NRL REPORT 3886

# MICROWAVE INSTRUMENTATION FOR MULTIFREQUENCY ATTENUATION MEASUREMENTS THROUGH PROPELLANT GASES



NAVAL RESEARCH LABORATORY

WASHINGTON, D.C.

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# MICROWAVE INSTRUMENTATION FOR MULTIFREQUENCY ATTENUATION MEASUREMENTS THROUGH PROPELLANT GASES

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February 13, 1952

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## ABSTRACT

In studying electromagnetic propagation through the exhaust flames of reaction motors, the need of improved instrumentation for determining the loss of energy in the flame was recognized. A system utilizing pulsed electromagnetic energy at S-, X-, and K-Band frequencies on a time-sharing basis has been constructed and used in the field to make such measurements. Lens antennas were used to focus the energy within the flames and a traveling frame provided a means of exploring the length of the flame. Data was recorded on film at the rate of 32 readings per second for each frequency. This system is here described; the measurements obtained will be given in a later report.


## PROBLEM STATUS

This is an interim report; improvement on instrumentation is continuing and further experimental work is planned.

## AUTHORIZATION


NRL Problem R11-13
RDB Project NR511-130

Manuscript submitted September 20, 1951

# MICROWAVE INSTRUMENTATION FOR MULTIFREQUENCY ATTENUATION MEASUREMENTS THROUGH PROPELLANT GASES

## INTRODUCTION

### General Specifications

Various phases of the problem of determining "Electromagnetic Wave Propagation through Propellant Gases" have previously been presented (1, 2, 3, 4, 5, 6, 7). Further experiments were planned, and based on previous theoretical and experimental investigations, a method of instrumentation was established to concurrently determine at three different frequencies losses of electromagnetic energy due to passage through a rocket motor exhaust flame. The following general specifications for instrumentation were established:

a. Three frequencies, one each in the S-, X-, and K-Bands, were to be used either simultaneously or on a time-sharing basis.

b. The electromagnetic radiations for the three frequencies were to be focused on a small area in the propellant gases.

c. The complete antenna system was to be such that it could be moved continuously and automatically parallel to the axis of the propellant gases during an observation run.

d. The field intensities in the propellant gases were to be as low as possible in order to minimize any disturbing influence on the gases, yet to be of sufficient strength to allow measurements to a level of approximately 40 db below the value observed in the absence of the heated gases.

e. An automatic recording system was to be provided.

f. Measurements were to be accurate to within ±1 db when operating in the strong vibration field produced by the larger rocket motors.

Such a system was constructed and was used to conduct experiments on the exhaust gases of rocket motors. It is the purpose of this report to describe the system used. Before describing the system used some of the requirements for the system and their relation to the methods chosen will be discussed.

### Measurement System Features

Measurements of the losses attending electromagnetic waves as they passed through a flame were desired. The word "losses" as used here, (and often referred to as "attenuation"), means losses due to reflection, refraction, and absorption phenomena. No attempt was made in the system to be described to separate these phenomena.

Where large energy losses occur in a flame, it is extremely important to reduce the signal traveling between antennas by extraneous path (reflections from ground, etc.) to a minimum. For example, if the signal were attenuated 20 db in the flame, the signal traveling between antennas by any path, other than directly through the flame, must be much less than one percent of the total energy received under the no-flame conditions in order to obtain a reasonable degree of measurement accuracy. Thus it was seen that extremely high gain antennas would be required. Experimentally it was determined that the desired directivity could be achieved at microwave frequencies by means of lens antennas (6) placed close to the flame and focused on the center of the flame.

Theoretical considerations indicate that the attenuation is a function of the frequency of the incident radiation. To investigate this phenomenon, three different frequencies were selected, one each in the S-, X-, and K-Band regions. Ideally these should be measured simultaneously and along the same path through the flame.

It appeared impractical to construct a single antenna system that would handle the three frequencies. Consequently, the essentially symmetrical radial characteristics of the flame were utilized, and three pairs of antennas (one pair for each frequency) were arranged radially around the flame, each antenna being focused on the center of the flame.

Previous experience had shown appreciable interference between signals when used simultaneously. Although this problem could be solved, it would involve more work than appeared expedient. Further there appeared to be little loss in time-sharing of signals, since previous experience had shown that data could be repeated to within experimental accuracy on successive motor runs. Consequently a pulse system was selected, the pulses of the three frequencies being synchronized but displaced from each other in time by approximately 40 microseconds.

A system that would direct the electromagnetic energy through the flame transverse to the line of flow of gases appeared to be the best method available for restricting essentially all the energy along paths within the flame. A thorough investigation of the flame then required that it be examined along its entire length. As a result, the radially mounted antenna system was situated on a car which could be moved automatically along the length of the flame during a single run of the reaction motor. The system was designed to give an independent reading of attenuation for each one-seventh inch interval along the length of the flame.

Previous experience had indicated that in order to obtain the desired accuracy most of the electronic equipment had to be well isolated and built to stand the strong vibration field which exists in the immediate vicinity of a rocket motor flame. This was accomplished by placing the transmitting equipment and the major part of receiving equipment in mobile trucks and locating the trucks in an area of low noise field, the signals between trucks and the antenna system being transmitted by means of waveguide and coaxial lines. Large losses in the transmission lines between the transmitter truck and the transmitting antennas presented no difficulty since relatively high power pulse-operated magnetrons were readily available. The problem of coupling the rigid waveguide used for transmission of X- and K-Band signals to the moving antenna system was solved by utilizing rotary waveguide joints.

Variable calibrated waveguide-type precision attenuators were installed in each receiving system just ahead of the detector crystals in order to calibrate the complete system.

Since the long-time stability of such detectors is questionable, calibration was performed just prior to and immediately following each run.

In order to keep the electromagnetic signal level within the flame as low as practical, and also to simplify the transmission-line problems, the detectors were mounted near the receiving antennas. The X- and K-Band crystals were situated on the antenna mounting frame and the S-Band crystal within the coaxial line approximately 25 feet from the receiving-horn throat. The rectified signals were then fed through flexible cables to the pulser, amplifier, and display equipment.

The pulser, amplifier, and display equipment was utilized to initiate the pulses and to amplify and display the amplitude of the received signals on a cathode-ray tube. The resulting signal traces were photographed with continuously moving roll film to provide a recording of the signal loss as a function of the position of the antenna system. This unit was designed to record the amplitude of signals over the complete working range of the crystals used, a range of approximately 60 decibels. (Under actual motor firing conditions the noise level limited measurements to a range of approximately 30 db.) The display unit also displayed a monitor signal direct from the transmitters, thus giving a pulse-by-pulse incident signal reference to be compared with the output signals.

A block diagram of the electronic components of this system is shown on Figure 1. The antenna system on its movable platform is shown on Figures 2 and 3. The transmitter truck is shown on the extreme right of the latter figure. An inside view of the transmitter truck is shown on Figure 4. The receiver van and an interior view are shown in Figures 5 and 6. This position of the receiver van was selected, with the building shown, Figure 5, between the truck and the reaction motor test cell, in order to reduce the noise level. A view of the rotary joint system of hinging waveguide is shown in Figure 2.

Since the instrumentation for this system was designed for a particular display of information and its recording, this phase will next be considered.

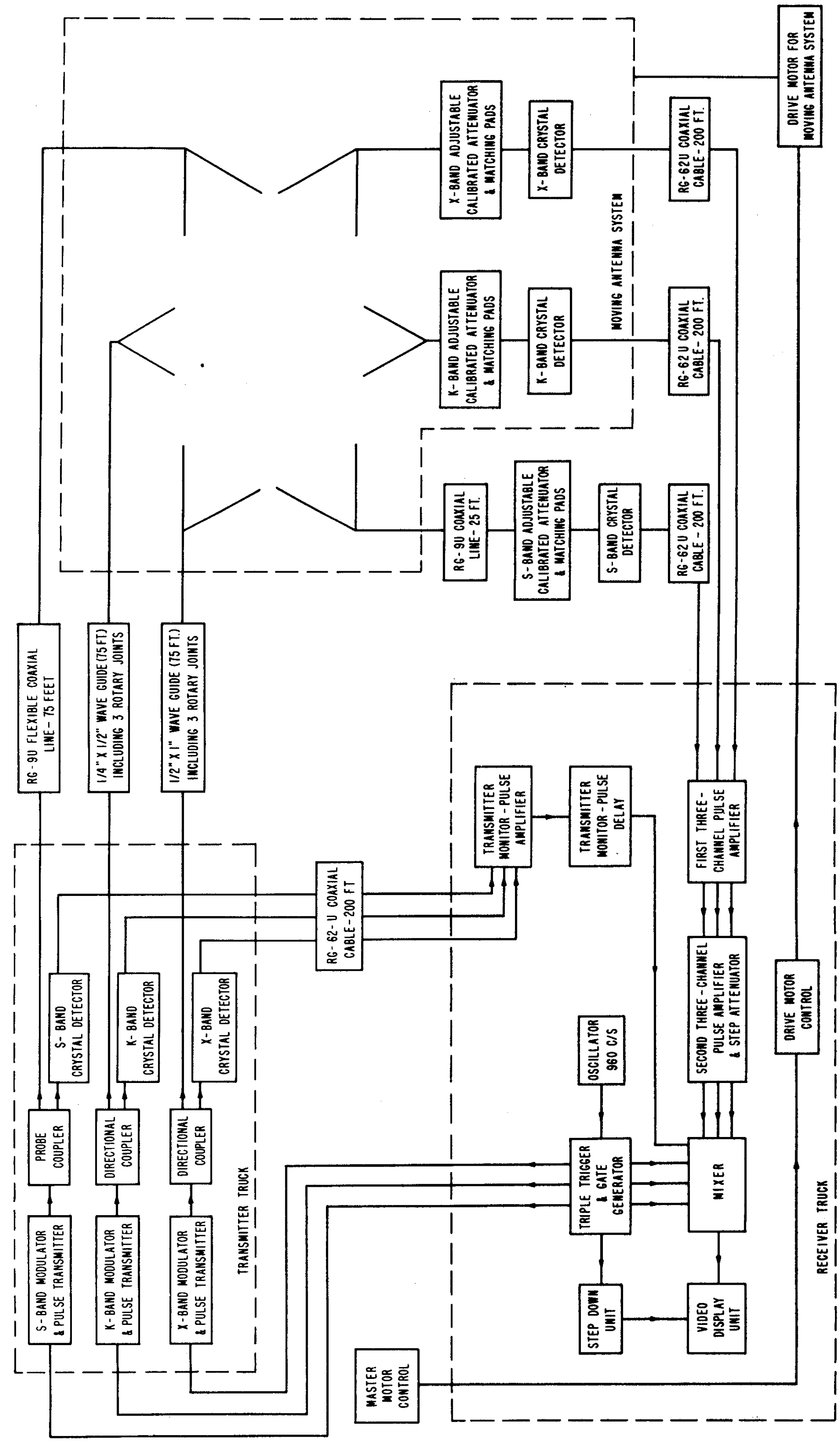


Figure 1 - Block diagram of instrumentation for multifrequency attenuation measurements through propellant gases

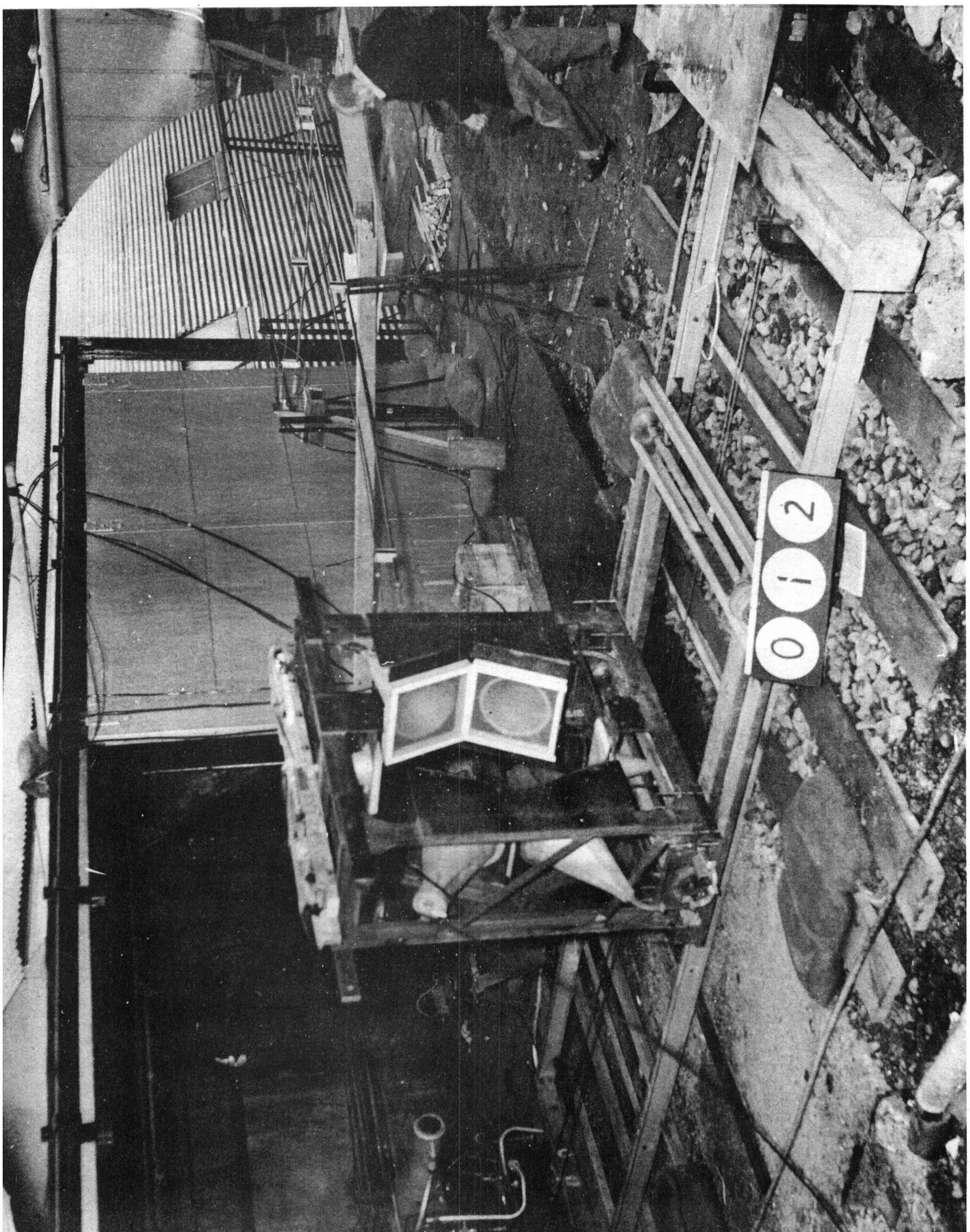


Figure 2 - Antenna system and railway mounted in firing position at rocket-motor test cell

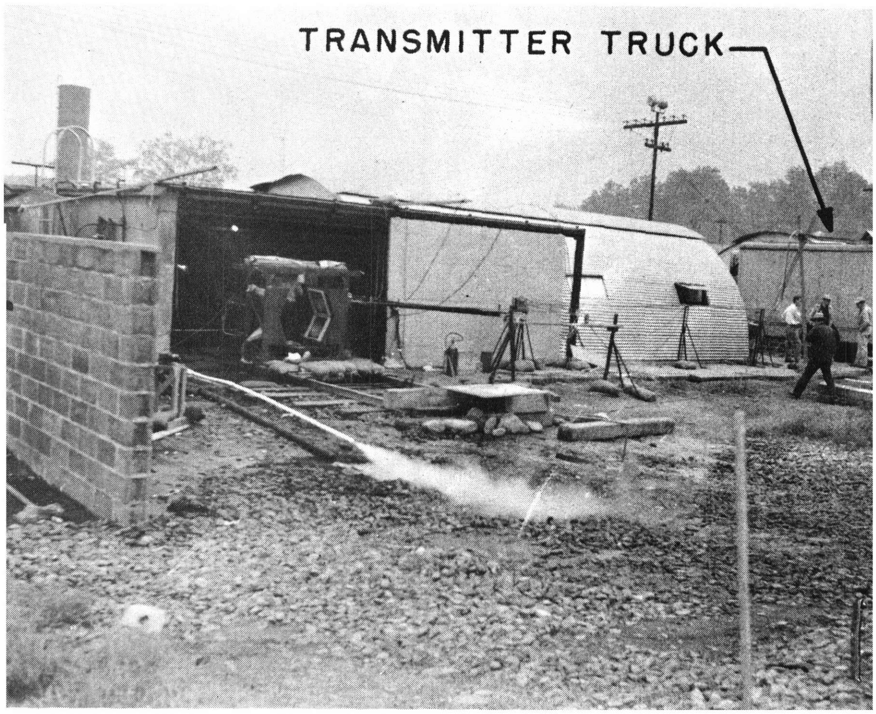


Figure 3 - Railway system and transmitter truck as located at rocket-motor test cell

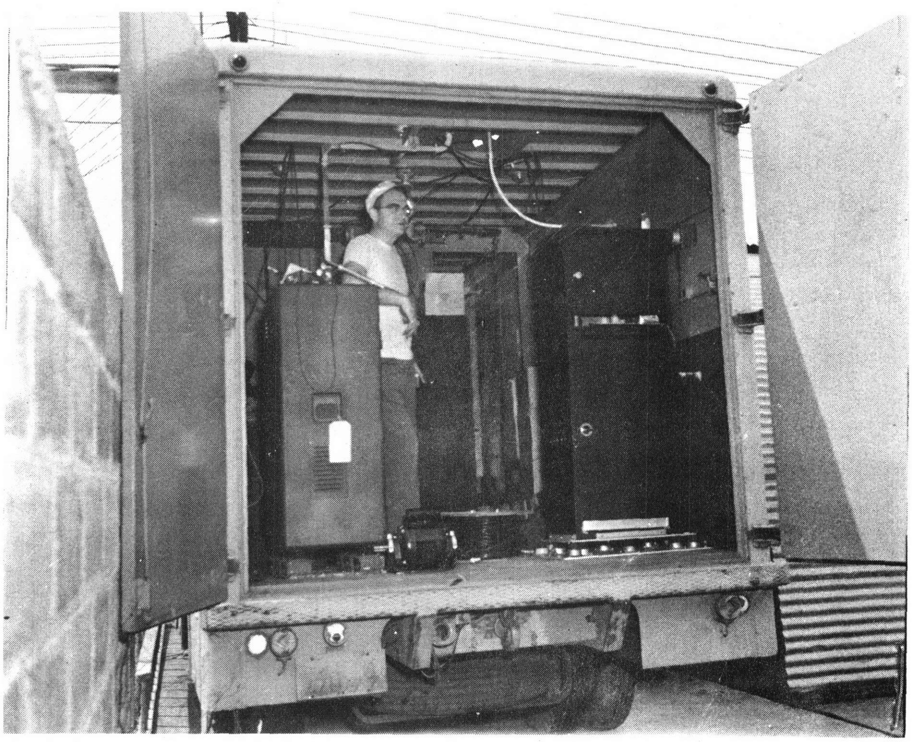

Figure 4 - Inside view of transmitter truck, showing equipment

Figure 5 - Location of receiver van (test cell containing rocket motor is behind Quonset hut)

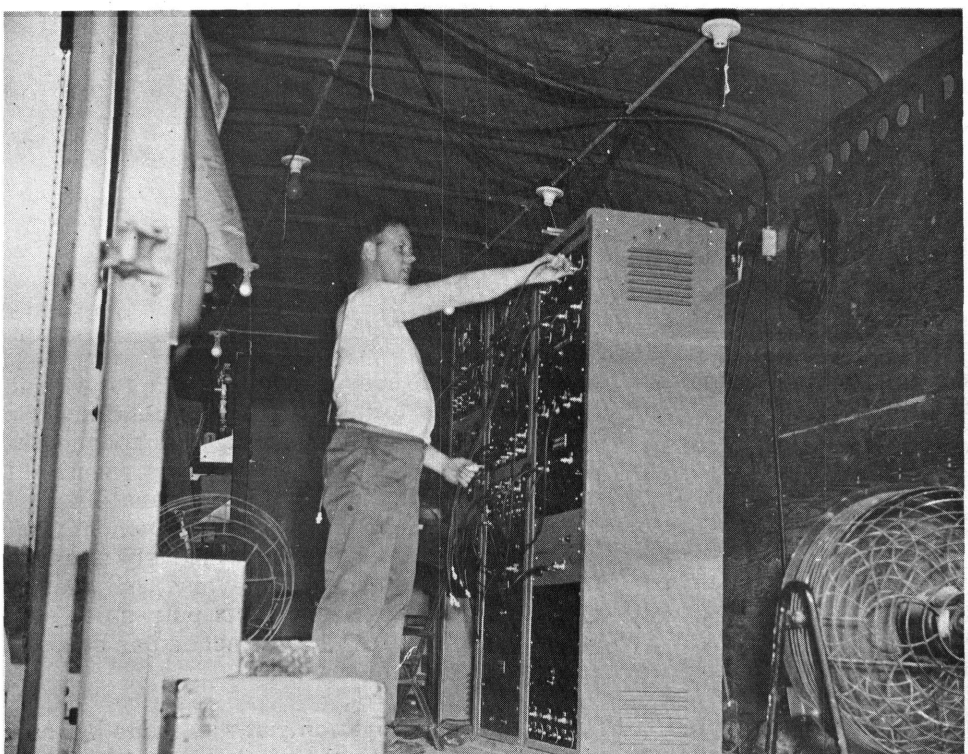

Figure 6 - View of equipment in receiver van (only the first two racks were utilized for the multifrequency attenuation measurements)

RECORDING METHODS

The data was recorded on film by photographing a cathode-ray-tube presentation of the signal amplitudes. A representative section of the recording is shown on Figure 7. The first, third, and fifth pulses of any group of six in this figure are the amplitudes of the S-, K-, and X-Band signals respectively after having passed through the attenuating medium on which experiments were conducted. The second, fourth, and sixth pulses are monitoring signals, showing the amplitude of the transmitted signal which caused the corresponding received signal.

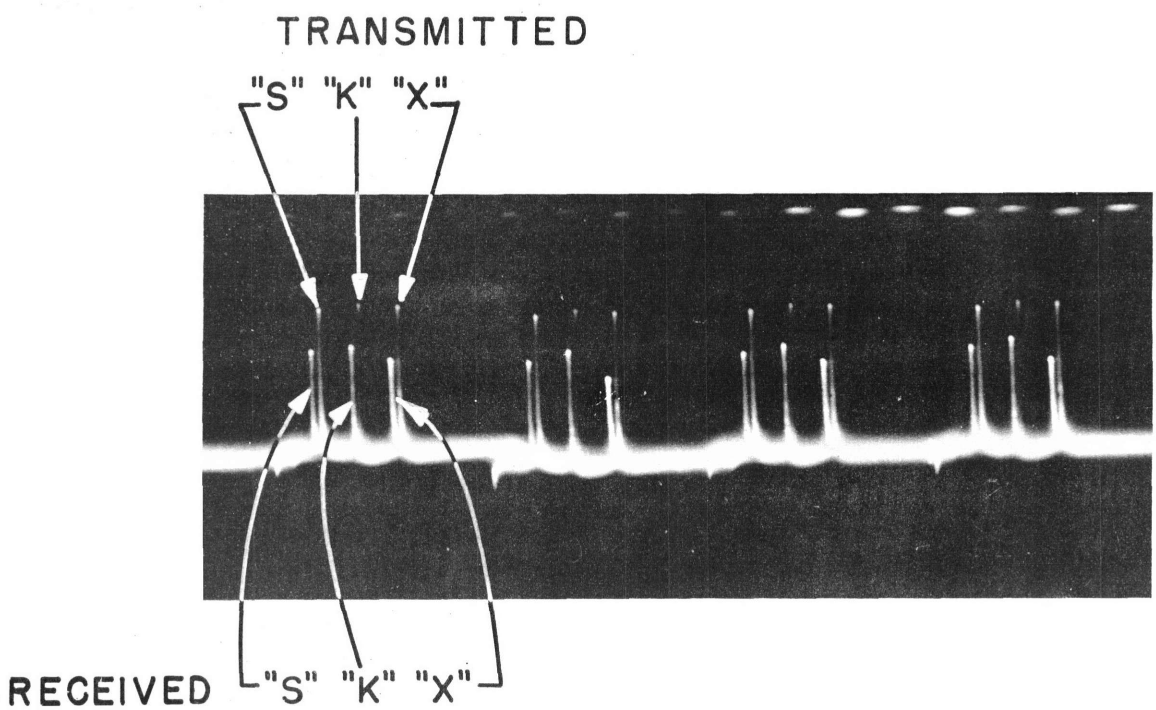


Figure 7 - Sample of photographically recorded data

In obtaining this data, two 5-inch oscillograph tubes were used, one for visual monitoring of the signals during a motor run and the other for the purpose of obtaining a photographic record. This record oscillograph used a 5CP11 cathode-ray tube with an accelerating potential of about fifty percent above rated maximum voltage, this potential being required to provide sufficient intensity for the required maximum writing speed of approximately $5 \times 10^6$ inches per second. Data records were made on Linograph Ortho film with a Dumont Oscillograph Camera, type 314, with a 2-inch, f/1.5 lens. The film moved continuously at approximately 18 inches per second. The oscillograph was blanked except for every 32nd group of pulses out of the transmitters, thus giving approximately 32 groups of six pulses per second. With the antenna carriage moving at a speed of approximately 4-1/2 inches per second this gave a record about every 1/7 inch of travel along the flame.

Prior to and after completion of each run, a calibration run was made by inserting a known attenuation in the transmission line. A sample of this photographic data is shown on Figure 8. Comparison of the record data with the calibration data readily gives the results to within the desired accuracy of plus or minus one db.

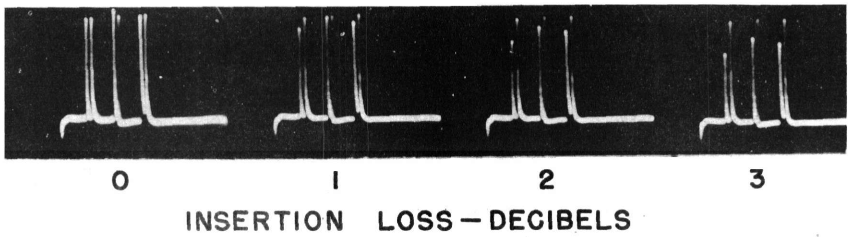


Figure 8 - Sample of calibration data

## MICROWAVE POWER SOURCES

The S-, X-, and K-Band transmitters, modulators, and associated power supplies were mounted in a separate truck, Figure 4. The keying signal of 960 pulses per second was fed into the respective equipments by cables from the pulser, amplifier, and display equipment.

A Model 12 modulator and power supply (built by Wholesale Radio Laboratories, Boston, Mass.) was used to drive a 2J32 magnetron for the S-Band signal of one microsecond pulse length. This complete unit, shock-mounted to the truck floor, is shown in Figure 9. Another Model 12 modulator and power supply (built by Henry Dormitzer Electronics, Newton, Mass.) was used to drive a 2J31 magnetron to supply the K-Band signal of one-half microsecond pulse length. This complete unit is shown, shock-mounted to the truck floor, by Figure 10.

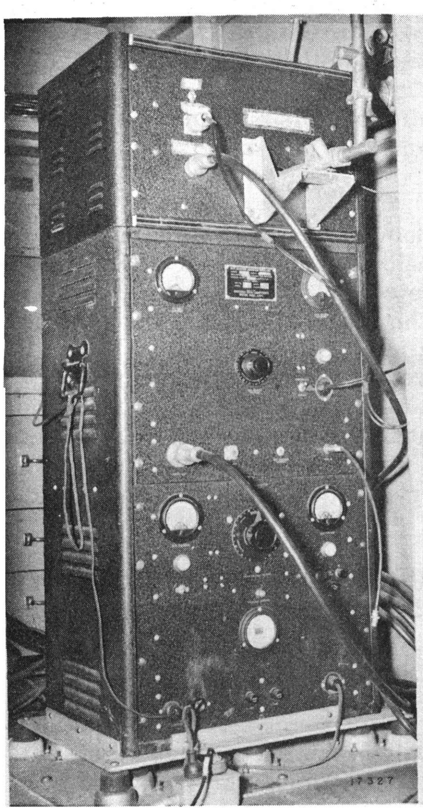

Figure 9 - S-Band transmitter, modulator, and power supply

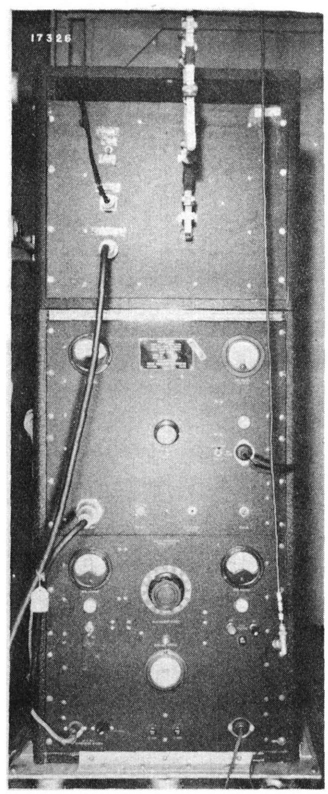

Figure 10 - K-Band transmitter, modulator, and power supply

A type AM-44/CPN-6 modulator driver, type T-79/CPN-6 transmitter modulator, and type PP-93/CPN-6 transmitter power supply (built by Galvin Manufacturing Corp., Chicago, Ill.) was used to drive a type 2J55 magnetron to supply the X-Band signal of one microsecond pulse length. The transmitter modulator is shown on the left in Figure 4.

## PULSER, AMPLIFIER, AND DISPLAY EQUIPMENT

The group-pulse generator, amplifier, and display equipment was designed to key three pulse-transmitters operating on different frequencies, and to amplify and display certain phenomena quasi-simultaneously.

The timing unit of the equipment is a group-pulse generator designed to produce three keying pulses, whose time displacements are continuously variable, and also to generate a fixed trigger pulse that operates the sweep of the presentation unit. Simultaneously with each keying pulse a gating pulse is generated. This gating pulse can be utilized to cut off two of the channels when displaying the pulses from the remaining channel.

The display unit contains a sweep generator, a video amplifier, and two five-inch cathode-ray tubes. One cathode-ray tube provides a means for visual observation; the other, a means for photographic recording.

The composite-pulse signal is fed into the presentation unit from a mixer amplifier which provides one output from four separate inputs. Three input channels are alike, each containing a gating circuit and suitable amplifier; the fourth is a simple amplifier. A switching arrangement is provided in the gated channels to enable a gated or nongated mode of operation. All channels have individual gain controls and input pulse polarity-selection switch. The mixer section of this unit combines the signals of the four channels into a composite signal in one output channel.

A grouped-pulse signal is fed into the fourth channel from the transmitter monitor section, which contains a mixer with three input channels and appropriate amplifiers. The monitoring pulses are obtained from crystal detectors located in the radio-frequency portion of each of the three transmitters. Before the composite monitor signal is applied to the fourth channel of the mixer amplifier unit, it must travel through a delay line to provide good visual separation between each received and transmitted pulse.

The received-pulse amplifier is a three-channel, two-section unit with a continuous gain control and a step attenuator in each channel. The input connection to each channel can be made directly to a terminated line from a crystal detector or to an additional low-level amplifier.

A block diagram, Figure 11, illustrates how the units are connected to make up the pulser, amplifier, and display equipment. Figure 12 shows a photograph of this equipment.

### Master Oscillator

The master oscillator in this equipment determines the recurrence rate of all of the pulse and gate signals, and this rate of operation is determined chiefly by the power limitations of the lowest-powered magnetron. Originally the oscillator used was an audio oscillator (Hewlett-Packard Model 200A) set at approximately 960 cycles per second.

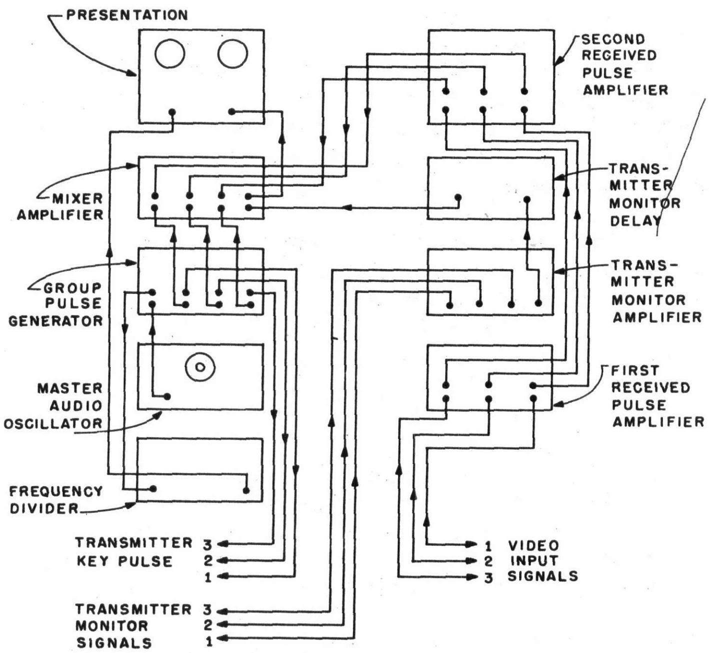


Figure 11 - Block diagram of pulser, amplifier, and display equipment

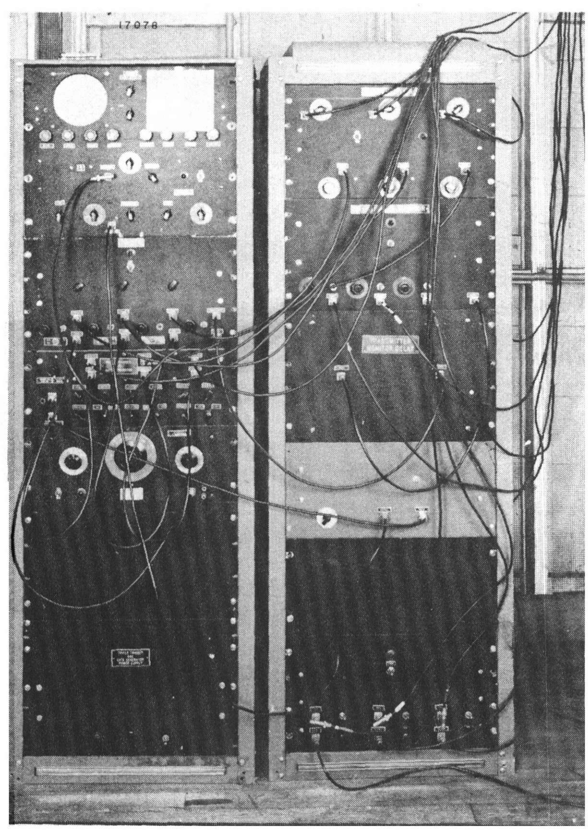

Figure 12 - Pulser, amplifier, and display equipment

The output of this oscillator was fed into the shaping circuit in the group-pulse generator, which is described in the discussion of the latter unit. When used in the field, the video portions of the equipment displayed a hum modulation pattern on the amplitude of the monitored and received pulses. Subsequently a synchronous oscillator was developed and incorporated into the equipment so as to make this hum modulation of minimum consequence. This latter oscillator takes the form of a frequency multiplier, multiplying sixty cycles to nine-hundred-sixty cycles in two multiplication steps.

The first multiplication is accomplished by applying a large amplitude sixty-cycle wave to a clipper tube and circuit to produce a squared or clipped wave. This signal is applied to the grid of a beam pentode whose plate circuit is an inductance-capacitance parallel resonant circuit with a resonant frequency four times line frequency, or two hundred and forty cycles. A beam pentode tube was chosen because a large output could be obtained with the available input signal and the plate resistance of the tube will not appreciably lower the Q of the toroid inductance employed.

The output from the first multiplier circuit is coupled into a second clipper like that of the first. This squared or clipped signal is fed into a second multiplier stage to be multiplied four times. The output of this stage produces the desired nine-hundred-sixty-cycle frequency. The circuit for the second multiplier is the same as that for the first, except for differences in the value of the inductance and capacitance in the tuned circuit.

The nine-hundred-sixty-cycle signal is clipped in the same manner as in the previous clippers and is then differentiated in a diode differentiator circuit to produce positive pulses. These pulses are connected to external circuits through a cathode follower. Figure 23 in the Appendix shows a detailed schematic diagram of the master oscillator system described.

## Group-Pulse Generator

The group-pulse generator produces three keying pulses displaced from each other in time, and simultaneously with each of these pulses, also produces a gating pulse. A fixed trigger-pulse is additionally produced and occurs ahead of the first keying-pulse. The time displacement between the trigger pulses and the fixed pulse can be continuously varied. The group-pulse generator can be operated from a sine wave or pulse input of frequency up to one thousand cycles. Figure 13 is a block diagram and Figure 24 in the Appendix, a schematic diagram of the group-pulse generator.

This unit is composed of four separate sections; the first is a shaping circuit which enables the use of a sine-wave source of frequency; the second, third, and fourth produce the keying and gating pulses.

The first section consists of two high-gain pentodes in a cascade clipper-circuit which will accept a sine-wave signal of large amplitude and produce square-wave output. This output is differentiated, and the positive pulse signal operates a pulse-forming circuit using a triode-connected pentode to ring a diode-damped inductance. The pulse from this circuit is coupled to the input of each of the three channels through a cathode follower. It is also brought out to a jack for a fixed trigger which synchronizes the presentation unit.

The second section consists of the pulse-spacing circuits. The fixed trigger plate keys a multivibrator with a variable grid-leak resistor to introduce pulses up to two hundred microseconds long. This pulse is differentiated, the negative pulse being used to give the

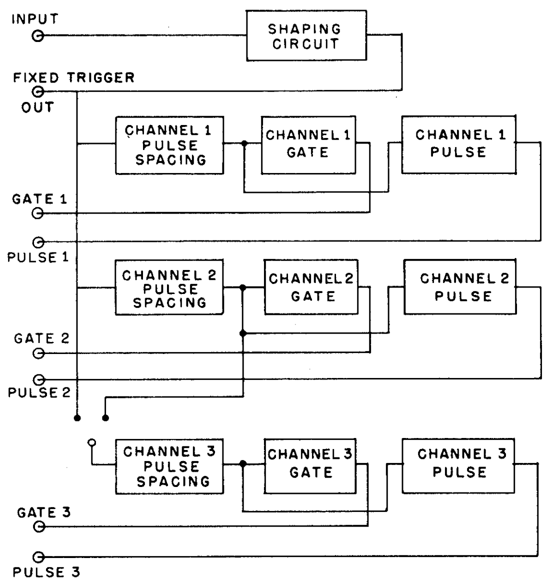


Figure 13 - Block diagram of group-pulse generator

desired delay. This differentiated signal operates a pulse-forming circuit using a triode to ring a diode-damped inductance. This pulse is connected to other circuits through a cathode follower. In channel number one it drives the pulse output and gating circuits; in channel number two it drives the pulse output and gating circuits, and through a switching arrangement can trigger the input multivibrator in number three channel so as to introduce an additional amount of delay in the third channel.

The third section is the pulse output circuit which takes the differentiated pulse from the pulse-spacing circuit and drives a pulse-forming circuit using a 6AN5 pentode to ring a 6X4-diode-damped inductance which produces a two-microsecond output pulse in excess of one hundred volts. In order that no distortion or deterioration of this pulse be present after driving it through a length of coaxial cable, a cathode follower is incorporated in the output.

The fourth section is the gate generator. It uses the differentiated pulse of the pulse-spacing circuit to plate-key a cathode-coupled bistable multivibrator having a variable grid leak so as to vary the width of the gating pulse. This signal is amplified, and a dual potentiometer is used as the plate- and cathode-load resistors for gain control. By switching from plate to cathode, the polarity of the output pulse can be reversed. This gating pulse is then fed into a cathode follower capable of driving a chosen length of coaxial cable.

The power supply for the group-pulse generator consists of a 500-volt 500-ma power transformer with full wave rectification and a two-section condenser-input filter circuit. The output incorporates two voltage-regulator circuits, one with three 6B4G tubes to regulate the 250-volt output, and the other with two 6B4G tubes to regulate the 150-volt output. A schematic drawing of this power supply is shown by Figure 25 of the Appendix.

## Three-Channel Pulse Amplifier

The first three-channel amplifier unit provides a voltage gain of approximately fifty. A reversing stage (2C51) is used on the input to provide for either polarity of pulses. This is followed by two amplifier stages (6AK5 and 6AQ5) using standard video amplifier circuitry, but with reduced values of coupling capacitors to reduce the low-frequency response. The output of the last stage is fed to the input of the second amplifier unit described subsequently. A circuit diagram of one of the channels and the power supply for the three-channel unit is shown in Figure 26 of the Appendix.

The second amplifier unit contains three separate two-stage video amplifiers each with a calibrated-step attenuator at the input. The step attenuator is a broadband resistance-capacitance voltage divider of known ratio for each step. There are as many voltage dividers as there are steps; and, upon switching, a completely different voltage divider is placed in the circuit. In the case of the first step (or 1 to 1 step) there is a shunt parallel resistance-capacitance circuit to ground. This is in the circuit to enable additional multiplications that can be equalized for broadband use to be placed ahead of the existing divider.

Each amplifier is two-stage, cathode-follower coupled with a continuously variable gain control at the grid of the second stage. Each of the two stages are alike, containing a pentode 6AK5 amplifier with a 6C4 triode cathode follower. The amplifiers are shielded from each other to avoid crosstalk between channels, and decoupling of the plate supply voltage is employed to reduce hum. The power supply is voltage-stabilized to prevent any possibility of amplitude change of signal due to change in voltage of the power source. Figure 27 of the Appendix shows a schematic diagram of one representative amplifier channel and the power supply for all three channels.

## Transmitter Monitor

The transmitter monitor unit is one which amplifies the monitoring pulses from the three individual transmitters and mixes these three channels into one output. The input to each channel is arranged to accept pulses of either polarity from a cable connected to the crystal detector. The gain control is a low-resistance potentiometer of such value as to minimize capacity loading of the crystal detector by the cable. If extremely long cables are to be used, a cathode follower should be connected between the crystal detector and the long cable. The signal from the gain-control potentiometer is coupled into a 6AK5 pentode amplifier and then into a 6C4 triode amplifier. A switching arrangement is placed in the coupling circuit to the input of the mixer tube. This switch enables pulses of either polarity at the input to appear as positive pulses at the output of the mixer. The mixer circuit contains three remote-cutoff pentodes with the grid of each coupled to the external circuits through a cathode follower. The external circuit of this unit is a delay line whose delay is approximately 7 microseconds. This delay line is coupled to the monitor input channel in the mixer-amplifier unit, and displaces the monitor pulse from the received pulse, thus giving three groups of pulse pairs on the presentation unit. The power supply requirements are met by the use of a carefully designed voltage-stabilization circuit and by decoupling the direct-voltage source into each channel.

Figure 28 of the Appendix shows the schematic of a representative single channel the mixer section, and the power supply for the unit.

## Mixer-Amplifier

The mixer-amplifier unit amplifies, gates, and mixes four separate input channels into one output channel so as to enable presentation on the dual-tube presentation unit.

The input to each of the three signal channels is arranged to accept either a positive or negative pulse signal but always present a positive pulse signal to the grid of the gating tube. The gating circuit contains a 6AS6 tube chosen because of its particular control properties in the suppressor grid. The control grid is biased in such a way that the tube would operate as a class-A amplifier, and the suppressor grid is biased for plate cutoff. At quiescence the screen grid is the only element in the tube that is conducting. If a pulse signal comes to the grid there will be no signal at the plate, but if at the same time a gating-pulse signal occurs at the suppressor grid, then both signals will appear at the output. The output from the gate stage is amplified through a triode and then a pentode stage that is biased beyond cutoff. The bias on this pentode stage may be changed at will from the front panel so as to cause the gating pulse (or pedestal) to appear or disappear. The subsequent output is coupled into the grid of a mixer tube.

The mixer circuit contains four remote-cutoff pentodes with separate inputs to each control grid, and all plates connected to a common plate-load circuit. This in turn is fed into the presentation unit through a cathode follower to minimize capacity loading from the interconnecting cable. Figure 29 of the Appendix shows the schematic of one amplifier channel, the mixer channels, and the associated power supply.

With the gate circuit activated, the amplitude response is nonlinear. Figure 14 shows a plot of this amplitude response with a gating pedestal of 0.06 volt amplitude. Switches are provided on the front panel to disable the gating circuits thus feeding the signal directly to the mixer. The latter case exhibits linear amplitude response characteristics.

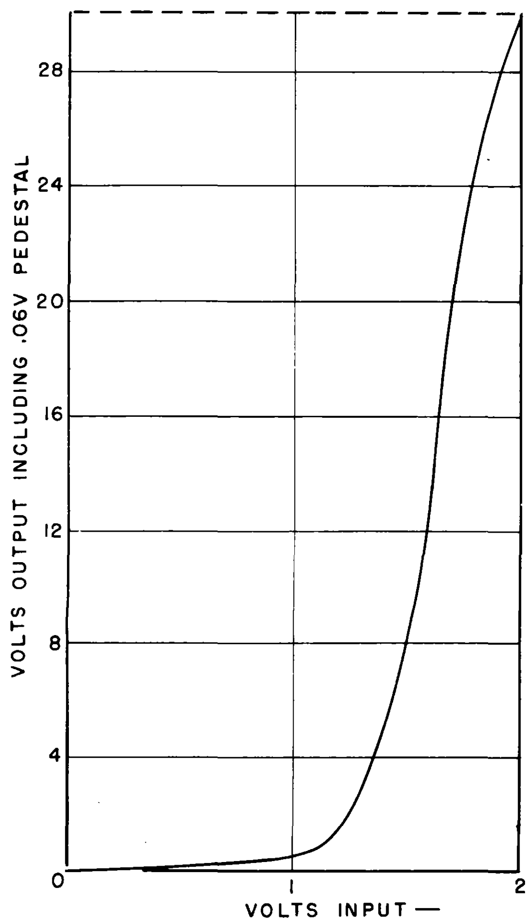


Figure 14 - Response of mixer-amplifier when used with gating

## Pulse Divider

A divider unit receives the pulses from the otuput of the shaping circuit in the group-pulse generator and gives a pulse output at 1/2, 1/4, 1/8, 1/16, 1/32, or 1/64 the rate of the input pulse, depending upon the number of binary dividers used. This output rate is adjustable by means of a step switch on the front of the panel which selects the desired state of division. A block diagram of the divider unit is shown in Figure 15. The input pulse-shaping circuit, one of the binary dividing circuits, the output pulse-shaping circuit, and the power supply are shown in the Appendix in Figure 30.

The received pulse passes through a shaping circuit before application to the first decade-divider. The first stage (6AU6) clips the pulse and passes the peak into a differentiating circuit. The output of the differentiating circuit is fed into the second stage (6AU6), which keys a cathode-coupled flip-flop circuit (6J6). The output of this flip-flop circuit rings a circuit (2.5 millihenry inductance plus stray capacitance) which is damped with a 6AL5 diode to give out a single positive pulse output. Each binary divider consists of a dual triode (6J6) and two crystal rectifiers (IN34). If triode 1 is conducting, the voltage on crystal 1 connected to that plate will be approximately half of that on crystal 2. The applied pulse will then pass through this crystal 1 and will drive the grid of the nonconducting triode positive, causing it to conduct. This then drops the voltage on the grid of the other triode and cuts it off. The next input pulse reverses this procedure. The output is taken from the plate of one of the triodes, thus giving out one pulse for each two pulses in.

The number of stages of binary division desired are selected with a step switch which applies the divider output to an output pulse-shaping network. The first stage (6AU6) of this output circuit keys a cathode-coupled flip-flop circuit (6J6). The output of the flip-flop circuit rings a circuit (2.5 millihenry inductance plus stray capacitance) which is damped with a 6AL5 diode to give a positive-pulse output. This pulse drives a cathode follower (6AG7) whose output is fed into a cable which connects to the synchronizing input of the display unit.

This divider then permits the display of a reduced number of the transmitted pulses on the display unit, and is required in photographing individual pulses, since the speed of the film moving across the face of the cathode-ray tube is limited.

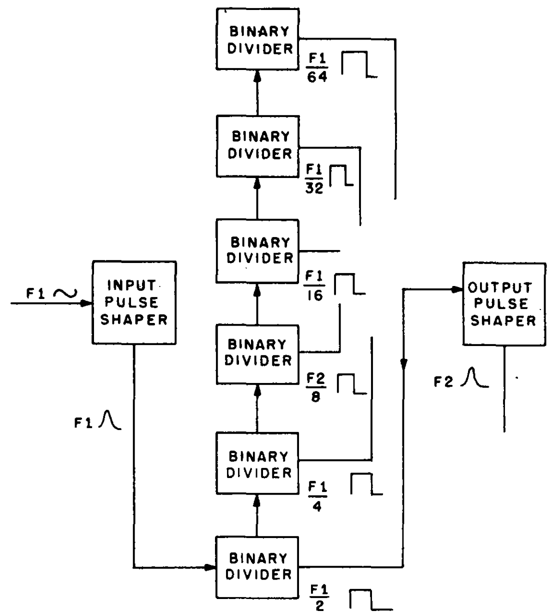


Figure 15 - Block diagram of pulse-rate divider unit

Display Unit

The presentation of the received and the monitored pulses is accomplished by means of a dual-tube oscilloscope. One of the presentation tubes provides a means for visual observation of the pulse phenomena; at the same time the other tube provides the same image for photographic recording. Since both tubes are to present the same image, the horizontal and vertical deflection plates are driven simultaneously, and both tubes are unblanked simultaneously. Figure 31 of the Appendix shows a schematic diagram of the unit. Most of the circuitry used is similar to that used in the oscilloscope TS239. Consequently an instruction book (8) on this equipment may be referred to for a more detailed description.

The sawtooth generator consists of a trigger amplifier that is diode-coupled to a plate-keyed monostable multivibrator, a sawtooth generator, and a final amplifier tube. The trigger amplifier is a resistance-coupled amplifier with a gain control, and is designed to accept synchronizing signals of either polarity to produce an output suitable to trigger the multivibrator. The negative pulse output of the multivibrator is applied to the grid of the sawtooth-voltage-generator tube, and the positive pulse-output is coupled to an unblanking voltage generator. The pulse circuits of the multivibrator are carefully peaked or equalized to provide the pulses with good rise and fall characteristics.

The sawtooth-voltage generator is a series resistance-capacitance circuit with a high-$\mu$ pentode, normally in conduction, connected across the capacitor. When the negative pulse is applied to the grid of the pentode switch tube, this tube cuts off and the condenser charges through the series resistance on an exponential rise. The time constant of this circuit and the pulse duration time are carefully controlled so as to make use of only the most linear portion of the exponential rise of the voltage across the capacitor.

The output of the sawtooth generator is coupled to the clamped grid of a push-pull, cathode-coupled output amplifier which is directly connected to the deflection plates of the visual observation tube. Centering is accomplished by varying the d-c voltage on the undriven grid of the output stage.

The unblanking monostable multivibrator operates from the positive-pulse output of the main multivibrator. This pulse is differentiated so as to form two triggering pulses, one positive and one negative. The positive pulse will trigger and the negative pulse will restore the multivibrator, reproducing the unblanking pulse in time, but with much larger amplitude. The 6AQ5 beam power tube was chosen for this use in order to obtain a large output from a relatively small triggering input. The large-amplitude unblanking signal is needed to allow visual cutoff and still produce high-intensity trace with the increased gun and accelerator voltages. The time constants of the multivibrator are chosen so as to afford proper unblanking operation only when the coarse-sweep switch is set on 100.

The video channel of the dual-tube presentation unit is a four-stage, broadband amplifier with push-pull power output. The input of the amplifier is a three-step multiplier with 1, 10, and 100 voltage ratio.

The first two stages of the video amplifier are alike; each contains a 6AK5 pentode amplifier coupled directly to a triode tube. A low-resistance gain-control potentiometer is placed after the paraphase amplifier of the first stage. This enables the preservation of the broadband characteristics of the whole amplifier for all gain-control settings. The signal-channel synchronizing signal is taken from the plate of the 6C4 in the first stage. The second stage of video amplification is a 6AK5 pentode directly coupled to the grid of a 6C4 cathode follower, which in turn is coupled to a power-pentode driver-amplifier, 6AG7. The output from the 6AG7 driver is coupled into the push-pull beam-power output stage, which is carefully designed to preserve as nearly as possible the desired linearity between input and output amplitude and at the same time to maintain broadband characteristics.

The recurrence rate of the transmitted pulses is nine-hundred-sixty cycles; however, for photographic recording of the six-pulse sets of data, limitations on film velocity (about 18 inches per second) restrict the rate of recording to about 32 recordings per second. This is accomplished by a binary counter (previously described) counting down or dividing the fixed trigger-pulse rate from the pulse generator by multiples of two, and using this reduced repetition rate for triggering the oscillograph sweep.

Each of the cathode-ray tubes has its own centering, brilliance, and focus controls, a switch for unblanking to the recorder tube, and a switch for reversing the mode of deflection on the recorder tube. The switch will produce normal presentation, or will produce the pulses horizontally without sweep. Other controls are sweep fine and sweep coarse, synchronizer selector, and synchronizer polarity. All these controls enable various modes of operating the sweep circuits. The video amplifier is controlled by the gain control and the step multiplier.

## TRAVELLING AIR GAP AND ASSOCIATED APPARATUS

### Railway System

A system is provided for moving the electromagnetic gap longitudinally along the flame. This arrangement, with the antennas positioned on the movable carriage or car, is shown in Figure 2. The over-all length of the rail is approximately 20 feet, providing a car travel of 14 feet. The car is moved in either direction, by a drum-driven 1/4-inch steel cable.

Three and one-half turns of the 1/4-inch steel cable wrapped around the drum provide the necessary friction drive. Driving power is provided to this drum by a 3/4-horsepower motor (capacitor-start, 1800 rpm, 110 v ac) through a reduction gear (Boston Reduction Gear Model ATW38, reduction ratio 124 to 1). Both local and remote control positions were provided for starting, stopping, and reversing the carriage-drive motor. The motor, reduction gear, friction drive drum, and local control box are shown in Figure 16. A more detailed view of the car with antenna mounting frame in position is shown in Figure 17.

A flexible line connected to the car drove a cam which actuated a microswitch for every inch of travel of the car. The switch, in turn, actuated an indicator light mounted on the face edge of the recording cathode-ray tube, thus giving a mark on the record film for each inch of travel of the car.

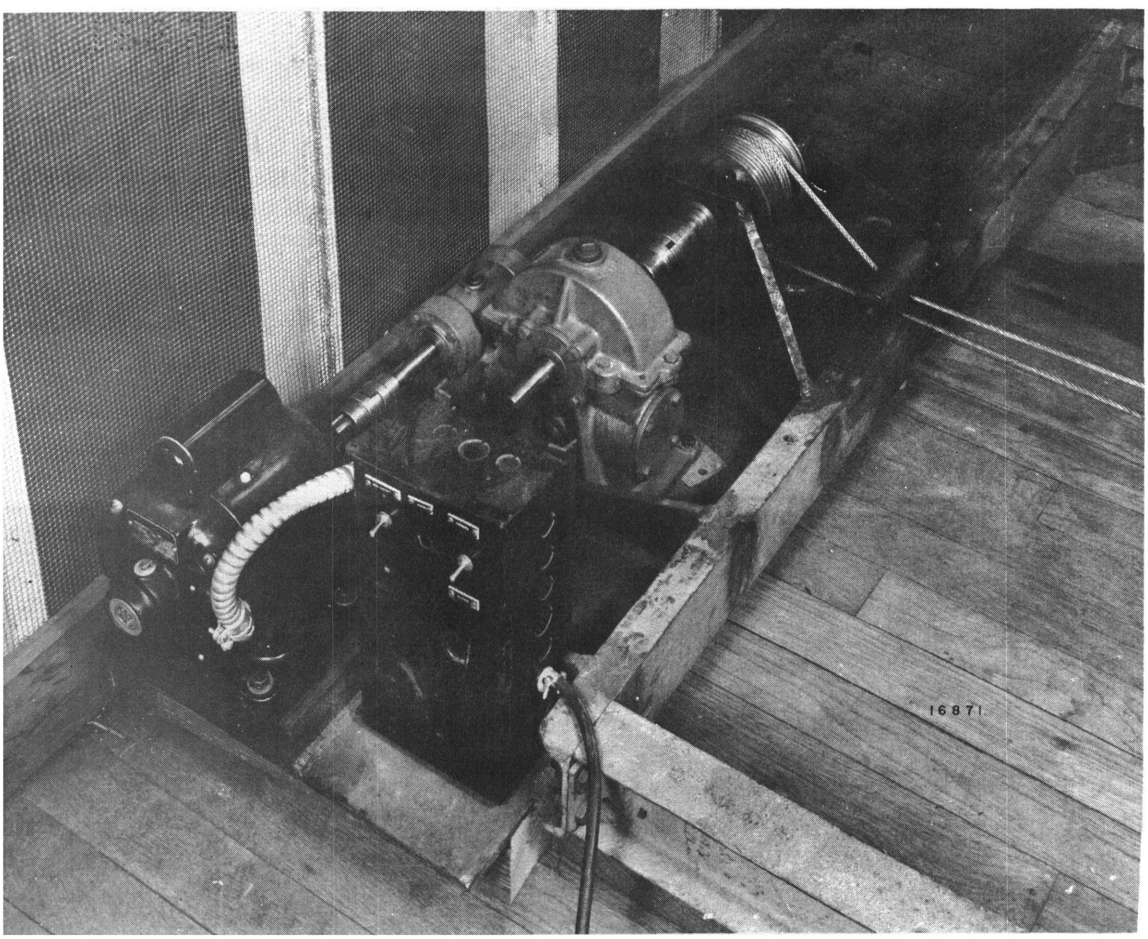


Figure 16 - Motor drive system for movable carriage

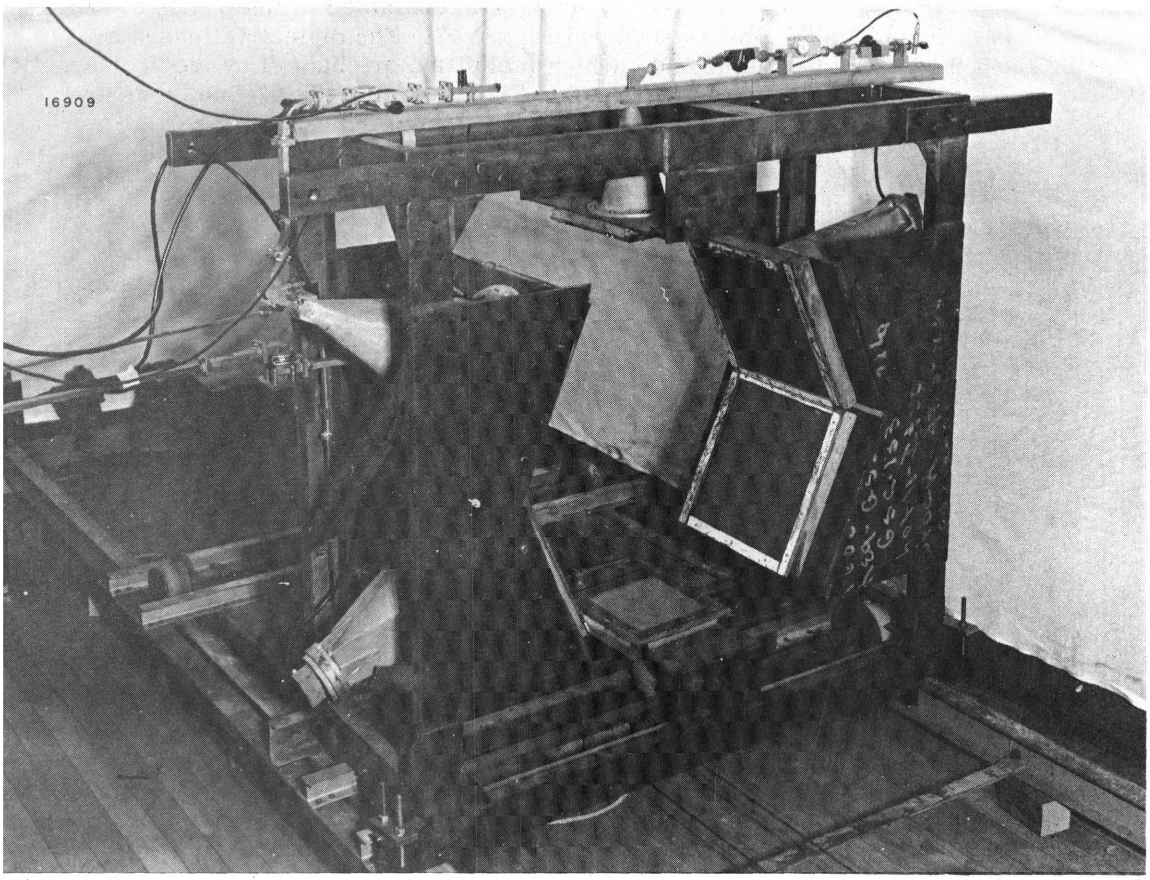


Figure 17 - Details of antenna mount and railway car

## Waveguide Power Feed

Rigid waveguide and rotary joints are used to feed X- and K-Band energy to the moving antenna system. The complete rotary joint system is shown in Figure 18. The separate rotary joints and their mounts are shown in Figures 19, 20, and 21. DeMornay Budd, type DB488 rotary waveguide joints are used for the K-Band feed system and Western Electric type D153023 rotary waveguide joints for the X-Band system. Investigation indicated variations in power output due to motion of the rotary joints to be at all times less than 0.25 db over the range of motion used. No attempt was made to obtain a more accurate indication since 0.25 db is about the minimum detectable change for the recording system used.

## Antenna System

The horn antennas contain a dielectric lens system. Each antenna consists of a converging hyperboloidal lens fed by an electromagnetic horn. Each antenna is so placed that its focal image is formed on the axis of the flame. A complete description of these antennas along with an exposition of their advantages is contained in Reference 6. These antennas were mounted on a frame as shown in Figure 17. The dielectric lenses are protected from the heat of the flame and burning fuel at motor shut-off by electromagnetically transparent covers as shown in the same figure. The covers for the K-Band lens are Micalex; those for the S- and X-Band antennas are Synthene XXX P IR3.

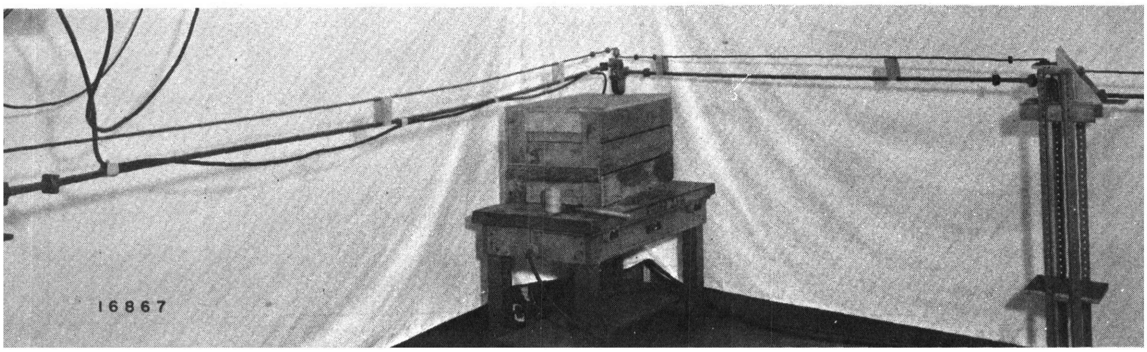


Figure 18 - Complete rotary joint system

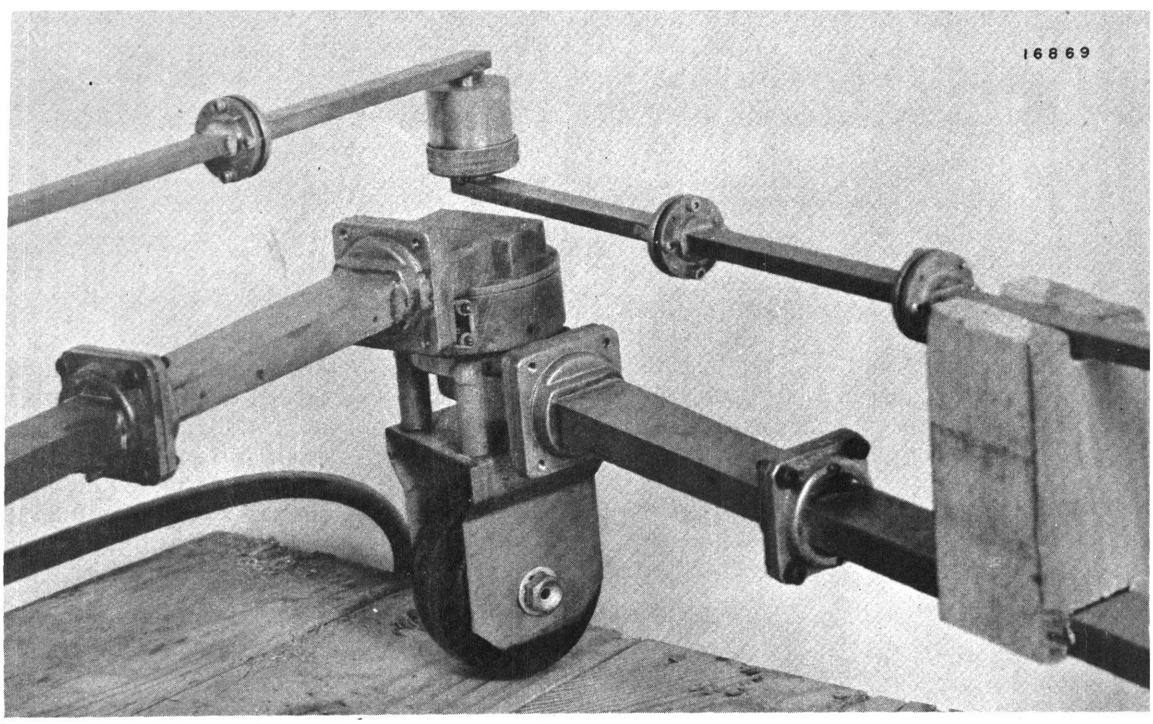


Figure 19 - Close-up view of movable rotary joint

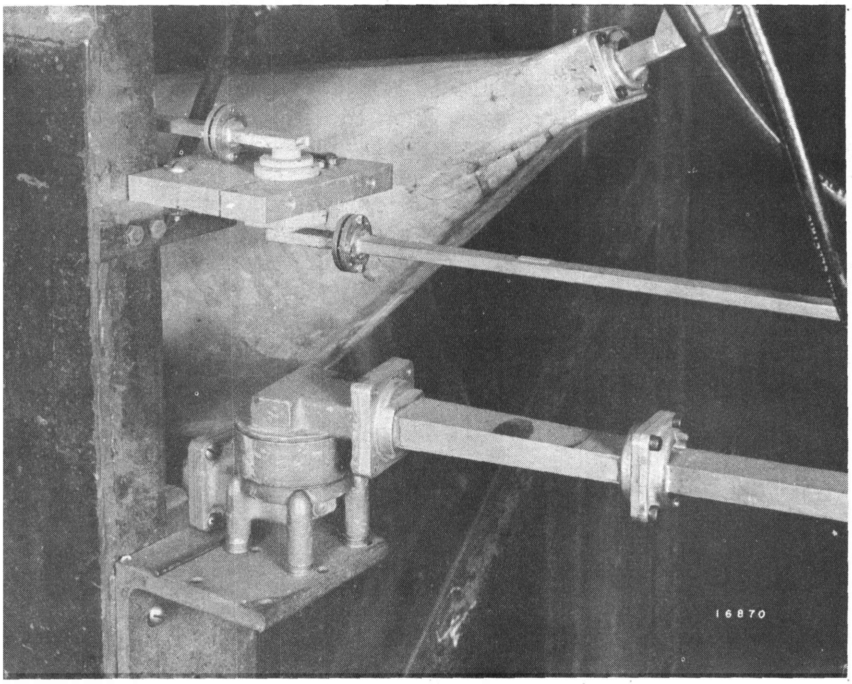


Figure 20 - Close-up view of rotary joints on antenna mount

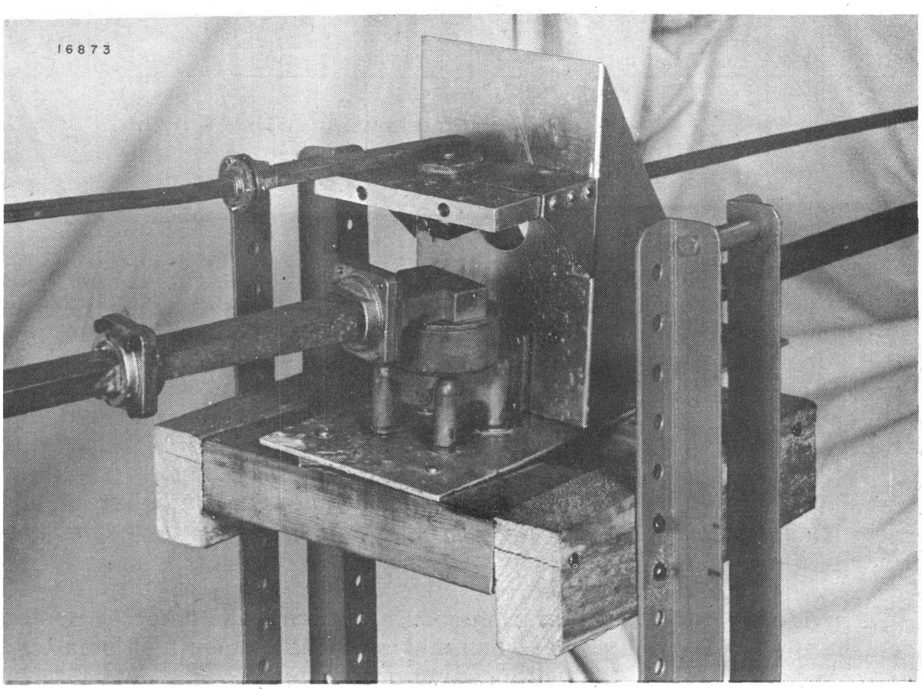


Figure 21 - Close-up view of fixed-position rotary joint

R-F, Detection, and Video Lines

The necessary interconnecting lines used are shown in block diagram form in Figure 1. The line details from receiving antenna to detectors are shown in Figure 22. The components shown for X- and K-Band were coupled with waveguide sections. The couplings for the S-Band components are shown on the block diagram. The matching pad used in the S-Band system was made by inserting a tapered attenuating strip in a 12-inch length of 1-1/2" x 3" waveguide. Pressurized fittings are used on all waveguides and antennas to assist in keeping out moisture and the guides are blown out periodically with dry nitrogen to remove any moisture which might have leaked in during shut down periods. Pin guides are used in the waveguide flanges for alignment purposes.

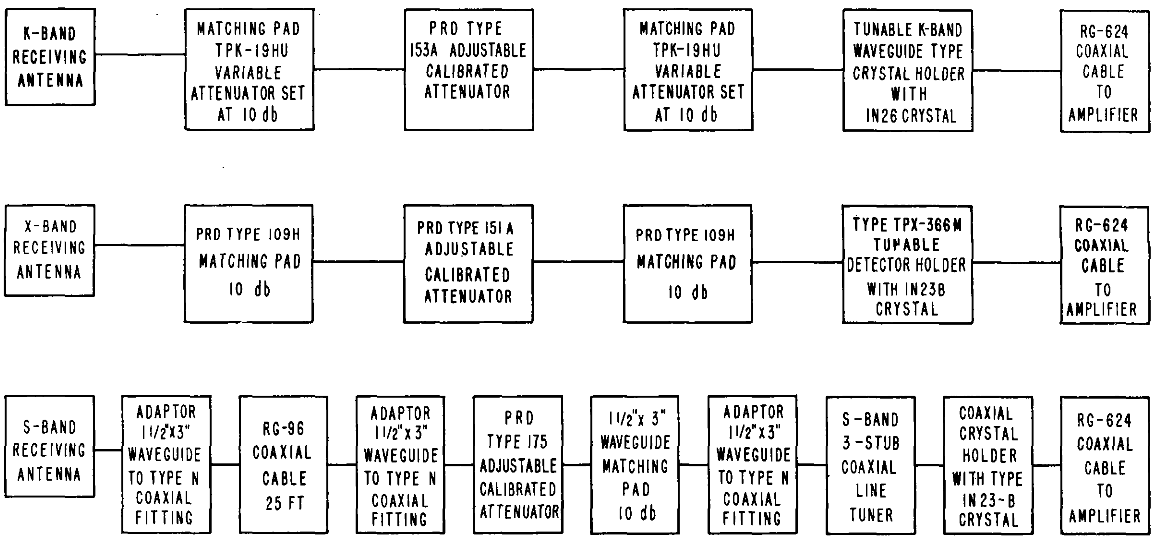


Figure 22 - Block diagram showing r-f lines from receiving antennas through detectors

CONCLUSIONS AND RECOMMENDATIONS

The system was used in June 1950 to conduct experiments on the exhaust gases of a 1500-pound-thrust oxygen-alcohol motor and of a 400-pound-thrust acid-aniline motor at Reaction Motors, Inc., Dover, New Jersey. The equipment performed satisfactorily under the rather rugged conditions encountered at the rocket-motor test stands and a large amount of propagation data was obtained. This data is being analyzed, and the results will be published at a later date.

As a result of the field use of this equipment, the need for a number of improvements was observed. Consequently, the following changes in the system have been recommended and are either under way or are contemplated in the near future.

1. Provide an 8.6-millimeter transmitting antenna and detector system to replace the S-Band equipment when making measurements on smaller flames in order to obtain satisfactory focusing properties.

2. Provide recording voltmeters to read the average amplitude of the pulses for each system. This will eliminate the necessity for transferring most of the point-by-point data from the film, the film then being used only to give the deviation from the average.

3. Modify the antennas and mounting system to provide greater separation between antennas. On the field trip, measurements could not be made out to the end of the 1500-pound-thrust flame because of the larger hot area near the tip of the flame.

4. Improve the gating system or obtain isolation of different frequencies with transmission-line filters.

5. Provide an automatic calibration system to eliminate the time-consuming, individually hand operated attenuators.

6. Provide a more satisfactory car-position indicator system, since the cable-driven cam system is too cumbersome and not always reliable.

7. Modify circuitry to cut off low-frequency response (below 10 kc) and otherwise reduce microphonics. As previously used, a flame attenuation of approximately 30 decibels was the maximum that could be measured.

8. Modify the display unit (a) to stabilize the position of the base line on the oscilloscope tube, (b) to increase the intensity of the trace and thus allow higher writing speeds, (c) to partially blank off the base line to make its intensity comparable to the intensity of the displayed pulse and (d) to eliminate interaction between the controls for the two parallel-operated display tubes.

9. Provide a pulse-stretching network to equalize the length of each pulse of the three sets of pulses in order to simplify the photographic problems.

After completion of modifications further experiments are planned on various types of rocket motors including solid fuel motors.

* * *

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8. "Instruction Book for Oscilloscope TS-239A/UP," Lavoie Laboratories, Morganville, New Jersey, or NAVSHIPS PUBLICATION NO. 91,148, December 15, 1948


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# APPENDIX
## Schematic Diagrams

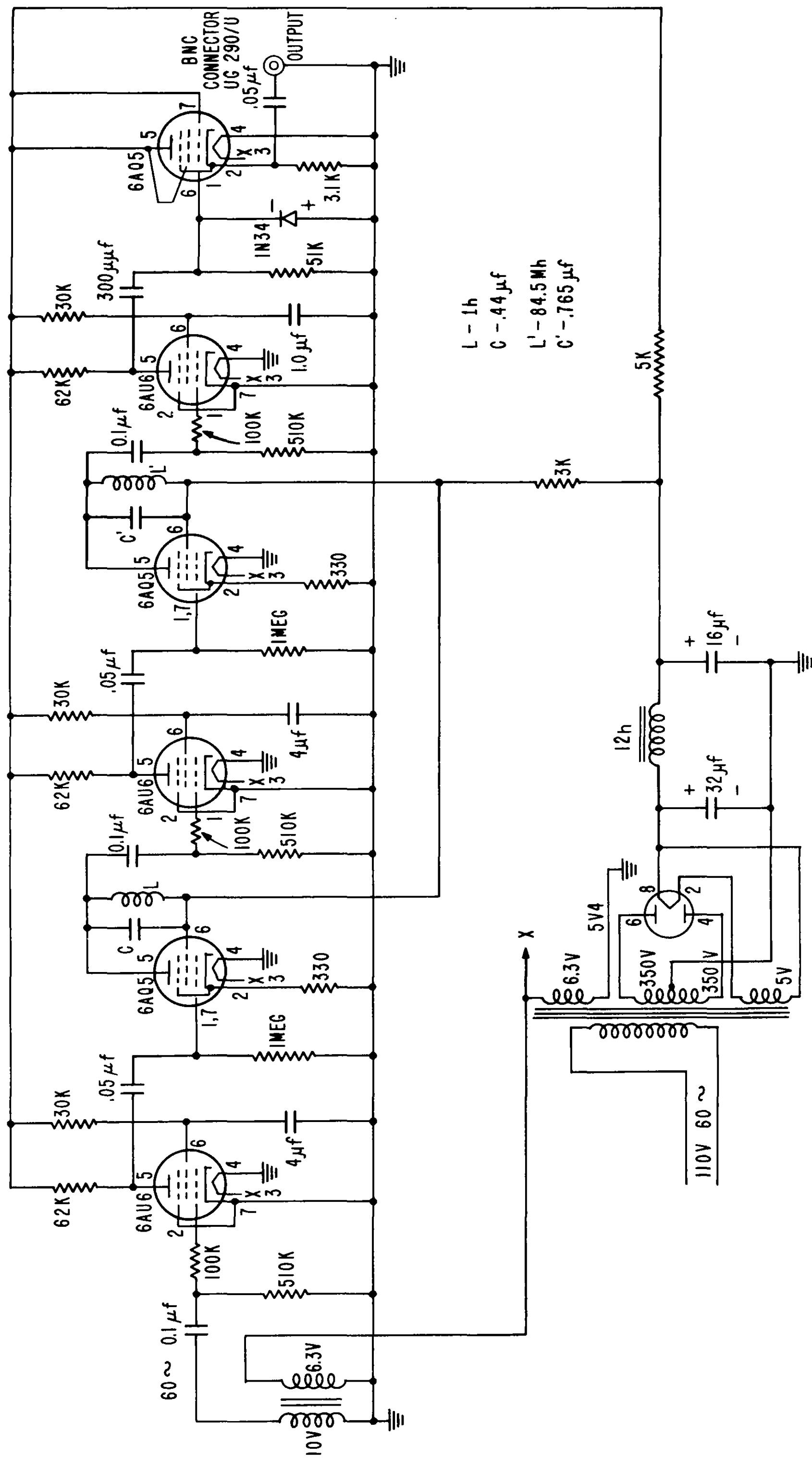


Figure 23 - Master oscillator

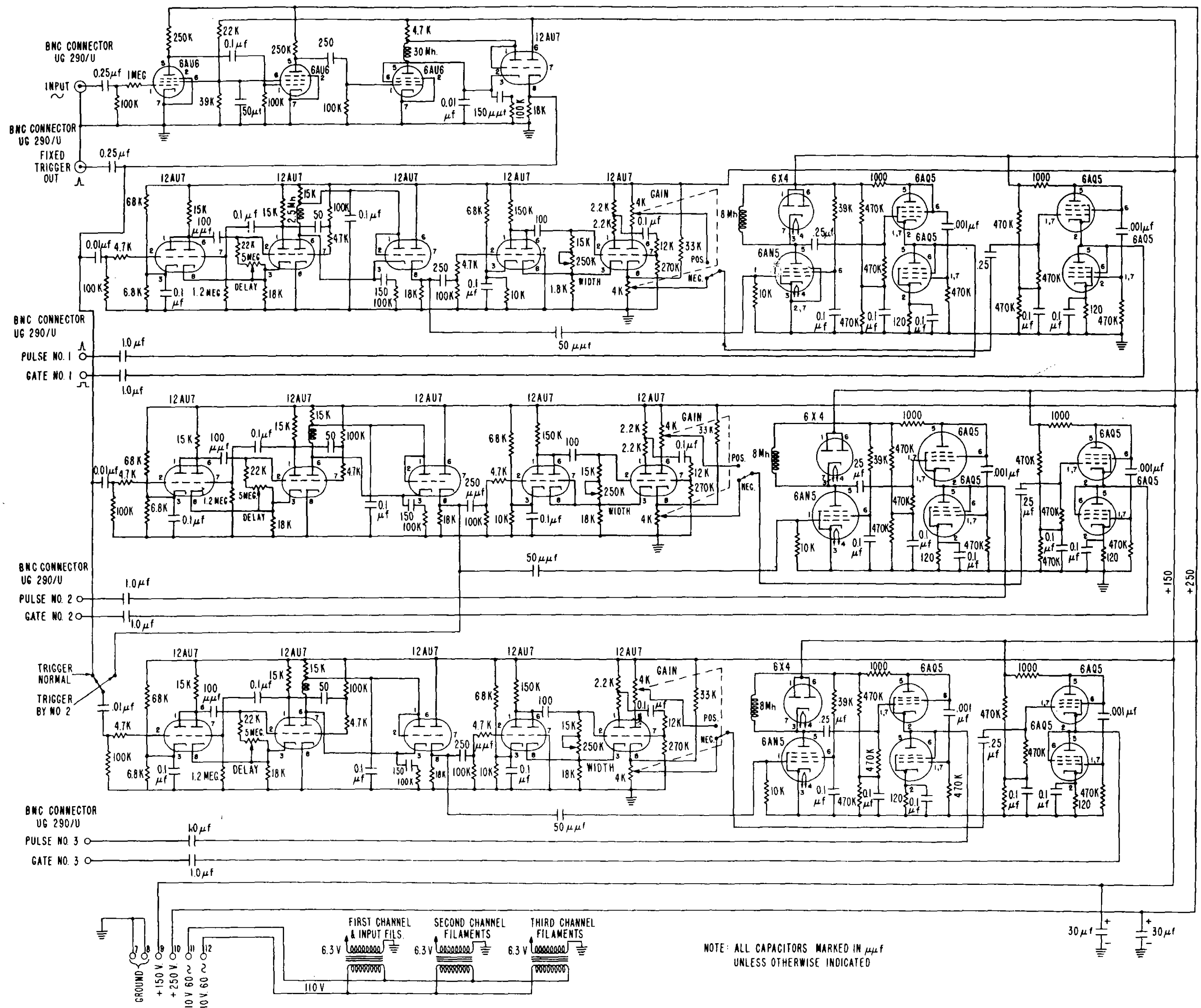


Figure 24 - Group-pulse generator

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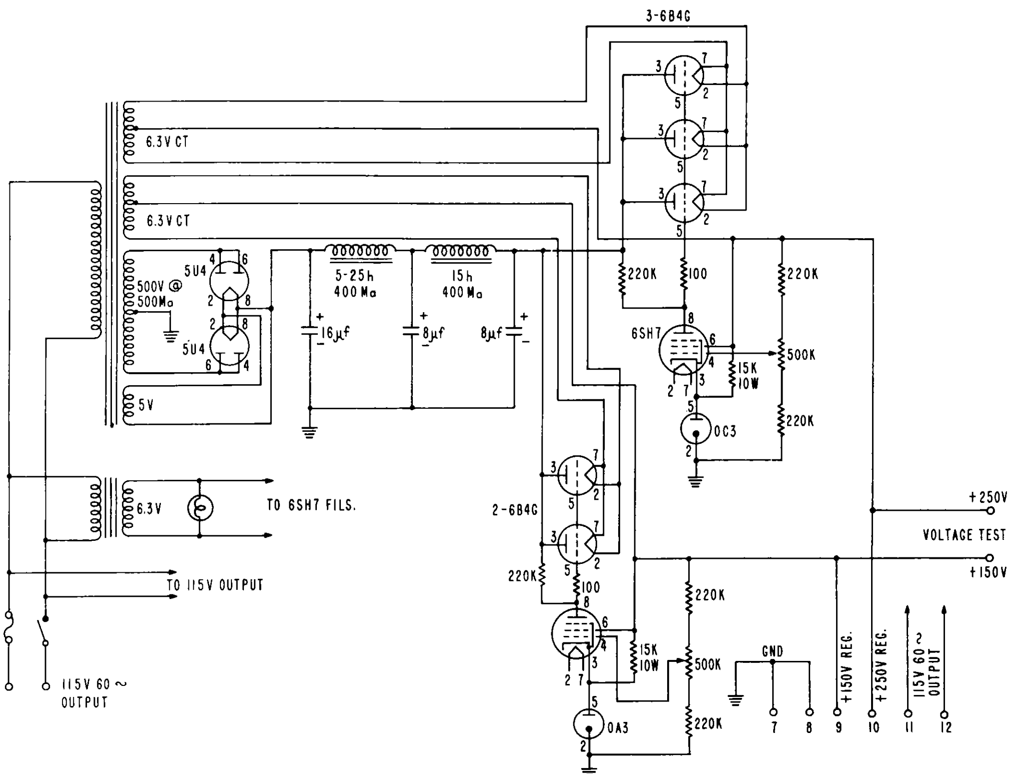


Figure 25 - Power supply for group-pulse generator

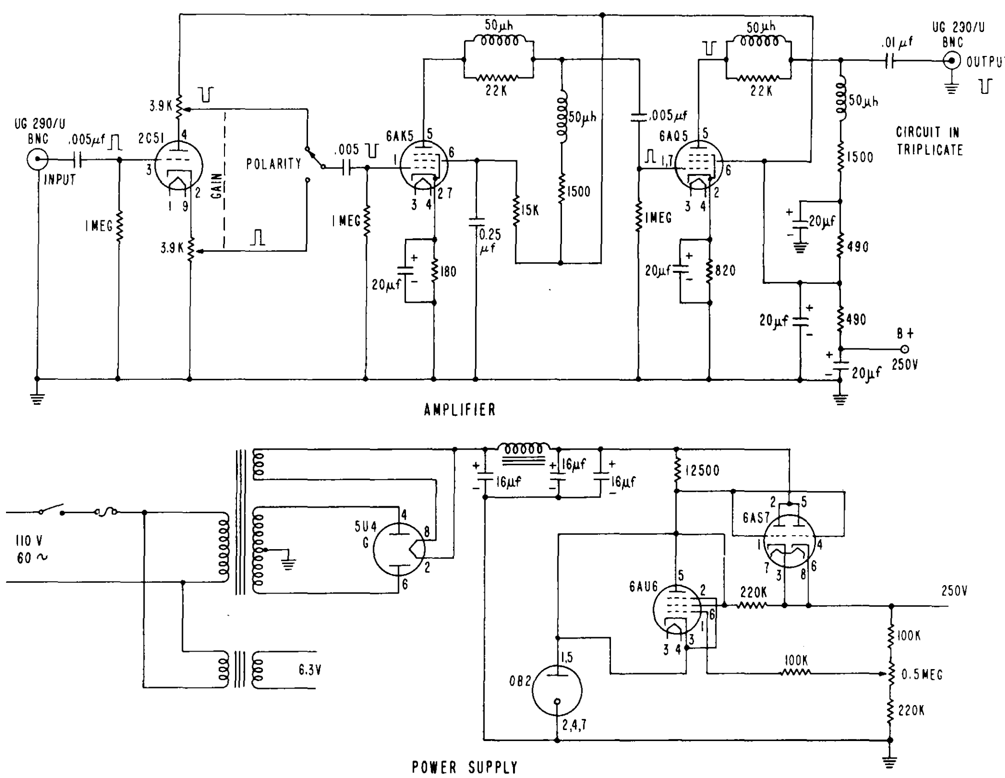


Figure 26 - First three-channel pulse amplifier

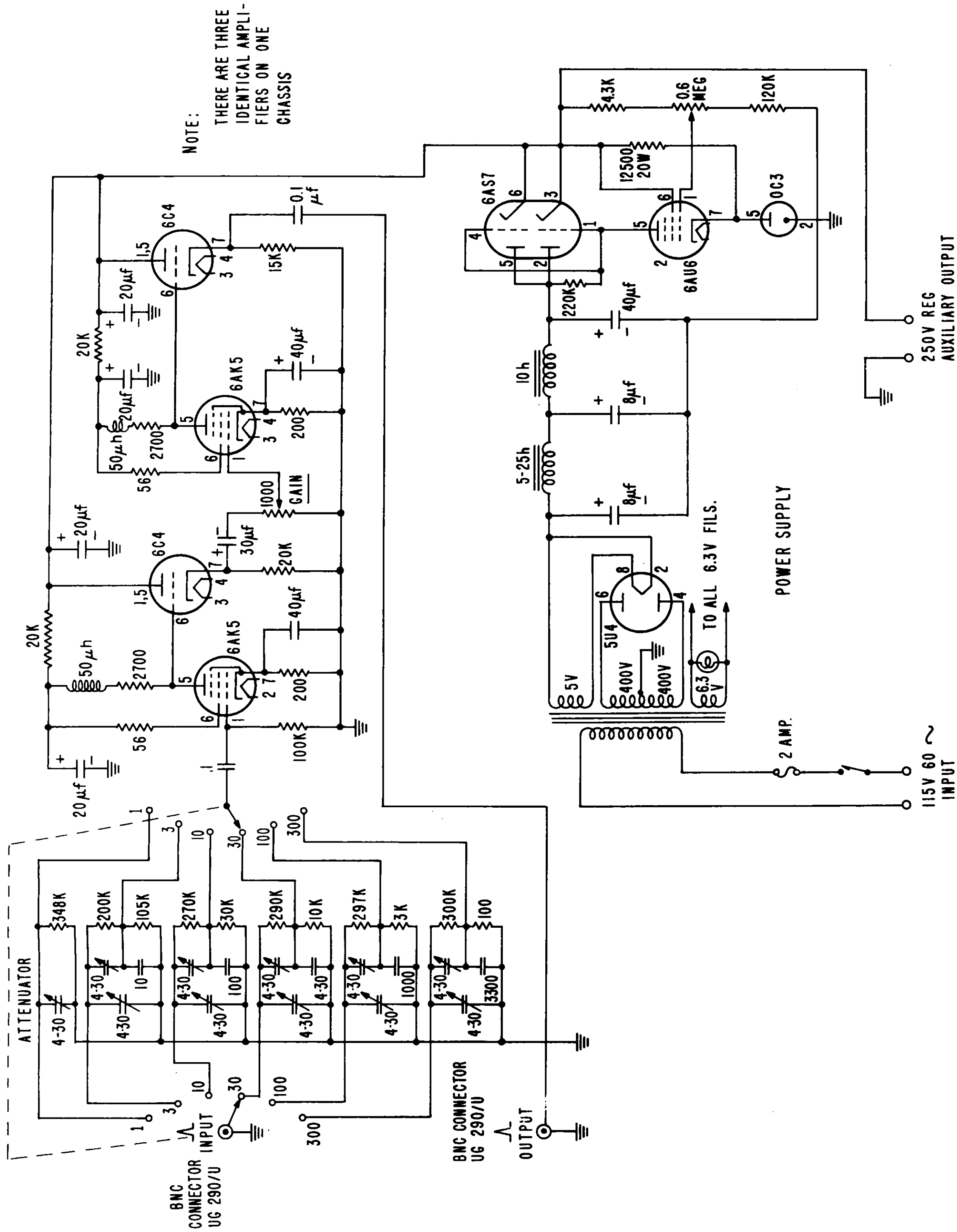


Figure 27 - Second three-channel pulse amplifier

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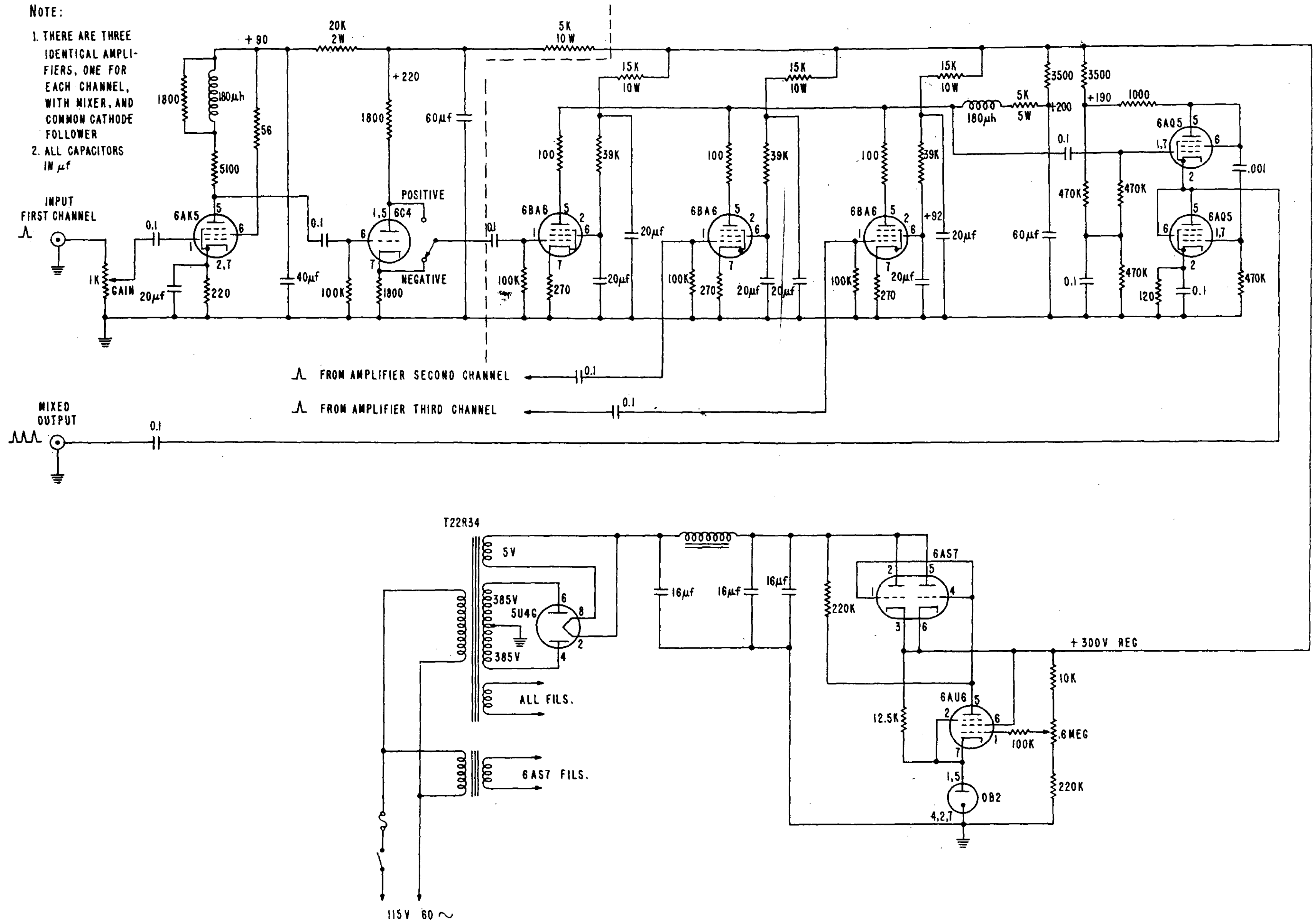


Figure 28 - Transmitter monitor, amplifier, and mixer

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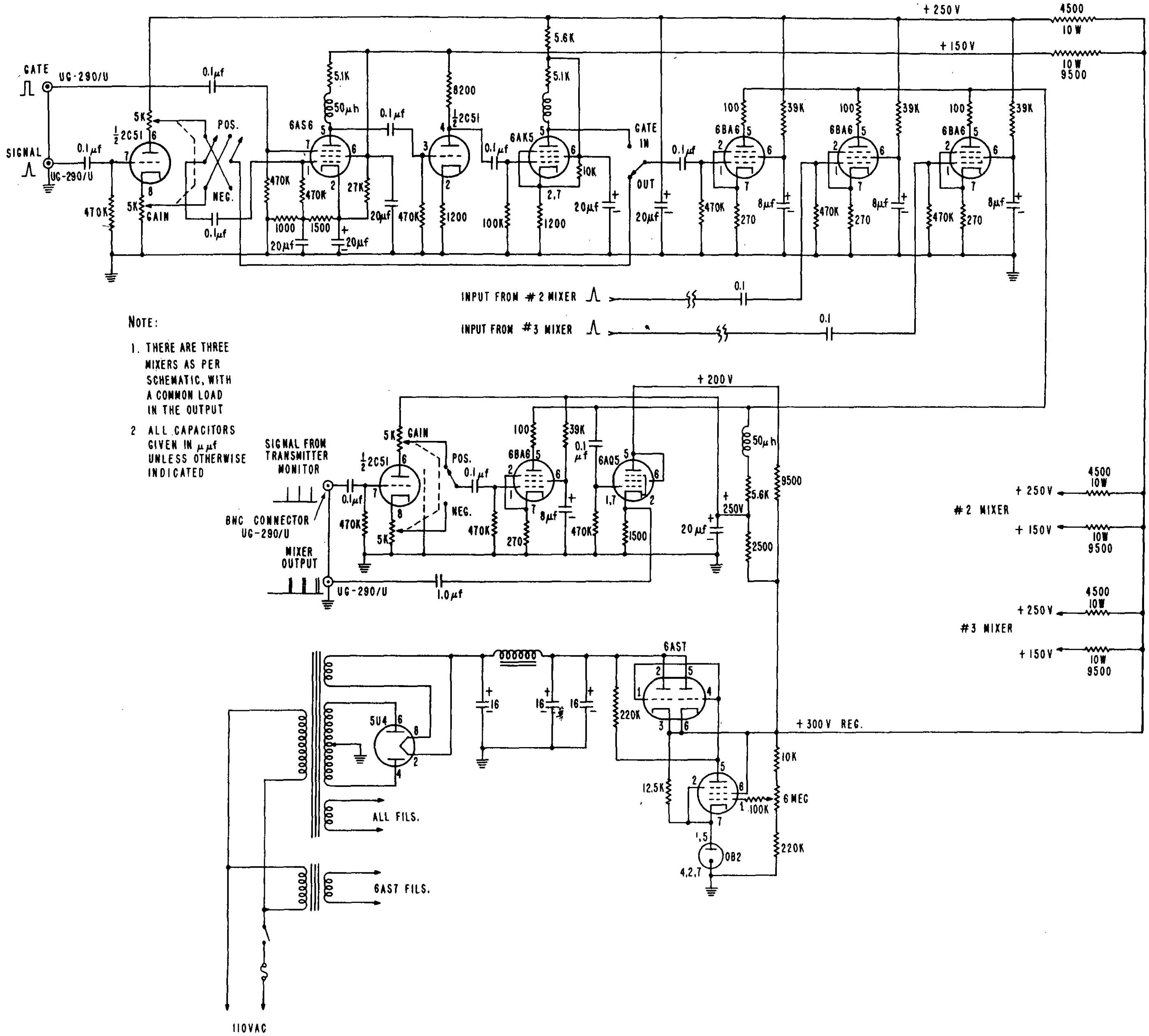


Figure 29 - Mixer-amplifier unit

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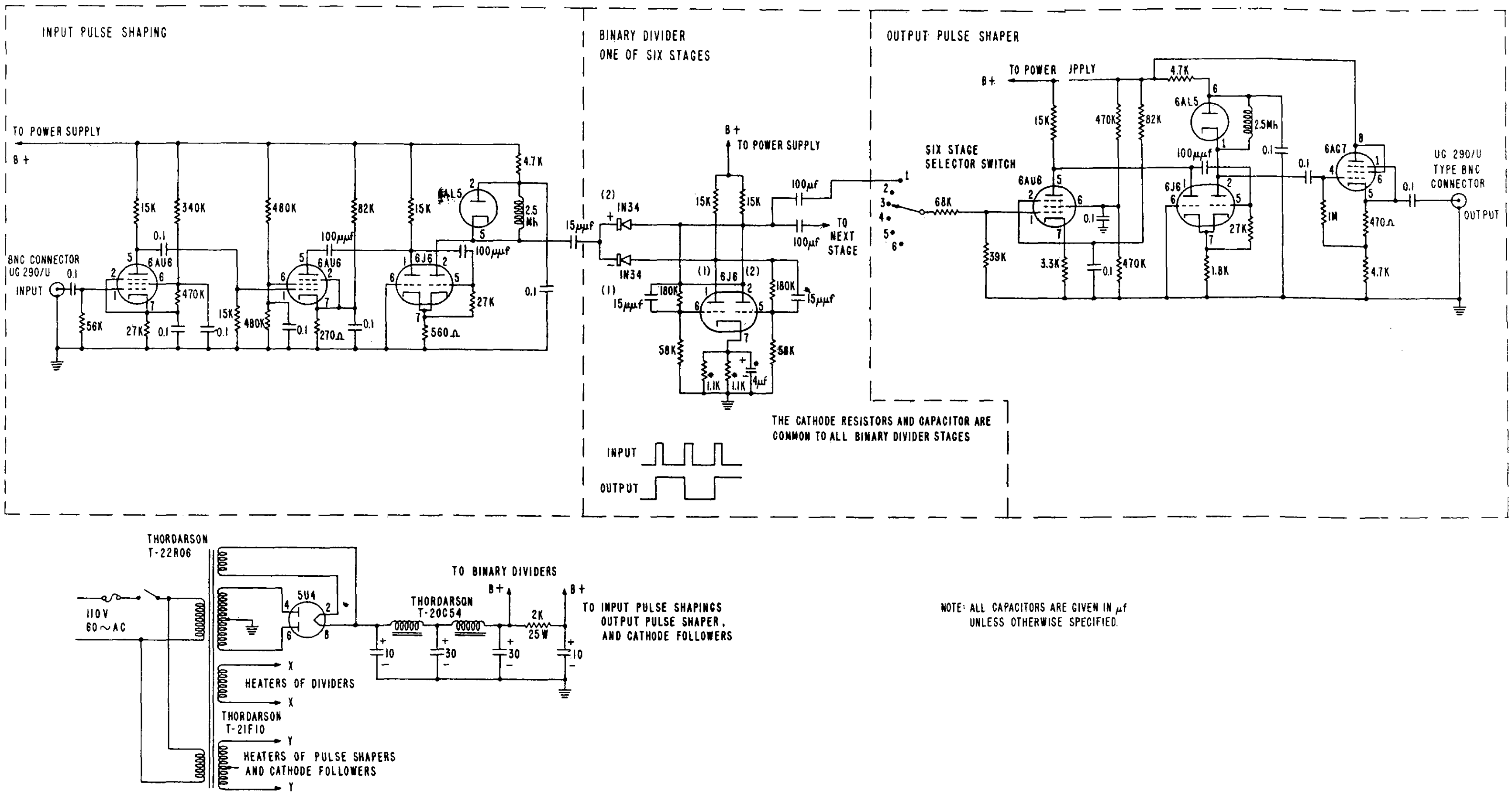


Figure 30 - Pulse-divider unit

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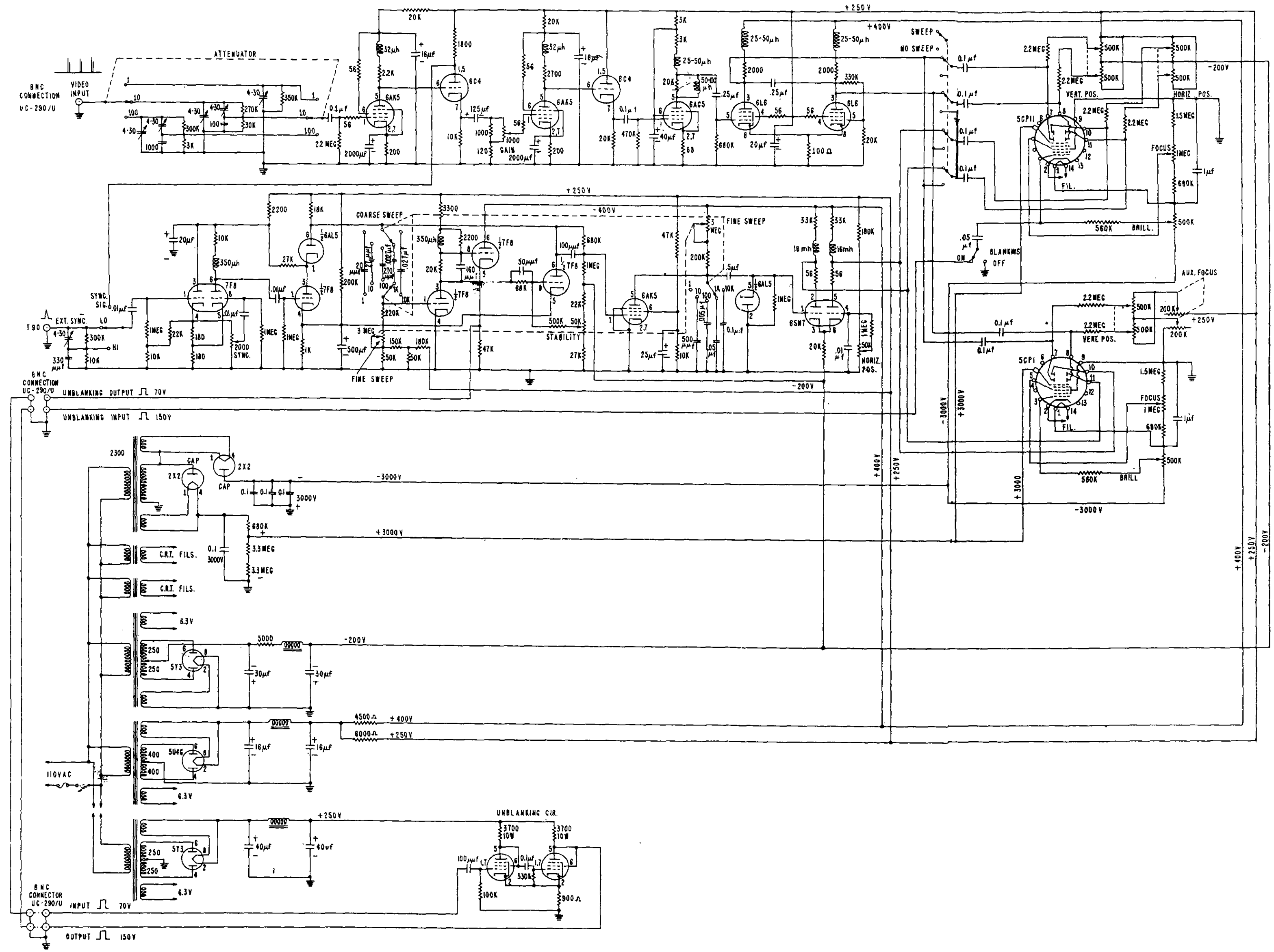


Figure 31 - Display unit