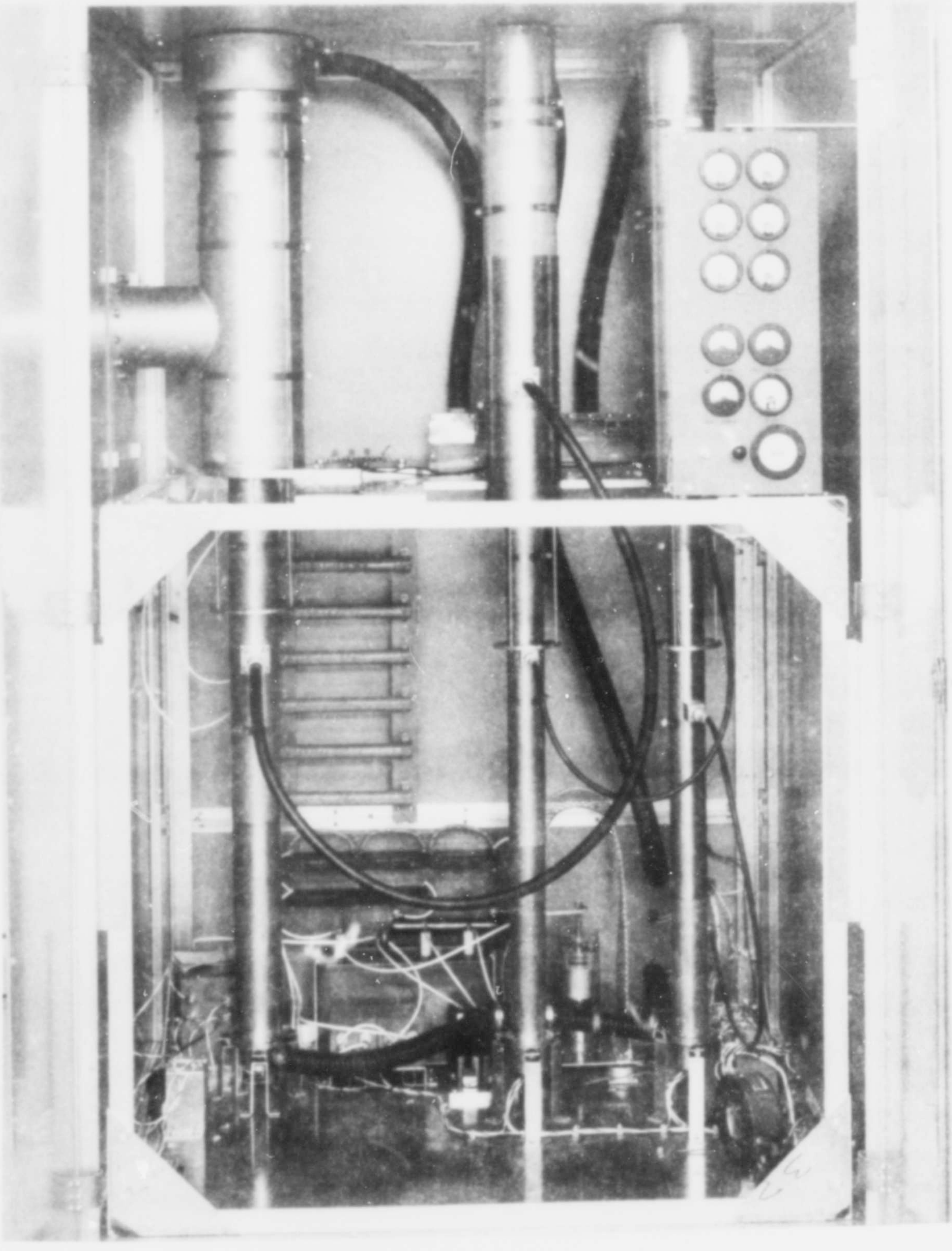


Figure 2-2. Interior View of Transmitter Cabinet

permissible in all cases other than the plate blocking condenser. The plate blocking condenser is wrapped very tightly and Dow Corning silicone grease is used to fill the voids. In addition, the condenser is cylindrically clamped along the split on the axis of the plate tank.

All three stages are air-cooled and as can be seen in the photograph, flexible hose enters at the bottom of each amplifier and exits at the top. It was necessary to pressurize the cooling air, particularly at the final stage. This final stage will normally provide somewhat in excess of 1 megawatt of power when operated at sea level; however operation at White Sands at some 5000 feet above sea level required pressurization in order to prevent arc-over across the plate-to-screen ceramic. It should be noted here that this ceramic is about 1 inch long and normally has approximately 30 kilovolts of direct current pulse applied to it, on which is of course superimposed the r-f swing. Clearly, it is the limiting factor in the final amplifier.

In order to provide both adequate cooling and pressurization, a heavy totally positive displacement blower of better than 2 horsepower was provided. The Roots-Connersville blower had sufficient capacity to provide the cooling air required and also permit throttling of the air exhaust to achieve the 2 to 3 pounds per square inch of pressurization required. Although not clearly visible in Figure 2-2, entrance air was by-passed in such a manner that some 60% of the total air was delivered to the final stage. Pressurization of all three stages was identical in order to simplify the air supply. Exhaust air was piped outside the operations building both to get rid of the heat and to lessen the noise of the attendant high pitched whistle.

Shown in the right-hand portion of Figure 2-2 is the metering panel. Three plate meters, three grid meters and three heater current meters were provided as well as an elapsed time meter. The remaining meter is a hydrogen reservoir volt meter for the modulator thyratron. The three current meters on heaters were provided since this line of RCA tetrodes is made of two heaters in parallel and quite often it is possible that one heater will open up. This would not be detected by just a volt meter check, hence current monitoring equipment was provided in lieu of volt meters.

The final output power is one megawatt peak, its input 100 kilowatts peak. The intermediate stage has an input power of 10 kilowatts peak and the first coaxial stage an input of one kilowatt peak. In essence then, the final transmitter cabinet shown in Figure 2-2 has delivered to it one kilowatt of r-f power and provides one megawatt at its 6 inch output port. The one kilowatt is derived from a crystal operating through two doublers and is finally raised through final stages of lumped constant amplifiers to the one kilowatt level. In order to provide the gain bandwidth product required, excessive gain has been provided throughout the system. For instance, the lumped constant amplifier, when pushed, can provide as much as 5 kilowatts of output power and the three final distributed amplifier stages of the transmitter which are nominally 10 db power gain per stage can, when pushed, be adjusted to provide some 36 db of gain.

As a trial run in the laboratory, the transmitter was operated with one of the intermediate amplifier stages removed and the full megawatt of power was achieved without overstressing any of the components. As a design feature, however, it was felt safer to reinsert the additional 10 db of gain thus insuring the ability to provide the one megawatt or better over the entire bandwidth of interest. The transmitter can be operated anywhere in the region of 90 to 110 megacycles by an appropriate change of crystal.

2.3 FILTER AND OUTPUT RACK

Figure 2-3 is a view of the output rack with its covers removed. The main system filter shown in the photograph is constructed in 6-inch coaxial line hung from a short section of aluminum I-beam. This end of the filter connects directly to the transmitter output cabinet shown in Figure 2-2. Power passes through the filter, then through the directional coupler used for monitoring system power and then to a coaxial switch used to connect the transmitted power either to the water cooled dummy load or to the antenna proper. The output connection to the antenna proper is in 3-inch coaxial line coming from the bottom of the coaxial switch and then connecting to the TR and ATR pipes. These can be seen running vertically in the approximate center of the photograph. They are separated by 1/4 wavelength and are 3/4 of a wavelength long. At the lower right-hand portion of Figure 2-3 is a 3-inch connection

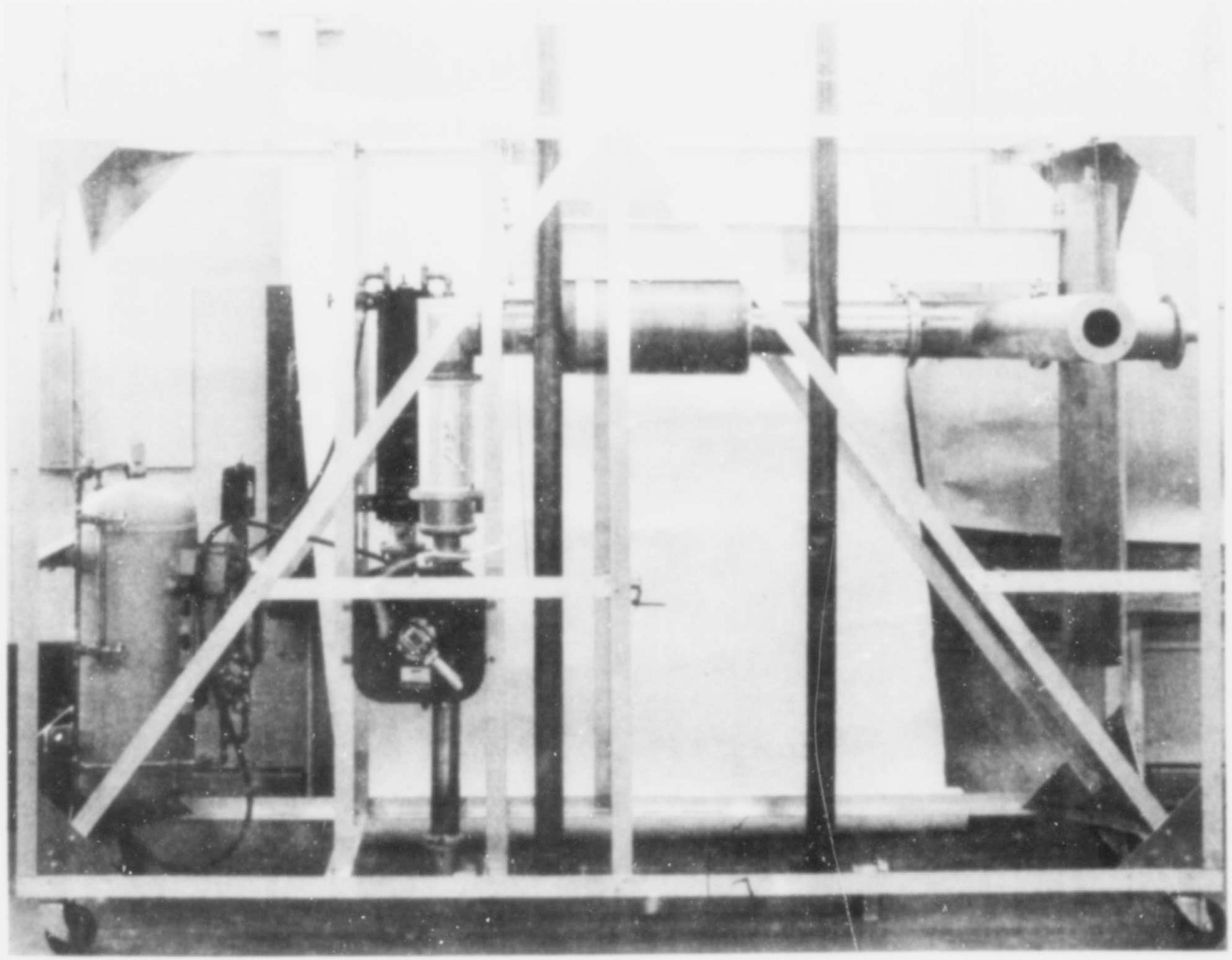


Figure 2-3. Photograph of Output Rack with Covers Removed

to an underground line which terminates in a manhole near the base of the antenna mount. This line operated underground is pressurized with nitrogen to a pressure of 25 pounds per square inch.

2.3.1 Output Filter

The output filter (Figure 2-4) was installed in order to meet the stringent specification requirements concerning harmonic content of the transmitter output. There are two 90° stubs at the end of the filter nearest the transmitter. The shorting bars on the long ends of these stubs are used to suppress the second harmonic. On the extensions of these stubs (only one is visible in the photograph) are tunable capacitor probes used to suppress the third harmonic. It is of interest to note here that the two stubs are placed at 90° to each other even though this constituted an awkward mounting arrangement. They were so placed in order to minimize the coupling between the two stubs. This coupling was particularly obnoxious in the 6-inch line and showed up in a scale model of the filter which was built at high frequencies. The operation of the filter was vastly improved by the 90° configuration. Somewhat to the left of these two stubs is a large horizontal cylindrical section which is, in essence, a tuned iris. This is tuned to minimize the higher order of harmonics, 4th, 5th, 6th etc.

2.3.2 Dummy Load

The dummy load is a commercially available water cooled load. Overflow water tankage controls, etc. are visible in the lower left-hand corner of Figure 2-3, and a coolant flow diagram is show in Figure 2-5. The

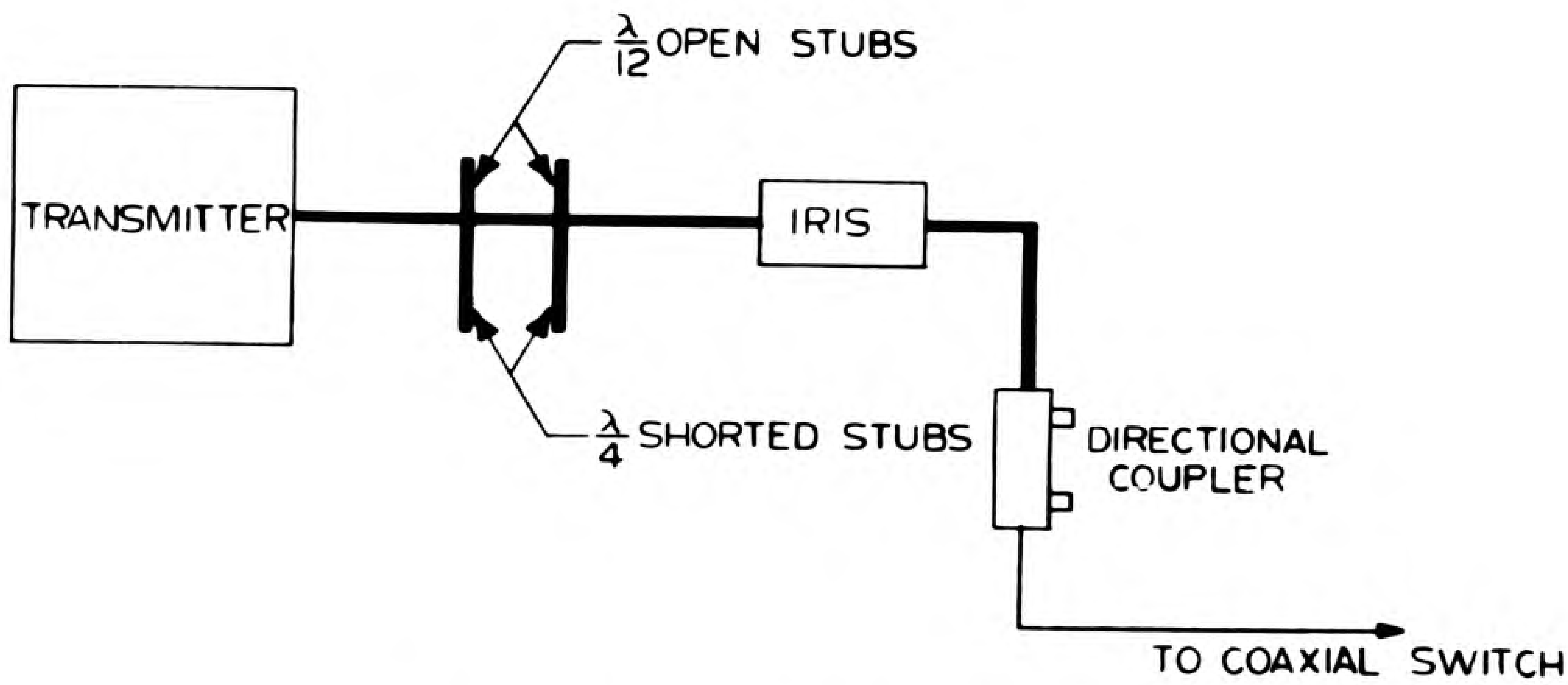


Figure 2-4. Block Diagram of R-f Filter

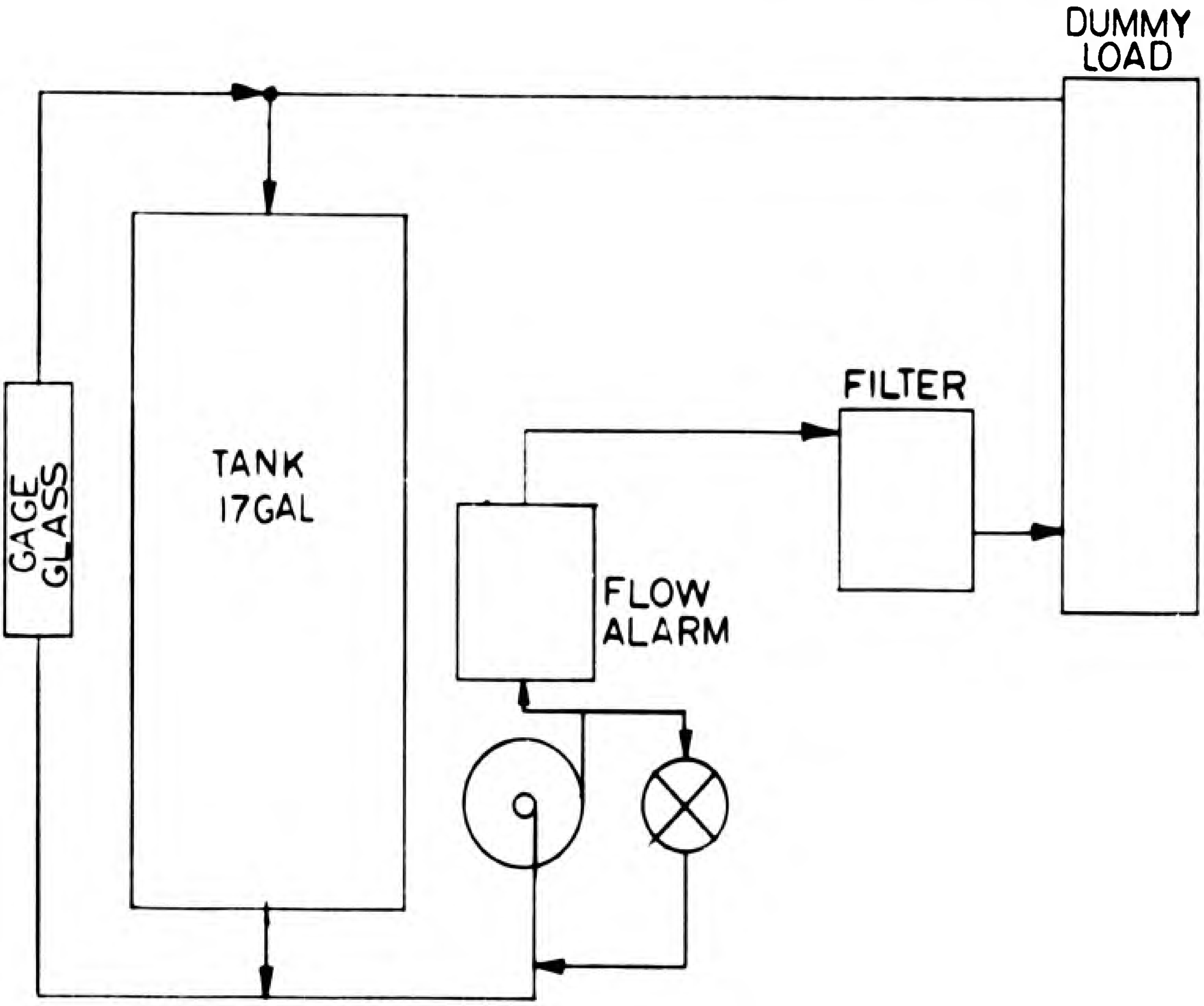


Figure 2-5. Coolant Flow Diagram

load was provided to absorb the full power of the transmitter in order that complete system calibrations, maintenance checks, etc. could be performed without radiating on the range. The coaxial switch is provided to permit the switching from antenna to dummy load. It is manually operated but necessary, due to its frequent use in both post and pre-flight calibrations.

2.3.3 TR-ATR

The TR-ATR, shown in a schematic diagram in Figure 2-6, is a standard stub TR. The two stubs, both the TR and ATR sections, are spaced 1/4 wavelength apart. At the 1/4 wavelength point a short is provided that is incomplete; that is, it provides iris coupling to the remaining 1/2 wavelength section. At the center of the 1/2 wavelength section is an air gap with tungsten electrodes and micrometer adjustment for spacing, that provides a short between the inner and outer conductor. At the topmost end of the 1/2 wavelength section is an adjustable shorting bar for tuning the high Q 1/2 wavelength section to the precise frequency of the transmitter.

The TR and ATR sections are identical except that in the TR section a 50-ohm tap is brought out to a coaxial connector for connection to the receiver input. It should be noted here that this receiver input is a vertical polarization input; that is, it uses the same antenna to transmit as to receive. The number two receiver input (the horizontal polarization input) comes from a totally separate yagi element of the antenna and is not subjected to the full transmitted power. It is, of course, coupled to the transmitter by its close

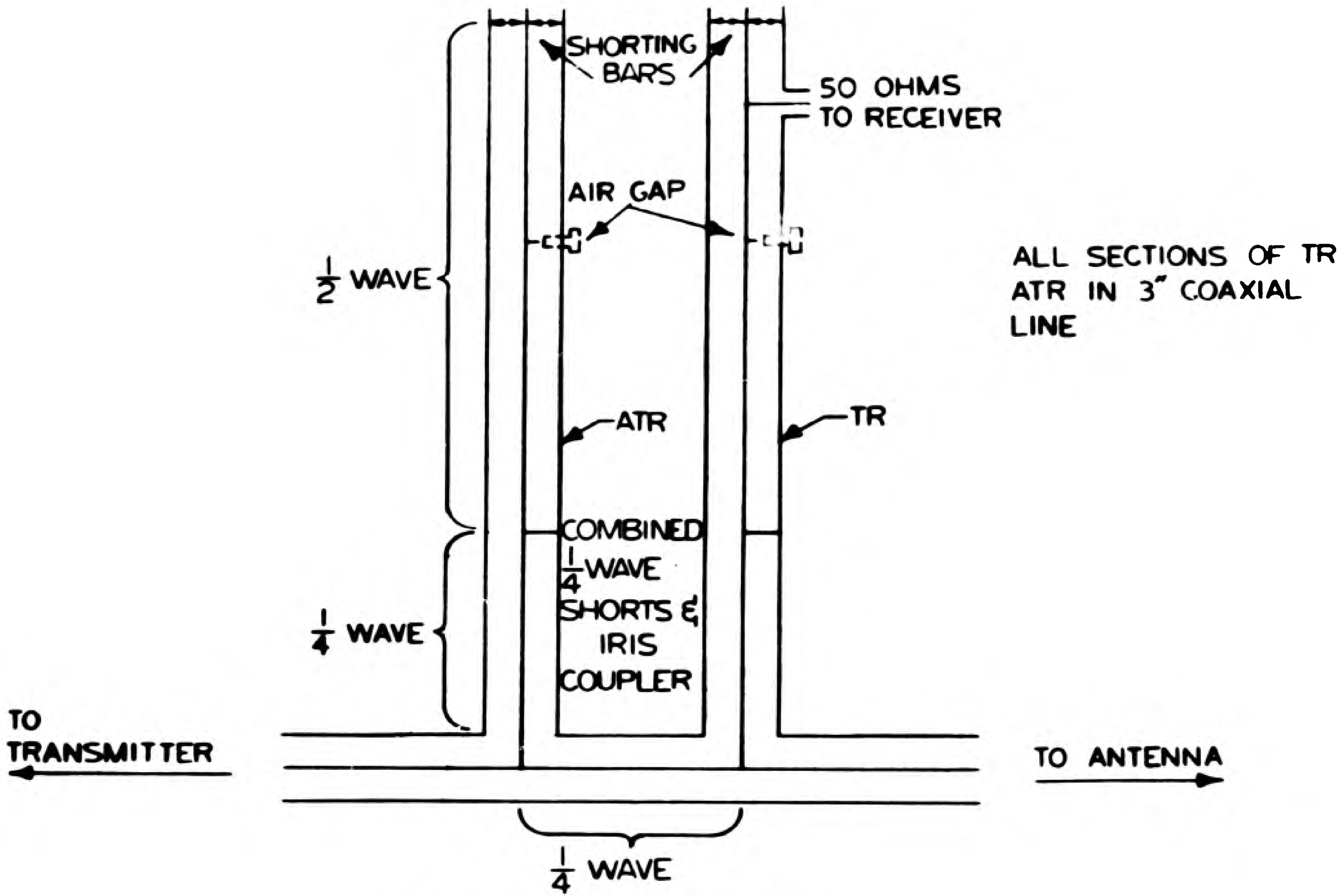


Figure 2-6. Schematic of TR-ATR

proximity in the antenna and requires some TR protection. A separate gas switch tube is used for this purpose. The isolation between the number two receiver and the transmitter due to the antenna itself is some 30 db. In point of fact, even though the main TR provides some 60 db of isolation, an additional gas tube is used across the input of both receivers as an added safety feature.

Air gaps are used in the main TR-ATR in order to provide a simple means of handling the high powers involved. Gas tubes at the one megawatt level are tricky to operate and usually provide long deionization periods. Unless their conditions are continually watched, it can well be that they desensitize the receiver out to ranges of as much as 10 to 20 miles. This is a range within which this radar was required to operate at maximum sensitivity. The air-gap TR's provided give a deionization time of the order of a few microseconds (less than a mile). Admittedly they do require adjustment about once a month for gap wear. It was felt that this occasional adjustment was a nuisance well worth putting up with in view of all the other considerations.

2.4 MODULATOR (Figure 2-7)

The modulator is a soft tube modulator using a single thyratron to provide six separate d-c pulses. The network has a high voltage switch to provide either 5, 2.5 or 1 microsecond pulses. Three separate pulse transformers driven by the same thyratron are used. The main pulse transformer feeding the final amplifier stage provides a positive plate pulse of 30 kilovolts maximum, and a negative pulse of 2.5 kilovolts dc which is applied

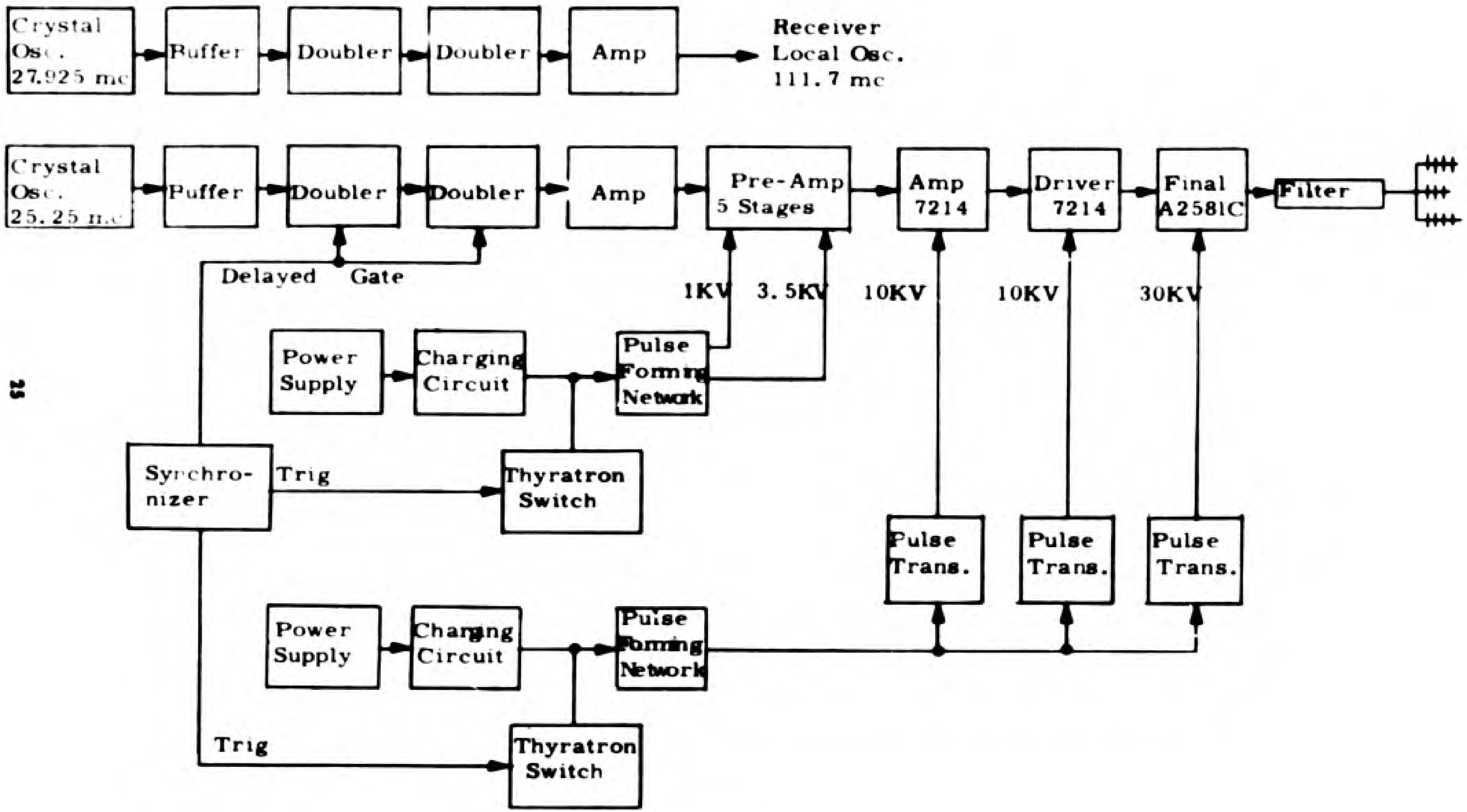


Figure 2-7. Modulator and Transmitter Block Diagram

to the grid and cathode essentially together. The grid is tied to the cathode by approximately 10 ohms of grid resistance.

Since the screen is grounded because of r-f considerations, the d-c drive on the gird and cathode is in effect the screen voltage. It can therefore be said that the coaxial amplifiers are both plate pulsed and screen pulsed simultaneously. Two smaller pulse transformers, each with the same type of positive and negative going windings, are used to pulse the two intermediate stages using the RCA 7214. In this case a positive plate pulse of 10 to 12 kilovolts is applied and approximately 1500 volts negative is applied to the grid and cathode. Here again this corresponds to 1500 volts positive on the screen.

As originally designed, the pulse forming network was switched three ways, namely for 5, 2.5 and 1 microseconds with a completely separate but smaller modulator provided for keying the five feeder stages to the three coaxial stages. With this configuration, it was found difficult to obtain the full power at the one microsecond pulse despite the existence of appropriate delay lines in the various sections of the pulsing circuits to insure that feeding was appropriately timed. The pulses that resulted were essentially triangular when the one microsecond timing was used. The 1 microsecond pulse succeeded in giving one megawatt of power only when everything was pushed to the limit. In order to obtain 1-megawatt power more gracefully, a change in the modulator circuitry was made whereby the pulse forming network providing the d-c power to the last three stages was left in the 2.5 microsecond position for running both the 2.5 and 1 microsecond pulse. In order to provide the 1 microsecond pulse, the lower level stages only were keyed at 1 microsecond and the r-f pulse at 1 microsecond which ensued was bracketed with appropriate delay lines within the 2.5 microsecond d-c pulses provided in the final stages. This resulted in the sharpening of the rise and decay times of the one microsecond pulse and permitted a longer dwell time at the one microsecond level.

Powerwise, the modulator is operated from 400 cycles which is generated by a motor generator set converting 3-phase, 60 cycles to single phase, 400-cycles. The modulator is variac controlled so that any power level desired by the operator can be achieved. The probable maximum power level of the final amplifier is of the order of 10 kilowatts. This could have been reduced still further if it had been desired but there seemed no operational need for it.

2.5 RECEIVER DISPLAY

One of the receiver-display units is shown in Figure 2-8. The receiver section consists of an r-f amplifier, mixer circuit, and i-f amplifiers. The local oscillator is supplied from the synthesizer. The display utilizes cathode ray tubes with associated circuitry. The center A-scope display is used for operator manual tracking and attenuator control. The lower displays are normal and expanded sweeps for camera recording.

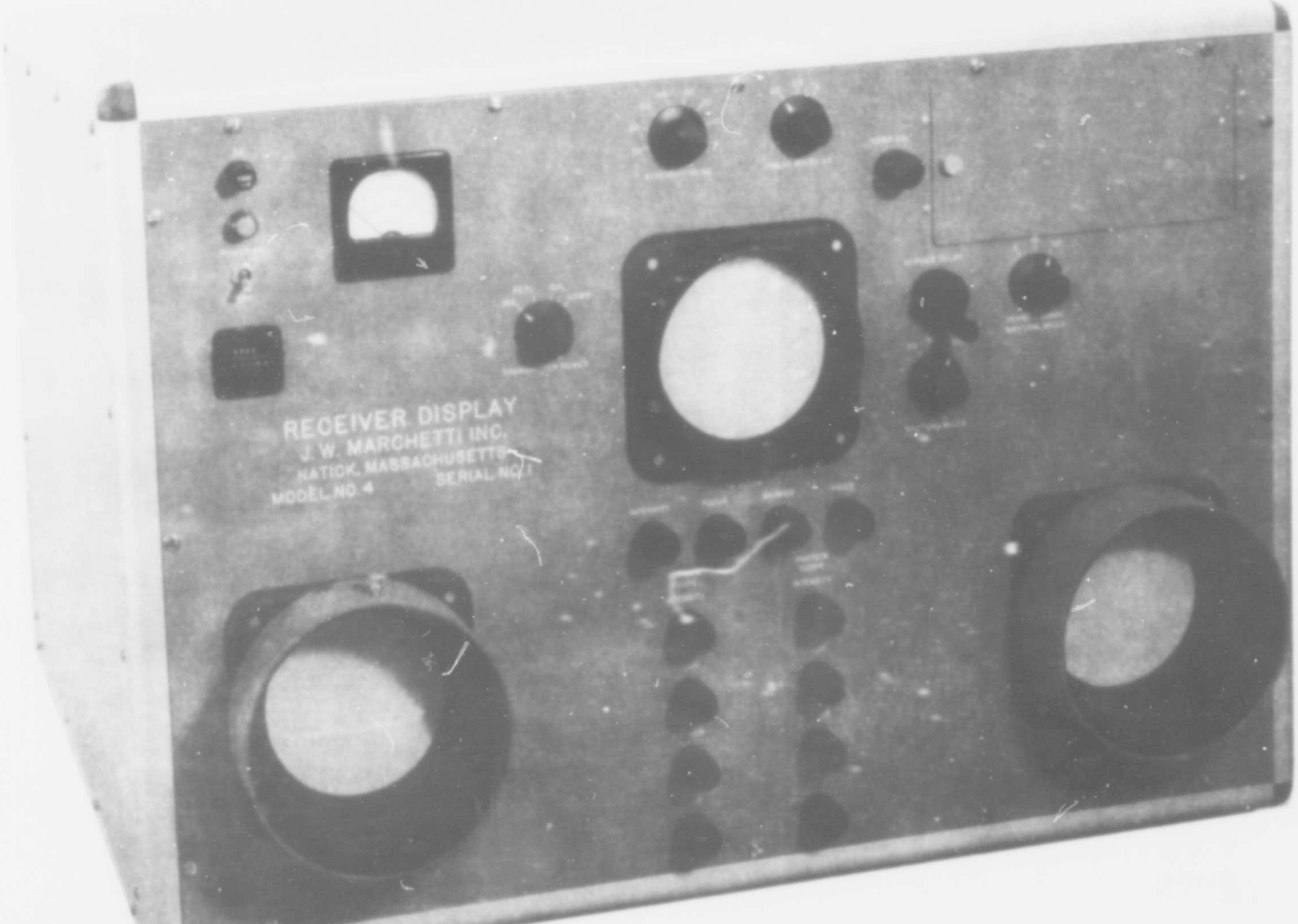


Figure 2-8. Photograph of Receiver Display Unit

2.5.1 R-f Amplifier

The r-f amplifier is a two stage, standard, broad-band, grounded grid amplifier with a bandwidth of 20 megacycles and a frequency range from 90 to 110 megacycles with a gain of 30 to 34 db. The noise figure as measured with a noise source and noise figure meter is approximately 2.5 db. Voltage requirements are +184 VDC, -13 VDC and 6.3 VAC which is the heater voltage. Two GE 7768 tubes are required. The mixer is a balanced type for low local oscillator injected noise and uses MA 416B diodes. The local oscillator is magnetically coupled to the mixer input. A low level output is provided at the mixer output for monitoring of the input to the i-f amplifier. Input and output impedances are a nominal 50 ohms.

2.5.2 I-f Amplifier

The i-f amplifier consists of four stages of amplification, a detector and video amplifier for the video channel and a driver stage for a high level i-f output. A step attenuator is located between the first and second stages and bandwidth filters between the second and third. Each of the first three stages consists of two transistors in a grounded emitter-grounded base configuration. The input circuit is a double tuned, top capacity coupled type with a 3 db bandwidth of 1.5 megacycles. It provides both selectivity and impedance transformation. The first stage has an equal input and output impedance of 1000 ohms and a gain of 20 db. The isolation between input and output is better than 40 db so neutralization is unnecessary. The attenuator which follows this stage consists of a tapped load resistor for the stage with taps proportional to the correct gain steps. A second stage of amplification which is identical to the first, is fed from the attenuator and this stage in turn drives the bandwidth filter. The bandwidth changes are accomplished by changing the coupling between the coils and also their loaded Q's.

A third stage of amplification identical to the first two follows the filter. The output of this stage is single tuned and has a bandwidth of 2 megacycles. The signal is then applied to the inputs of both the detector driver and high level i-f output driver. Both these circuits have single tuned outputs.

The detector is a half-wave doubling type and is followed by a low pass filter. The video amplifier is a single transistor in common emitter configuration. A limiting circuit is provided at the output of this video stage which prevents saturation of the following video amplifiers.

2.5.3 Display Unit

The display unit consists of three cathode ray tubes with associated sweep generation, range mark generation and video amplification circuitry. Two of the CRT's use a P-11 phosphor which is suitable for photographing while the third uses a P-1 which is suitable for direct viewing. Two of the scopes are capable of displaying any one of three possible ranges(50, 100 and 180 nautical miles) which are independently selectable. The vernier sweep may also be placed at any position along the main sweep to allow an expanded view of that portion covered by the vernier.

Range marks are provided on each main and vernier sweep. For the main sweep, the range mark interval is one-tenth the length of the main sweep. For example, if a 50 nautical mile range is chosen, the range mark interval would be 5 nautical miles. Range marks for the vernier sweep are controlled by the main range switch and are one one-hundredth the length of the main range selected. For example, if a main range of 50 nautical miles were chosen, the vernier range mark interval would be 1/2 nautical mile. With the length of the vernier sweep indepedently selectable from that of the main sweep, it is possible for a different number of range marks to appear on the vernier sweep, depending upon the length of the main sweep chosen. For example, if a 50 nautical mile main sweep and 20 nautical mile vernier sweep were chosen, ten marks would appear on the main sweep with a 5 nautical mile interval while 40 marks would appear on the vernier sweep with a 1/2 nautical mile interval.

The main and vernier sweep voltages are generated in a conventional bootstrap circuit. Biased diode feedback is used to keep the sweep voltage constant for any sweep timing. The output voltage of the sweep generator is approximately 15 volts. As the deflection sensitivity of the cathode ray tube is approximately 25 volts per inch, this particular voltage does not lend itself to suitable presentation on the CRT so it must be amplified. For this purpose a circuit called a common emitter paraphase is used. Identical circuits are used for each tube. Each circuit is fed from the arms of identical pots which are used as amplitude controls. The horizontal deflection plates of each tube are fed directly from the individual paraphase circuits.

With a trace on the tube it is necessary to add range marks to designate particular distances. Range mark generation is accomplished by the use of a clamped oscillator which oscillates at one of the following three selectable frequencies: 161.7 kilocycles for 1/2 mile markers, 80.86 kilocycles for 1 mile and 40.43 kilocycles for 2 mile markers. The oscillator output that is then fed to two blocking oscillators, produces pulses at the selected rate but offset by 1/2 cycle. The pulses in phase with the trigger are designated full clocks and those offset by 1/2 cycles are designated half clocks. These half clocks are fed to a decade counter where a division is performed and by gating, every tenth full clock is chosen and reshaped. These are designated as main markers. The undivided full clocks are designated as vernier markers. Due to the deflection sensitivity of the CRT it is necessary to amplify the range markers for proper presentation of the CRT. The amplifier amplifies both the main range and vernier range markers. The output of this circuit is fed to one vertical deflection plate of each CRT.

Since the signal from the first video amplifier is not large enough to allow proper presentation on the face of the CRT, it must be amplified further. The video amplifier consists of a single buffer stage and an individual amplifier for each CRT. The buffer consists of two transistors connected as a feedback amplifier. This circuit is used for linearity and stability.

With its low impedance, the gain controls for the individual drivers it feeds do not interact. An individual amplifier is also provided for external video output.

The display also contains a meter and drive circuit for indication of transmitter output power as well as VSWR. The circuit is insensitive to pulse width.

Each switch in the display has the capability of indicating to an external source its position in binary code.

2.5.4 Power Supplies

The receiver-display unit contains seven different d-c power supplies. The a-c input to these supplies is 120V, 400 cps. There are two transistor regulated supplies of +100 VDC and -100 VDC; one zener diode regulated supply of +184 V; and four unregulated supplies of -10, +28, -1500 and +3500 volts.

2.6 ANTENNA

The antenna is mounted on the pedestal through a cross braced, diamond shaped frame having a pair of legs running vertically and a pair horizontally. Mounted off the apexes of this frame are four vertically polarized yagis. In the center of the frame is a single horizontally polarized yagi. These are appropriately cross braced by fiberglass tie rods. At the back of the mount is a counter-weight and wind vane. The mount swings about 8^{o} above the overhead position before hitting the elevation stops.

All of the yagis are identical in construction and consist of five directors, two driven folded dipoles and one reflector. The two driven dipoles used are cut of slightly different lengths in order to provide broad banding and also to assist in taking the high power to which they are subjected. The four vertically polarized yagis are connected together via equal length cables. These cables terminate in four type "N" connectors located at a coaxial transformer which is mounted within the aluminum frame of the main antenna support. This transformer is 1/4-wavelength long and has a single 50-ohm input connection from the main 1-inch, 1-megawatt cable, and transforms from 50 ohms to 12.5 ohms at its output where the previously mentioned four 50-ohm connections in parallel connect to the transmitting yagis.

The four vertically polarized yagis are capable of handling the voltage and power levels involved but one must be extremely careful concerning the VSWR. The VSWR under any circumstance must be held to better than 1.5 to withstand the gradients involved. To this end, each of the radiating elements has across its open circuit a high voltage tuning condenser. These condensers are tuned in each yagi to provide the best match. When installed, each yagi was set to a VSWR of better than 1.03. To achieve such a low value careful measurements had to be made and as the final position was approached, readings could only be taken with the operator well out of the field of the antenna. With each yagi set to 1.03 or better, the overall VSWR with the four yagis connected through the transformer was better than 1.2 A check of this overall VSWR was made from time to time and in a period of some six months it had not shifted by more than a few percent.

The horizontally polarized yagi, although a receive-only yagi, has similar high voltage condensers and is tuned in an identical manner. In this case the high voltage condensers were not necessary but all were made identical for purposes of interchangeability.

Care should be taken particularly if the antenna is ever disassembled, to connect all four of the transmitting yagis in phase. No means is provided for controlling this phase other than to insure that the yagis are mounted identically on the frame as viewed from the front of the antenna. It is quite easy to mount one of the vertically polarized antennas 180° out of phase with the rest by merely rotating it through 180° mechanically. If this were the case it would not be obvious to a casual observer but would destroy the gain of the array and broaden the beam. Even a careful observer can easily be fooled by this. In point of fact, the designers of the equipment operated this equipment for the first three months with one of the yagis so out of phase. The loss of some 6 db was not noticed until very careful measurements were taken of the antenna gain.

The best way to check for this condition is to insure that all of the cylindrical condensers on the feed dipoles are on the same side, one relative to the other. Although the antenna itself, because of the dual driven element arrangement and equal length cables to the power splitter, is quite broad band, it is advised that a recheck of VSWR be made whenever frequency of the radar is shifted. It probably will stay within limits but trimming of the 10 cylindrical capacitors will lower it to a safer value.

This point is stressed here because permanent damage to one or more of the main driven elements will result if any flashover in the coaxial cable ever occurs. Usually when this obtains, the dielectric will burn and carbonize and then no repair is possible other than to replace that section of cable. The cables usually damaged are the coaxial feeders inside the driven elements. These cables must be cut to the right length but are relatively easy to replace when damaged. All fittings and connectors, should replacement be necessary, must be filled with Dow Corning silicone grease before reapplying power.

2.7 ANTENNA PEDESTAL AND CONTROL SYSTEM

2.7.1 Pedestal

Figure 1-1 gives a view of the antenna pedestal which is a Model 7625-20 Antlab commercial pedestal with a three-foot extension ring for raising the pedestal to an appropriate height above the concrete slab. The pedestal is completely enclosed for protection against the sandy environment. No rotary joints are used either in azimuth or elevation. This is accomplished by using flexible coaxial connection for the r-f drive to the antenna proper. Two coaxial connections are used, one in 1-inch coaxial which can be seen in Figure 1-1 draped in an s-curve around the pedestal proper. This coaxial cable has 1-1/2 turns around the pedestal and is appropriately supported by flexible mounts. The coaxial cable is passed through conduit in the base concrete slab and terminates in a manhole which is not visible in the photograph.

In the manhole an appropriate r-f transformation connects the flexible cable to 3-inch pressurized coaxial cable which constitutes the main underground run to the building proper. In addition to this main r-f drive which carries the 1 megawatt of power, there is also a half inch coaxial flexible line which connects to the receive-only central horizontally polarized yagi. It similarly has a turn and a half around the pedestal, and is flexibly supported, in lieu of rotary joints. The remaining cables to the pedestal are, of course, control power and azimuth-elevation motor drive circuits.

2.7.2 Control System

The control system of the pedestal is an Antlab Model 3005D mounted inside the building in a separate relay rack. Thyratrons are used to control the speed of two d-c motors driving the pedestal in azimuth and elevation. A control transformer mounted in the pedestal is nulled by the two servos against the incoming, slave pointing information.

Besides the automatic control operating in the slave mode, the mount can be controlled locally, that is from the radar building proper, on a rate basis or a positioning basis. For the positioning basis a joy stick control is provided. These controls are used when no external tracking information is available. During runs made on a predicted time angle basis, either the joy stick is used or, should two operators be available, the normal position controls, one for azimuth and the other for elevation.

Due to the fact that neither an azimuth rotary joint nor elevation rotary joint was provided, electric and mechanical stops were provided on the antenna to prevent its turning more than approximately 380° in azimuth and 105° in elevation. No dead sector resulted, but it certainly meant that all round tracking would be impractical. This provided no operational difficulty since the area of interest was generally north, west and south. The pedestal's switching zone (it is not a dead zone) was placed approximately due east. The control system is provided with azimuth and elevation readout dials and means are provided for recording these angles on paper analog recorders.

2.7.3 Alignment of FPS-16 or L/UHF with VHF Radar

The FPS-16 precision radar, which is located some 1000 feet from the VHF site, provides tracking information as does the L/UHF radar. An underground synchro cable connects the buildings. It was necessary to put a pair of mechanically connected 1:1 synchros in the FPS-16 building in order to isolate the two radars electrically. This pair of synchros was provided with mechanical yoke control to assist in coarse orientation.

An attempt was made early in the installation of this radar to transmit only error signals directly from the FPS-16. This was a 60-cycle error signal developed from the FPS-16 synchros. It was found totally impractical to use this method due to the fact that the FPS-16 main power transformers were delta connected whereas those of the VHF radar were "Y" connected.

This resulted in a 60° error in phase. An attempt was made to null this out electrically but even this had to be abandoned since as load varied on the FPS-16 power lines the 60° shift would not remain constant within the FPS-16 itself. Such a shift of phase angle caused no error at the FPS-16 since the reference varied along with it; however in order for the VHF radar to have operated under these conditions the FPS-16 would have had to provide the pedestal control system with its total a-c power. It was felt that this was impractical, therefore electrical isolation of the synchros by mechanical means was resorted to. This provided a very clean system with no undue loading of the precision radar control system. The Continental L/UHF radar provides one-to-one synchro data on each axis directly from pedestal-mounted synchro transmitters. Since the VHF radar provides the reference voltage, no buffer package is required as for the FPS-16.

Servo alignment, both in azimuth and elevation, can be performed in the three following ways to align the VHF with a precision tracking radar:

1. Rotation of the synchros in the antenna mount itself.
2. Rotation of control transformers in the control system rack in the main radar building.
3. Rotation of the housing of the 1:1 synchro installed in the FPS-16 building.

From the point of view of accessibility it was found that the most practical way to accomplish this orientation was by the third method. The 1:1 synchros in the FPS-16 building have mechanically controlled stator drives that are easy to turn and are easily accessible. Furthermore, the orientation can only be done by means of telephone communication with both the FPS-16 operator and the VHF operator and this seems to be fairly central location for making the telephone connection. The procedure for doing this is usually to point the FPS-16, by means of its telescope, at the moon and also to sight the moon on the VHF radar by viewing it through one of the axes of the yagis (the axes are open aluminum tubes). With both mounts reporting that they are on target, a man located at the 1:1 synchros will rotate the stator until the VHF reads the identical azimuth and elevation as the FPS-16.

A switching control allows the VHF radar to be synchronized with any of the three radars or disconnected so that no error signal is introduced when the radar is not slaved. An on-track light indicates when the AN/FPS-16 radars are on track and the closing of a relay gives the reference voltage. Open or standby position is used for aligning the antenna for automated tracking.

2.8 OPERATION AT HIGH ELEVATION

The operation at high elevation was planned for early in the design of this radar and the known critical points designed for adequate pressurization down to sea level. The critical points were as follows:

1. Transmitter final amplifier.

2. Transmitter intermediate stage.

3. Coaxial cable (underground feeding of the mount).

4. Antenna matching condensers (cylindrical).

In all cases the pressurization was successful in coping with the operating conditions at White Sands. A test was run to decrease the pressurization and it was found possible to operate at 2-1/2 pounds gauge, rather than the 4 to 5 pounds gauge that the system had been designed for. In view of this, the system has been operating at this lower level since it permits a less noisy operating run due to the smaller amount of exhaust air. The underground cable has given no difficulty and has maintained its charge of nitrogen with only minimal leaks. The antenna high voltage condensers were over-designed because pressurization of the antenna was considered impractical. They were designed with a standard voltage of 50,000 volts and calculations had shown the possibility of their being stressed as high as 15 kilovolts. During runs at high power, these condensers were inspected in total darkness and no signs of corona were visible. Even for brief over-stressing, no corona was visible.

In general, no operational difficulties due to the operation at high altitude were observed. As a matter of fact, the operation seemed to have a higher safety factor insofar as voltage breakdown is concerned. We belive this safety factor is due to the fact that the atmosphere at White Sands is normally very dry. In extrapolating our results from the equi pment at sea level, we assumed a fairly humid atmosphere that did not exist at the test location.

2.9 DATA PROCESSING

Cameras, analog recorders and event recorders are used to record data for post-flight processing. A detailed description and instructions on the use of the Hathaway cameras are provided in Appendix A of the Handbook of Operating and Maintenance Instructions for the VHF Radar for WSMR. Brush Instruments manuals on both types of recorders are supplied at the site.

2.9.1 Cameras

Each display unit has two Hathaway Instruments, Inc. C6 Oscilloscope continuous-motion recording cameras for permanent recording on black and white 6-inch photographic film. One camera photographs one of the normal A-scopes while the other photographs an expanded sweep. The range at which the expanded sweep is set is indicated by a block of range marks on the normal A-scopes. The operator is able to view the scope through the direct viewer of the camera. Film speeds of 100 inches per second allow 12 seconds of recording time with 100 foot rolls of film. Sweep to sweep presentation is spaced according to the film speed, PRF and sweep rate. Single frame operation, as may be required, may be accomplished by depressing the SINGLE FRAME ADVANCE switch. Recording can be accomplished only when the shutter is opened.

The camera has an enlarging Wollensak Rapter 3-1/2 inch f4.5 lens and uses F TRI-X Aerecon Safety film, Special 801, on 6-inch wide by 100 feet long rolls. Figure 2-9 is a film sample of a continuous recording, including timing marks. The defocusing noted is probably caused by excessive intensity on the CRT. The echo which is referred to as the Holloman echo, at 70 n.m., is the result of diffraction over the mountain range between Holloman and the Site. This echo is used as a means of tuning the transmitter. The saturated clutter at 15-20 n.m. is ground reflection.

The motor drive was modified to operate at 400 cycles to be compatible with the radar supply. The timing light assembly was mounted to the back of the camera shutter assembly so that the timing markers would be at the edge of the film. A connector was mounted so that the cable for the timing light assembly would enter through the camera case assembly next to the power cable. The camera magazine is thus removable by use of mating connectors on the camera shutter assembly, so it is unnecessary to disconnect any cables.

Instead of rotating the camera, which would unduly complicate the mount, the CRT sweep was rotated 90° so that it sweeps from bottom to top. A special table provided for the display unit and the camera mount allows easy removal of the camera.

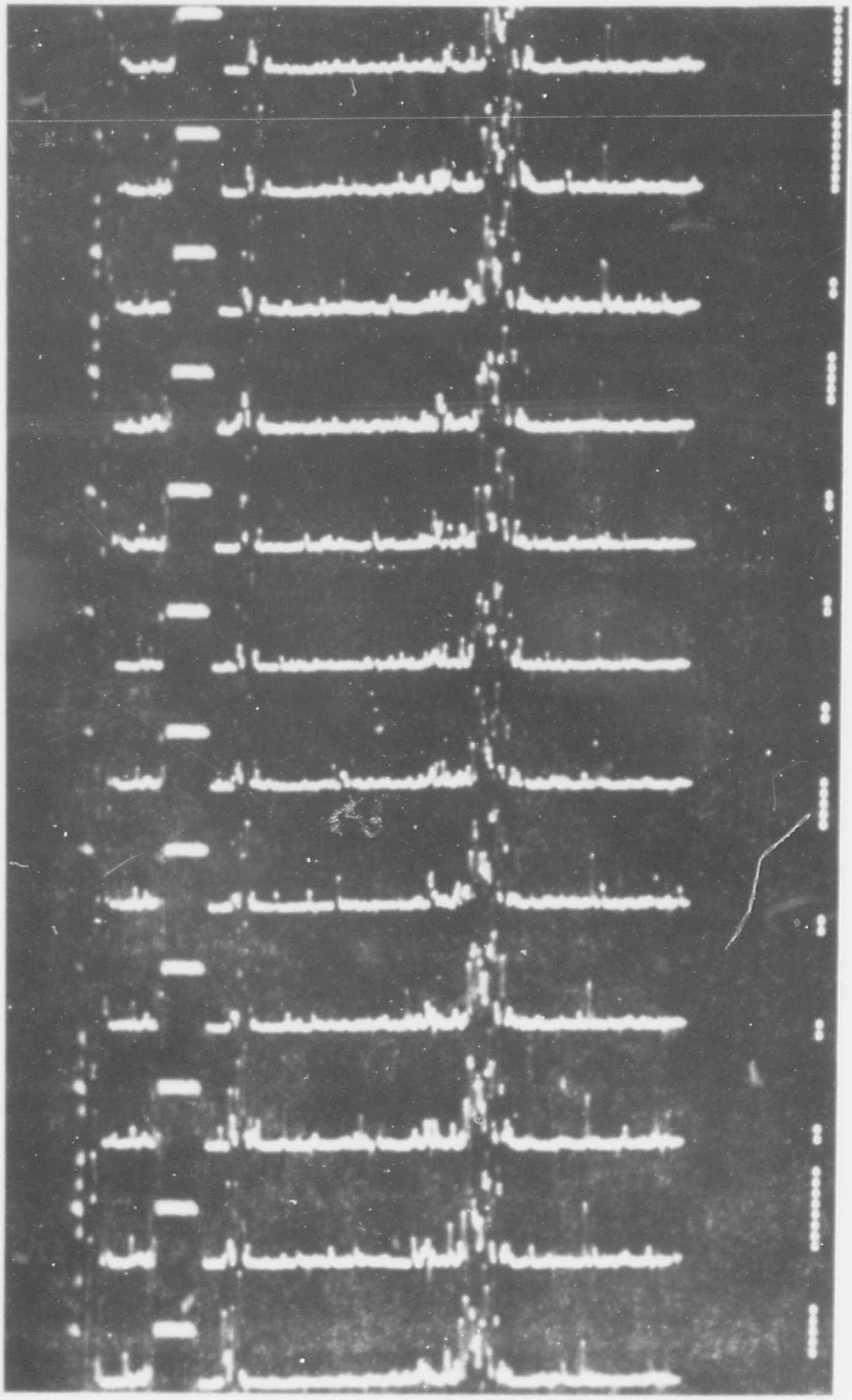


Figure 2-9. Continuous Recording of Vertically Polarized Signals Including Timing Marks. (1 MW peak power, 4 ms pulse vertical polarization, 100 NM sweep 155° Az, 0° el.)

2.9.2 Data Outputs

The external outputs available from the display unit, and their intended uses, are as follows:

1. Video output: 5-volt peak into 50 ohms - for the test scope.
2. I-f output: High level 10.7 megacycles just preceding the detector, 8 milliamps rms into 100 ohms - for future coherent operation.
3. I-f output: Low level out of mixer - for observing signal before it goes through bandwidth filter.
4. Range gate: 5-volts into 50 ohms - for expanded display of leading edge trigger output. Used for synchronizing external cameras to be installed later.
5. Main trigger: 5-volts into 50 ohms - for test equipment.
6. Range markers: 5-volts into 50 ohms - for test scope and external cameras as needed.
7. Attenuator settings: Three binary bits - for cameras.

2.9.3 Analog Recorder

The Brush Instrument model RD 1684-10 eight-channel recording system consists of an 8-channel thermal writing oscillograph, RD 2684-50; second timer, RD 5211-15; fixed gain amplifiers, RA 5681-02; and frame, power supply and rack. The amplifiers have 50 millivolts per millimeter of pen deflection sensitivity and single ended inputs.

The 8 channels record the following data:

1. Incident power
2. Reflected power
3. 35mm camera

4. Azimuth position

5. Elevation position

6. Azimuth error

7. Elevation error

8. Camera on

Internal one second time markers are recorded on the left side of the paper (Figure 2-10); lift-off indication is recorded on the right side.

2.9.4 Event Recorder

The Brush Instrument RA 1152-60 mobile rack contains a 30-channel event recorder RE 3303-10 which records "on-off" type data on a permanent strip chart. The styli respond to either the absence or presence ("on" or "off") of traces on the chart. The recorder records PRF, pulse length, bandwidth, sweep range, camera shutter indicator displays, film drives, manual-slave antenna pointing, time and PRS synch. The function of each channel is given in Table 2-2. A sample of the event recorder paper is shown in Figure 2-11.

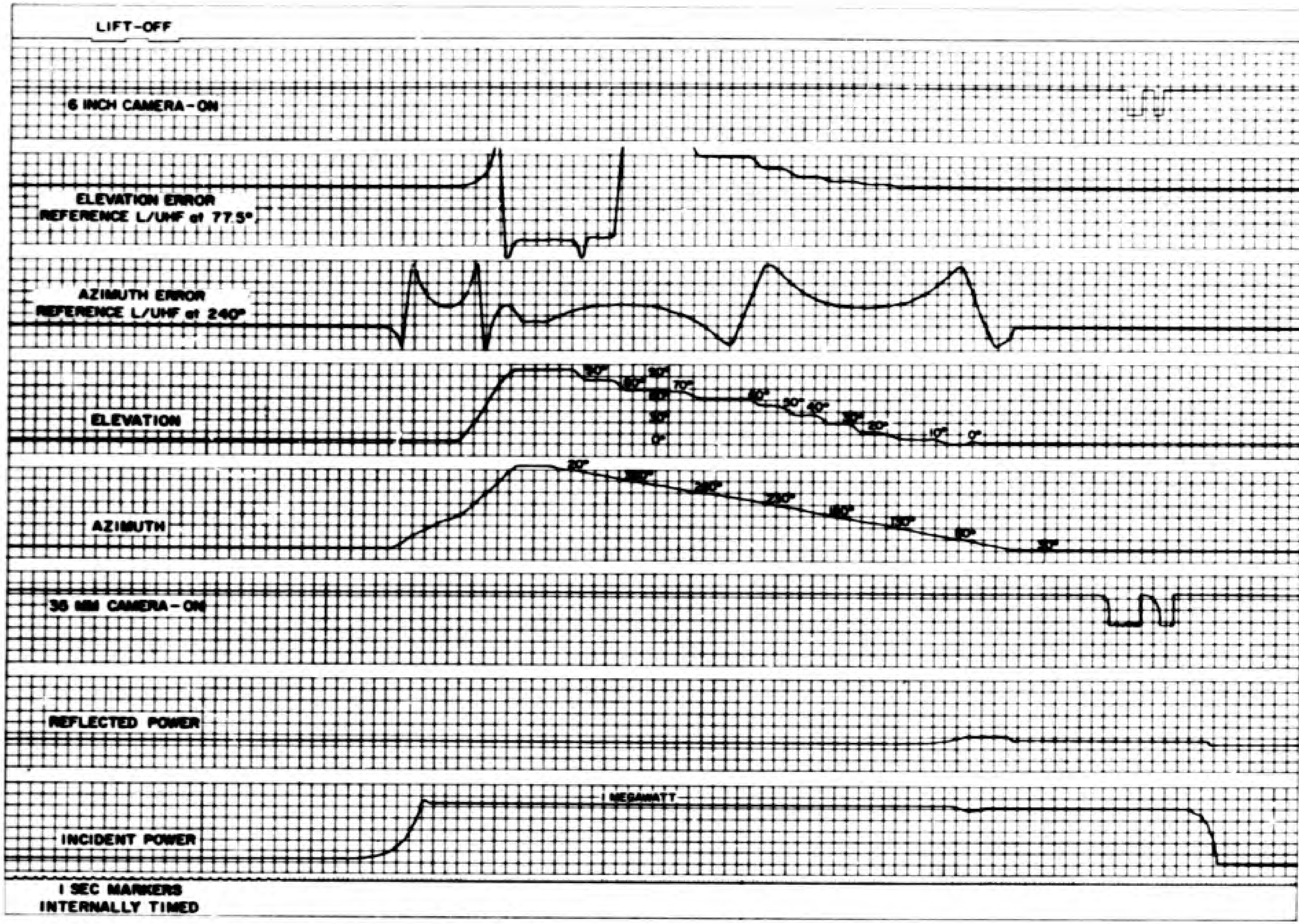


Figure 2-10. Sample of Analog Recording

Table 2-2. Event Recorder Channel Functions

Channel Function	Channel No.	Write	No Write
Camera Shutter Indicator Display 1 Expanded Range	1	Closed	Open
Camera Shutter Indicator Display 1 Full Range	2	Closed	Open
Camera Shutter Indicator Display 2 Expanded Range	3	Closed	Open
Camera Shutter Indicator Display 2 Full Range	4	Closed	Open
Camera On-Off Indicator Display 1 Expanded Range	5	Off	On
1 Full Range	6	Off	On
2 Expanded Range	7	Off	On
2 Full Range	8	Off	On
1 Second Time Bit (info not available)	9		
10 Second Time Bit (info not available)	10		
Display #1			
Main Range 50 miles	11 & 12	12	11
Main Range 100 miles	11 & 12	11	12
Main Range 200 miles	11 & 12		11 & 12

Table 2-2. Event Recorder Channel Functions (cont'd)

Channel Function	Channel No.	Write	No Write
Display #1 (cont'd)			
Vernier Range 5 miles	13 & 14	14	13
Vernier Range 10 miles	13 & 14	13	14
Vernier Range 20 miles	13 & 14		13 & 14
Bandwidth 1 μsec	15 & 16	16	15
Bandwidth 2.5 μsec	15 & 16	15	16
Bandwidth 5 μsec	15 & 16		15 & 16
PRF 400 pps	17 & 18		17 & 18
200 pps	17 & 18	18	17
100 pps	17 & 18	17	18
Pulse Width 1 μsec	19 & 20	20	19
2.5 μsec	19 & 20	19	20
5 μsec	19 & 20		19 & 20

Table 2-2. Event Recorder Channel Functions (cont'd)

Channel Function	Channel No.	Write	No Write
Display #2			
Main Range 50 miles	21 & 22	22	21
Main Range 100 miles	21 & 22	21	22
Main Range 200 miles	21 & 22		21 & 22
Vernier Range 5 miles	23 & 24	24	23
Vernier Range 10 miles	23 & 24	23	24
Vernier Range 20 miles	23 & 24		23 & 24
Bandwidth 1 μsec	25 & 26	26	25
Bandwidth 2.5 μsec	25 & 26	25	26
Bandwidth 5 μsec	25 & 26		25 & 26
Internal External Sync	27	Internal	External
Antenna Operation	28	Auto &	Manual
Lift Off (Manual Switch)	29	Standby	Lift Off
35 mm Camera	30	Off	On

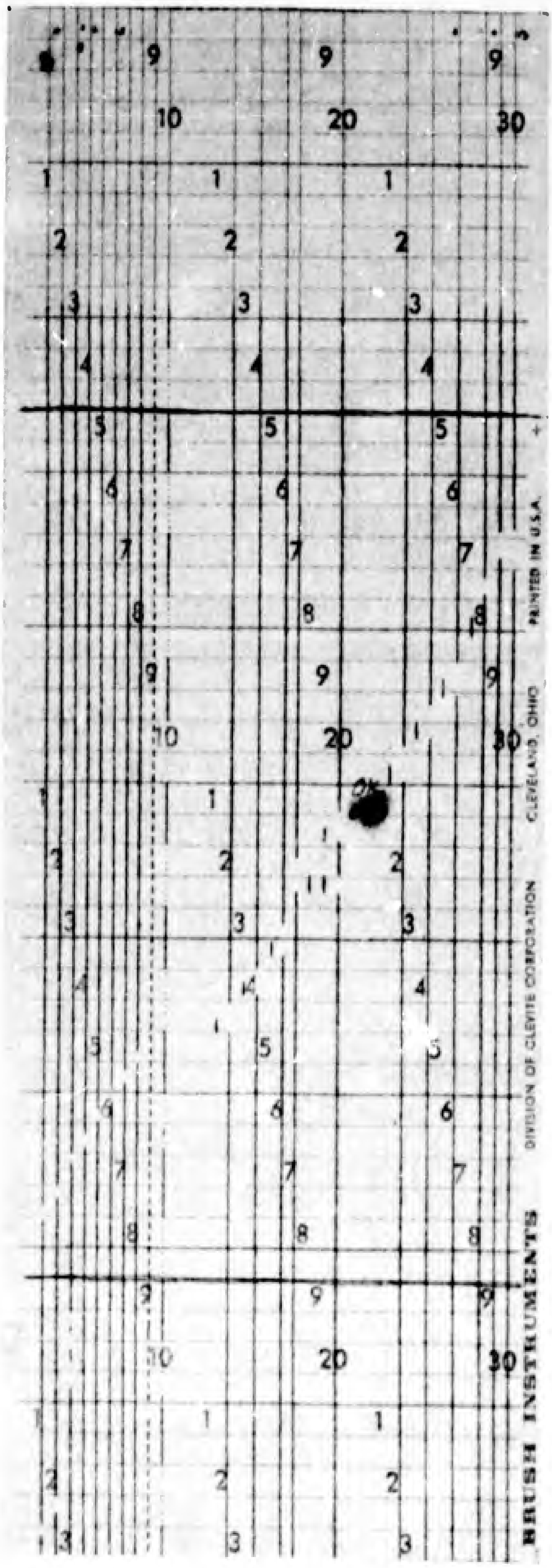


Figure 2-11. Sample of Event Recorder Paper

SECTION 3.0

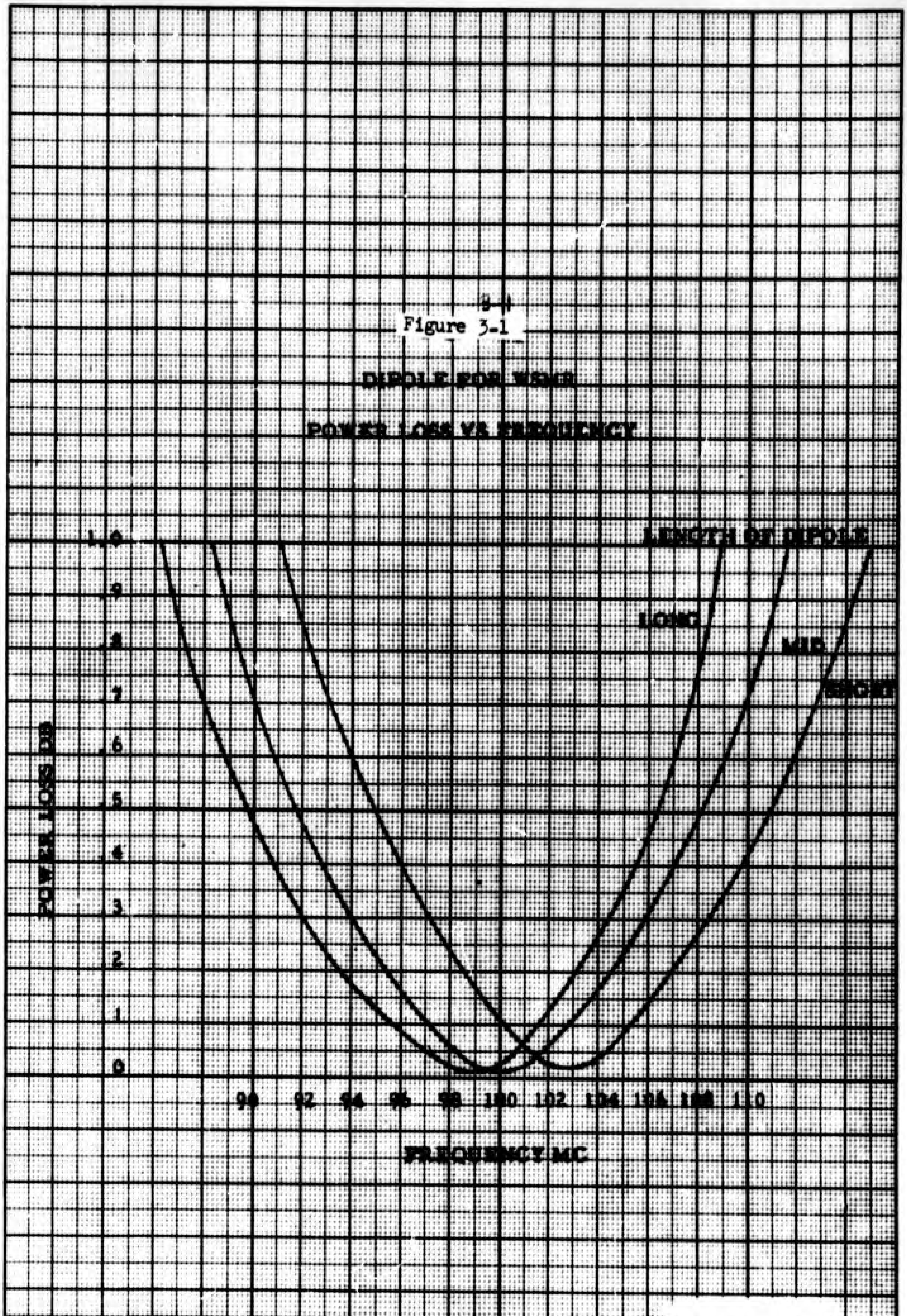
SYSTEM CALIBRATION

3.1 GENERAL

Standard antennas were installed for use in periodically checking and measuring the VHF radar system calibration. In essence, the equipment consists of two towers, one used as a transmitting source and the other as a reference located closer to the VHF antenna for the purpose of calibrating out spurious reflections. The equipment was designed to be shipped in several small packages when disassembled, and was primed and painted white according to requirements at the White Sands Missile Range.

Two standard dipoles, which can be rotated 90° for vertical and horizontal polarization, are mounted on 12 x 12 foot reflector screens. The standard antenna used as a transmitting source is mounted 1000 feet in front of the yagi array at an angle of 220 degrees from the array. Its center is 20 feet above ground. The second standard dipole, which is 12 feet above ground, is used as a reference for the yagi array. It is mounted approximately 40 feet from the yagi on a line perpendicular to the line between the yagi and the transmitting standard. The dipoles are adjustable in length by means of a sliding cap on the dipole ends. Measurements were made at the laboratory from which the power loss was calculated and plotted (Figure 3-1) for maximum, center and minimum dipole lengths.

Figure 3-1


POWER LOSS VS FREQUENCY
LENGTH OF DIPOLE
LONG
MID
POWER LOSS DB
FREQUENCY MC

Both dipoles are connected to the building by armored 214U cable entrenched approximately one foot deep. The cable to the transmitting antenna is separated from the receiving cable to eliminate direct feedthrough. The reference dipole located close to the yagi array may be lowered using a permanent winch. Figure 3-2 is a layout of the over-all calibration equipment and Figure 3-3 a schematic diagram of the equipment in the VHF radar building. The inside connections permit a pulsed signal generator, which is part of the normal station test equipment, to be connected to the transmitting dipole which then radiates toward the array. The transmit cable goes directly to the test bench where the oscillator is located. The coaxial switching arrangement is installed in the lower section of the camera control cabinet adjacent to the displays.

Receivers 1 and 2 (Figure 3-3) can be switched to receive the signal from either the calibration array or the normal yagi being checked. The absolute gain of the yagi being checked can be obtained by comparing the signals received at these two positions.

3.1.1 CALIBRATION METHOD USED

The gain of the standard dipoles was determined by the "two antenna system", in which two identical scale models were constructed and tested at 700 mc. Field intensity patterns, impedance and gain measurements were made, with the scaled antennas permitting a better approximation of the conditions necessary for making an absolute gain determination. As a result of

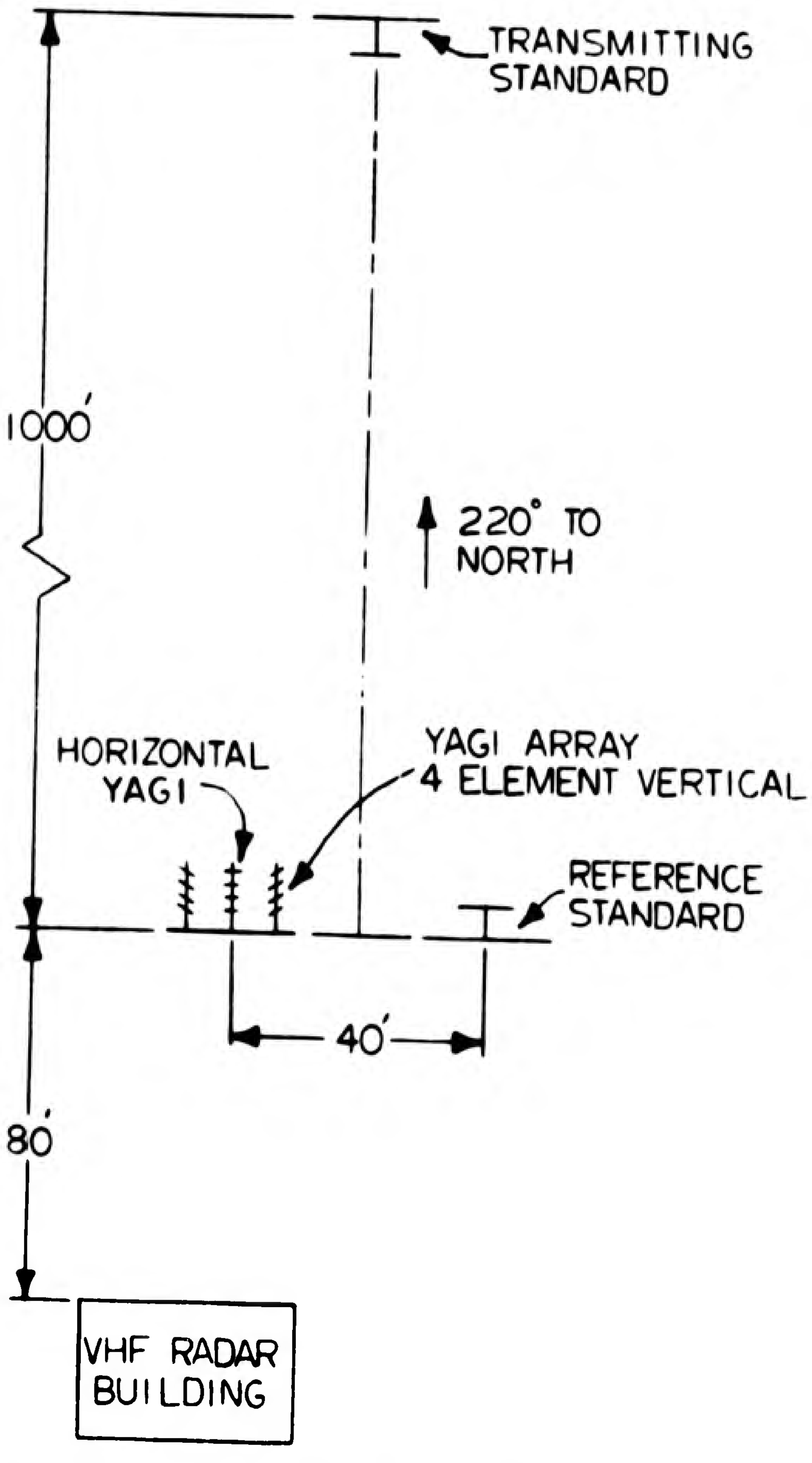


Figure 3-2. Calibration Antenna Layout

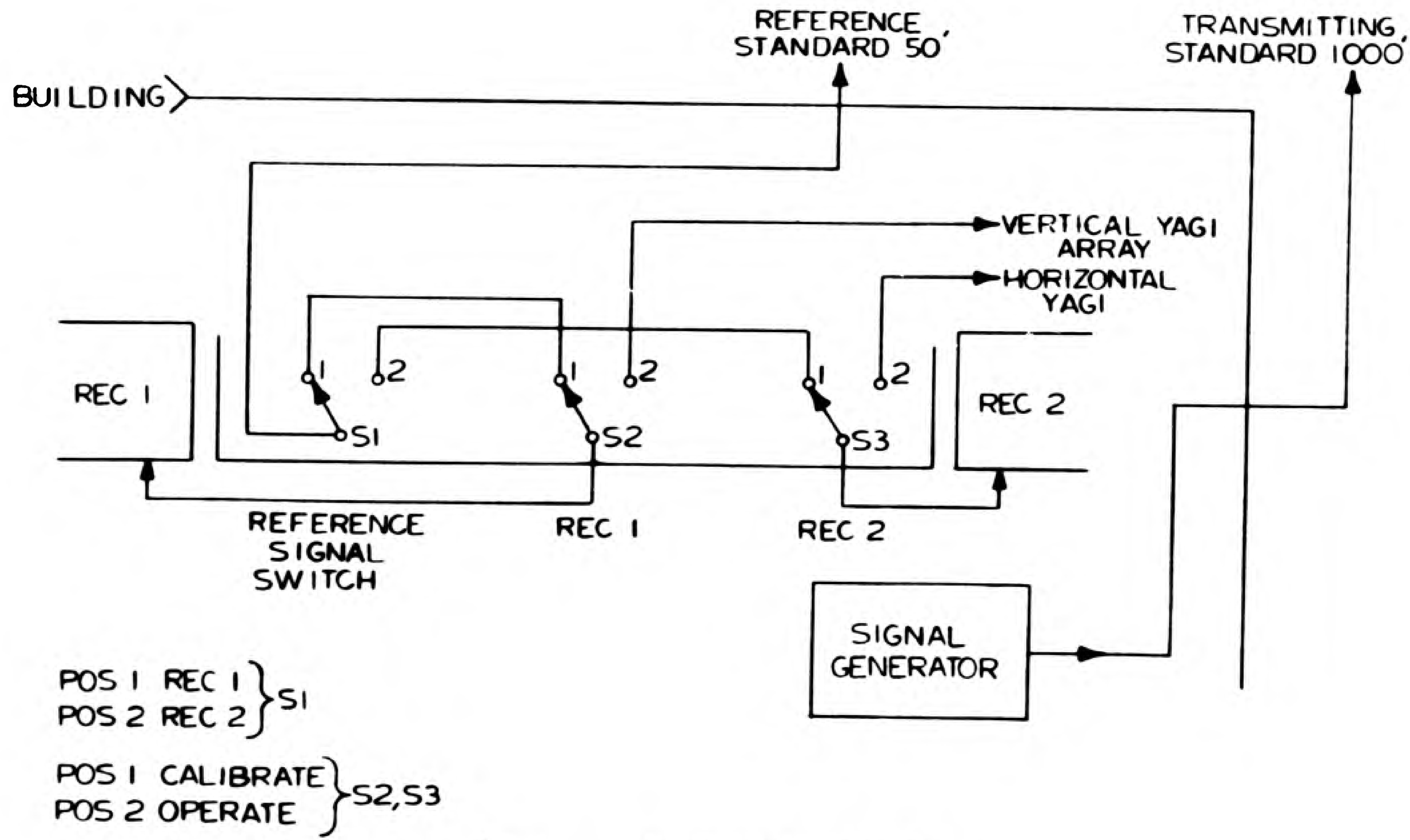


Figure 3-3. Cabling and Switches Inside VHF Radar Building

these tests, the two identical dipoles mounted on 12 by 12 foot reflection screens were constructed.

The gain of the radar yagi antenna is measured by a direct substitution method, i. e., substitution of the reference standard for the yagi. The transmitting standard located 1000 feet from the yagi is a source of energy for both the yagi and the reference standard to which it is compared. Since the path between the yagi and the transmitting standard is essentially the same as that between the reference standard and the transmitting standard, reflections from the ground, absorption etc. may be neglected in the comparative measurement.

3.1.2 ANTENNA PATTERNS

To obtain the required antenna patterns a CW signal source was used to apply energy to the transmitting source located 1000 feet in front of the yagi array. Point by point patterns were made on the yagi array as it was rotated on its mount. Since the point to point method was time consuming, the signal intensity on the transmitter array was continuously monitored by the reference standard situated close to the yagi, to avoid drift errors during data-taking. Both vertical and horizontal polarization patterns of the yagi array were taken.

The vertical readings were taken in increments of 3 degrees through elevations of 15 degrees; in increments of 5 degrees from 15 degrees through 30 degrees; and in increments of 10 degrees from 30 degrees through 60 degrees.

The number of points taken in azimuth varied according to lobe structure, and in many instances were required every 5 degrees to achieve accurate definition. These measurements resulted in 12 patterns of the total azimuth coverage for the elevation angles indicated.

For horizontal polarization patterns, only the single yagi element of the radar was involved. In order to run these patterns, the transmitting element at the 1000 foot point was rotated to horizontal polarization and again azimuth patterns were taken for the following 12 elevation angles:

0°, 3°, 6°, 9°, 12°, 15°, 20°, 25°, 30°, 40°, 50°, and 60°.

Elevation patterns were then taken for both antennas of the array at fixed azimuth positions.

The patterns discussed in this section constitute the fundamental antenna pattern information required for the radar. After the patterns were taken, a measurement of the cross polarization gain of the antennas was made. That is, with the transmitting source radiating in vertical polarization, the energy received in the horizontal was measured.

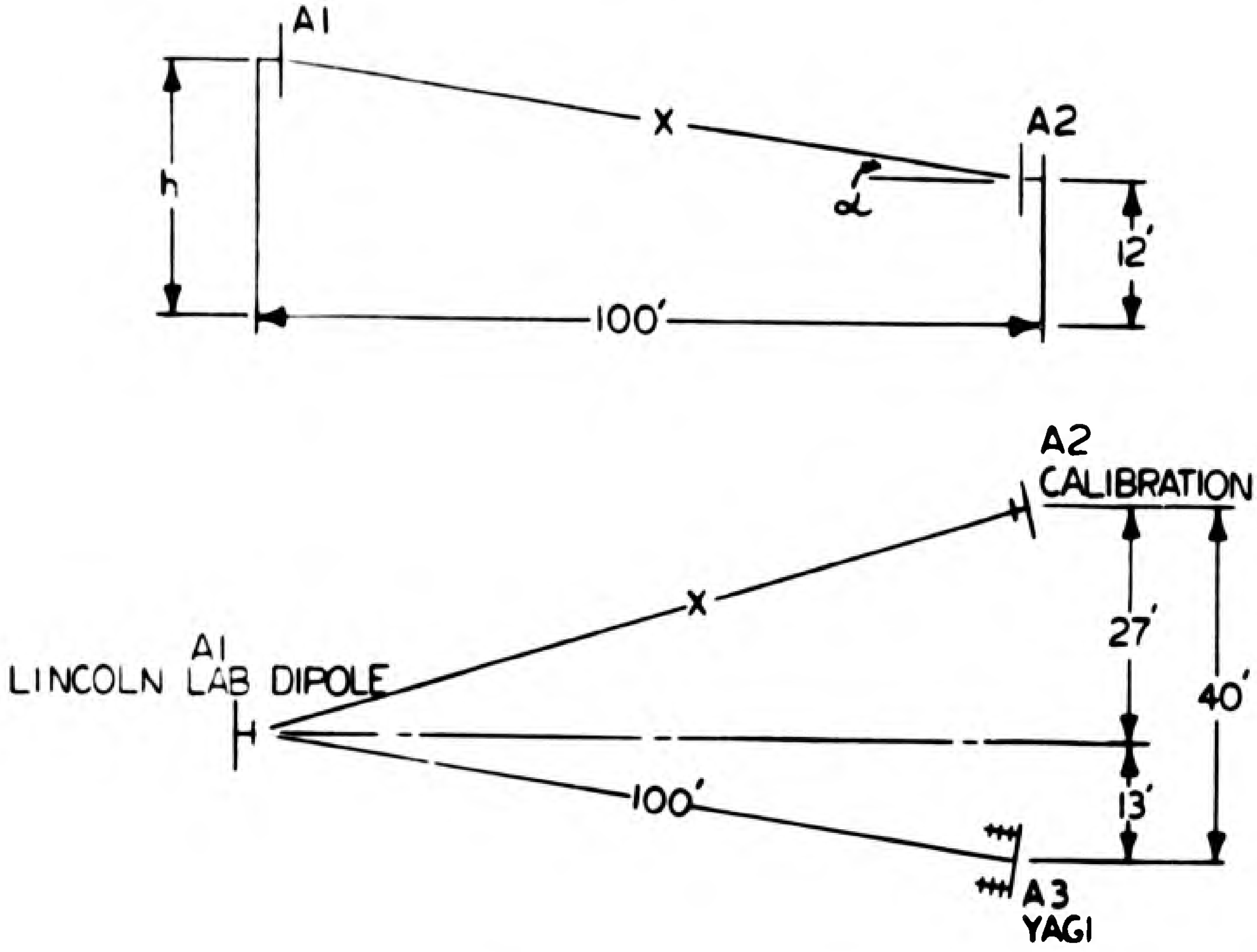
SECTION 3.2

CALIBRATION OF STANDARD ANTENNAS

3.2.1 MEASUREMENTS USING ISOTROPIC DIPOLE

Prior to the tests using two identical antennas, measurements were made using the Lincoln Laboratory dipole without a reflector, mounted at various heights on a temporary wooden pole located 100 feet in front of the VHF yagi antenna. The placement of one calibration antenna 40 feet from the yagi resulted in the triangular arrangement shown in Figure 3-4, with a distance of 104 feet between the Lincoln Laboratory dipole and the calibration antenna. Transmission loss was measured at three heights between the Lincoln Laboratory antenna and the calibration antenna in an untilted position. The transmission loss between the Lincoln Laboratory dipole and the yagi was also measured. Results are shown in Table 3-1.

The transmission distance X was calculated for the various heights for both the tilted and untilted positions. As shown in Figure 3-5, a block diagram of the test measurement setup, a reference of 54 db was set into the Arenberg Ultrasonic Lab attenuator. Using appropriate attenuator pads for isolation, a reference on the General Radio detector was recorded when Points A and B were connected. The cable losses were as follows: 11.2 db for the cable to the Lincoln Laboratory dipole; 3 db for the cable to the calibration antenna; and 6 db at 101 mc for the cable to the yagi plus the TR device.



h	X	α
36	106.3	13.0
24	104.3	6.6°
13	103.6	0°

X UNTILTED DISTANCE

Figure 3-4. Antenna Calibration Dipole Without Reflector

Table 3-1. Transmission Loss Between Lincoln Laboratory Dipole Without Screen Mounted on Wooden Pole, and (1) 12-foot High Calibration Antenna, (2) Yagi.

Freq. (mc)	Ht. of Lincoln Lab Dipole (ft)	Receiving Antenna	Ground Dist. (ft.)	Direct Path Dist., X (ft)	Tilt (T) or Untilt (U)	Measured Transmission Loss (db)
101	36	cal	103.6	106.3	U	31.8
	36	cal	103.6	109.1	T	31.7
	36	yagi	100.8	102.6	T	27.0
	24	cal	103.6	104.3	U	31.7
	24	cal	103.6	105.7	T	31.6
	24	yagi	100.0	100.6	T	22.7
	13	cal	103.6	103.6		33.4
	13	yagi	100.0	100.0		24.0
99	36	cal	103.6	106.3	U	31.6
	36	cal	103.6	109.1	T	30.3
	36	yagi	100.0	102.6	U	26.0
	36	yagi	100.0	102.6	T	26.0
	24	cal	103.6	104.3	U	30.6
	24	cal	103.6	105.7	T	30.3
	24	yagi	100.0	100.6	T	22.2
	13	cal	103.6	103.6		33.0
	13	yagi	100.0	100.0		23.8
103	36	cal	103.6	106.3	U	31.8
	36	cal	103.6	109.1	T	32.0
	36	yagi	100.0	102.6	U	27.3
	36	yagi	100.0	102.6	T	27.3
	24	cal	103.6	104.3	U	30.8
	24	cal	103.6	105.7	T	30.6
	24	yagi	100.0	100.6	U	24.4
	24	yagi	100.0	100.6	T	25.0
	13	cal	103.6	103.6		33.7
	13	yagi	100.0	100.0		24.4

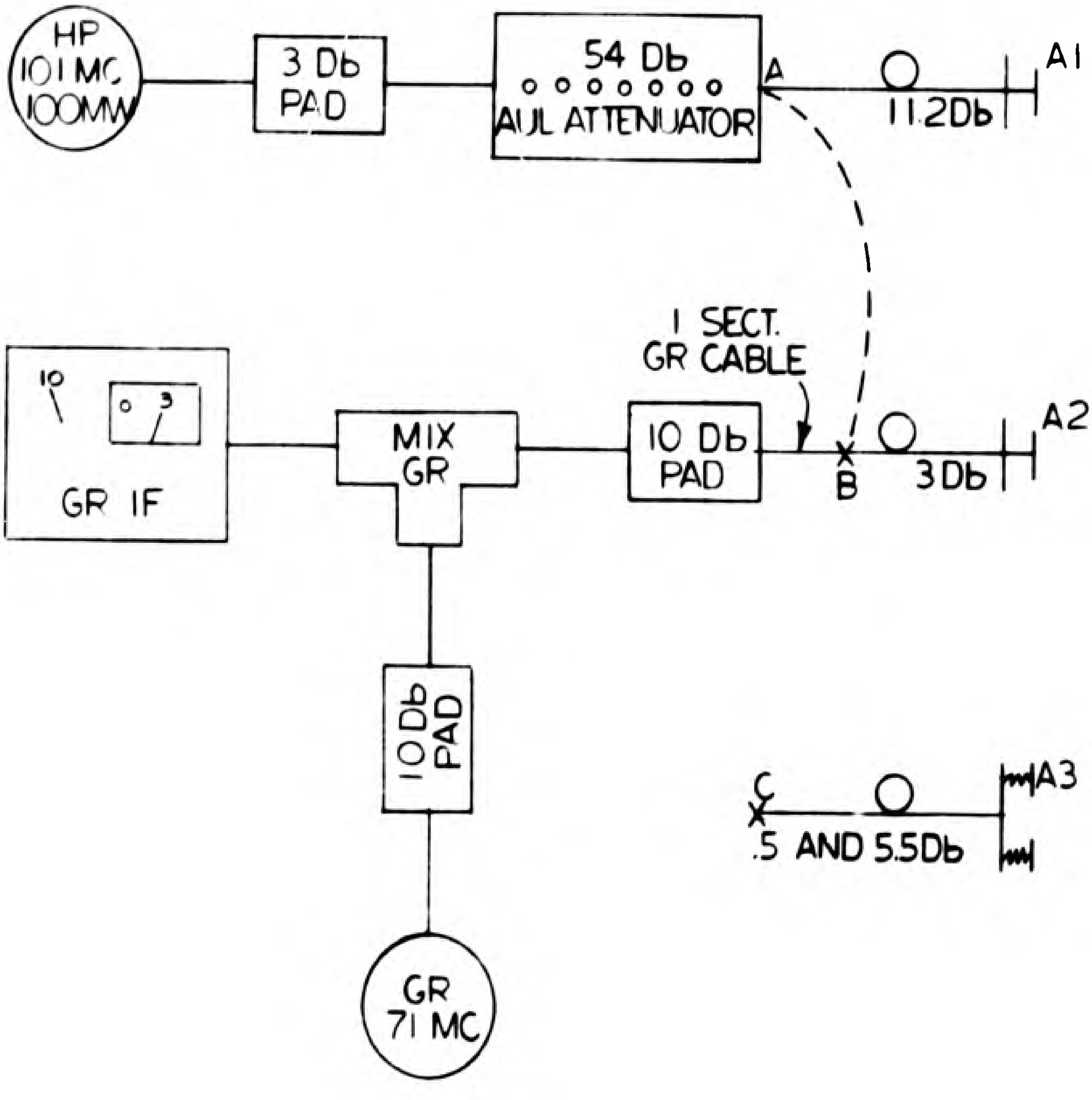


Figure 3-5. Test Set Up to Measure Transmission Loss

3.2.2 MEASUREMENTS USING TWO ANTENNA SYSTEM

The second series of tests was performed using both calibration antennas. The 20-foot high calibration antenna was positioned 29 feet in front of the yagi and the other as shown in Figure 3-6. The direct path distances(X) were calculated and recorded as shown inthe table of Figure 3-6. Transmission losses were measured between antennas A1 and A2, and between A1 and yagi A3 at three frequencies: 99mc, 101mc, and 103mc. A2 and A3 were then tilted toward A1 and the transmission loss was again recorded for the three frequencies. Calibration antenna A2 was replaced by the Lincoln Laboratory dipole with a screen and measurements were taken and recorded as before. Results are tabulated in Table 3-2.

The test measurement setup described in paragraph 3.2.1 was used again to determine cable loss, and a reference recorded when points A and B were connected as shown in Figure 3-7. The loss of the 25.5 foot cable to antenna A1 was measured to be 7.2 db.

3.2.3 TEST RESULTS

The transmission loss (less the cable loss) results shown in Table 3-1 for the measurements relative to the Lincoln Laboratory dipole at 100 feet are comparable to the measurements made by Lincoln Laboratory personnel.[1]

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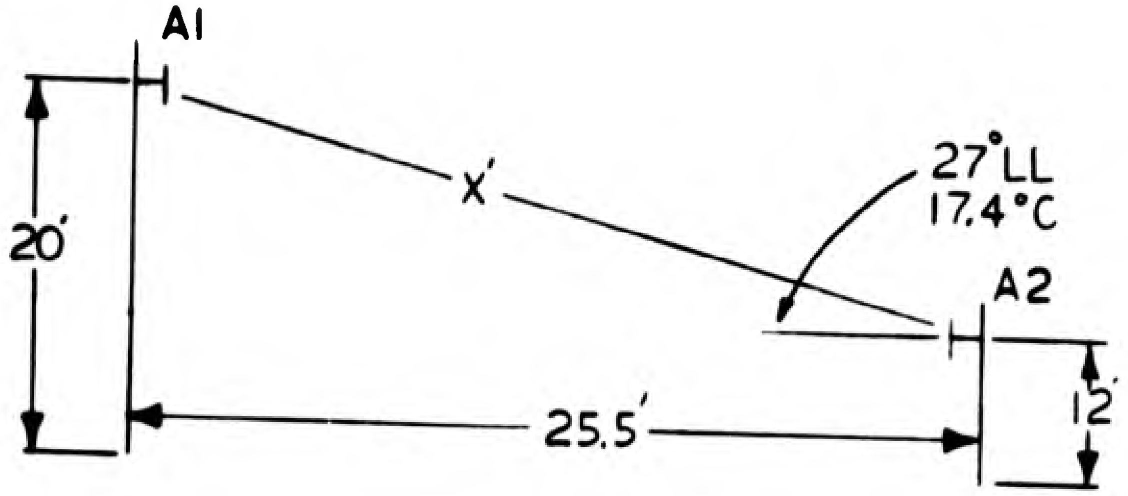
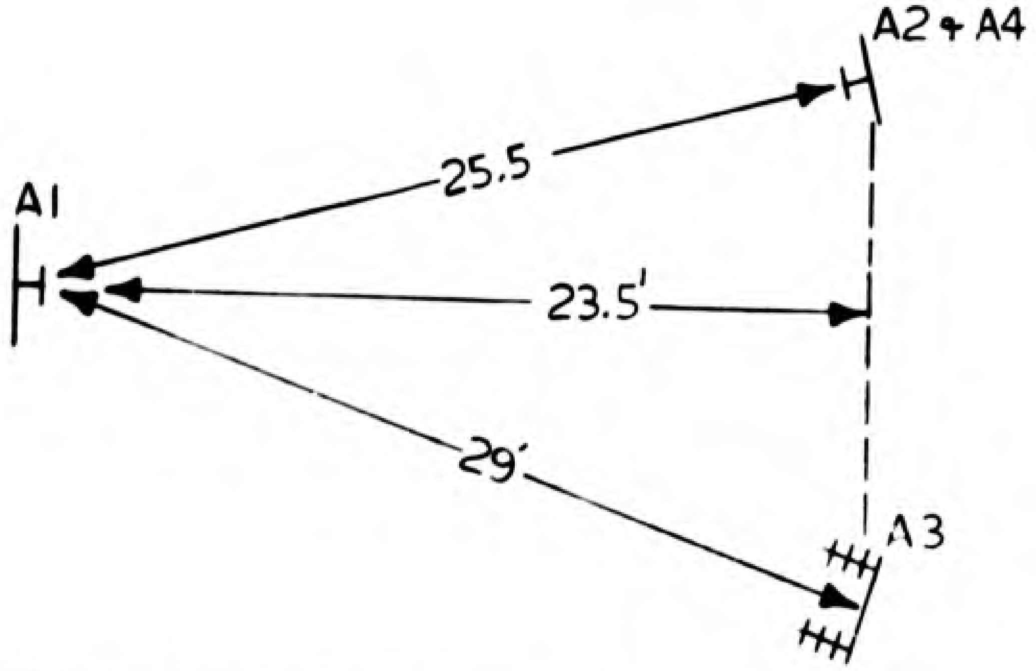
1. André R. Dion, "Gain and Pattern Measurements of VHF Stallion Antenna", M.I.T. Lincoln Laboratory memo, 10 October 1963





ANT	X	X	α
C	26.7	29.5	17.4°
LL	28.6	31.5	27°
YAGI	30.1	30.1	

Figure 3-6. Antenna Calibration
Two Identical Antennas

Table 3-2. Transmission Loss Between Standard 20-foot High Calibration Antenna, and (1) 12-foot High Calibration Antenna, (2) Yagi, and (3) Lincoln Laboratory Dipole with Screen

Freq. and Polariz.	Receiving Antenna	Ground Dist. (ft)	Direct Distance (ft)	Antenna Ht. (ft)	Tilt (T) or Untilt (U)	Measured Transmission Loss (db)
101 mc Vertical	cal	25.5	26.7	12	U	18.6
	cal		29.5		T	19.0
	LL	25.5	28.6	7	U	20.8
	LL		31.5	7	T	19.7
	yagi	29.0	30.1	12	U	17.2
	yagi	29.0	30.1	12	T	11.0
99 mc Vertical	cal	25.5	26.7	12	U	20.3
	cal		29.5		T	18.4
	LL	25.5	28.6	7	U	20.9
	LL		31.5	7	T	19.0
	yagi	29.0	30.1	12	U	16.6
	yagi	29.0	30.1	12	T	11.2
103 mc Vertical	cal	25.5	26.7	12	U	20.3
	cal		29.5		T	19.9
	LL	25.5	28.6	7	U	21.8
	LL		31.5	7	T	20.6
	yagi	29.0	30.1	12	U	16.0
	yagi	29.0	30.1	12	T	10.7

Table 3-2. Transmission Loss Between Standard 20-foot High Calibration Antenna, and (1) 12-foot High Calibration Antenna, (2) Yagi, and (3) Lincoln Laboratory Dipole with Screen (cont'd)

Freq. and Polariz.	Receiving Antenna	Ground Dist. (ft)	Direct Distance (ft)	Antenna Ht. (ft)	Title (T) or Untilt (U)	Measured Transmission Loss (db)
101 mc Horizontal	cal	25.5	26.7	12	U	19.0
	cal		29.5		T	20.5
	LL	25.5	28.6	7	U	23.3
	LL		31.5	7	T	21.4
	yagi	29.0	30.1	12	U	19.7
	yagi	29.0	30.1	12	T	18.5
99 mc Horizontal	cal	25.5	26.7	12	U	18.9
	cal		29.5		T	20.0
	LL	25.5	28.6	7	U	22.8
	LL		31.5	7	T	21.3
	yagi	29.0	30.1	12	U	19.4
	yagi	29.0	30.1	12	T	18.8
103 mc Horizontal	cal	25.5	26.7	12	U	18.8
	cal		29.5		T	20.8
	LL	25.5	28.6	7	U	24.5
	LL		31.5	7	T	22.4
	yagi	29.0	30.1	12	U	19.8
	yagi	29.0	30.1	12	T	18.2

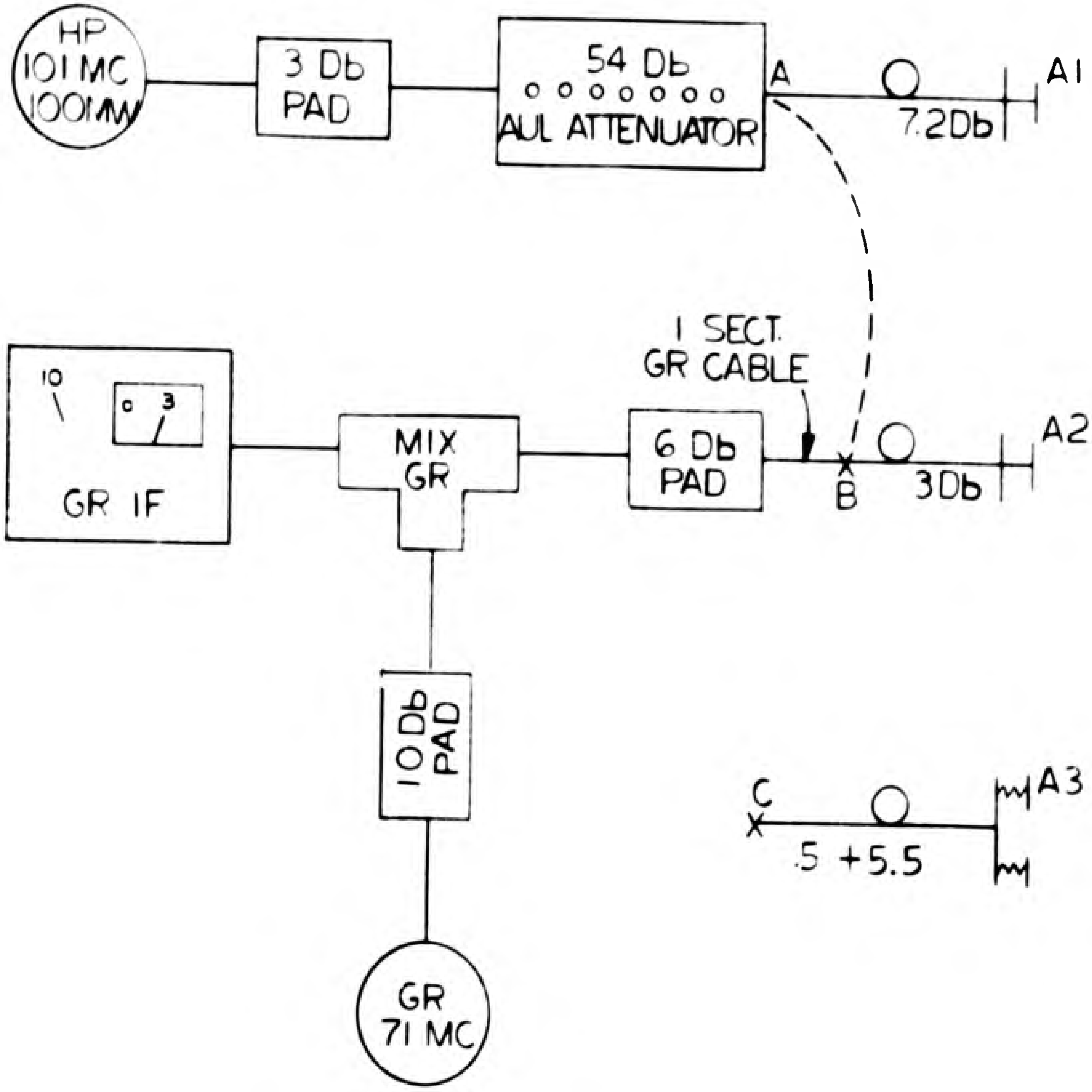


Figure 3-7. Test Set Up To Measure Transmission Loss

The losses given in the table for the untilted calibration antenna as a receiver correspond closely to the expected free space losses, namely 33.1 for the transmitter at 36 feet, 32.9 for the transmitter at 24 feet and 32.8 for the transmitter at 13 feet. It appears therefore that the reflected wave from the ground is of little consequence in this case. That this is indeed true can be seen from a consideration of the actual performance of the reflection coefficient for the vertically polarized waves in the neighborhood of the following reflection angles achieved during this experiment.

Reflection Angle	Antenna Height (feet)
13.5^{o}	13
19.2^{o}	24
24.8^{o}	36

Based on the best available information, normal values of soil conductivities in the area of the radar site are from 2×10^{-3} to 4×10^{-3} mks, and relative dielectric constants are between 4 and 10, with the most likely value being in the neighborhood of 4 or 5.

In the following equations, the reflection coefficient is designated as $R = r/\underline{\rho}$, where r is the ratio of magnitude of reflected and incident waves and ρ is the modification of the phase produced by the imperfections of the earth. The exact value of the reflection coefficient depends upon the dielectric constant and conductivity of the earth, the frequency, and the angle of incidence with which the wave strikes the surface of the earth, according to the relations

Vertical Polarization:

$$\frac{\text{Reflected wave}}{\text{Incident wave}} = r/\underline{\rho} = \frac{\epsilon' \sin \psi_2 - \sqrt{\epsilon' - \cos^2\psi_2}}{\epsilon' \sin \psi_2 + \sqrt{\epsilon' - \cos^2 \psi_2}}$$

Horizontal polarization:

$$\frac{\text{Reflected wave}}{\text{Incident wave}} = r/\underline{\rho} = \frac{\sqrt{\epsilon' - \cos^2\psi_2} - \sin \psi_2}{\sqrt{\epsilon' - \cos^2\psi_2} + \sin \psi_2}$$

where ψ_2 = angle of incidence.

$\epsilon' = \epsilon - j6\sigma\lambda \times 10^{12}$

ϵ = dielectric constant of earth (air taken as unity).

σ = earth conductivity (emu).

λ = wave length, meters.

$j = \sqrt{-1}$

The parameter "X" evaluated for the conductivities described above has values ranging from 0.36 to 0.72.[2] We observe that for reflection angles between 15 and 45 degrees, the reflection coefficient for vertically polarized waves is less than 0.2 and if the dielectric constant were 10, the reflection coefficient for angles between 14 and 22 would be less than 0.1. These results hold relatively independently of the ground conductivity as long as it is not excessive. What is in fact occurring is that at the intermediate

2. F. E. Terman, Radio Engineer's Handbook, Sect. 10, para. 5, Figs. 26a, 26b, 26c, McGraw-Hill Book Co., New York, 1943, pp. 700-705

grazing angles encountered in the 100 foot measurements, the reflected wave is almost exactly at the Brewster's angle and can expect to be greatly attenuated. It is interesting to note that theoretical calculations attempting to take the ground reflection into account, produce only small improvements over experimental results, although the trend of the data seems to favor the lower dielectric constant.

Also in connection with Table 3-1, it may be seen that at the lowest transmitting antenna heights, the difference between the calibration antenna loss and the radar yagi antenna loss is about correct, namely about 9 or 10 db. This correspondence breaks down at the higher transmitting antenna heights. This is of course due in part to variations in angle of arrival for the considerably smaller component of the reflected wave. The 29 foot data shown in Table 3-2 presents in general the same picture. The agreement of the apparent measured relative gains of the calibration antenna and the yagi for vertical polarization is again a consequence of the fact that the reflection coefficient for vertical polarization is never extremely large. The disagreement for horizontal polarization reflects again the fact that the reflection coefficient for horizontally polarized waves remains large for the angles in the neighborhood of 30 or 40 degrees encountered in this configuration.

An extensive calculation was undertaken for one particular case in this configuration, namely that of untilted antennas and vertical polarization in an attempt to ascertain the efficiency of the ground planes utilized with the calibration antenna. This calculation yielded consistent results within the degree of uncertainty generated by the ground conditions and bore out the hypothesis utilized for the 100 foot calculations that the calibration antenna gain could be taken as 7.5 db with a probable error of somewhat less than 1/4 db. The gain of this antenna is slightly less than the theoretical maximum of 8 db inasmuch as the ground plane screen is somewhat larger than optimum.

The 1000 foot data in Table 3-3 presents an interesting study. It is normally assumed that vertical polarization will undergo less path loss over a nearly grazing path than will horizontal polarization. However, for the measurements at hand this appears to be the reverse. If, however, reference is made to the values in the reflection coefficient expected for the grounds at the site, the agreement between predicted and actual path losses are reasonably good. For example, theoretically the transmission loss for a ground with a dielectric constant of 5 should be 57.3 db for horizontal polarization and 57.8 db for vertical polarization. Again considering the uncertainties of the ground, and in particular a certain degree of difficulty induced by the departure of the ground from perfect level, the concordance appears to be quite adequate. It is of interest in this regard that a small but quite noticeable ground wave is present for the vertically polarized case. This ground wave makes a very small difference and is partly responsible for the slight lowering of the vertically polarized transmission. Estimation of the magnitude for this type of case is extremely difficult inasmuch as the launch conditions are ill defined. However,

Table 3-3. Transmission Loss at 101 Megacycles Between (1) Transmitting Standard and Reference Standard and (2) Transmitting Standard and Yagi

Transmitting Standard (12 ft. high at 1000 ft.)	Receiving Antenna	Measured Loss (db)	Cable Loss (db)	Measured Transmission Loss (db)
Vertically Polarized	Reference Standard	86.0	26.8	59.2
	Yagi (Vertical)	77.8	29.8	48.0
	Yagi (Horizontal)	115.0	28.6	86.4
Horizontally Polarized	Reference Standard	83.6	26.8	56.8
	Yagi (Horizontal)	81.8	28.6	53.2

the measured transmission losses agree with those predicted by the formula of Josephson and Blomquist.[3]

3.2.4 CONCLUSIONS

The conclusions drawn from the results of these preliminary experiments may be summarized as follows:

1. The calibrating antenna can be considered to have a gain of 7.5 db with an error of less than 0.25 db.

2. Ground effects can be taken into account with an error of less than about 1 db, by assuming a dielectric ground of relative dielectric constant form.

In these terms it appears that the equipment as set up will calibrate the gain of the radar antenna, which is 18.7 db, to within 1 db. The horizontal yagi gain is 10 db ± 1 db.

3. A. Blomquist, "Local Ground Wave Field Strength Variations in the Frequency Range 30 - 1000 MHz", Electromagnetic Wave Propagation, edited by M. Desirant and J. L. Michiels, Academic Press, New York, 1960, Eq. (1), p. 127

SECTION 3.3

CALIBRATION PROCEDURES

3.3.1 DAILY OPERATING PROCEDURES

Normal daily checkout of the equipment includes the procedures listed below which should be accomplished daily as well as before the pre-flight count-down when a mission is scheduled. The procedures are based on the daily check made during the year following installation, and may change according to changes in the installation. Table 3-4 gives a typical set of meter readings which were taken for the conditions prevailing on December 31, 1963.

1. Turn on 400 cycle power unit, allowing 20 to 30 minutes for stabilization.
2. Turn on test equipment and place on standby.
3. General check of station: Check operation of air conditioner or heating unit, water supply and radio station. Also inspect for damage caused by water, sand or wind, and for the entrance of sand or water into the building.
4. Check antenna mount and array for wind damage or any obstruction to operation.
5. Check power unit output for 116 volts, turn on 400 cycle power to system, and turn on synchronizer.
6. Turn on antenna control, display no. 1 and display no. 2.
7. Turn antenna position to zero elevation and rotate in azimuth observing display units for interference.
8. Make minimum discernable signal checks on both display units and record if abnormal.

Table 4-4. Typcal Meter Readings for Operation of Antenna Calibration Equipment*

Meter	5 μsec Pulse		2.5 μsec Pulse		1 μsec Pulse	
	Grid	Plate	Grid	Plate	Grid	Plate
Driver Ampl. 1	0.5 ma	5 ma	0.5 ma	2.5 ma	0.5 ma	2.5 ma
Driver Ampl. 2	1.8 ma	6 ma	1 ma	2.5 ma	0.5 ma	2.5 ma
Final Ampl.	4.5 ma	23 ma	2.25 ma	12 ma	1.5 ma	12 ma
Modulator	2.6 kv	6.9 ma	2.5 kv	3.6 ma	2.8 kv	2.25 ma
HV Power Supply	6.5 kv	155 ma	6.7 kv	84 ma	8 kv	100 ma

*Data was taken on 31 December 1963 with a pulse repetition rate of 100 p.p.s. and a power meter reading of 10 (1 megawatt peak).

9. Turn on cooling and pressurizing system and check pressure gauge in transmitter.

10. Turn on transmitter filaments. Check meters on transmitter for normal operation.

11. Switch coaxial switch to dummy load.

12. Check cooling system to dummy load.

13. Turn on preamplifier modulator after checking that output control of MODULATOR VOLTAGE ADJ is set fully counterclockwise.

14. Set pulse rate switch (P. R. F.) to 100pps with a 5 microsecond pulse.

15. After READY light of preamplifier modulator and transmitter turns on, turn on preamplifier modulator. Turn up preamplifier output control to 2.5 kv; current should read 6.75 milliamperes.

16. Check that high voltage variac is fully counterclockwise, and turn on high voltage.

17. Turn up high voltage variac slowly to approximately 1/2 power, checking the high voltage supply and transmitter meters and the output meter on the display for normal indications. If abnormal indications are observed, turn down power and check for trouble. Leave transmitter at 1/2 power for approximately 5 minutes, then turn up to full power.

18. Turn down high voltage on transmitter and preamp modulator and change pulse width to a 2.5 microsecond pulse. Repeat steps 15, 16 and 17.

19. Turn down power as above, change pulse width to 1 microsecond and repeat steps 15 through 17. Turn down power, after operation, to standby.

20. Obtain permission to radiate from frequency control.

21. Switch coaxial switch to antenna output and point antenna down range.

22. Turn up transmitter power as described above. During time transmitter is at approximately 1/2 power, check spark gaps to be sure they are firing.

23. With transmitter turned up to full power, turn antenna to 140° in azimuth and observe Holloman echo for normal reception.

24. Operate transmitter on all pulse widths for approximately 15 to 20 minutes for each pulse width.

25. Operate cameras and check shutter operation.

3.3.2 PRE-FLIGHT COUNTDOWN

Prior to a scheduled flight, approximately four hours should be allowed for checking and calibration of the radar. This countdown must be preceded by the performance of the daily operating procedures described in section 3.3.1.

-8 hours or more	1. Determine the mission status, and obtain the code word and operating instructions such as which pulse width is to be used, and which control radar for slaving the antenna.
-4:00	2. Measure transmitted pulse width and shape using scope (see section 3.3.4.8).
-3:15	3. Check IRIG timing; check camera magazines to be sure indicator lights are operating.
-3:00	4. Measure noise figure (N. F.)(see section 3.3.4.4).
-2:30	5. Measure IF bandpass response at pulse setting to be used on mission. Check center frequency (see section 3.3.4.2).
-1:40	6. Focus and adjust all displays.
-1:30	7. Load camera magazines.
-1:15	8. Check antenna tracking with master radar for mission.
-1:00	9. Calibrate receiver with signal generator (see section 3.3.4.5).
-0:30	10. Check event recorder's paper supply and operation.
-0:15	11. Turn on transmitter and stand by for countdown.

-0:02	12. Turn on event recorders.
-0:00	13. Throw zero mark switch on event recorder.
	14. Turn on cameras after opening shutters (time determined by mission).
	15. Turn off cameras (close shutters) at end of film.
	16. Turn down transmitter to standby.
	17. Unload camera magazines.

3.3.3 POST-MISSION CHECK

Before turning off the radar after a mission, a quick check of display calibration and transmitted power should be made. Verification of the pre-mission calibration will minimize errors, particularly if delays in mission result in long operating time.

3.3.4 DETAILED CALIBRATION OF UNITS

3.3.4.1 General

Prior to a mission, the radar must be calibrated. These calibrations are not a part of the normal daily checkout but augment it on the day of a scheduled mission. Sufficient time must be allowed to make the necessary calibrations in addition to the daily operating procedures. Four hours is estimated for the full check. Experience on the site will add to the proposed procedures contained herein. Overall tests that can be performed to detect misalignment of the receiver chain are: connect the sweep generator to the far field transmitting standard antenna for a bandwidth check, tune the TR device, and check the sensitivity. Also included in this section for completeness are procedures for retuning the transmitter, making VSWR measurements, etc. as may be required.

3.3.4.2 IF Bandwidth Measurement (Figure 3-8)

Since the Vari-Sweep generates a voltage far too great for the input of the receiver, 40 or 50 db of attenuation is needed to prevent saturation of the receiver. Attenuator pads can be used for the required terminations of all cables, if sufficient signal is available. Twenty db of attenuation should be set into the Vari-Sweep, and the 70 to 50 ohm matching pad attached to the Vari-Sweep output. A 10 db pad is added and 40 db more obtained by using the M. C. Jones directional coupler. The display is connected to the receiver by means of the Sage directional coupler on the back of the display. The matching pad, then the detector, are connected to the receiver output for displaying on the Tektronix scope, Model 545A, which should have an external horizontal sweep supplied by the Vari-Sweep.

Center frequency can be located by use of the oscillator contained in the Vari-Sweep or by feeding in a signal from the HP 608 oscillator. The external signal can be inserted in a number of ways. No more signal than that required to produce a minimum signal should be fed from the oscillator. The oscillator can be fed into the directional coupler as shown in Figure 3-8, or as suggested in the manual for Kay's Sweep Generator, Model 866A (Vari-Sweep), at the detector. If the variable attenuator is used in placed of

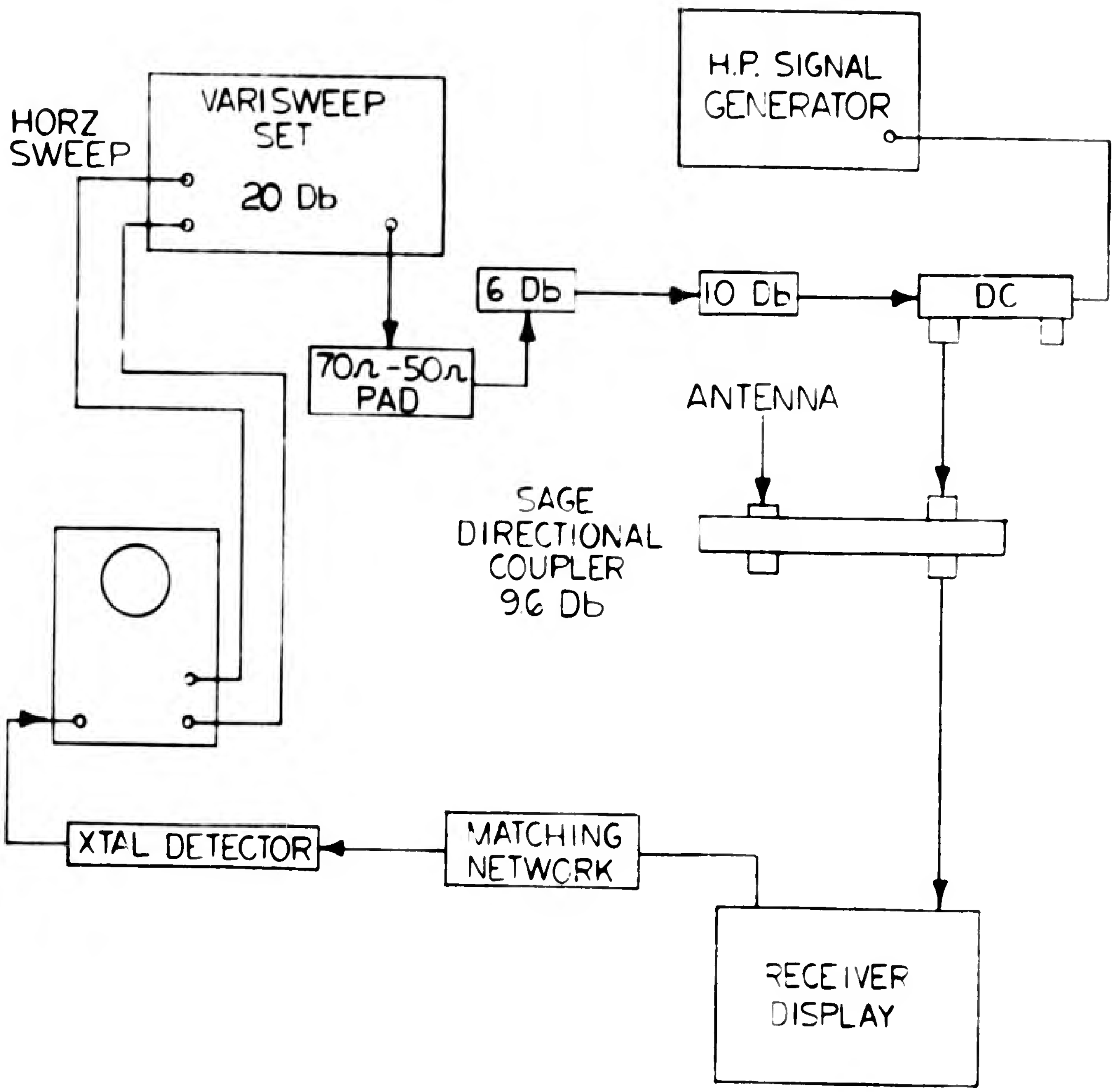


Figure 3-8. IF Bandwidth Measurement

the 10 db pad, a direct measurement of the ripple amplitude can be made. The receiver was aligned with a bandwidth sufficient to accommodate the narrow pulse. It should only be necessary to tune the trimmers at the filter to recenter the band. Adjustment of the other trimmers will cause the bandpass to be asymmetrical. Overall bandwidths between the 3 db points are 1.2 megacycles, 600 kv and 250 kv for the respective pulse widths of 1, 2.5 and 5 microseconds.

3.3.4.3 Minimum Discernible Signals (MDS)

MDS is checked by observing the minimum signal that can be detected in noise on the display as the HP oscillator signal is reduced. This should be done several times and an average value taken. The reading of the HP attentuator must be modified by the 9.6 db of the Sage directional coupler plus 0.5 db of the cable and any additional pads used. An input of 118 db below 1 mw corresponds to the 3 db noise figure.

Sensitivity of the receiver as a function of range (with transmitter on) can be determined by using the minimum signal measurement. Losses not inherent in the receiver alone can be detected quickly by moving the test signal to various parts of the range interval and measuring the power of the minimum detected signal. System losses due to TR deionization or desensitizing of the receiver as a result of the large blocks of ground returns can be determined.

3.3.4.4 Noise Figure Measurement

Because the receiver input tube can be damaged by inadequate TR protection, the TR must be adjusted so that it fires at all times. Noise figures are measured by following the instructions supplied with Hewlett-Packard Noise Figure Meter, Model 304B. The noise figure should be 3 db or less. This measurement is a more reliable measure of the receiver's performance than that described in section 3.3.4.3 since it is not dependent upon the operator's skill.

The measurement of noise figure using a noise generator involved measuring the noise power output of the receiver on a suitable thermal meter and wide band amplifier. The receiver total noise power is first measured on the meter and an equivalent noise power is added from the noise generator to increase the meter reading (voltage) by 1.414. Under these conditions, the noise source will be delivering noise power equal to the total receiver noise and the noise figure is read directly from the generator calibration.

3.3.4.5 Display Linearity

Since the display may not be perfectly linear, it is desirable to insert a calibrated signal on the film prior to the mission run. This should not be done until the display has reached its operating temperature. Instruments should be connected as shown in Figure 3-9 and the signal generator output set for 2.5 centimeters peak amplitude on the display. The video should be adjusted so that it does not saturate. After the HP generator attenuator

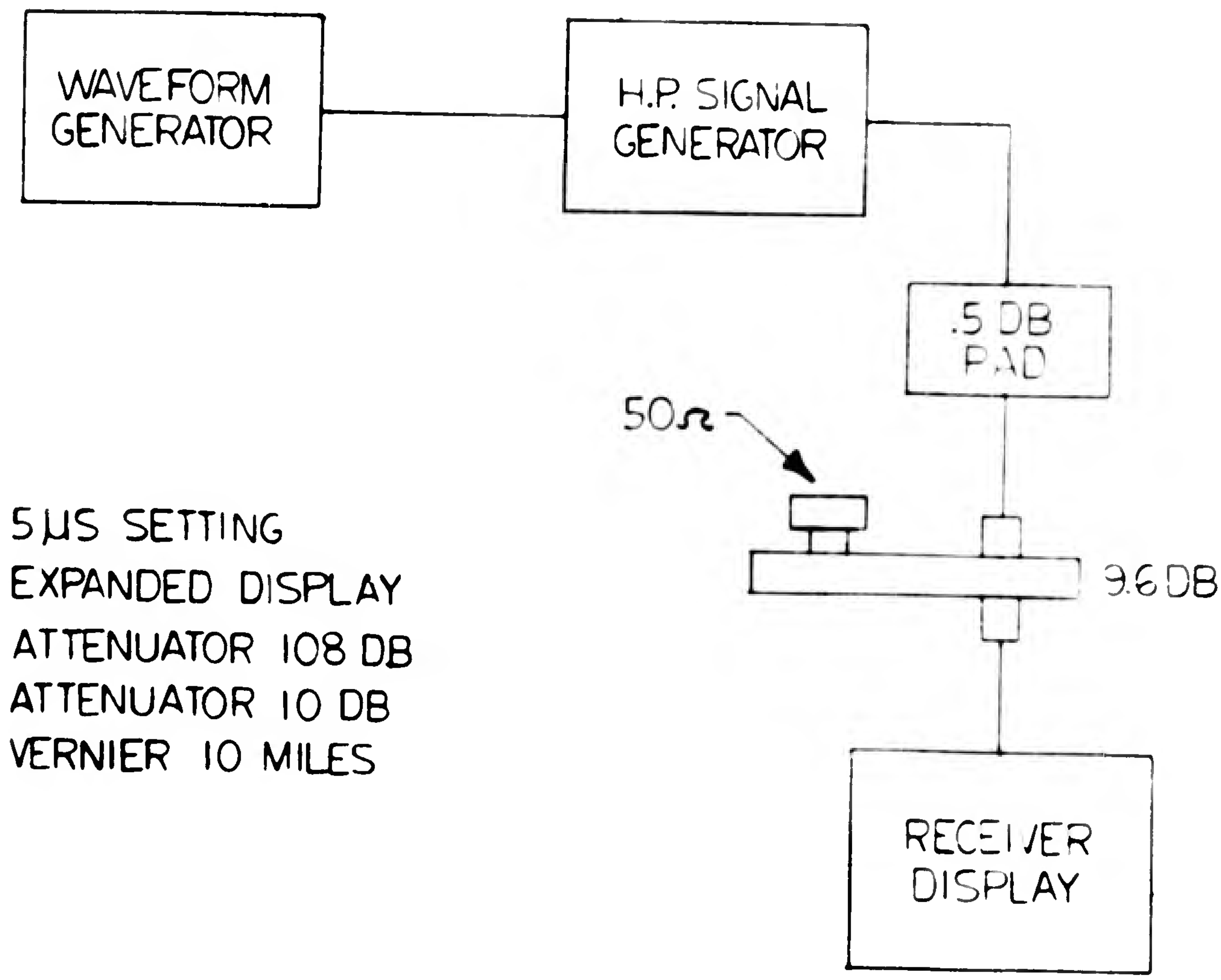


Figure 3-9. Display Calibration

setting is read, the generator is adjusted for pulse amplitudes of 2, 1.5, 1 and 0.5 cm, and the HP attenuator settings recorded each time. These should be recorded on the first part of the films by single frame operation of the camera. At the option of the operator, it may be preferred to set definite db steps on the HP generator instead of fixed display steps.

Linearity of the IF is measured by inserting a pulsed R-F signal into the front end of the receiver. The output taken at the high level IF output plug at the rear of the display is padded and then connected to a test oscilloscope. This measurement checks the IF linearity including the additional stage at high level. As the signal level from the RF source is raised, padding is increased in the IF output to maintain a constant level of signal output on the scope. For convenience, a fixed level of output attenuation is switched in and the signal generator attenuator increased to match the reference signal level on the scope. Three or six db steps will be found convenient. The points are then plotted and deviations, if any, from linearity noted and measured. To insure that scope levels and noise levels are adequate, it is suggested that an overall quick check be made using a single 40 db attenuation step to set the limits of measurement.

[illegible].[illegible].4.6 Transmitter Power Measurement

The measurement of transmitter power is made against the Hewlett Packard

VHF signal generator Model 608D as reference standard, using the main system directional coupler as a source from the transmitter. This coupler has a nominal 60 db coupling to the incident power in the line at 100 mc. For accurate measurements at other frequencies than 100 mc, the coupler coefficients as a function of frequency should be consulted in Figure 5-10. At a frequency of 101.0 mc the coupler is down 61.0 db. The output of the signal generator should be padded with 3 db and then connected to a crystal holder holding a 1N21BR crystal. The d-c output of the crystal should then be connected to a Tektronix scope. The signal generator is pulsed from the Tektronix type 683 Pulse Generator and set to a calibrated output of 2 milliwatts (3 db above 0 dbm). This will give an output of about 2-1/2 divisions of pulse signal when viewed on the Tektronix scope on the 0.05 volt per division scale. When this calibration operation is set accurately, it corresponds to 0 dbm of r-f power into the crystal. Using an RG-58/A cable with a resistive termination of 1000 ohms, the crystal holder should be disconnected from the signal generator, a total of 29 db of padding inserted, and the crystal holder connected to the incident power connector of the system directional coupler. One has at this time a total attenuation of 90 db from the calibrated 0 dbm level to the crystal (61 db from the coupler and 29 db of external padding). The transmitter power should be raised until the same deflection is obtained as previously on the scope (approximately 2-1/2 divisions). The transmitter power output at this deflection is 1 megawatt. Note all meter readings such as Input KV, Final

Figure 3-10

CALIBRATION OF 100 Mc M.C. JONES 60 db COUPLER

S.N. C-5934

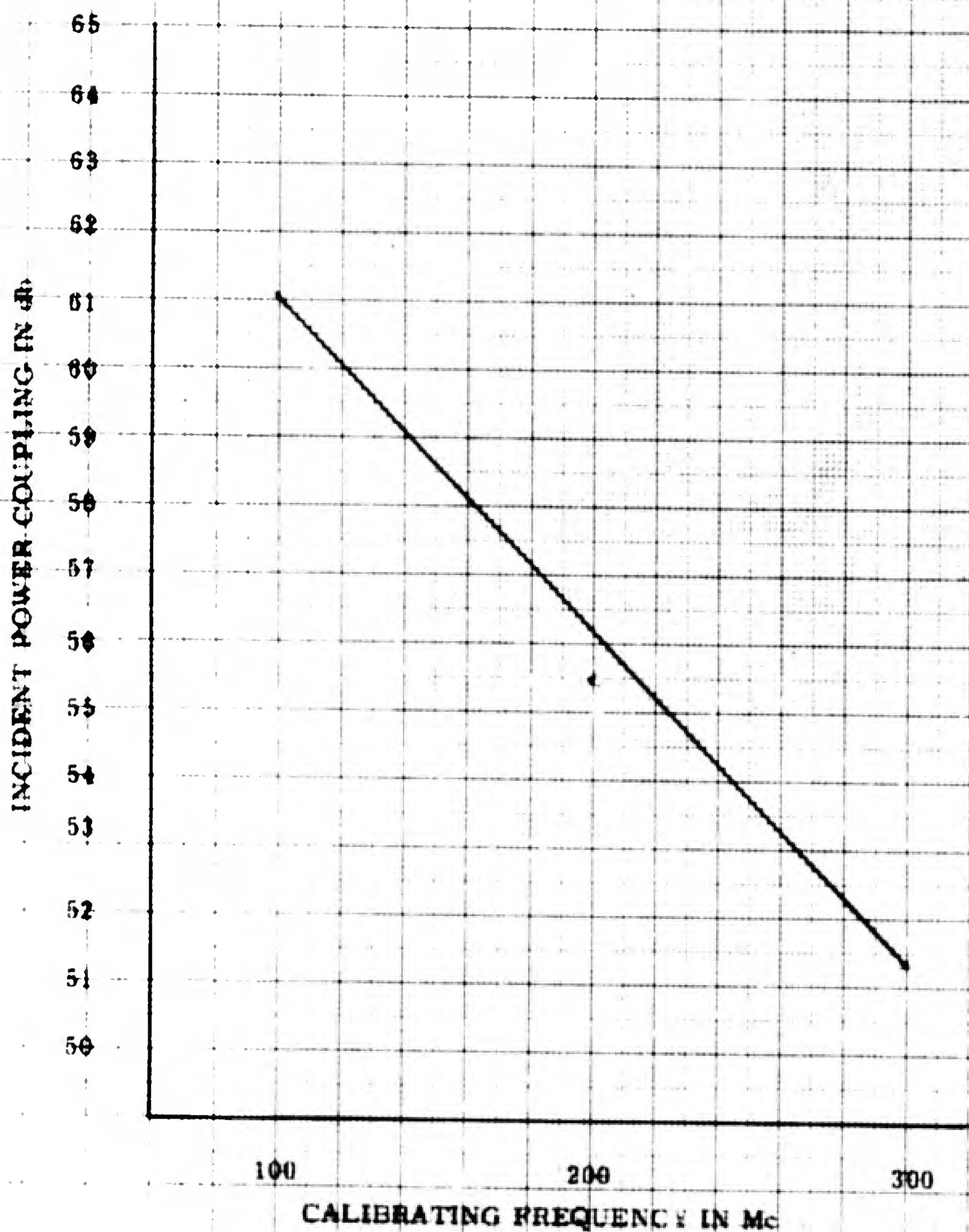


Plate Current, etc. will provide continuous monitoring levels that will serve as a guide to system performance.

The power can also be measured by measuring the signal received by the far field transmitting standard antenna and converting to power. The gain of the antenna is 7.5 db, cable attenuation is 23.8 db, and the free space loss is 60.2 db including loss in the detector used. The total attenuation is then 60.2 + 23.8 - 7.5 = 76.5 db.

3.3.4.7 Calibration of Power Meters

Each display cabinet is provided with a power level meter, and each must be calibrated on incident power. When the transmitter is set at the 1 megw level, the two crystal holders should be connected at the main system directional coupler via the RG-58/A cables provided with the display cabinet whose power meter is being calibrated. The crystal holders at this time should have varactor diodes, since 1N21BR crystals used in the test of paragraph 3.3.4.6 will not withstand the power when used at the coupler unpadded. With all connections made and zero power coming from the transmitter, the 400 cycle power on the display is turned on and 10 minutes warm-up time allowed. If any incident power is noted, the meter should be set to zero by turning the mechanical zero-centering screw on the front of the meter. The power level is raised to 1 megw in the manner described in paragraph 3.3.4.6. The incident power should now read 10. If it does not, the small potentiometer on the first card should be adjusted. This is card No. 85201 which can be reached at the upper right hand end of the display after the top cover of the display is removed. This control is purposely made difficult to reach, since after it is set, it should not vary over a period of months.

The metering circuit is stable and aside from total failure of a component, continual adjustment of this level indicator is undesirable. The displays are provided with a switch for measuring system VSWR when both incident and reflected power are brought to one display. Under these circumstances, to measure VSWR, the switch is set to calibrate, and the knob labelled VSWR CAL adjusted until the power meter reads full scale, i.e. lines up on the index marked CAL (see meter face). The meter switch is next turned to VSWR and the meter will read directly on the lower scale. It may be desirable to monitor both the incident and reflected power continuously. This can be achieved by connecting the incident power cable to one display and the reflected power to the second display cabinet. Under this dual mode of operation, both meters must be calibrated to correspond with the 1 megw level.

Power can be measured by a conventional power meter, if available at the directional coupler, and then multiplied by the duty cycle.

3.3.4.8 Pulse Shape

The pulse shape can be adjusted by detecting the signal received by the far field transmitting standard antenna and comparing it to that detected at the directional coupler output. It is necessary to have good shielding, good grounds, and to keep the signal below saturation. Direct leakage from the transmitter and/or modulator can result in erroneous readings.

3.3.4.9 Transmitter Bandwidth (Untuned)

In order to check the transmitter bandwidth, it is necessary to disconnect the crystal oscillator normally used to control transmitter frequency and, in its place, provide a variable signal source such as a General Radio test oscillator. With this oscillator set at 101 mc, the transmitter is operated into the dummy load and power raised in the normal manner.

The power output is measured on the output meters. The power supply level is set to supply 1 megw output at 101 mc. The d-c output power under these conditions is noted, the power level reduced to half voltage, and the input frequency of the variable frequency oscillator tuned to 95 mc.

At this frequency and at about half the input power, the three plate plungers are retuned for maximum output. The input power is raised to the normal 1 megw level (101 mc measurement) and power output read and noted.

The same procedure is followed at 105 mc. If desired, intermediate frequency points can be taken, but this is the bandwidth under which the transmitter will operate without major retuning. In most instances, even the plate retuning described above will not be necessary.

3.3.4.10 Transmitter Bandwidth (Tuned)

The test setup of the preceding test for untuned bandwidth is used for checking the bandwidth between the limits of 90 and 110 mc. Although generally even the 110 mc limit can be reached by the method described in paragraph 3.3.4.9, it is necessary to resort to major retuning if full power is to be obtained below 95 mc. The most important parameter in this instance is the resetting of the plate input tap position on the final amplifier and the two input drivers. These are adjusted by loosening the Breeze clamps and lowering the plate tap position about two inches. Lowering the tap position on the drivers is relatively simple since flexible cable is used in their output circuitry. However, on the final amplifier, a lowering of the entire filter section is required. This can be done by disconnecting the TR and ATR assembly from the coaxial switch, loosening the bolts on the dummy load support and lowering the filter approximately two inches by means of two adjusting cables which are crank operated.

For setting the transmitter at 90 mc, it is assumed that initial tests will be performed using the dummy load. Having changed the tap positions on the plates, the tap positions on the input circuitry are also optimized under load and at approximately one half power. Although it is possible to use the output meter as an indicator for optimizing, it is somewhat more convenient to use the directional coupler and a Tektronix scope directly. An RG-58/A test cable, which is provided with the equipment, is connected between the incident connector of the directional coupler and a Tektronix scope. The resulting d-c pulse is viewed and optimized. At full power, approximately 8 volts of pulse is available from the varactor diodes, when a cable terminated in 1000 ohms is used.

The next procedure is to optimize the three plate shorting bars in sequence from the low level stage on to the final. As an aid during this procedure, it may be desirable to view the grid and plate current meters of the various amplifiers. This can be achieved by rotating the meter panel behind the transmitter cabinet door through 90° so that the meter will then be clearly visible to an operator at the tuning positions. Having optimized the various stages, the input voltage is raised to 8 kv, at which time a megawatt of power will be available at 90 mc. The same procedure is followed to optimize the transmitter at 100 mc except that in this instance a smaller excursion upward, this time of the plate tap, is required (approximately 1/2 inch). The rest of the optimizing procedure is identical to that previously described.

3.3.4.11 Transmitter Stability at Spot Frequencies

The transmitter frequency is controlled by a Valpey crystal operating in a crystal oven. A similar crystal is used to stabilize the local oscillator. These crystals will maintain stabilities of one part in 10^7 for short term, and one part in 10^6 for long term. A simple test can be made to check the stability against the Hewlett Packard signal generator, first insuring that at least a one-hour warmup time has been obtained for both the radar crystals and the generator crystal. A sample of the r-f output from the transmitter is obtained from the incident connector of the directional coupler. This is connected to a General Radio crystal mixer and beats with a CW output from the signal generator. The output from the mixer is viewed on a Tektronix scope and the frequency of the signal generator is adjusted for zero beat. The drift with time is then noted and measured.

3.3.4.12 General Setup for VSWR Measurements

A General Radio signal generator is used as a source of power at the frequency desired for conducting the test. This power is connected to an instrument type directional coupler having a coupling coefficient of 40 db. The output of the coupler is then connected to the section of the system which is to be tested as for instance, a single yagi, the entire antenna array, TR - ATR section, etc. Signal from the incident power output connector of the directional coupler is connected to a crystal mixer and local oscillator reference is provided to the mixer by a second General Radio signal generator appropriately padded. The output of the mixer (30 mc) is amplified by a General Radio i-f amplifier with built in attenuator and meter indicator. The local oscillator is tuned to the signal and an appropriate meter reading and attenuator setting noted. Using this as a reference, the receiver is switched to the reflected power connector of the directional coupler and a measurement made of the amount of reflected power in terms of db down from the incident power reference level previously noted. The difference in db represents the return loss power relative to the incident power, and VSWR can be read directly from the curve in Figure 3-11. The test setup described above is shown in block diagram form in Figure 3-12, together with a description of the apparatus.

3.3.4.13 VSWR of Individual Antenna Elements

These measurements must be made outside the building and close to the antenna. Using the VSWR setup described in paragraph 3.3.4.12 as well as the N to HN test cable, each element of the array is disconnected in turn at the brass feeder plug of each yagi and the four measurements of the vertical yagi arrays made. The horizontally polarized receiving yagi is measured in a similar manner.

3.3.4.14 VSWR of Overall Array

This measurement is made outside the building and close to the antenna. Using the VSWR setup described in paragraph 3.3.4.12, the four elements of the array are connected in their normal manner to the power splitter mounted in the center of the antenna. After the LC cable at the input to the power splitter is removed and an LC to HN adapter put in its place, the test cable is connected and the measurement made.

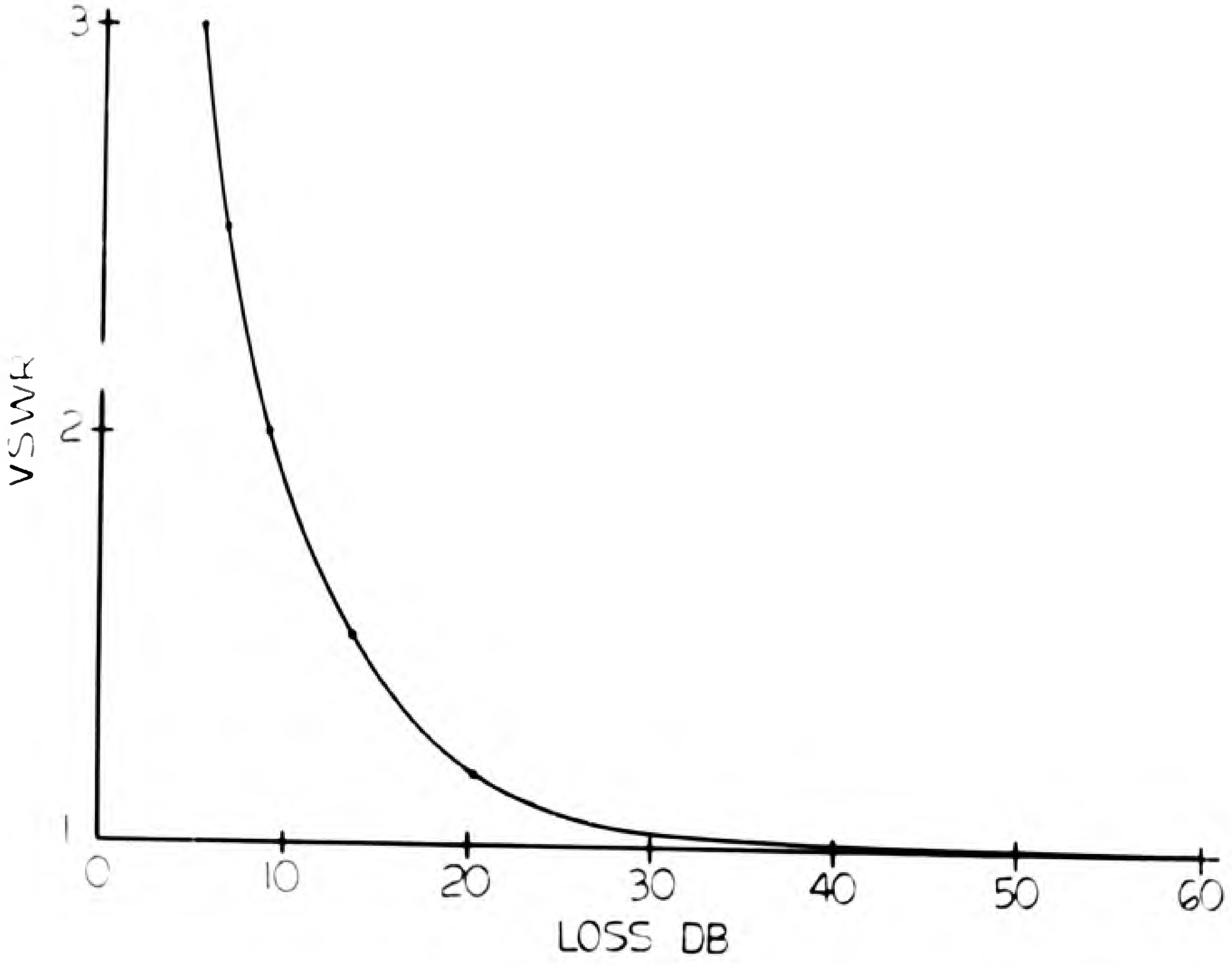


Figure 3-11. VSWR Vs Reflected Power

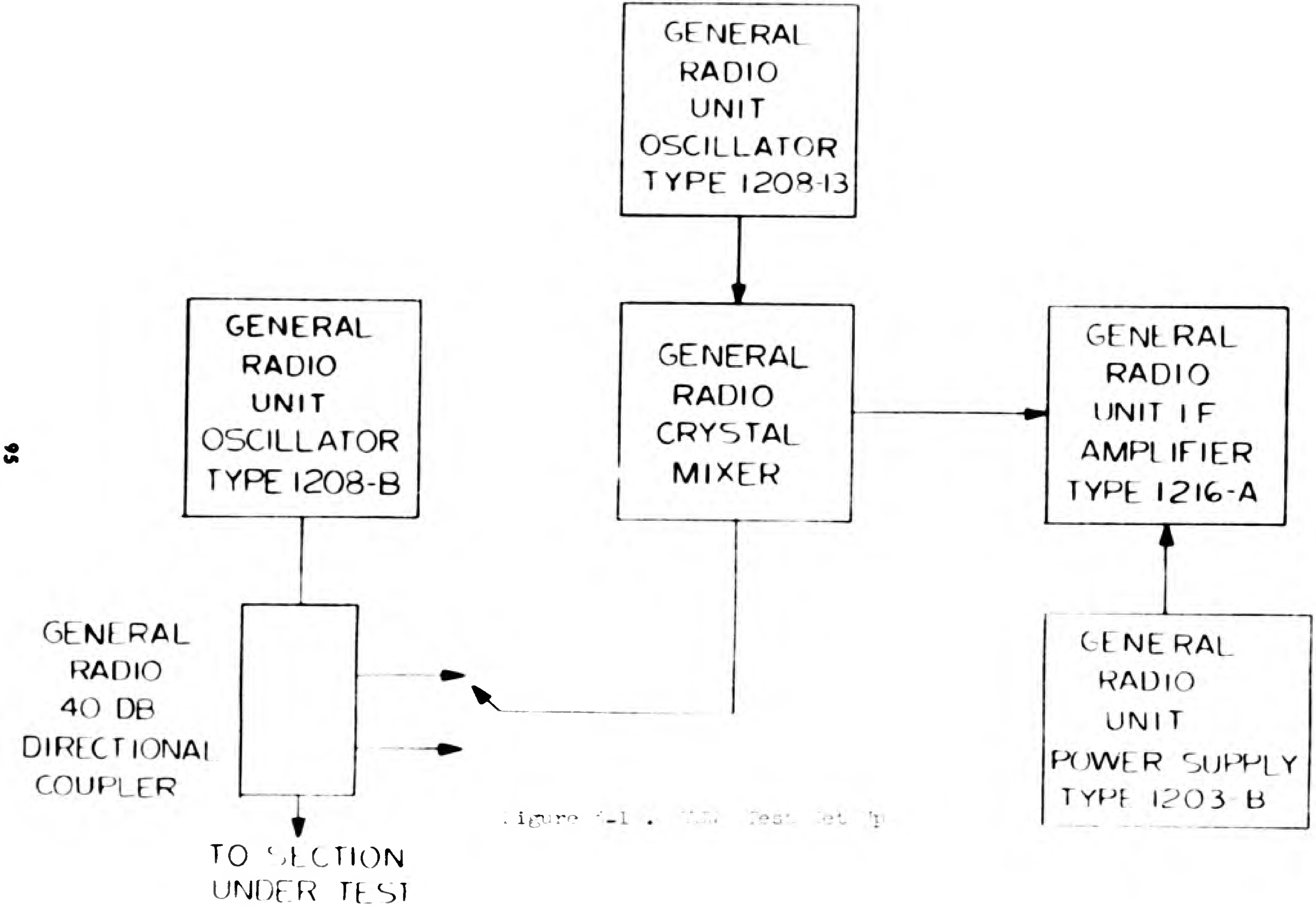


Figure 4-1. [illegible] Test Set Up

3.3.4.15 VSWR of Array Plus Pressurized Cable

This measurement is made inside the building and uses the setup described in paragraph 3.3.4.12. The pressurized cable is disconnected from the TR-ATR section which should be opened carefully at a point one section below the pressure seal (directly at flange of 90° elbow). The tapered adapter (3-1/8 inch to General Radio connector) is then connected to the pressurized cable and the measurement made.

3.3.4.16 VSWR of TR-ATR Section Alone

This measurement is made inside the building and uses the setup described in paragraph 3.3.4.12. The pressurized cable is disconnected at the flange of the 90° elbow that connects to the TR-ATR section. Care must be taken not to disturb the pressure seal. One tapered adaptor (3-1/8 inch to LC connector) is connected to the antenna side of the TR-ATR section and the other (3-1/8 inch to General Radio connector) to the transmitter side of the TR-ATR section. An LC to HN adaptor plug is attached at the LC connector. The test cable having HN to N connectors is connected and terminated with a 50 ohm load. The VSWR is then measured.

3.3.4.17 VSWR of System from Filter to Array

This measurement is made inside the building and does not require any disconnecting of system plumbing. A spare exit connection on the system coaxial switch permits access to the TR-ATR at the transmitter end. After the coaxial switch is placed in the dummy position, the adaptor (3-1/8 inch to General Radio connector) is mounted on the spare 3-inch terminal (lower right as viewed from the rear). The VSWR is then measured.

3.3.4.18 TR-ATR Insertion Loss

The pressurized cable from the TR-ATR section is disconnected carefully at the flange connection to the 90° elbow so that the pressure seal does not open. The pressurized cable is then moved toward the transmitter to obtain about two feet of clearance. After the TR-ATR section is unbolted at the flange on the transmitter near the floor, the entire TR-ATR section is moved about 1-1/2 feet toward the transmitter.

The adaptor (3-1/8 inch to General Radio connector) is mounted on the transmitter end of the TR-ATR section and terminated with a 50 ohm load. Another adaptor (3-1/8 inch to General Radio) is mounted on the load end of the TR-ATR section. The test signal generator with several attenuator pads is connected to this adaptor. A test receiver (mixer, local oscillator, etc.), is connected to the receiver output connector of the TR section located on the long vertical pipe nearest the transmitter. The TR and ATR shorting bars located at the top of the vertical sections are tuned for maximum signal output. Signal level and total attenuation are then recorded. The cable at the receiver output connector of the TR section, and the cable at the adaptor on the load end of TR-ATR section are both disconnected. The cables are connected together and the increase in power recorded. This value is the insertion loss of the TR in db. In making these measurements all signal sources must be well padded to avoid introducing spurious reflections which will produce measurement errors.

3.3.4.19 Protection

The TR-ATR section is dismounted in accordance with the description given in paragraph 3.3.4.17. An adaptor (3 1/8 inch to LC) is attached at the transmitter end of the TR-ATR section and fed by the signal generator at the load end; another adaptor (3-inch to General Radio connector) is attached at the load end of the TR-ATR section and terminated in a 50-ohm load. The TR and ATR gaps are short circuited to simulate the arc shorts that normally occur when they are being fed from the transmitter. Using a test receiver made up of a General Radio mixer and local oscillator, the output level from the receiver connector of the TR is measured when another General Radio oscillator used as a power source is feeding the transmitter end of the TR-ATR. A reference level should be noted on the receiver. After removing the power source from the TR-ATR, its level going into the receiver is measured. The padding must be changed until the reference level is the same as previously noted. The power difference in db is a measurement of the TR protection for the receiver. The test given above calls for the disconnection of the TR-ATR unit, a condition necessary for isolating the unit from the rest of the system. However, in most cases this measurement can be made without the handling of heavy plumbing if it is known that the rest of the system is satisfactory. Power can be inserted from a signal generator at the normally unused connection of the coaxial switch in a manner similar to that described in paragraph 3.3.4.17, and the antenna itself used as the 50-ohm termination. The test is then conducted in all other respects as outlined above.

3.3.4.20 Output Filter Harmonic Attenuation

This test is most easily performed using the transmitter itself as a source of power. The harmonic attenuation of the transmitter and filter as a combined unit may thus be measured. That is, a measurement is made of the amount of transmitter-generated harmonic power that the filter allows to reach the output circuit. A General Radio mixer and local oscillator are used as a test receiver connected to the incident power connector of the main system directional coupler through appropriate pads. It is advisable to run these tests with the transmitter operating at some intermediate power level and connected to the dummy load in order to prevent rf leakage from disturbing the measurements.

The receiver is tuned to the fundamental in order to establish a reference level. The absolute value of this level can be determined by reading its value on the power level meters located on either of the indicator consoles. The receiver is then tuned to detect the amount of 2nd, 3rd, 4th, 5th, etc. harmonic power that is being delivered to the antenna The shorting bars on the two 90° stubs of the filter are used to suppress the second harmonic; the capacitive probes at the other end of these stubs are used to minimize the third harmonic and the iris tuning inside the large horizontal cylindrical section is used to minimize the higher order harmonics.

3.3.4.21 Recorded Settings

If a fault is developing gradually, it can be detected by changes in the recorded readings. As an aid in preventing failures, meter readings and knob positions should therefore be read and recorded periodically.

3.3.5 RADAR CALIBRATION

Final calibration of the VHF Radar using the calibrated antennas is discussed in this section. The test setup and procedures are described for each test required to obtain the desired system parameters. These parameters are used in the radar range equation to calculate the expected system performance.

3.3.5.1 Path Loss Measurement

Figure 3-13 shows the test setup for path loss measurement. In both of the following measurements, use an extra cable that will reach from the test bench to the reference signal switches located on the camera control cabinet. Set 20 db into the attenuator and adjust the output of the oscillator for some arbitrary pulse level on the display scope. Record the pulse level and attenuator setting. Disconnect the cable at A and connect it to the receiver by removing cable B from the connection on the reference signal panel. Add attenuation until the pulse level on the display scope is identical to that recorded previously. Subtract the 20 db previously recorded to obtain total attenuation, L_a. Compute transmission loss L_s as follows:

$$L_s = G_1 + G_2 - L_1 - L_2 + L_a$$

$$L_s = 7.5 + 7.5 - 23.8 - 3 + L_a$$

$$L_s = -11.8 + L_a$$

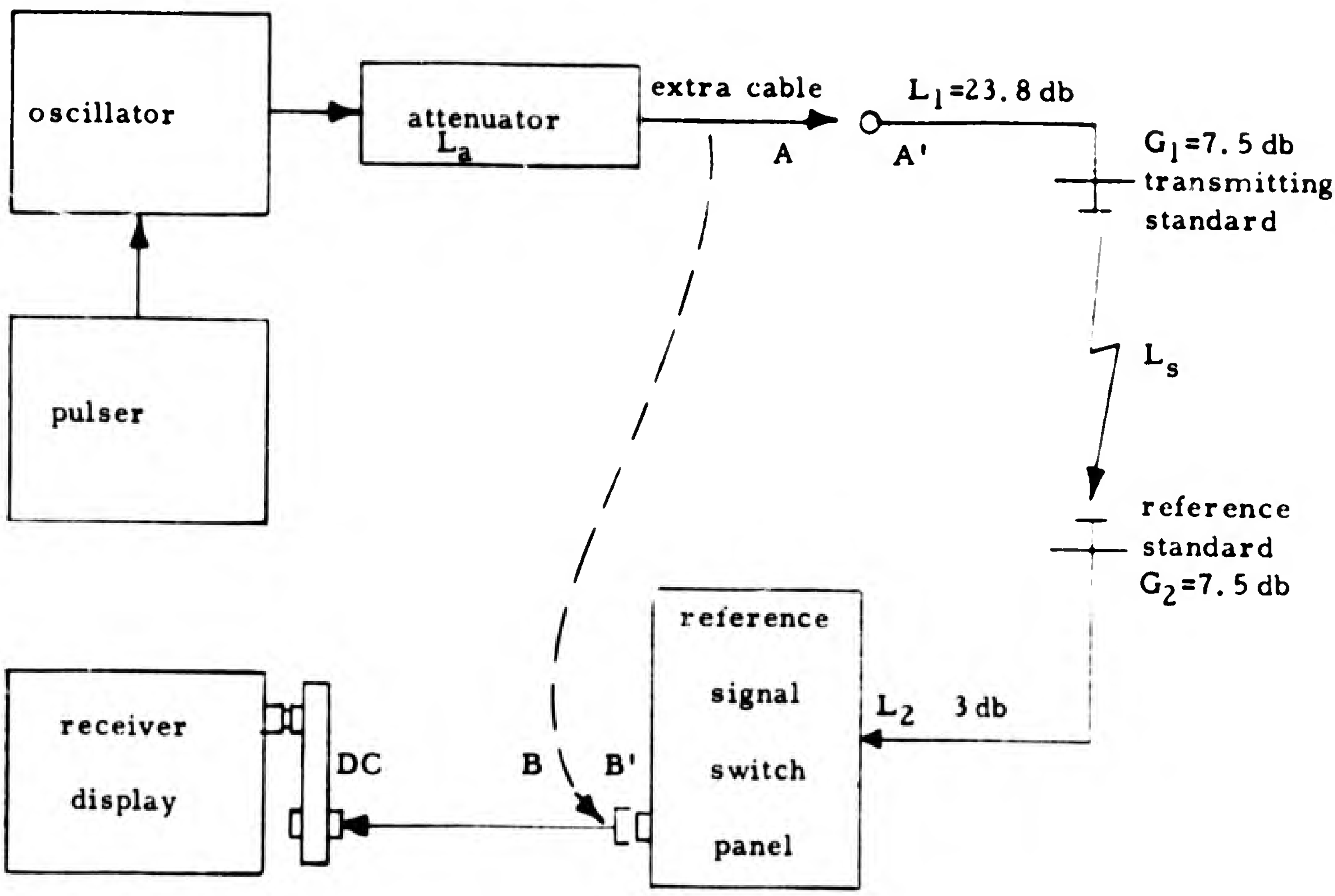


Figure 3-13. Test Setup for Path Loss Measurement

3.3.5.2 Receiver Line Loss Measurement

The test setup for measuring the receiver line loss is shown in Figure 3-14. In the following measurements use an extra cable, as shown in Figure 3-14, to reach from the test bench to the reference signal switches located on the camera control panel. Set 20 db into the attenuator and adjust the output of the oscillator for some arbitrary pulse level on the display scope. Record pulse level and attenuator setting. Disconnect the cable at A and connect it to the receiver by removing cable B from the connection on the reference signal panel. Add attenuation until the pulse level on the display scope is identical to that recorded previously. Subtract the 20 db previously recorded to obtain total attenuation L_a. Compute receiver line loss L_R as follows:

$$L_R = G_y + G_1 - L_1 - L_s + L_a$$

$$L_R = 18.7 + 7.5 - 23.8 - L_s + L_a$$

$$L_R = 2.4 - L_s + L_a$$

The receiver line loss can also be obtained by using the reference signal switches. With the oscillator connected to the transmitting standard as above, measure with an attenuator the difference between the pulse received from the reference standard and that received from the yagi. Receiver line loss is calculated as follows:

$$L_R = G_y - G_2 + L_2 - L_a$$

$$L_R = 18.7 - 7.5 + 3 - L_a$$

$$L_R = 14.2 - L_a$$

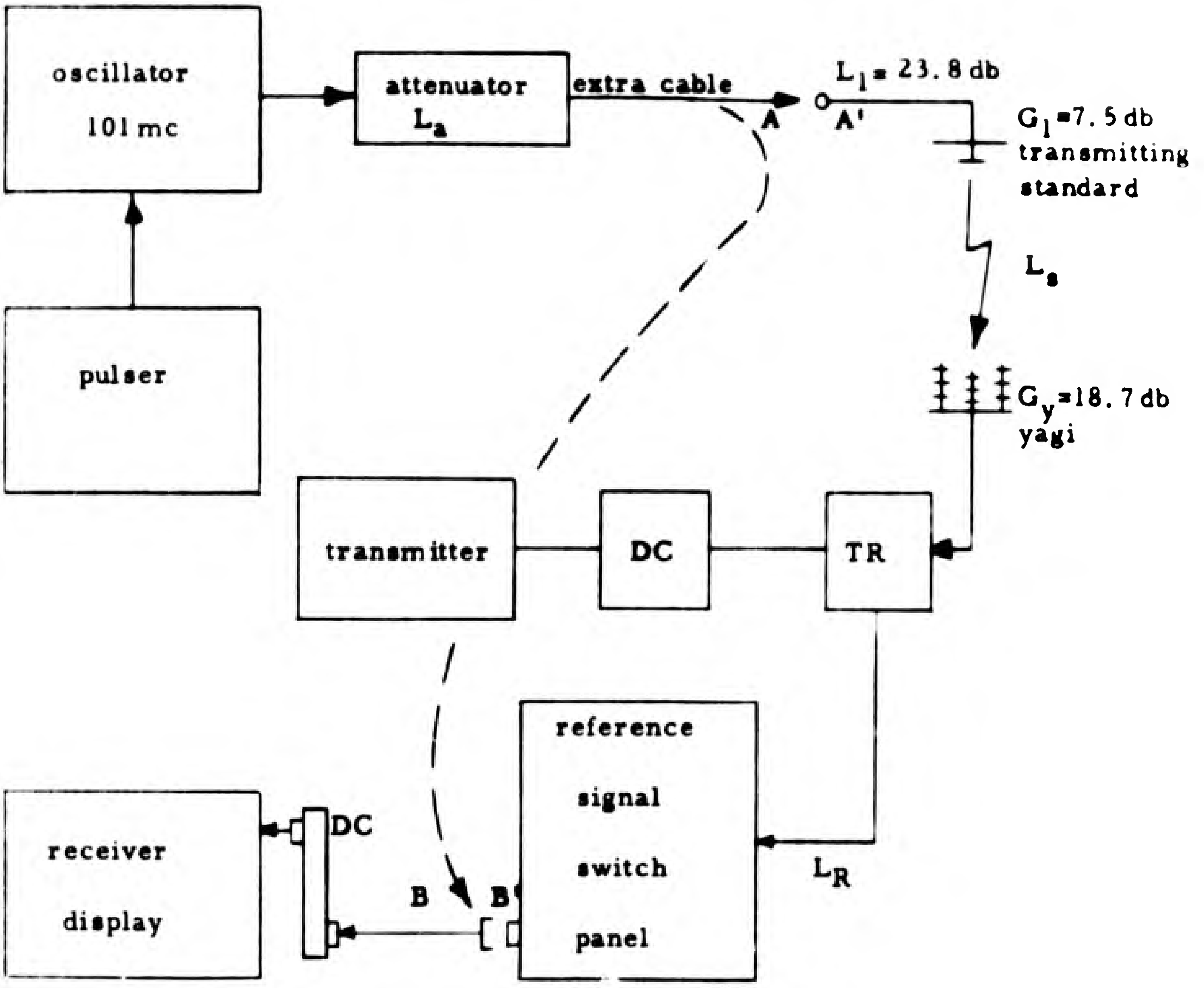


Figure 3-14. Test Setup for Receiver Line Loss Measurement

3.3.5.3 Transmitter Line Loss Measurement

Figure 3-15 shows the test setup for measuring the transmitter line loss. This test is performed with the transmitter on. Set the attenuator on the display for some arbitrary pulse level. Connect the attenuator and cable from the output of the transmitter directional coupler to the receiver after removing cable B from the connector on the reference signal panel. The cable used between the D. C. and receiver cable B must be calibrated. Adjust the attenuator until the pulse level on the display scope is identical to that recorded previously. Compute transmitter line loss L_t as follows:

$$L_t = G_y + G_l - L_l - L_s + 61 + L_a + L_c$$

$$L_t = 18.7 + 7.5 - 23.8 - L_s + 61 + L_a + L_c$$

$$L_t = 63.4 - L_s + L_a + L_c$$

3.3.5.4 System Performance Verification

System sensitivity can be verified by the test setup shown in Figure 4-9. Do not add cable unless it is calibrated and considered in the calculations. This test is performed with the transmitter on. A matching stub (M. S.) consisting of an open end RG-58/U cable whose length was chosen for maximum receiver sensitivity, is connected into the line with a TEE connector. This matching stub compensates for a 2 db receiver mismatch. Set the attenuator for a receiver signal-to-noise ratio of some readable value. System performance is verified by computing as follows:

$$90\,\text{dbm} - L_t + G_y - L_s + G_l - L_l - L_a = -119\,\text{dbm}$$

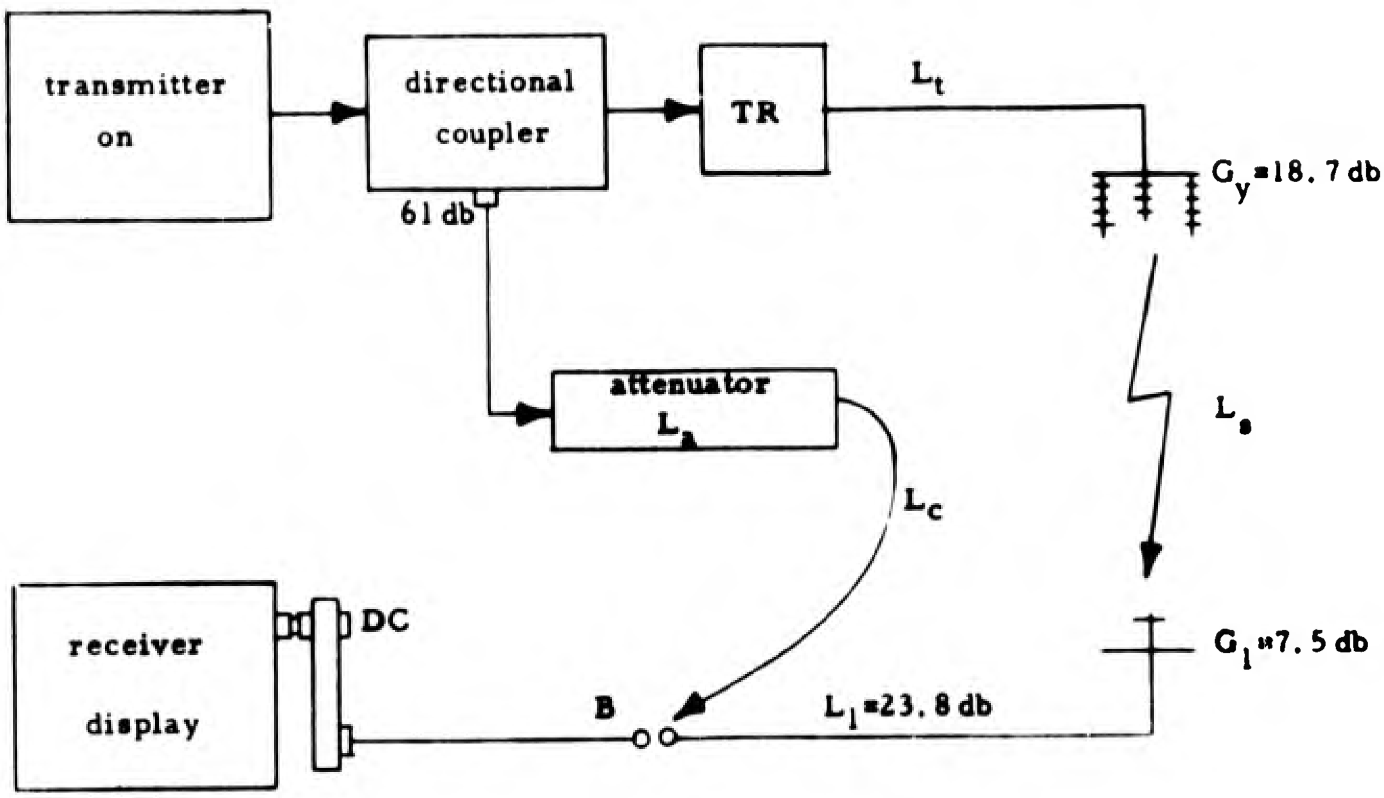


Figure 3-15. Test Setup for Transmitter Line Loss Measurement

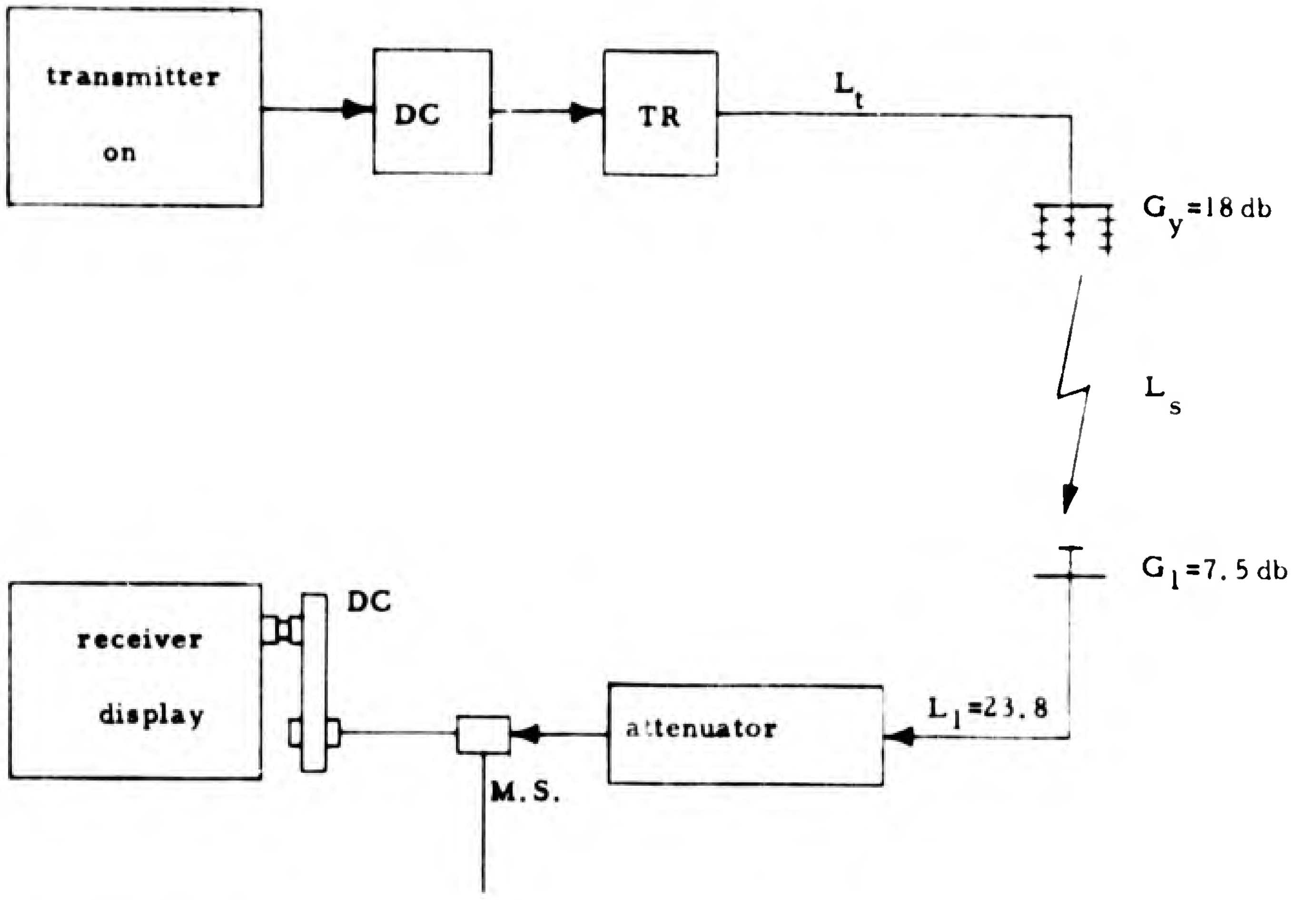


Figure 3-16. Test Setup for First System Performance Verification

A readable value of 0 db represents -119 dbm with a 5 microsecond pulse and a 3 db receiver noise figure. 90 dbm represents 1 megawatt

3.3.5.5. Second System Performance Verification

Another test to verify system performance can be made with the transmitter connected to the dummy load and the decoupler output connected to the transmitting standard antenna. The test setup is shown in Figure 3-17. Any cable added to make these connections must be calibrated and considered in the calculations. This test is performed with the transmitter on. Set the attenuator for a receiver signal-to-noise ratio of some readable values as described in paragraph 3.3.5.4. System performance is verified by the following computation:

$$90\,\text{dbm} - 61 - L_l + 7.5 - L_s + 18.7 - L_R - L_c - L_a = -119\,\text{dbm}$$

3.3.5.6 Radar Range

System performance can be computed from the radar range equation using the measured parameters obtained in the tests described in the preceding paragraphs. The range of the radar may be obtained as shown in the following example:

$$R^4 = \frac{P_t G^2 \lambda^2 \sigma}{S/N \ NF \ BW \ L_t \ L_R}$$

where R = Range

G = Gain of antenna

λ = Wavelength

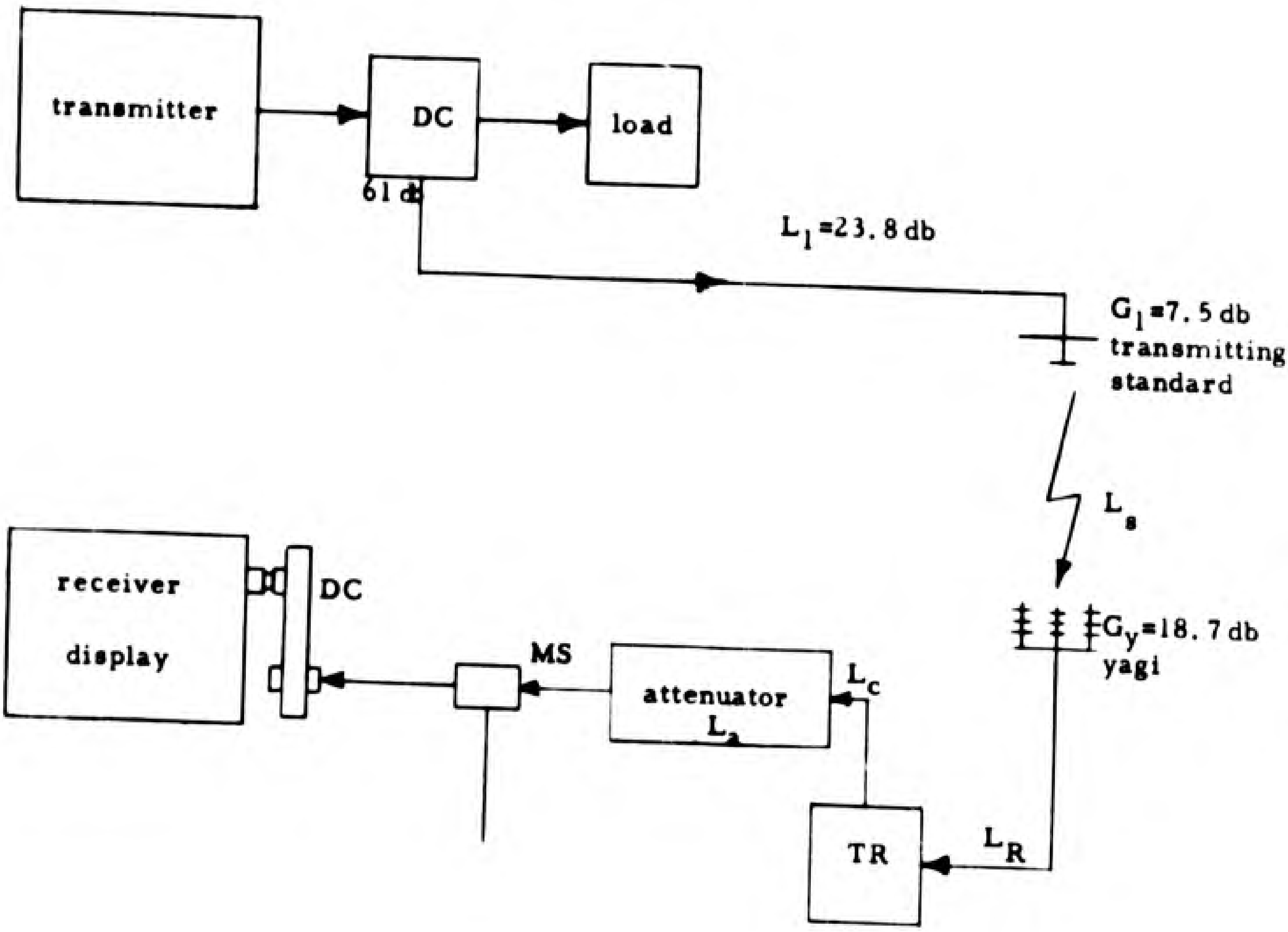


Figure 3-17. Test Setup for Second System Performance Verification

σ	=	Target area
S/N	=	Signal-to-noise ratio
NF	=	Noise Figure
BW	=	Bandwidth of receiver
L_t	=	Transmitter losses
L_R	=	Receiver losses

Example

P_t (1 mw)	=	60 db
G^2 (18.7db)	=	37.4 db (V.pol.)
λ^2 (300 cm)	=	49.5 db
σ (1 sq M)	=	0 db
		146.9 db

S/N	=	10 db
NF	=	3 db
BW (240 KC)	=	53.8 db (5 ms pulse)
L_t	=	3 db
L_R^*	=	8 db
		77.8 db

*Includes 2 db non-ideal receiver loss

$$R = \frac{146.9 - 77.8}{4}$$

R = 17.3 db (n. mi.)

R = 54 n. mi.

where P_t ref to 1w

λ ref to 1 cm

σ ref to 1 sq. M

BW ref to 1 cycle

R ref to 1 n. mi.

3.3.5.7 ACCEPTANCE TESTS RESULTS

The following are results of the VHF radar acceptance tests.

Transmitter Power at 101 Mc	10^6 watts or better on all pulse widths. Maximum input voltage required on the 1 microsecond pulse.
TR-ATR	Insertion loss 1.1 db
	Protection 59.0 db
Output Filter	
Harmonic Attenuation	2nd, 3rd harmonics, 30 db 4th, 5th etc. better than 25 db
Antenna Az. Velocity	22.3 degrees per second
Antenna El. Velocity	14.6 degrees per second
Antenna Az. Acceleration	2.8 degrees per second per second
Antenna El. Acceleration	1.6 degrees per second per second
Receiver Noise Figure	3.0 db
Linearity (high level IF)	plus or minus 1 db over 38 db
Attenuator Calibration	plus or minus 0.5 db at each setting
Transmitter Bandwidth Untuned	90 to 110 mc min. power, 3/4 megawatt
Antenna Gain (4 yagis vertical)	18 db
Antenna Gain (1 yagi horizontal)	10 db
Antenna Beam width-3 db pts - 4 yagi array	20 degrees
Antenna Beam width-3 db pts - 1 yagi	33 degrees

SECTION 3.4

ANTENNA PATTERN MEASUREMENTS

Measurements of the antenna patterns were obtained by using an antenna pattern recorder and by point to point measurements. Since a recorder was made available at the site, pattern runs were made at the same tilt angle as for the point to point measurements. The two types of measurements can therefore be correlated.

The signal generator was connected to the transmitting standard, at its permanent location 1000 feet from the yagi array. The General Radio IF amplifier, mixer and local oscillator were used as detector and amplifier for the pattern recorder. Pattern runs were made by sweeping the antenna 360^{o} in the azimuth plane starting at 40 degrees from north, with the yagi facing the transmitting standard at 220 degrees.

The first set of elevation patterns, for the vertically polarized array were recorded every 3 degrees to 15 degrees, then every 5 degrees to 30 degrees and lastly every 10 degrees to 90 degrees, making a total of 12 patterns.

The dipole of the transmitting standard was then turned to the horizontal position and the same azimuth sweeps made for the single yagi element of the array as for the vertical array.

Point to point measurements were made by using the same setup as for the transmission loss measurements. The generator was set for maximum output and a reference of 106 db on the Arenberg attenuator gave a minimum stable signal. The signal intensity from the reference standard antenna was continuously monitored since the point to point measurements were made over an extended period of time. The recorded attenuator setting was 19 db from the reference standard.

Recorded attenuator readings are tabulated in Tables 5-1 and 5-2 for both vertical and horizontal antennas every 10 degrees for the same tilt angles as previously. Readings were made to the nearest 0.1 db by using the meter on the General Radio amplifier in conjunction with the Arenberg attenuator. The resulting calculated data, shown in Tables 5-3 and 5-4, shows the difference between the attenuation of the array and the reference standard. The cable attenuations as measured are:

Cable to transmitting standard	23.8 db
Cable to reference standard	3.0 db
Cables and TR to vertical array	6.0 db
Cables and TR to horizontal array	4.8 db

Final measurements for the overall attenuation of the antenna setup are given in Table 3-3.

To obtain transmission loss plus antenna gain:

1. Subtract recorded values from 106 db (attenuator reference).

2. Subtract 29.8 db (cable loss) from recorded value.

Table 3-5. Pattern Data for Vertically Polarized Yagi Array

ELEV. ∠°	AZIMUTH															
	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290
0	11.4	5.5	6.2	6		8.6	21.7	27.8	28	24.6	12.8	-.6	7.5	10.3	4.4	3
3	10.5	5.6	7.5	7.4	1.2	11.5	23.2	28.2	29.2	25.2	13.6	.2	8.6	11.8	6.	6.2
6	12.6	6.	7.2	7.3	4.2	11.6	22.2	27	28.0	25.2	15.4	7.3	9.8	12.4	7.4	6.2
9	12.5	6.	8	8.4	9.1	13.2	22.8	27.8	28.6	25.	15.2	11.3	11.8	12.6	7.2	7.1
12	12.7	6.3	8	7.9	11.7	13.4	21.8	26.8	27.9	24.4	15.4	13.8	11.2	12.5	8.4	8.4
15	12.6	6.4	7.4	6.7	13.7	15.3	19.6	25.4	26.6	21.8	15.2	15.4	10.8	12.1	8.6	9.7
20	13.1	6.8	6.8	4.5	16.0	18.4	15.4	21.6	22.6	18.	18.1	18.6	11.8	11.1	8.8	10.6
25	12.	6.4	3.8	3.4	17.6	19.8	14.7	14.	16.9	14.2	20.5	19.6	12.5	8.6	7.	11
30	12.7	7.6	4.4	5.8	18.7	21.3	17.5	9	10.6	15.2	22	21.	13.8	6.8	5.5	11
40	12.3	7.8	5.3	.2	16.1	18.8	15.6	4.4		8.6	19.2	18.	10.2	1.8	2.	10.6
50	10.2	4.9	6.4	1.4	5.6	10.8	6.6		1.8	1.4	10.	8.4	0	3.1	1.	6.6
60	7.6	3.0	7.0	6.6	-.5	-.8	0					-4.	4.	5.6	1.8	4.3

Table 5-6. Pattern Data for Horizontally Polarized Yagi Array

To obtain transmission loss plus antenna gain:

1. Subtract recorded values from 106 db (attenuator reference)
2. Subtract 28.6 db (cable loss) from recorded value.

ELEV. ∠°	AZIMUTH															
	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290
0		-5		3.	12.7	17.	19.2	20.6	20.8	20.1	17.	13.2	7.8		2.	2.8
3		-1.1				19.1	21.3	22.0	[illegible].4	22.4	20.5	17.1	9.		3.6	3.2
6		-.5	n -3	5.	14.8	18.8	21.1	21.9	22.6	22.1	20.2	16.2	8.		.1	.6
9		.9	n-1.5	6.4	15.1	19.8	22.	22.5	22.6	21.6	20.	16.2	8.6		.6	1.
12	-.8	1.	-.5	6.	15.1	19.1	21.5	22.8	23	22.6	20.7	16.6	9.3		5.3	4.6
15	-.4	2.2	1.	6.2	16.	20.5	22.8	24.0	24.3	23.8	20.4	16.6	9.2		5.6	4.8
20	.6	3.1	2.4	6.5	15.4	20.0	22.8	23.9	24.3	23.4	21.	17.	8.4	-1.	7.1	5.5
25	1.4	3.6	3.	4.5	13.8	18.8	22.	23.1	23.4	22.8	20.2	15.6	7.	.4	6.9	5.4
30	2.0	4.5	4.4	4.4	12.4	17.8	21.2	22.5	22.8	22.	19.	13.8	5.2	2.8	6.8	5.
40	2.3	5.6	6.1	4.2	8.5	13.7	17.6	19.4	19.6	18.8	15.3	9.7	3.4	4.7	6.1	4.
50	2.4	5.8	7.4	6.2	3.5	5.4	9.7	12.	12.7	11.2	6.4	3.8	6.1	7.3	6.	2.5
60	-.2	5.1	8.2	8.6	6.8	4.5	2.4	2.3	2.9	3.1	6	8.3	9.4	9.1	6.8	2.

To obtain transmission loss plus antenna gain:

1. Subtract recorded values from 106 db (attenuator reference).

2. Subtract 29.8 db (cable loss) from recorded value.

Table 3-7. Pattern Data for Difference Between Reference Standard and Vertically Polarized Yagi Array

ELEV. ∠°	AZIMUTH 140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290
0	-5.6	-11.5	-10.8	-11.		-8.4	4.7	10.8	11	7.6	-4.2	n-17.6	-9.5	-6.7	-12.6	-14
3	-6.5	-11.4	-9.5	- 9.6	-15.8	-5.5	6.2	11.2	12.2	8.2	-3.4	-16.8	-8.4	-5.2	-11	-10.8
6	-4.4	-11.	-9.8	- 9.7	-12.8	-5.4	5.2	10	11.	8.2	-1.6	- 9.7	-7.2	-4.6	-9.6	-10.8
9	-4.5	-11.	-9.	- 8.6	- 7.9	-3.8	5.2	10.8	11.6	8.	-1.8	- 5.7	-5.2	-4.4	-9.8	-9.9
12	-4.3	-10.7	-9.	- 9.1	- 5.3	-3.6	4.8	9.8	10.9	7.4	-1.6	- 3.2	-5.8	-4.5	-8.6	-8.6
15	-4.4	-10.6	-9.6	-10.3	- 3.3	-1.7	2.6	8.4	9.6	4.8	-1.8	- 1.6	-6.2	-4.9	-8.4	-7.3
20	-3.9	-10.2	-10.2	-12.5	- 1.	1.4	-1.6	4.6	5.6	1.	1.1	1.6	-5.2	-5.1	-8.2	-6.4
25	-5.	-10.6	-13.2	-13.6	.6	2.8	-2.3	-3	- .1	-2.8	3.5	2.6	-4.5	-8.4	-10.	-6.
30	-4.3	-9.4	-12.6	-11.2	1.7	4.3	.5	-8	-6.4	-1.8	5.	4	-3.2	-10.2	-11.5	-6.
40	-4.7	-9.2	-11.7	-16.8	- .9	1.8	-1.4	-12.6		-8.4	2.2	1	-6.8	-15.2	-15	-6.4
50	-6.8	-12.1	-10.6	-15.6	-11.4	-6.2	-10.4		-15.2	-15.6	-7	- 8.6	-17.	-13.9	-16	-10.4
60	-9.4	-14.0	-10	-10.4	-17.5	-17.8	-17.					- 21.	-13.	-11.4	-15.2	-12.7

To obtain transmission loss plus antenna gain.

1. Subtract recorded values from 106 db (attenuator reference).
2. Subtract 28.6 db (cable loss) from recorded value.

Table 3-8. Pattern Data for Difference Between Reference Standard and Horizontally Polarized Yagi Array

ELEV. ∠°	AZIMUTH														
	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290
0		-20.8		-17.3	-7.6	-3.3	[illegible]	.3	.5	-.2	-3.3	-7.1	-12.5		-18.3	-17.5
3		-21.4				-1.2	1.	1.7	2.1	2.1	.2	-3.2	-11.3		-16.7	-17.1
6		-20.8	-23.3	-15.3	-5.5	-1.5	.8	1.6	2.3	1.8	-.1	-4.1	-12.3		-20.2	-19.7
9		-19.4	-21.8	-13.9	-5.2	-.5	1.7	2.2	2.3	1.3	-.3	-4.1	-11.7		-19.7	-19.3
12	-21.1	-19.3	-20.8	-14.3	-5.2	-1.2	1.2	2.5	2.7	2.3	.4	-3.7	-11.		-15.	-15.7
15	-20.7	-18.1	-19.3	-14.1	-4.3	.2	2.5	3.7	4.0	3.5	-.1	-3.7	-11.1		-14.7	-15.5
20	-19.7	-17.2	-17.9	-13.8	-4.9	-.3	2.5	3.6	4.0	3.1	.7	-3.3	-11.9	-20.4	-13.2	-14.8
25	-18.9	-16.7	-17.3	-15.8	-6.5	-1.5	1.7	2.8	3.1	2.5	-.1	-4.7	-13.3	-19.9	-13.4	-14.9
30	-18.3	-15.8	-15.9	-15.9	-7.9	-2.5	.9	2.2	2.5	1.7	-1.3	-6.5	-15.1	-17.5	-13.5	-15.3
40	-18.	-14.7	-14.2	-16.1	-11.8	-6.6	-2.7	-.9	-.7	-1.5	-5.	-10.6	-16.9	-15.6	-14.2	-16.3
50	-17.9	-14.5	-12.9	-14.1	-16.8	-14.9	-10.6	-8.3	-7.6	-9.1	-13.9	-16.5	-14.2	-13.	-14.3	-17.8
60	-20.5	-15.2	-12.1	-11.7	-13.5	-15.8	-17.9	-18.0	-17.4	-17.2	-14.3	-12.	-10.9	-11.2	-13.5	-18.3

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