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A HIGH-FREQUENCY BROADBAND TRANSMITTER FOR MONOSTATIC SYSTEMS.(U)
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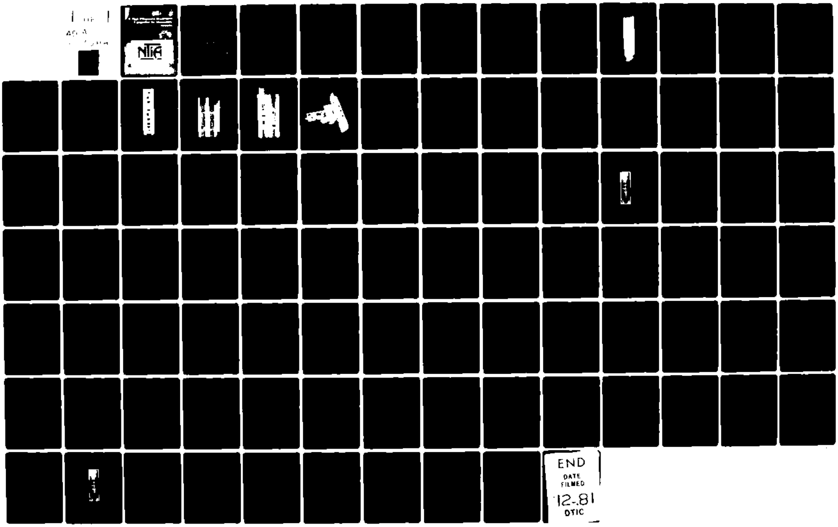

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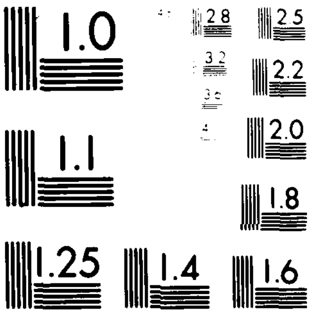

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A High-Frequency Broadband Transmitter for Monostatic Systems

Donald H. Layton*

This report describes the design and fabrication of a broadband amplifier for the Sea Watch Radar on San Clemente Island. The amplifier is capable of 1400 watts peak output with a maximum duty cycle of 33%. Twenty-seven units were built with a typical amplitude deviation of 0.2 dB. Receiver preamplifiers are included in each unit to provide 8 dB of gain to overcome cable and phasing system losses. Each unit is self-cooling and sealed from the salty atmosphere.

Key words: solid-state; broadband; environmentally sealed

1. INTRODUCTION

The requirement was to design a transmitter-receiver unit which would be largely maintenance free, sealed from the salty atmosphere, remotely locatable, and controllable from a central operating facility.

A vacuum tube transmitter was the first approach to the problem. A commercial unit containing a pair of high conductance triodes was obtained to which broadband input and output circuits were added. The unit worked well; however, a key problem concerned the required forced-air cooling. Extensive air filtering would be required to allow it to survive the salt spray and humidity. Several cooling techniques were investigated, such as conduction cooling, vapor cooling, etc., but were subsequently rejected as bulky and inefficient for the power levels involved.

A solid state design was the final approach using medium power transistors as the power generators. This design would allow distribution of the heat sources (transistors) to obtain optimum cooling.

A heat sink extrusion normally employed with high power diode devices was the start of the enclosure design, Figure 1. This extrusion was available in long lengths and could be readily machined. All of the various power amplifier transsistors and power-supply devices were mounted to a pair of the heat sinks. Completion of the enclosure involved mounting the heat sinks atop a power transformer box which when sealed with side and top plates created a self contained, self cooling assembly which would be nearly impervious to the seaside environment. All exterior surfaces of the unit were anodized black to enhance heat dissipation and to protect the aluminum from the corrosive effects of the salt air. Sun loading

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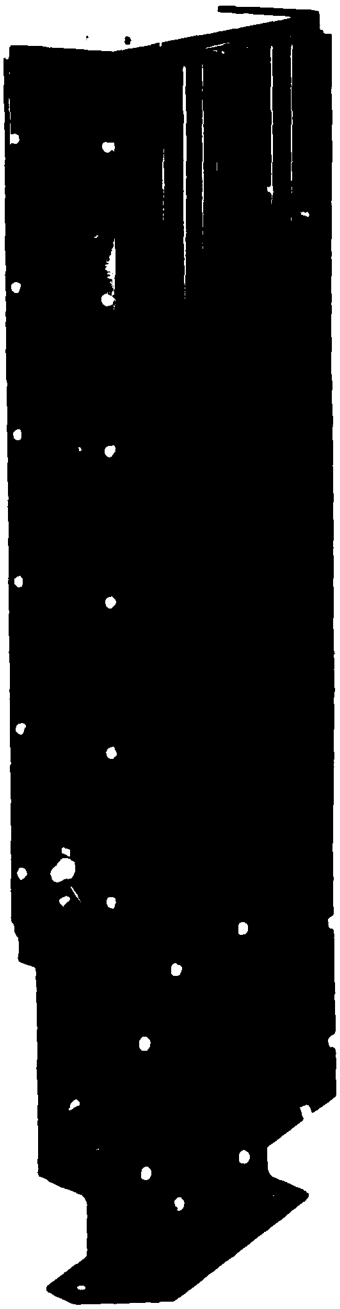

Figure 1. ITS broadband transmitter.

of the black cooling surfaces, while of some concern at an altitude of 5,000 feet, proved to be nil at sea level due to the denser atmosphere and constant sea breeze.

A receiver preamplifier is also included in each unit to overcome coaxial feed line and power combining losses in the control array. The amplifier is designed to have high inter-modulation rejection and good noise figure.

The transmitter/receiver performance is as follows:

Transmitter

Power input (rf)	37 mW
Power output (nominal peak)	1400 W
Power deviation from rated output (each unit)	+0 to 1.5 dB
Frequency range (bandwidth)	2 to 27 MHz
Phase shift maximum (unit to unit)	± 6.5°

Receiver Preamplifier

Noise figure	6 dB
Overall noise figure (including diode switches)	12 dB
3rd order intercept point	+30 dbm
Bandwidth (See 3.8)	2 to 27 MHz

Power Input (AC)

Line voltage	208V 3 Phase
Line current at 30% d.f.	6A

Limiting the maximum peak power of the transmitter to 1400 W insures that the rf devices operate within safety limits. Tests have been made on each unit insuring that they will operate without component failure into antenna impedances from open- to short-circuit. The system block diagrams are shown in Figures 2, 3, and 4.

Remote antenna selection is provided with small high-voltage relays which allow changing antennas at a high rate (typically 6 ms).

2. DESIGN SYNOPSIS

The design of the T/R unit included thermo-mechanical and electrical layout.

2.1. Thermo-Mechanical

The mechanical assembly consists of two 3-foot lengths of anodized heat sink to which all thermal devices are mounted. The thick mounting surface together with the radial fin design offers high thermal radiation efficiency for the

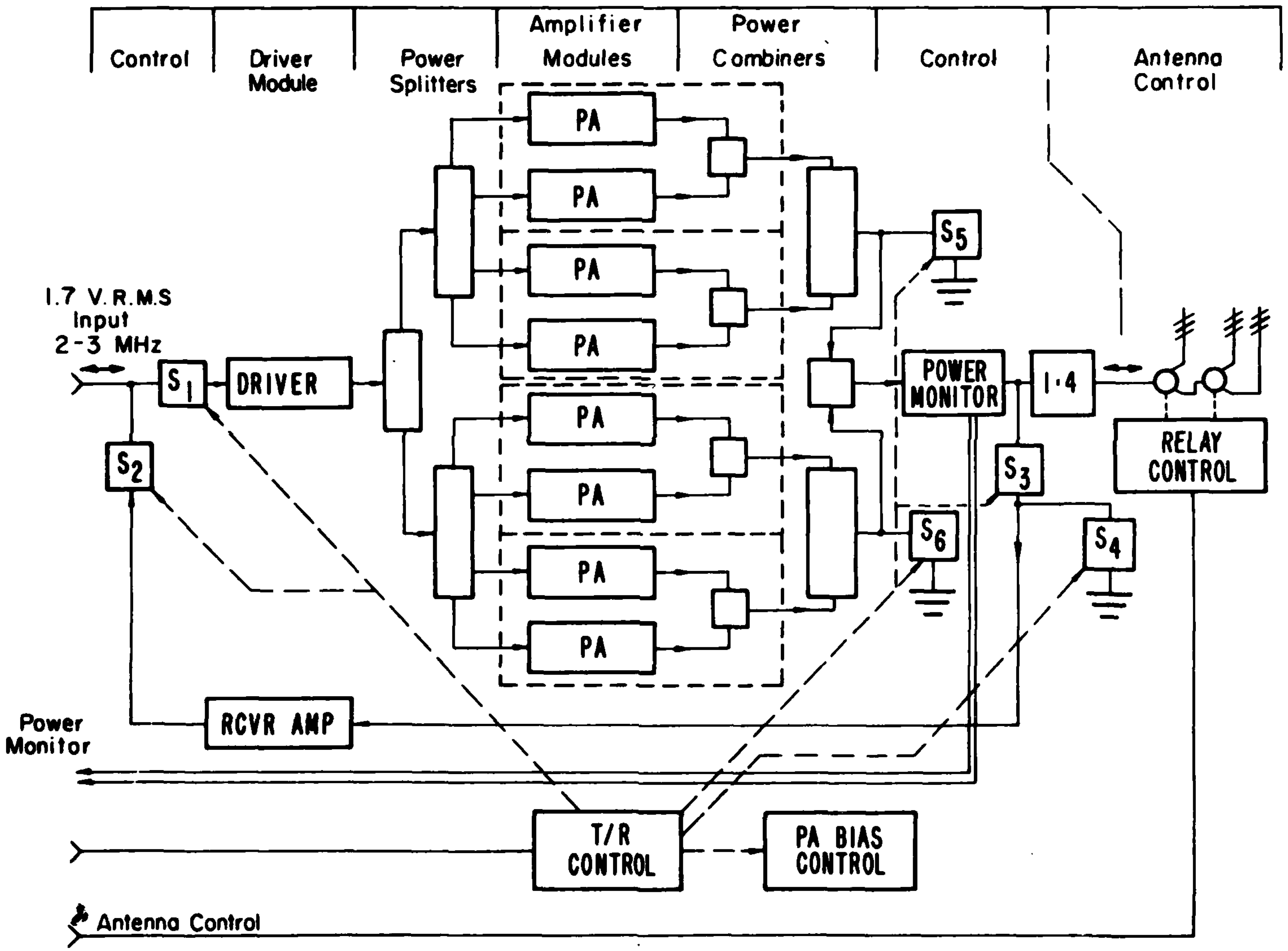

Figure 2. Block diagram of rf section.

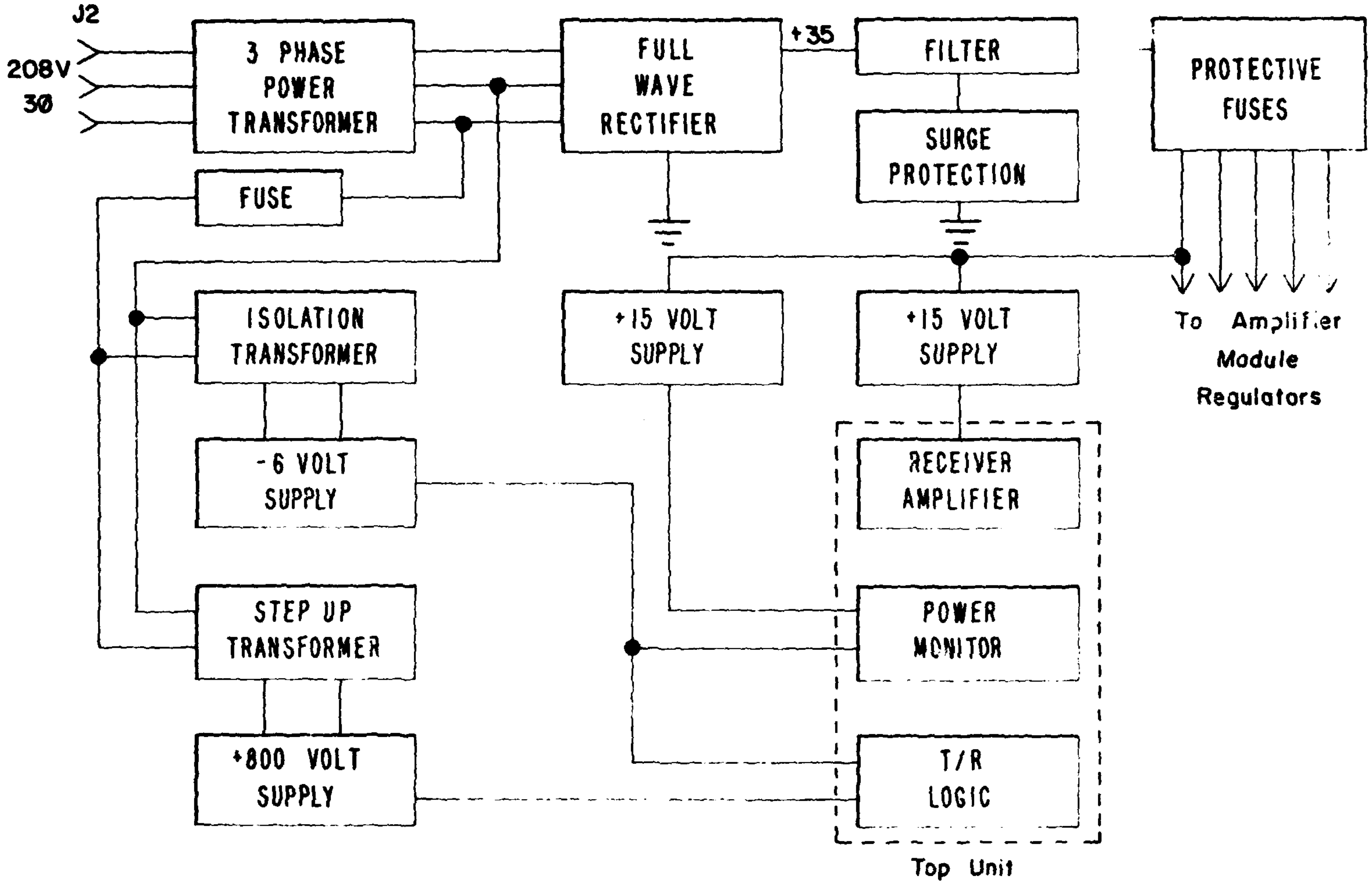

Figure 3. Block diagram of the power supply for the broadband transmitter.

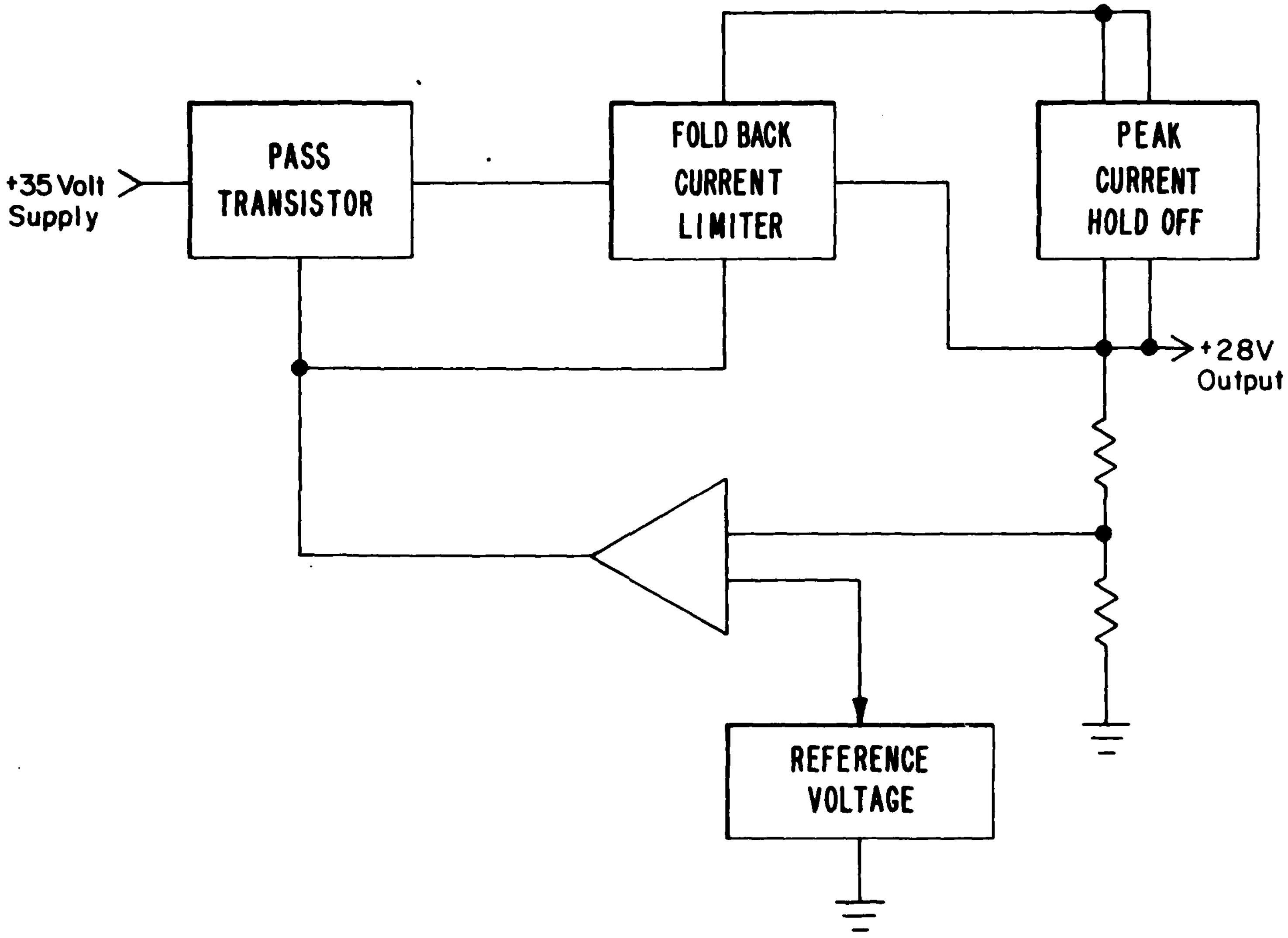

Figure 4. Transmitter module voltage regulator block diagram.

heat sources. Advantage of the solid state design is taken by distributing the thermal devices optimally along the length of each of these heat sinks.

Machined pockets in the black anodized heat sinks, Figure 5, provide for mounting of the various solidstate devices. Overlap placement of many devices, and thus a more compact arrangement, is also achieved as shown in Figure 6. The pair of heat sinks are mounted atop a box containing the single power transformer. The transformer box in turn has an I-beam mounting flange which will allow the transmitter/receiver assembly to be mounted to concrete blocks, etc. Assembly of the two heat sinks creates an internal cavity which houses components not needing ready access, Figure 7.

When the total package is sealed with the top unit (Figure 8), side and top plates, and rubber gaskets the environmental design requirements are met. Now nearly impervious to the external environment, the entire assembly can be pressurized for total protection.

2.2. Electrical

Eight power amplifier modules plus a driver comprise the transmitter power amplifier. All power amplifier modules are identical while the driver module has a low level class A input stage for additional gain. Careful study of many commercial units resulted in the design used in the power amplifier modules. An economical parts selection plus an easily reproduceable basic mechanical design were the criteria for this selection.

A single-stage design, the receiver preamplifier affords high dynamic range and low noise figure. Preamplifier gain is adjusted to compensate for losses in the transmission line and power combiners to the receiver. Roll off at the low frequency end of the passband reduces possible interference from local navigational radio transmitters.

Transmit- and receive-mode changeover is controlled by the T/R signal and the T/R switching logic. Discrete transistors and passive devices are used in the design due to the required complexity of the circuit, Figure 8.

Power output, pulse shape, and antenna match (VSWR) are detected by a reflectometer device at the antenna terminals. The demodulated rf signal is fed back to the control console on separate coaxial lines where transmitter operation and antenna condition are indicated by the voltage ratios. Changeover of the antenna between transmit and receive is done with an assortment of transistor rf switches and high-voltage diode switches which allow faster switching than could be accomplished with mechanical relays.

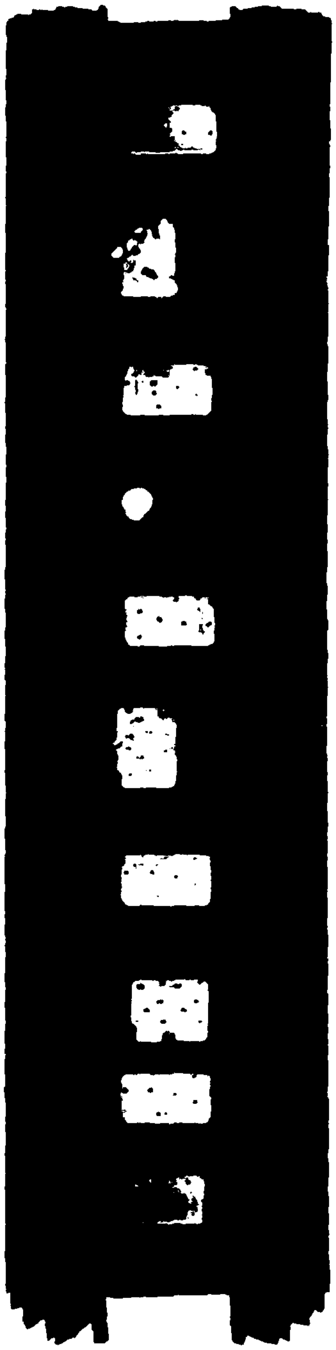

Figure 5. Front view of machined heat sink.

Figure 6. Front view of assembled heat sinks with rf components.

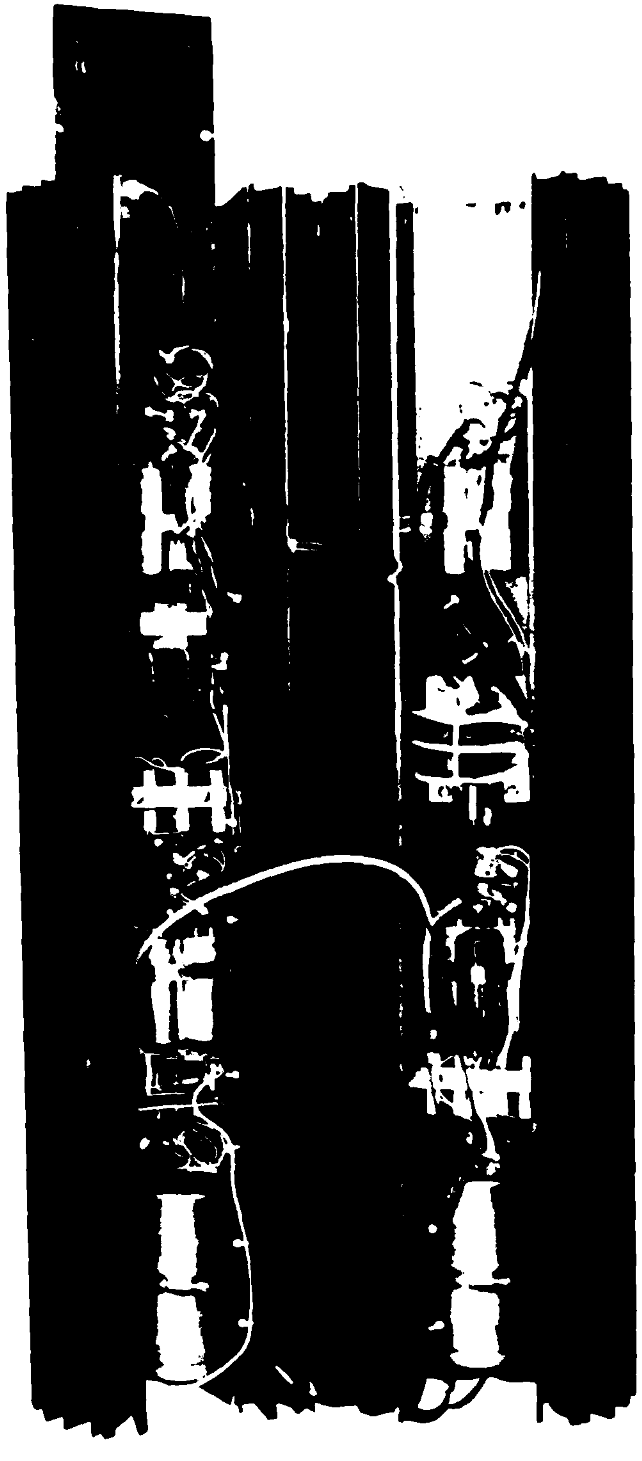

Figure 7. Open view of assembled heat sink units showing ac and dc circuits and final rf combiner.

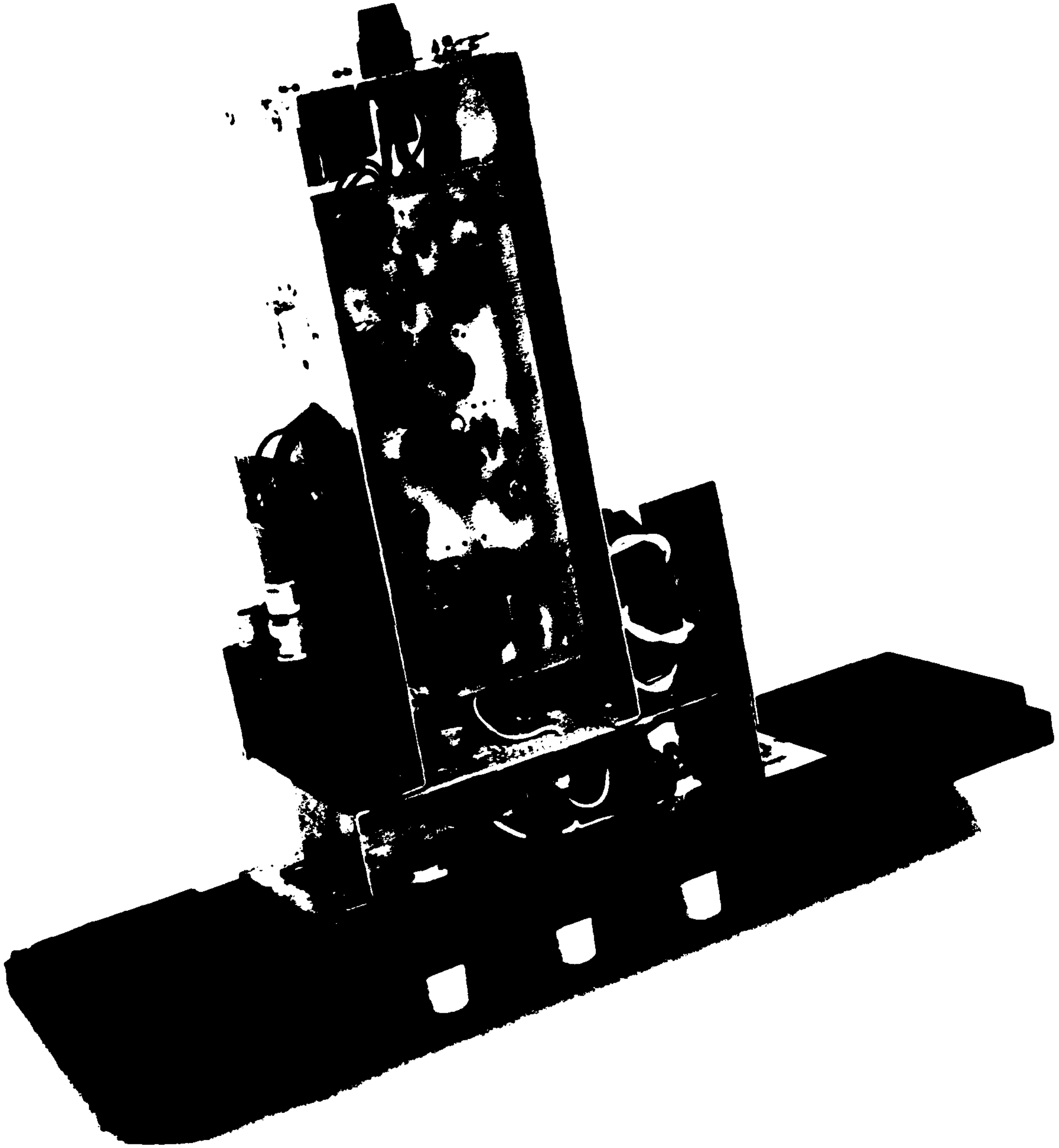

Figure 8. Top unit showing rf monitor/demodulator, receiver preamplifier and 4:1 step up transformer.

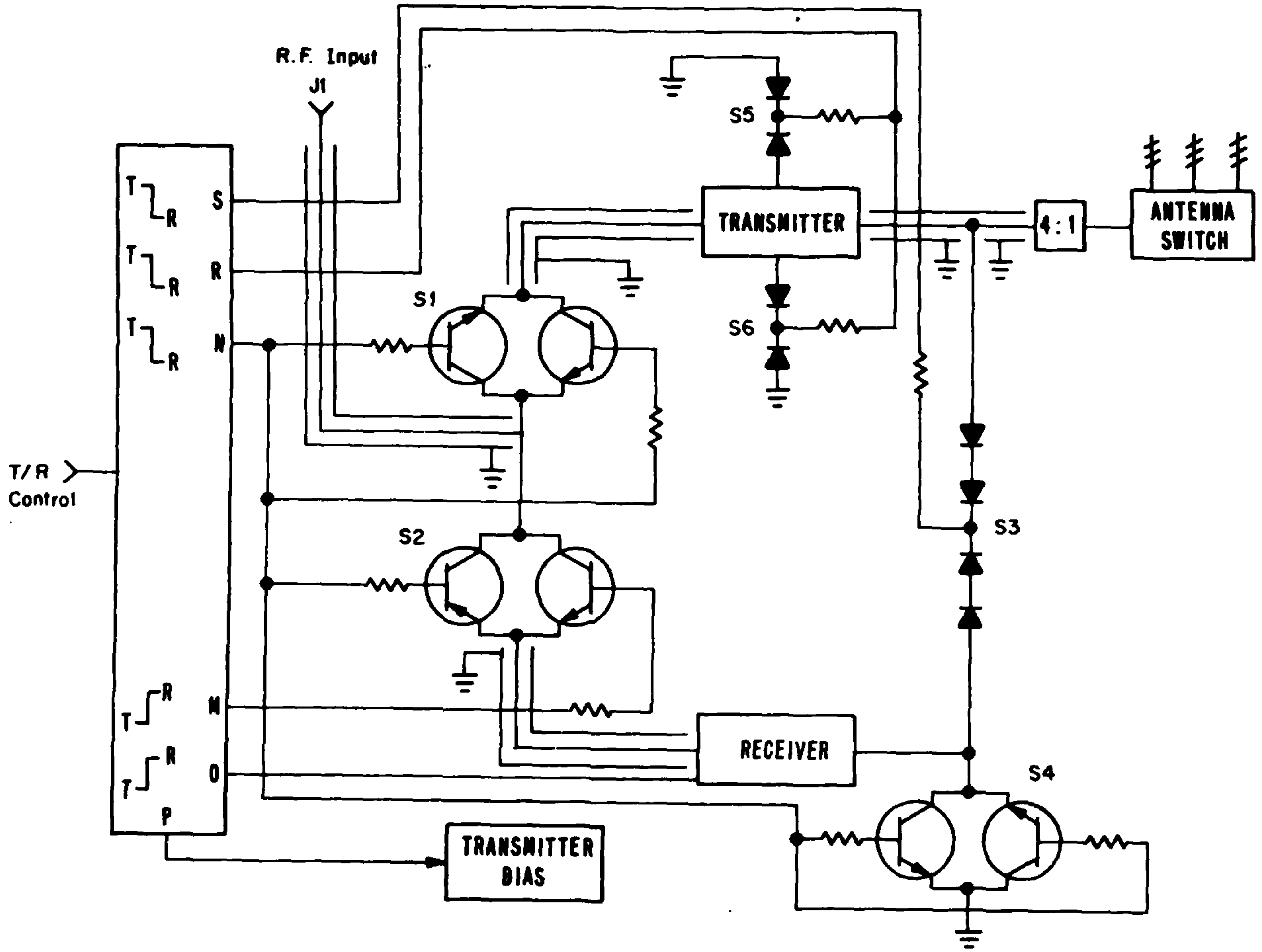

Figure 9. RF switching system showing types of rf switches used.

Selection of any of the three antenna elements is accomplished with high voltage mechanical relays since speed for this function is not critical. The mechanical relays chosen allow antenna changing within 6 ms which is sufficient to allow antenna change between pulses if desired. The control line to the antenna relay selection logic requires a bipolar voltage level on the antenna control line (+ to 0 to -) to select one of three antenna elements.

Two control signals, T/R control and antenna select, are all that are required for operation of the transmitter-receiver unit. These signals must, however, have certain constraints to obtain reliable operation of all circuits. The following discussion is intended to explain these constraints together with the general operation of the T/R unit.

2.2.1 Transmit-mode signal flow

Transmit-mode operation requires the T/R control signal to go high (+5 V) 100 μs prior to the application of the rf drive. This assures that all circuits have switched, bias levels have been established, and the receiver preamplifier is off. Failure to mute the receiver preamplifier will complete a destructive feedback loop through the transmitter.

An rf signal at the operating frequency (2 to 27 MHz) at a level of 37 mW is applied at the rf input connector, Figure 9. Signal flow is through S1 to the driver module with S2 open to prevent loading of the rf drive signal by the receiver output. Switch S2 also provides additional isolation through the receive path, to be discussed later.

Driver module output is fed into a group of hybrid power splitters which divide the power into eight equal rf sources for the power amplifier modules. Each source is approximately 3 W. A "swamping" resistor on the driver output reduces a hump in the gain which otherwise occurs at about 16 MHz, thus improving passband flatness.

Eight power amplifier modules amplify the rf signal to a level of 175 watts each. The outputs are then combined by high-power hybrid circuits giving a total power output of 1400 watts.

This signal passes through the power monitor/demodulator and the 4:1 step-up toroidal transformer. At this point the high voltage diode switch S3 is open, thus protecting the receiver input from the high power transmitted signal. Switch S4 is closed to provide additional isolation and protection for the receiver. The antenna now receives the full power signal via the antenna selection relays.

2.2.2 Receive-mode signal flow

When switching from the transmit to the receive mode, the rf drive and T/R control signal can go to zero simultaneously, the T/R logic contains a time constant which assures 10 μs delay in the T/R switching.

In the receive mode, the transmitter is turned off not only to lessen possible noise generation in the transmitter rf stages but also to reduce the possibility of a feedback loop through the transmitter channel.

The received signal passes from the antenna to the receiver input. Switch S3 is now closed and S4 is open, providing a clear path for the received signal.

To eliminate the need for a complicated high-power, high-speed switch, the transmitter output is left connected to the antenna during the receive mode. This normally produces a notch at 13 MHz in the receiver passband. However, adding shorting switches, S5 and S6, at the final combiner inputs essentially removes any loading effects of the transmitter output on the received signal.

The receiver preamplifier boosts the received signal 8 db. The amplified signal flows to the coaxial rf terminal on the T/R unit through S2 with S1 open to isolate the transmitter input.

2.2.3 Power supply

Power for the T/R unit is obtained from a single 3 phase transformer/rectifier system capable of 35 V at 50A, Figure 10. Filtering of the main supply requires two 60,000 μfd capacitors to reduce I^2R losses in the transformer. Automatic surge protection is also provided. Each transmitter rf module has its own regulator, Figure 11, which supplies 28 V at 5 A average, 18 A peak. A separate regulator is switched on during pulses to supply bias to all modules.

Special voltages are required for the receiver preamplifier T/R logic board. AC voltages are obtained from step-up transformers connected to one secondary phase of the main power transformer. These transformers power the dc supplies and the voltage multiplier circuits in the top assembly, Figure 5. Protection for the power supply is by a fuse to each pair of amplifier modules and to the step-up transformers; however, main fuses must be provided in the installation to protect the unit from catastrophic failure.

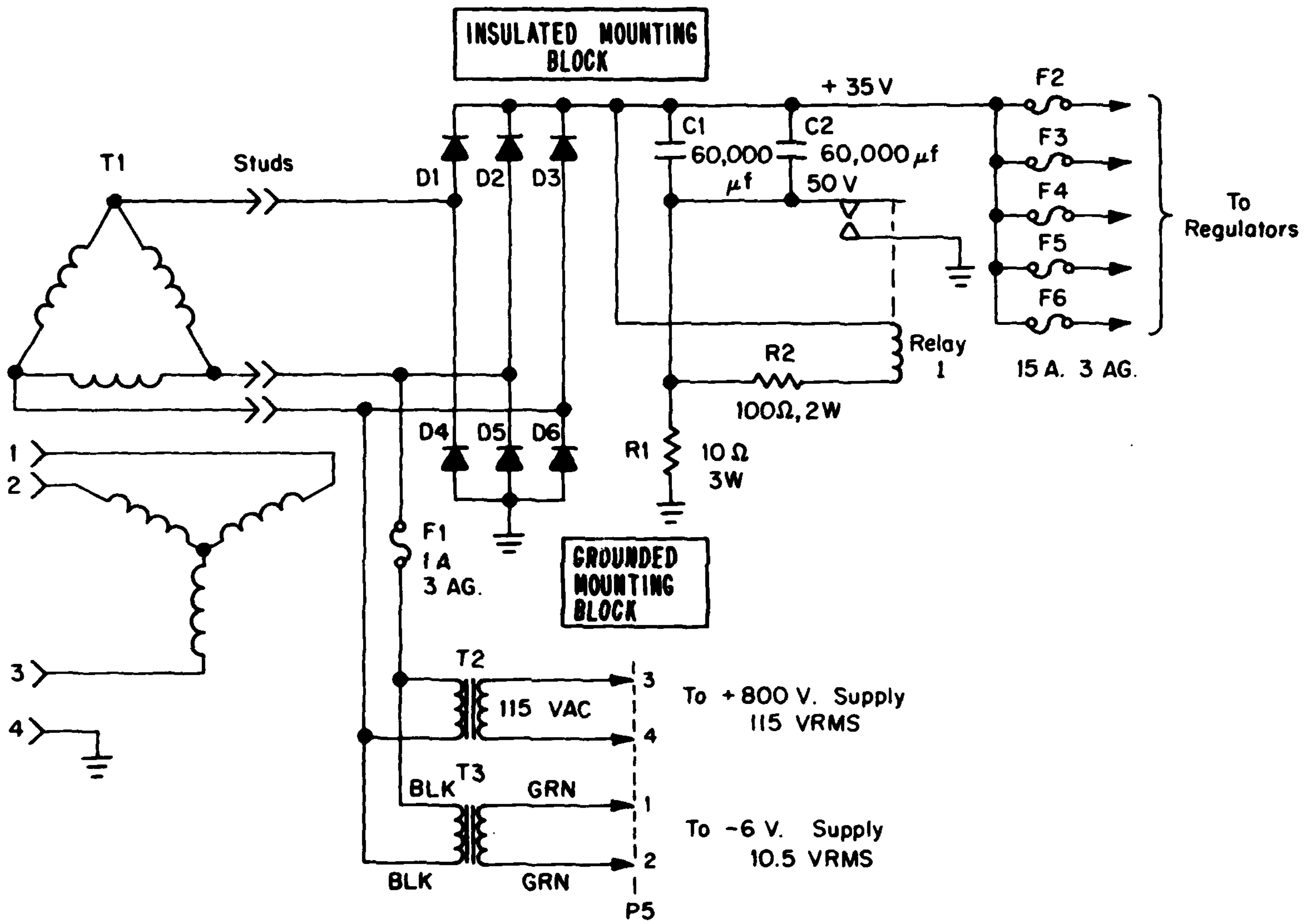

Figure 10. Schematic diagram of T/R unit power supply.

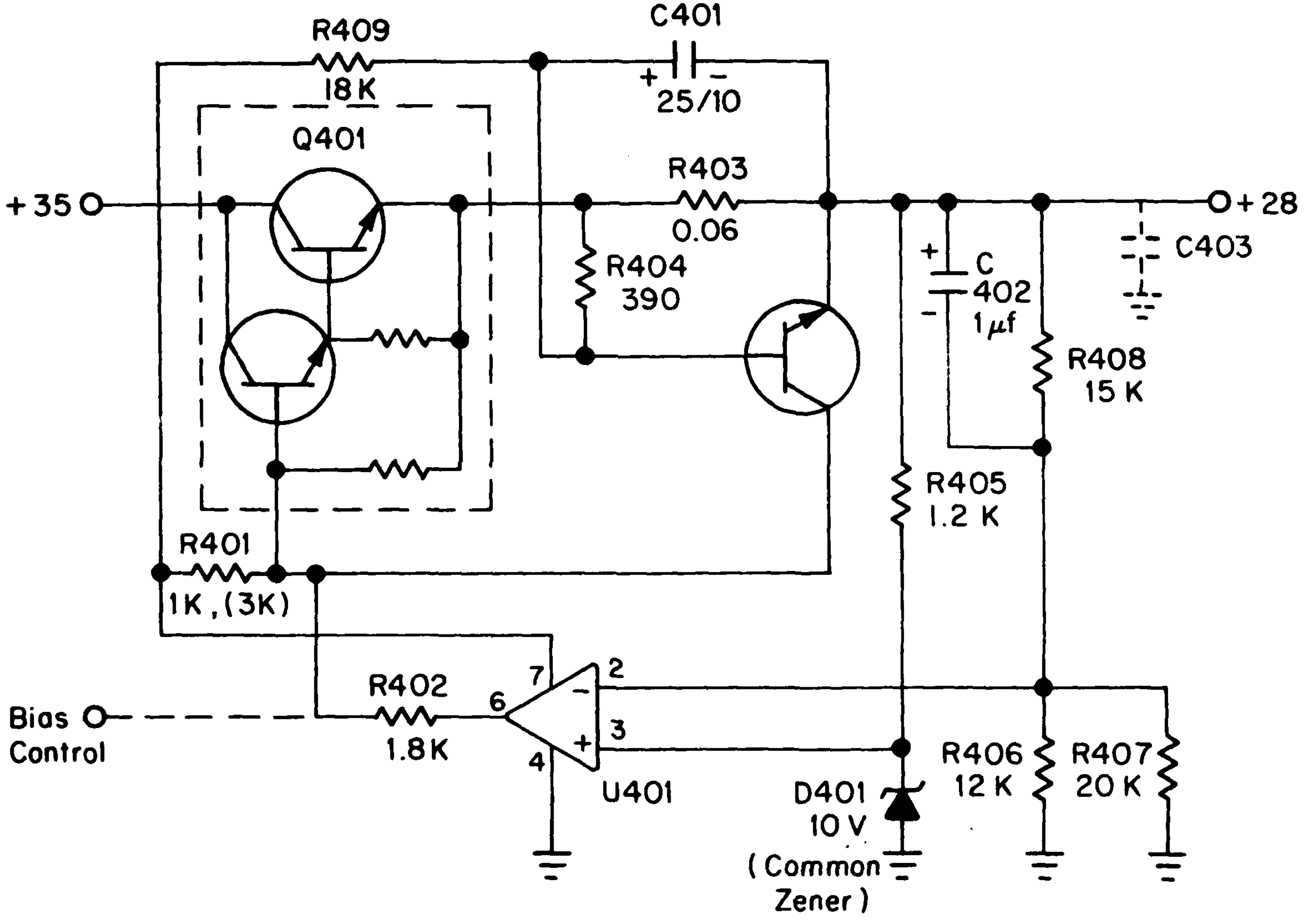

Figure 11. Schematic diagram of the 28 V regulator for rf modules.

3. TECHNICAL DESIGN

3.1. Thermo-Mechanical

An estimate of heat generated by all devices in the transmitter section was as follows:

19	rf transistors @ 40% eff.	1180W
10	Darlington regulators	350W
10	Bias resistors	41W
6	Rectifiers	175W
45	Total devices at	1271W

Average thermal resistance per device of .05° C/W was assumed giving an overall device thermal resistance of .001°C/W.

Heat sink selection was based on the maximum cooling area for each linear inch. From the curves supplied by the manufacturer it was determined that doubling the length of a specific extrusion increased the dissipation for a constant temperature by a factor of 1.5. A 3-foot length of the selected extrusion therefore would yield a thermal resistance of .066°C/W or .033°C/W for two units side-by-side.

Combined thermal resistance of device to heat sink and heat sink to air resulted in .034° C/W. Choosing a nominal device operating temperature of 65°C yielded a nominal heat sink rise of 41°C above ambient. These estimates were considered sufficient justification to proceed with the prototype.

Consideration was given to higher power transistors that were available. Fewer units would be required to achieve the same power output; the lower power units were selected, however, to give a better heat distribution for a safety margin in the design.

The heat sinks were machined to provide pockets for rf transistor and regulator transistor mounting. Bias resistors were mounted with thermal epoxy to the inside cavity of each heat sink. The remaining passive components (capacitors, transformers, and the final rf combiner) were also mounted in the inside cavity.

A top unit was designed to contain the receiver preamplifier, T/R logic, power supplies, power monitor, antenna select relays, 4:1 stepup transformer, and antenna terminals. This assembly mounts down into the top of the inside cavity between heat sinks leaving the antenna insulators protruding from the top.

The two heat sink units were mounted atop the main transformer box which also serves as the mounting pedestal for the transmitter. High current feed-through bolts for the transformer secondary are derived from two insulated heat-sink-to-transformer mounting bolts.

Environmental considerations were the next step in the mechanical design. It was decided to make the units sealable so they could be pressurized with dry air keeping the units from drawing in the outside air with its salt, moisture, etc. All covers were designed with neoprene rubber seals or "O ring" gaskets.

3.2. Power Supply

The power supply requirements for the transmitter were to provide pure dc free from any 60 Hz components. Total current requirements for the entire transmitter, as well as the need for isolation between amplifier stages, led to the selection of a common power supply, Figure 10, with individual requlator boards for each amplifier module, Figure 11.

Two separate regulators with a common zener diode reference were incorporated into the regulator cards. Each regulator section drives a Darlington pass transistor which is thermally conductive to the transmitter heat sink assembly. Foldback current limiting protects each regulator from output short circuits and provides power limiting for the rf amplifier modules. The average current limiting is set by fixed resistors R406 and R408 to 6A. A hold-off RC network, C401/R409, establishes the maximum peak current at which the current limiting will not operate. This allows a peak current of 18 A for 10 ms during operation.

All regulators are identical with the exception of the bias supply regulator. Components on this board have been changed in value or removed to accommodate high speed switching requirements.

3.3. Power Amplifier rf Modules

All rf power amplifier modules are identical, as shown in Figure 12. The input and output transformers, T101 and T102 respectively, are constructed from 0.193 in.-OD brass tubing and copper-clad glass board for the low impedance side. The tubing is loaded with ferrite beads to lower the Q. Several turns of teflon wire drawn through the copper tubes makes up the high impedance winding.

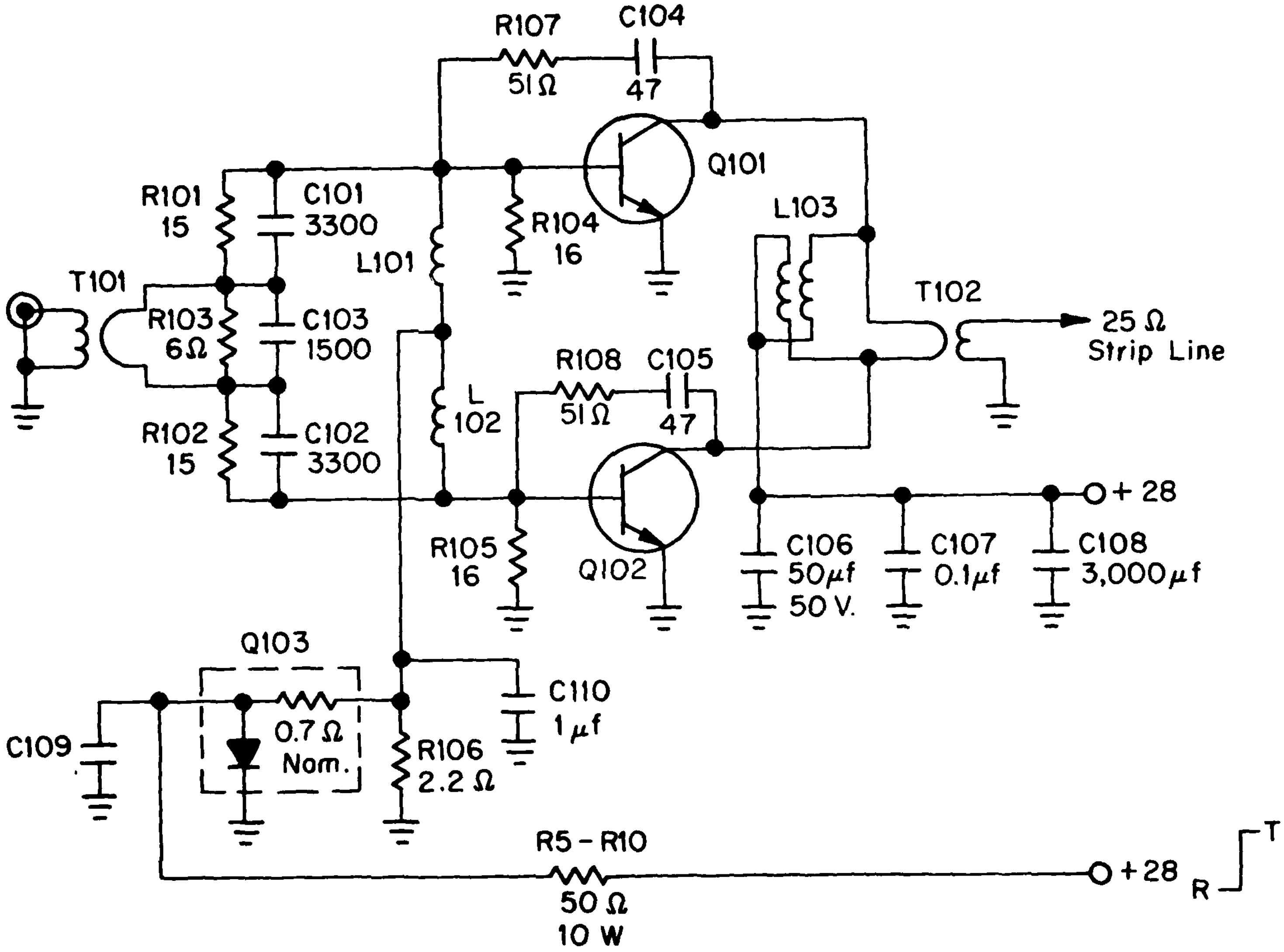

Figure 12. Schematic diagram of the basic rf amplitude module.

Impedance transformation can thus be controlled by varying the number of high-impedance turns. The output impedance is set at 25 ohms, 2 turns, and the input impedance at 50 ohms, 3 turns.

The input transformer includes a 6-ohm swamping resistor to reduce the low-frequency gain and a 1500-pf capacitor to provide peaking at the high frequency end. Collector-to-base feedback provides additional control of the low-frequency gain. Moreover, the feedback networks stabilize the amplifier module in the no-load and short-circuit conditions where parasitic oscillations can occur.

The toroidal bifilar-wound rf choke, L103, is designed to enhance waveform symmetry at the low frequency end (increased harmonic reduction) and to keep the high peak current from saturating the output transformer.

Bias for all rf transistors is provided by a "byistor" device, a diode of the same material as the rf transistors. It is mounted in close proximity to the rf transistors for close thermal tracking. Additionally, the byistor contains a positive-temperature-coefficient resistor. As the heat sink temperature rises, the diode junction voltage decreases and resistor value increases to virtually eliminate thermal runaway in the output transistors. Current to each byistor is supplied through a 50 ohm, 10 W resistor mounted inside the heat sink assembly with thermal epoxy. The 28 V source for all the bias resistors is switched on during the transmit phase.

Operating bias of the output transistors is adjusted by the value of the byistor load resistor. The criteria for bias adjustment is the quiescent rf-transistor collector current of 50 mA.

The power amplifier modules are mounted in pairs. Each 25 ohm output is connected via a 25 ohm strip line to the hybrid first combiner.

3.4. Driver Amplifier

As mentioned above, the driver amplifier is the same as an rf power module except for the addition of a class "A" driver stage, Figure 13. The single transistor input stage has its own byistor, Section 3.3, for improved stability. Transistor bias in this stage is set for 400 mA collector current which provides a sufficient dynamic range for operation with a nominal 37 mW of rf drive. Collector-to-base feedback is used to enhance driver low-frequency gain flatness.

Input, intermediate, and output transformers are constructed as per the discussion in Section 3.3. The turns ratios are as depicted in Figure 13; the

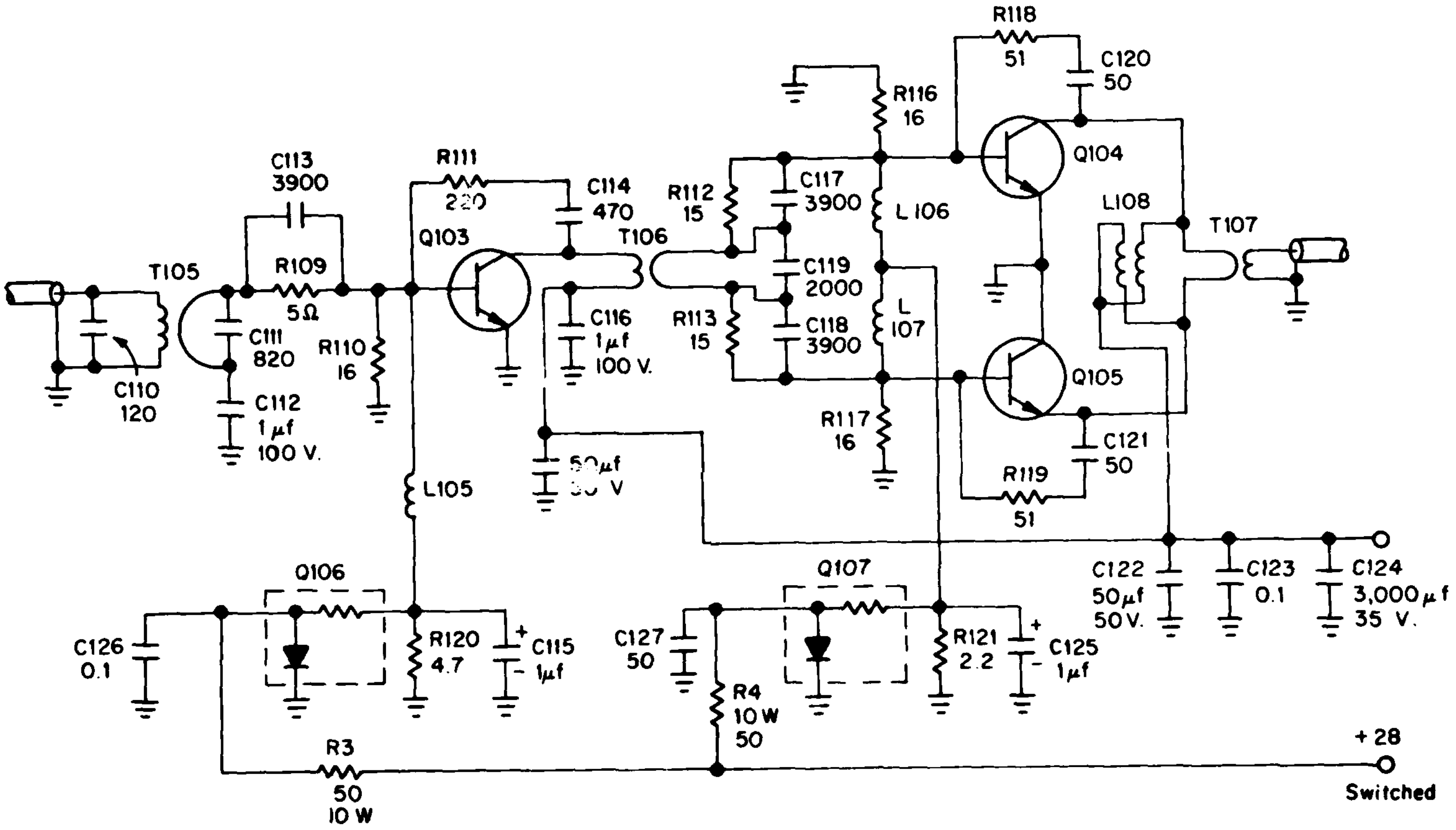

Figure 13. Schematic diagram of the driver amplifier module.

nominal input impedance of the power amplifier section of the transmitter is 45 ohms. The output of the driver, however, is wound for 27 ohms. This intentional mismatch was found to decrease the harmonic content of the driver output. Driver-stage output includes a 115-ohm swamping resistor which provides a minimum fixed load to the driver. At 16 MHz, a 6 dB hump caused by a gain increase and impedance increase to the transmitter output modules normally would occur. This hump is reduced by the swamping resistor to a maximum of 1 dB.

Finally, the gain of the overall transmitter assembly is adjusted by a fixed attenuator at the driver input.

3.5. Power Splitters and Combiners

Driver amplifier output is divided eight ways by a tree of toroidal hybrid power splitters. Each of the eight ports must supply a nominal power of 5 watts. Several types of networks are used and are discussed in Appendix B. These splitters are effective in providing isolation between amplifier modules. In addition to imbalance compensation, final tests show that harmonic energy is dissipated in the waster resistor. Selective use of 0° and 180° hybrids was used to obtain the lowest harmonic content and best passband flatness.

Figures 14 and 15 show the power splitters and the impedance levels used. Loss in the power splitters was found to be .1 dB per device although some sources indicate as much as .4 dB can be expected (Kraus and Allen, 1973).

Power combining of the rf module outputs required slightly different techniques from input power splitting due to the power levels involved. Larger toroids and wire with high-temperature enamel were required to keep the flux and resultant core heating as low as possible. In the second combining stage, Figure 16, additional teflon tape insulation was used to gain an operating-temperature safety margin.

Coupling between the primary and secondary combiners of the transmitter output was accomplished with printed circuit 12 1/2-ohm strip lines. These boards also allow for mounting the toroids and the diodes for the shorting switches. Feed lines from the secondary to the final combiner, Figure 17, were fabricated with parallel RG-58 lines to make the 25 ohm runs.

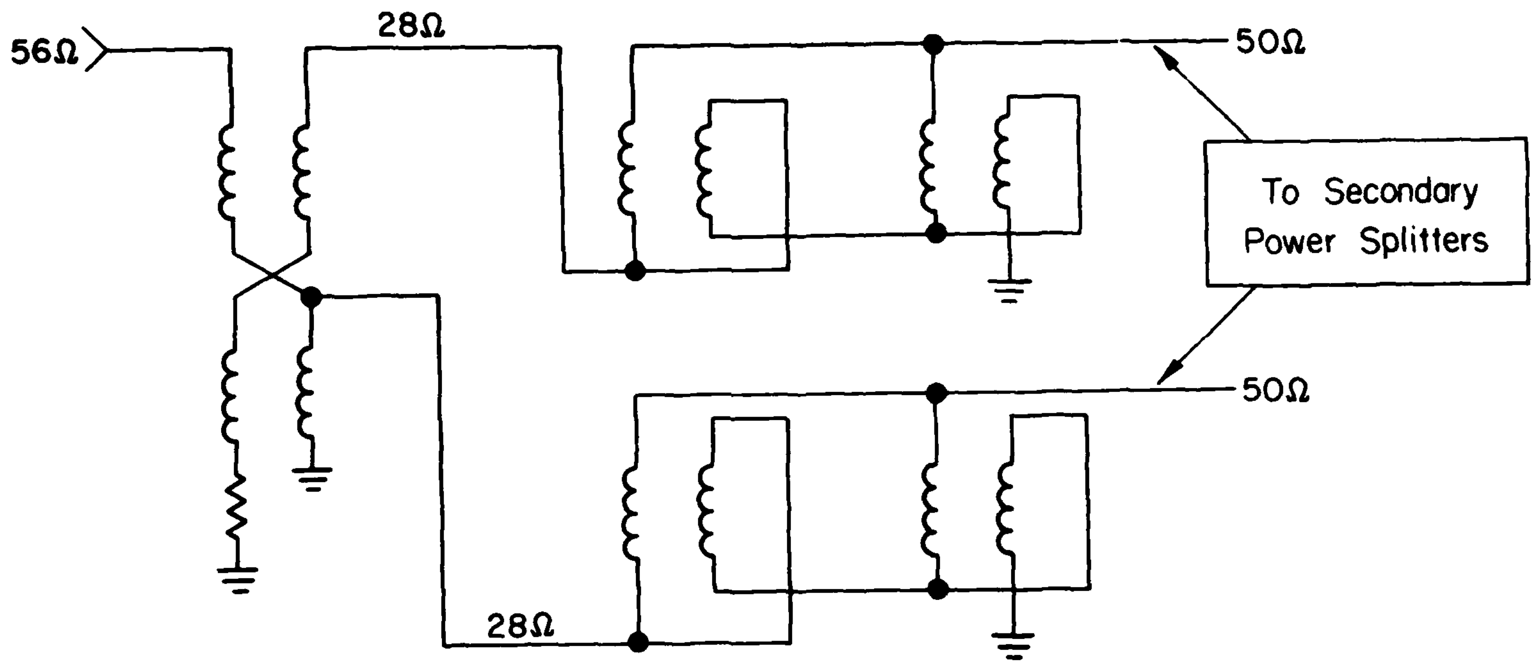

Figure 14. Driver output primary power splitter.

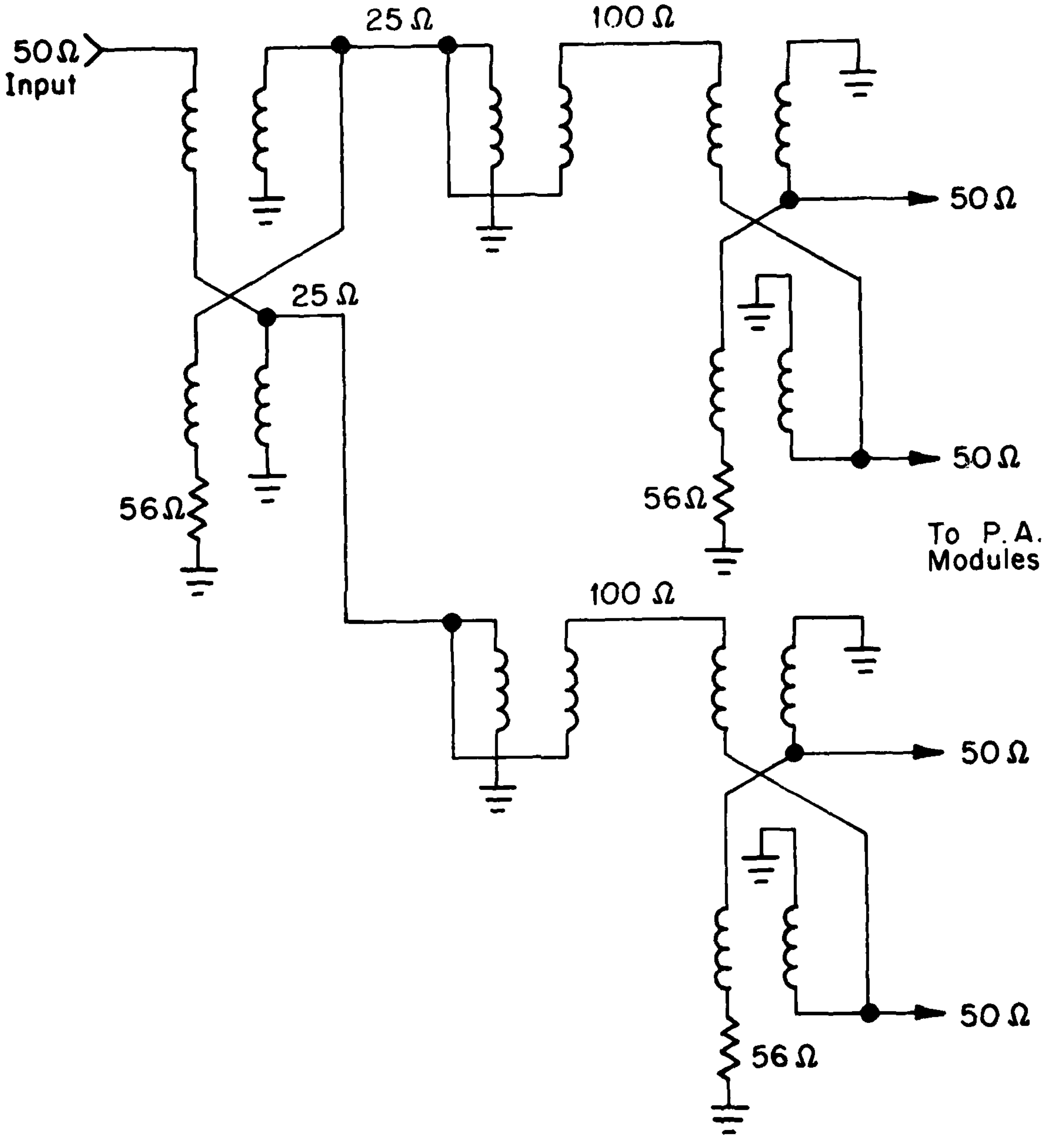

Figure 15. Driver output secondary power splitter.

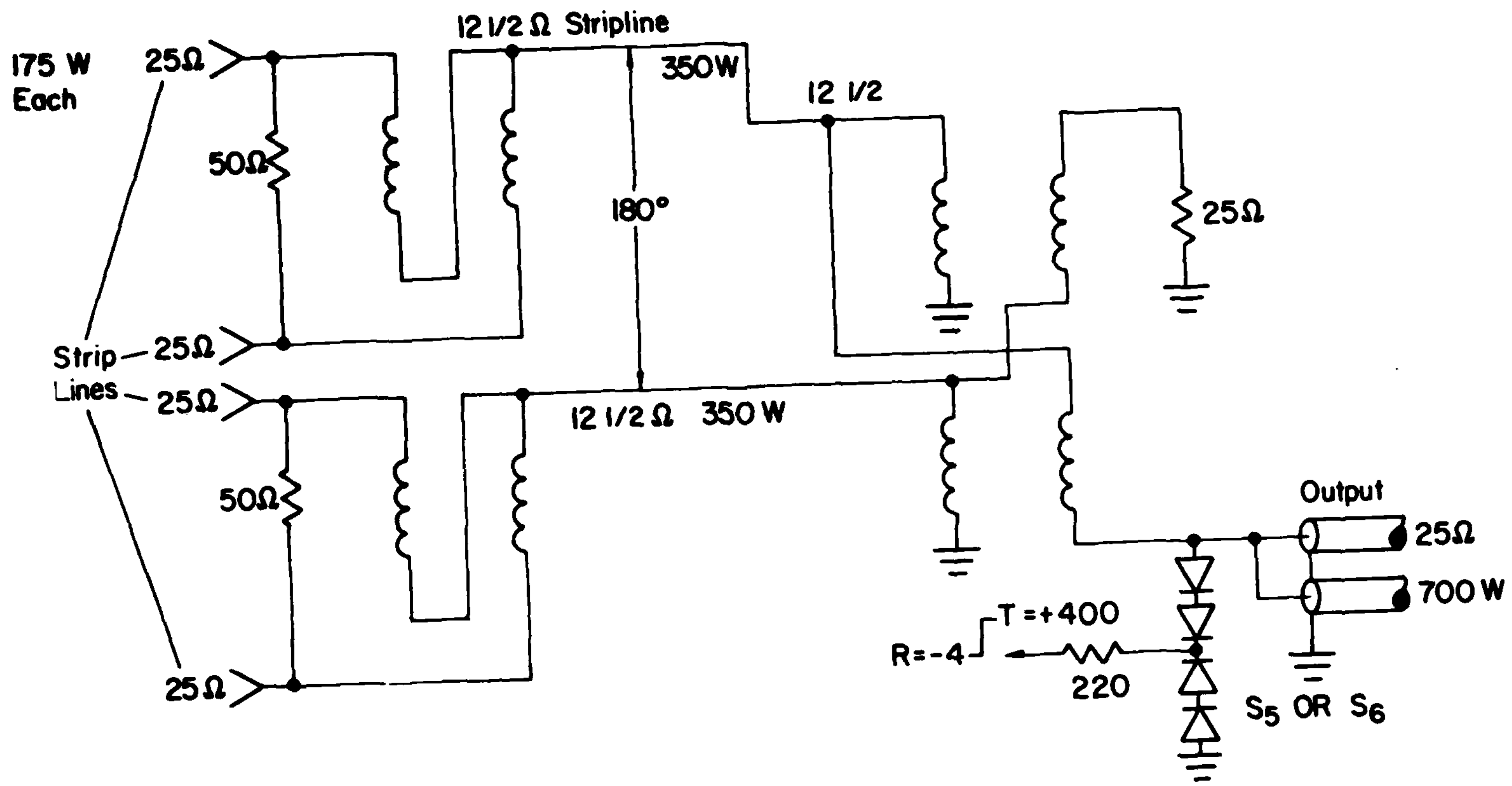

Figure 16. Output primary and secondary power combiners.

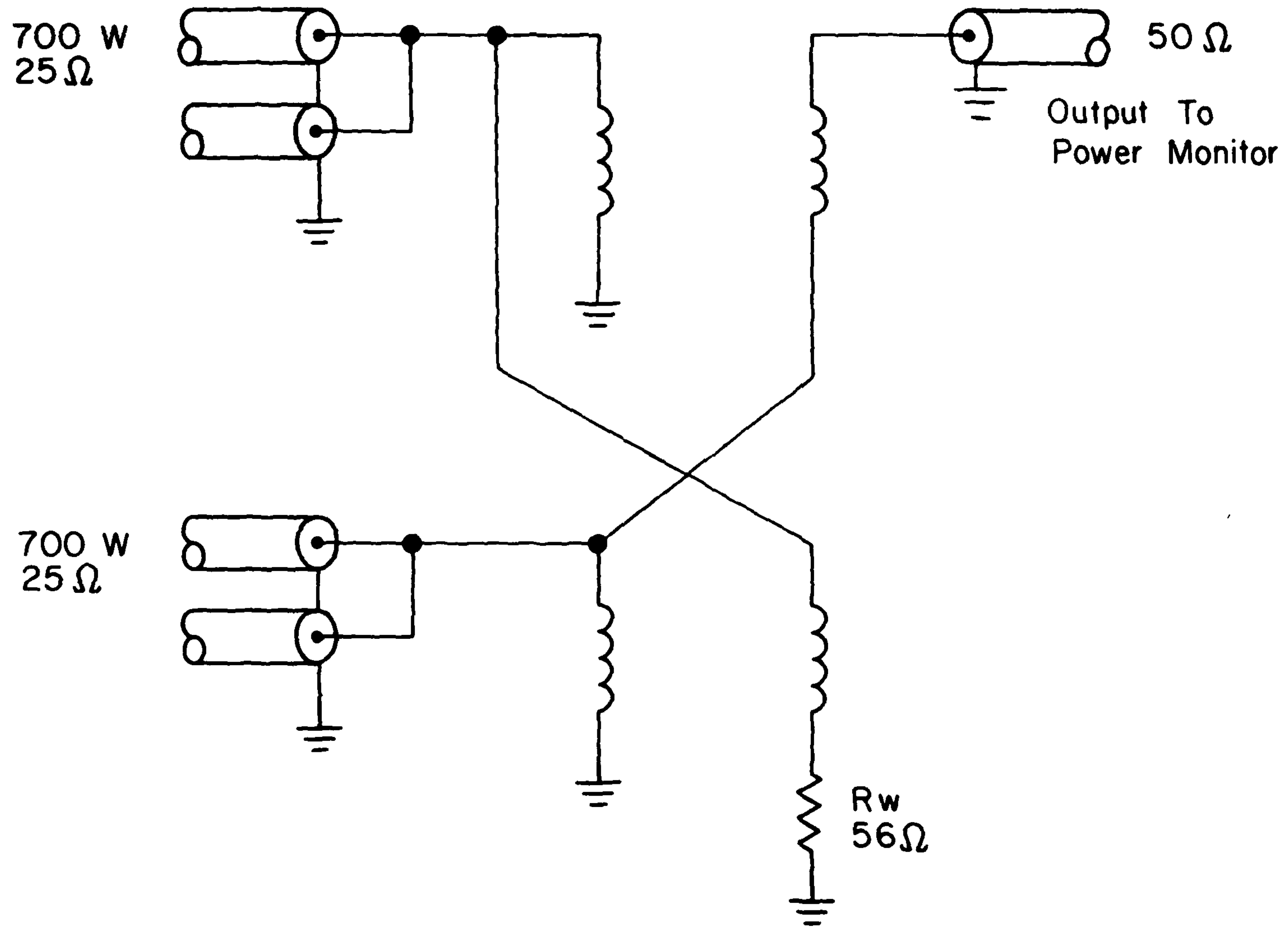

Figure 17. Final power combiner.

3.6. Power Monitor/Demodulator

Figure 18 depicts the power monitor/demodulator. Transmitter design required not only measurement of power output with reasonable accuracy but also monitoring the output pulse envelope as a check on transmitter operation. Antenna match was also to be monitored as a measure of the absolute radiated power.

Transformer T501 is a toroidal transformer through which the rf current is coupled. Diodes D501 and D502 rectify the phase voltages with respect to the voltage coupling from C503 or C504. The relative dc output is filtered with a short time constant, C506/R504, to preserve pulse rise and fall times to 1.5-μs minimum. The filtered outputs are current-amplified to drive terminated 50-ohm lines.

The power monitor/demodulator delivers a dc pulse at -34 dB from the output at the 50 ohm level; i.e. 9.1 Vdc = 1400 W.

The final combiner is wound on 2 1/2-inch toriods and is located in the inner cavity of the heat sink. Power flow from the final combiner is through a teflon coaxial line to the power monitor-demodulator then to the 4:1 step up transformer to the antenna relays. The output impedance is set for a nominal antenna impedance of 200 ohms.

3.7. Antenna Switch

Antenna selection is accomplished by use of high voltage vacuum relays. The driving circuit is arranged so that a bipolar level on one line will allow selection of one of three states. The peak-voltage rating of the relays allows operation into antennas of widely ranging VSWR in the 200 ohm range. Hot switching is not recommended with the relays provided.

3.8. Receiver Amplifier

The receiver preamplifier is of a type used in cable TV systems, Figure 19. A pair of 2N 3866's in Class A push-pull configuration is used keeping harmonic generation to a minimum. The preamplifier passband is normally flat from 2 MHz to 30 MHz. For this application, however, the passband has been tailored to roll off at 6 dB per octave below 4 MHz, Figure 20. Response below 2 MHz is thus reduced to attenuate high power navigation-radio stations in the equipment vicinity.

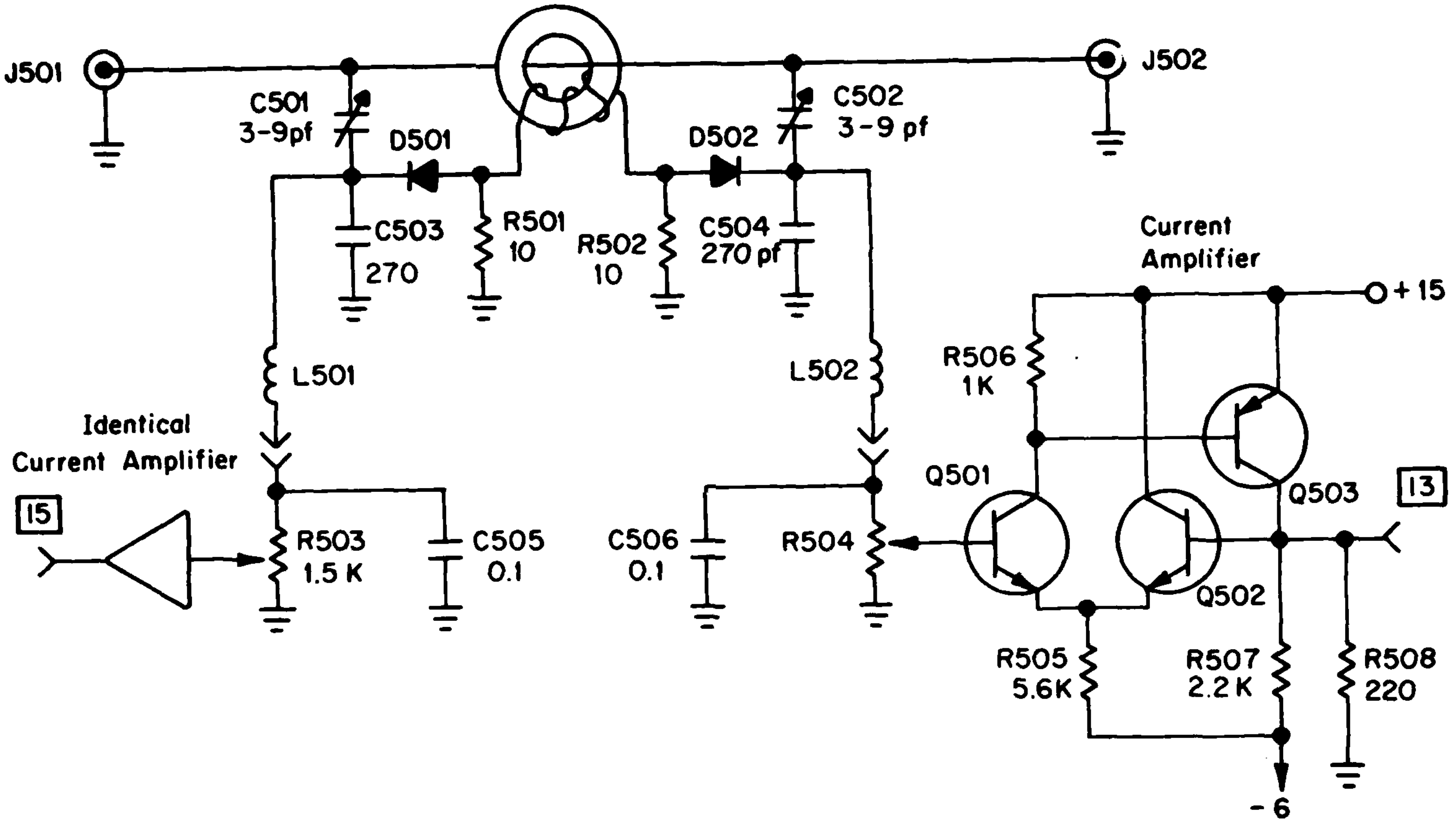

Figure 18. Schematic diagram of power monitor/demodulator.

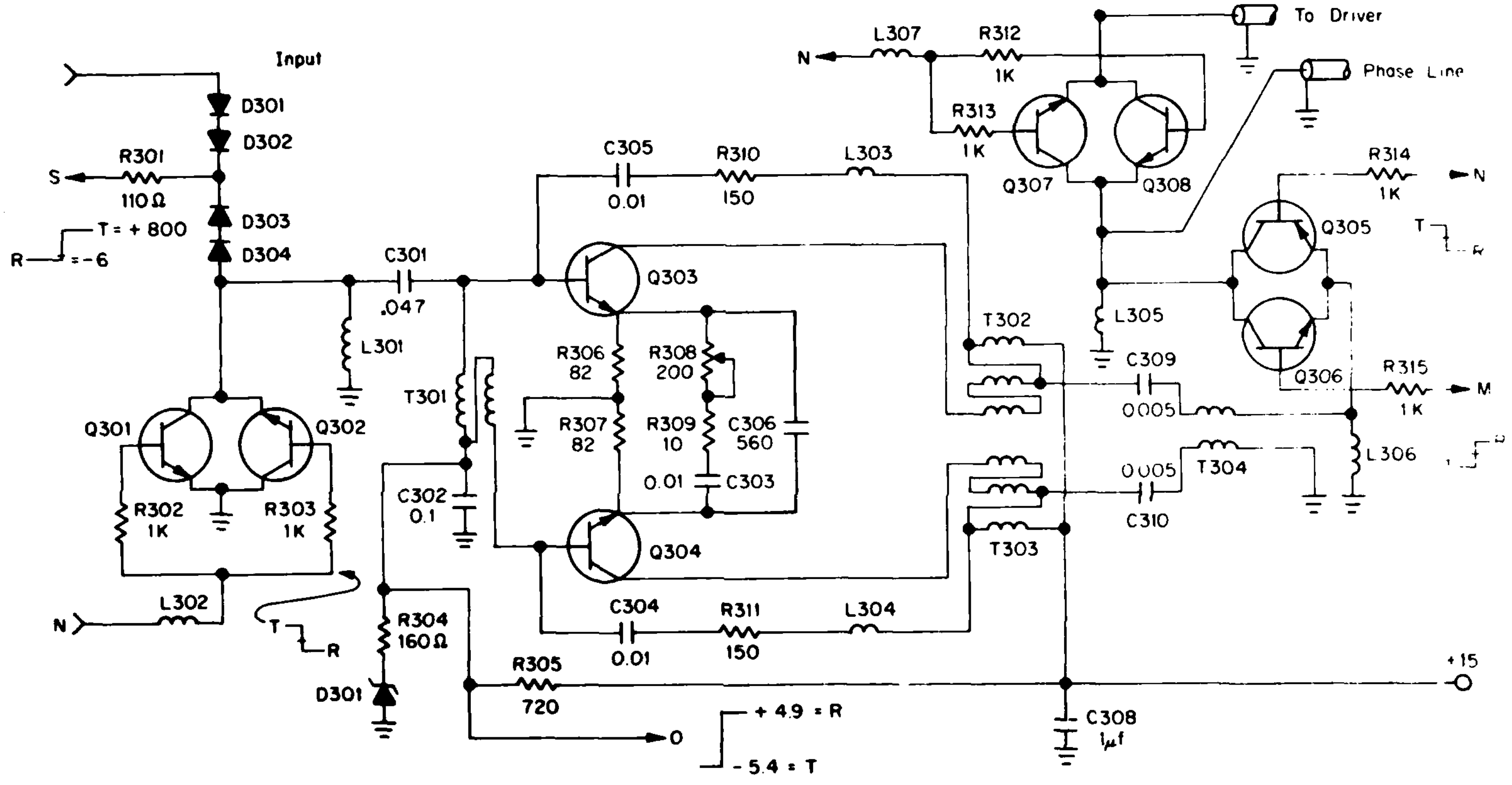

Figure 19. Schematic diagram of receiver preamplifier.

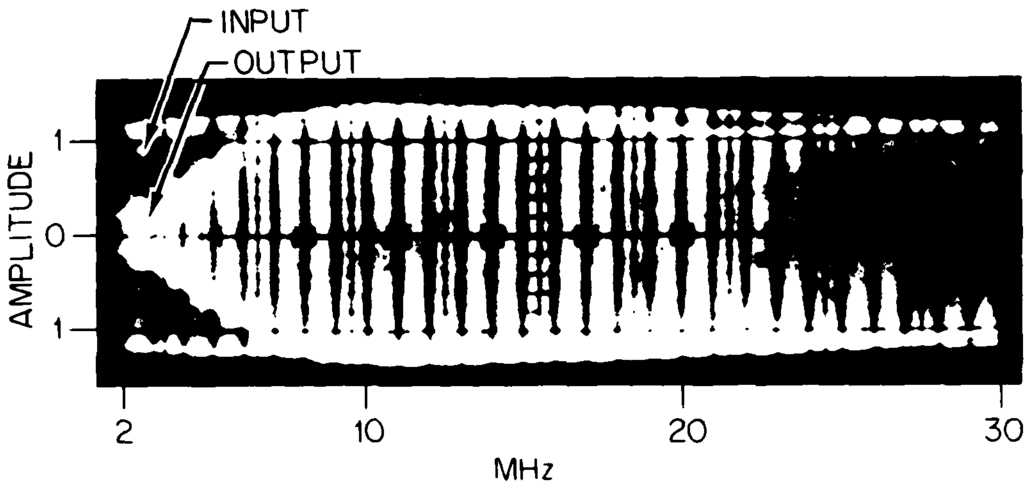

Figure 20. Receiver preamplifier passband response.

During the transmit mode of operation, the voltage driving the bias zener diode is switched to zero. Even though diode and transistor switches, to be discussed later, are provided for protection, turning off the bias keeps incremental rf voltages from being amplified and possibly leaking through the switches to drive the transmitter into destructive oscillation.

3.9. T/R Switching Logic

Figure 21 is the schematic diagram of the switch drive logic used in the Transmit/Receive change-over. The pulse polarities are shown as a general guide to operation. The logic output coding is also used on the circuit schematic diagrams in the troubleshooting section, Appendix C.

The logic outputs labelled R and S are the +400 and +800 V drive lines, respectively. Output R drives S_5 and S_6 (Figure 6), the shorting switches on the secondary combiners. The 400 V level back biases the diodes to withstand 400 V peak rf voltage. Output S, likewise, drives the diode switch S_3 enabling it to withstand up to 800 V-peak rf voltage. Outputs R and S are then driven to a negative voltage for forward bias of the diodes into a conducting state, Figure 7. Switches S_5 and S_6 short the output combiner ports to ground for receiver protection; S_3 allows the received rf signal to pass into the receiver. Switches S_1, S_2, and S_4 are transistor switches which are used only where low signal levels are anticipated; the logic output R is the control line which mutes the receiver amplifier during transmit.

3.10 Top Unit Power Supply

To provide the necessary operating voltages, a power supply board, Figure 22, is included in the top unit and powered by step up tranformers as stated in 2.3.

4. OPERATION

Input power and control signals are to be provided via J2 and J3 located on a side cover of the T/R unit.

4.1. Power Requirements

The T/R unit requires 208 V, 3-phase, at 6 A applied to pins 1, 2, and 3 of J_2 . The primary circuit should be fused externally to 6 A and contain a provision for turning the unit on and off. Pin 4 of J_2 is the frame ground and is connected to earth ground to protect the operator from shock hazard.

4.2. Control Requirements

Table 1 lists the external-control plug J_3 connections with the levels required for guaranteed operation. The following are additional operational requirements:

1. The T/R *control signal* *must* *be allowed to reach its "on" level 100 μs* prior to the application of the rf drive pulse.

2. The antenna change control levels should not be changed during the transmit pulse. To do so will shorten the life of the relays.

3. The reflectometer lines must be terminated in a 50 ohm resistive load. Failure to do this will result in distortion of pulse shape at the pulse monitor. Also, poor termination can allow oscillations in the current amplifier in the range of 5 MHz, depending on the length of the unterminated line.

The antenna impedance is nominally 200 ohms. A high range of antenna mismatch can be tolerated because of the capability of the unit to *operate into a short* circuit or open circuit. This privilege, however, should not be abused.

Table 1. Input Control and Monitor Signals

Function	Level	Connector and Pin
Phase line	37 mW rf drive	Type N Coaxial
Antenna relay	+5 = high antenna 0 = center antenna -5 = low antenna	Cannon # A
Return	Ground	B
T/R signal	+5 = transmit 0 = receive	C
Incident power	DC level (see text)	J
Return	Ground	I

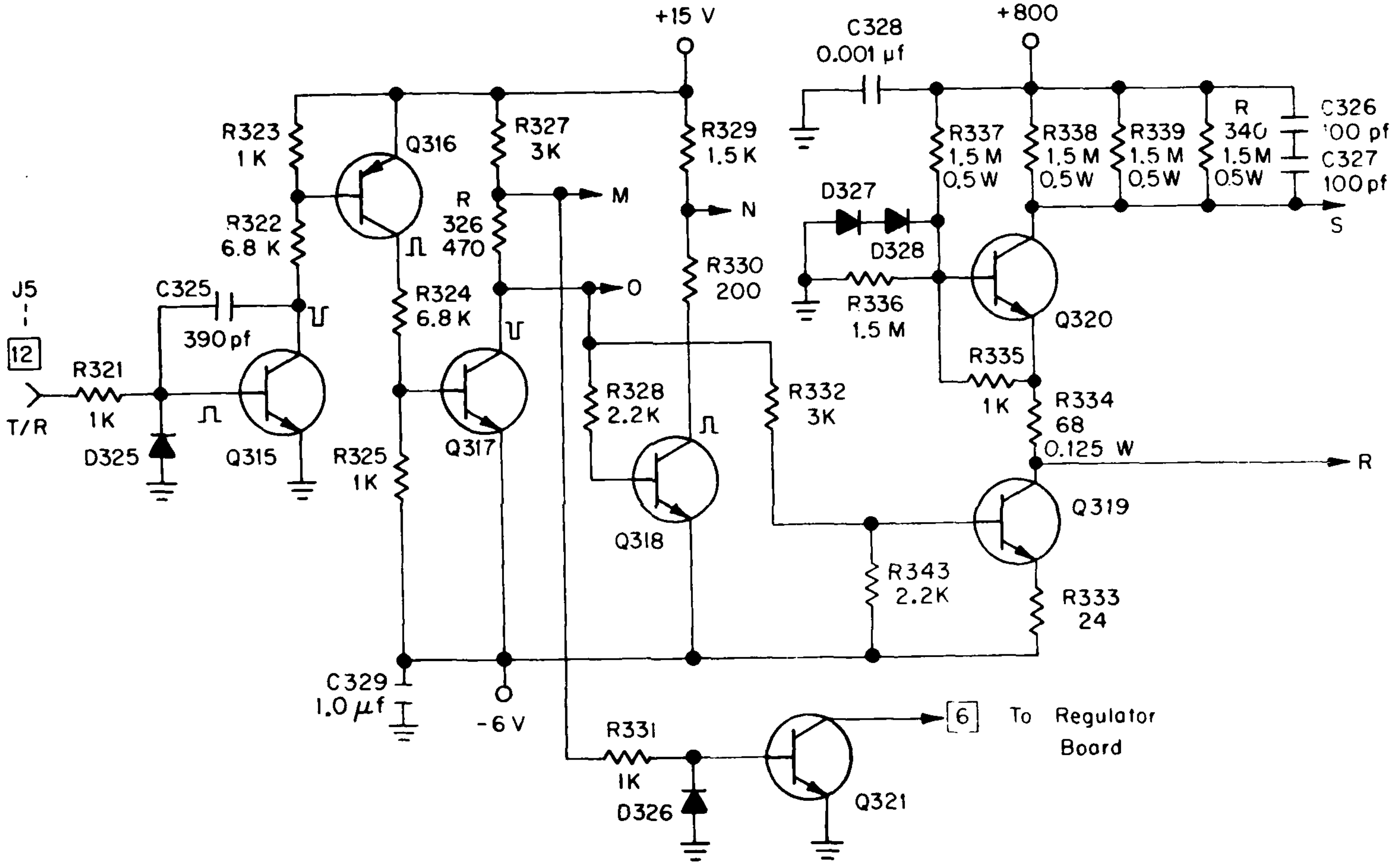

Figure 21. Schematic diagram of T/R switching logic.

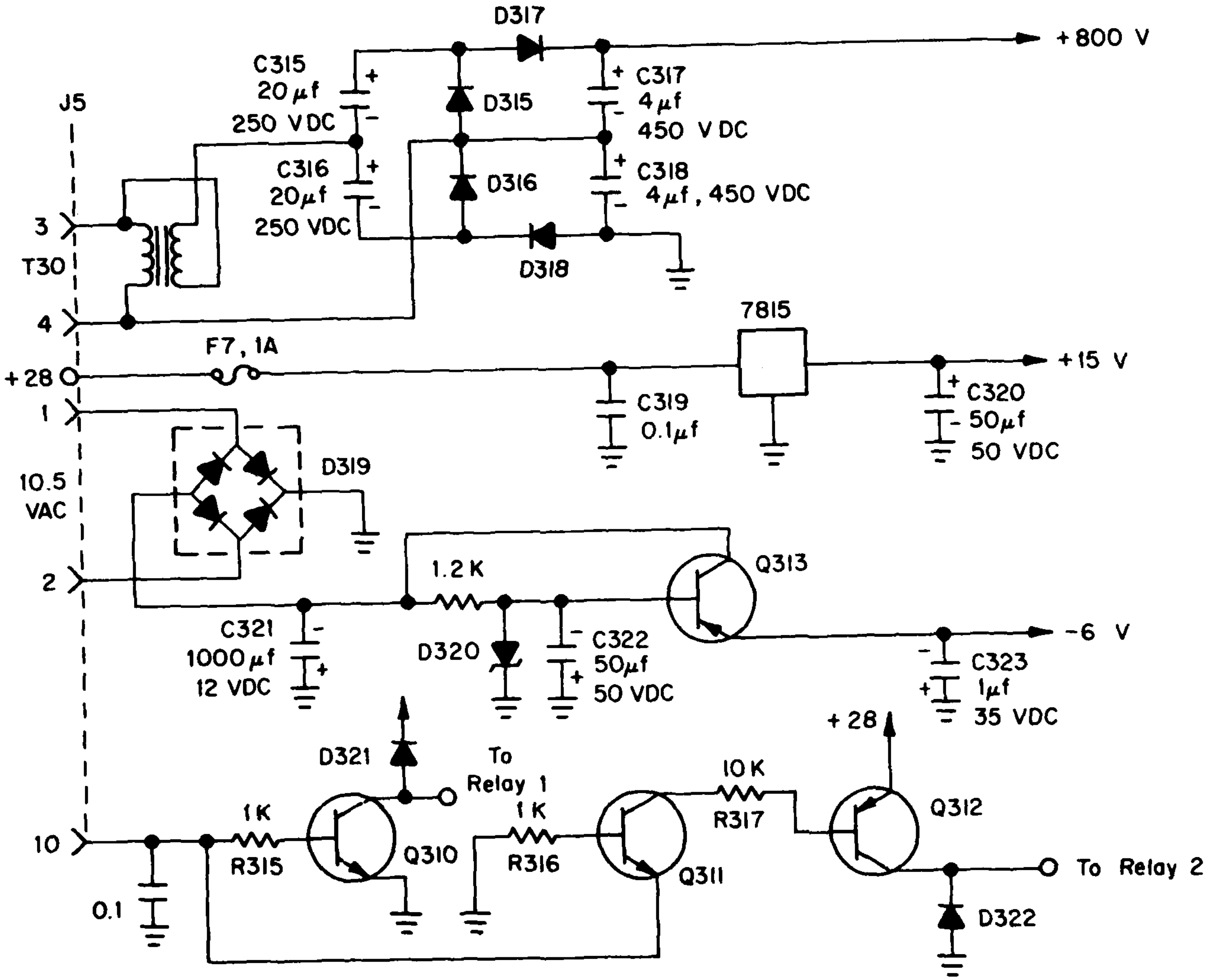

Figure 22. Schematic diagram of top unit power supply board.

5. CONCLUSIONS

The ITS Broadband transmitter/receiver proved to be a reliable state-of-the-art unit comprising many new techniques presently available to the designer. It showed many of advantages of solid-state design over vacuum tube design of broadband transmitters. Its strong points are:

Environmental immunity
High transmitter reliability
Simplicity of operation

Its weak point is:

Poor reliability in the T/R diode switches.

6. ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Lowell H. Tveten for his assistance and suggestions as project leader. Sincere appreciation goes to Laurence Melanson for his counseling, to Richard Chavez for his able assistance in the production of these units, and to the Naval Research Laboratory and the National Oceanic and Atmospheric Administration for their financial support.

7. REFERENCES

Kraus, H. L., and Allen, C. W. (1973), Designing toroidal transformers to optimize wideband performance, Electronics, August, p. 113.

8. BIBLIOGRAPHY

Pitzalis, O., Couse, T. P. (1968), Practical Design Information for Broadband Transmission Line Transformers. Proceedings of the IEEE Letters, April, p. 738.

Ruthroff, C. L. (1959), Some Broadband Transformers, Proceedings of IRE, Vol. 47, August, pp. 1337-1342.

APPENDIX A
SYSTEM OPERATION TESTS

R. W. Bogle*

Twenty-seven of the transmitter/receiver units described in this report were fabricated for use in the SEA ECHO HF radar at San Clemente Island, California. After approximately 1000 hours of operation, the 25 units comprising the normal radar complement were returned to ITS for reservice, minor modification, and testing. This appendix discusses the modifications and subsequent test results.

Modifications

In field use, occasional failures occurred in the transmit/receive diodes D7 through D14 and D301, D302, D303, and D304, Figure A-1. By the time the reservice took place, an improved PIN diode, was available, and one each of the new type was substituted for the combination D301 and D302, and for D303 and D304.

At the time the transmitter/receiver units were designed, a low-frequency roll-off was included for protection from possible intermodulation arising from the Pt. Arguello Loran A operating at 1.95 MHz and situated about 130 miles downrange in the radar field of view. Experience established that the expected interference was negligible and since a significant number of radar experiments were being conducted in a simultaneous band from 2 to greater than 10 megahertz, a flattened response was desired. This was achieved by increasing the value of L306 to 10 mHy.

During field operations, occasional tests were made to determine the uniformity of frequency-dependent phase shift through the receiving system. Since each transmitter/receiver is individually connected to one element of the 1200 foot 25 element antenna, preservation of antenna patterns and radiation side-lobe levels is critically dependent on consistency of phase shift through each unit. The tests performed in the field, after several hundred hours of system operation, indicated that the receive front-ends were not tracking in phase. Tests of the losses experienced in the 5/8" foam-flex cable which is used for feed lines and phasing cables showed that the receiver preamplifiers were not required to retain internal noise levels suitable

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below nominal external noise. Accordingly, the receive front-end units were modified to bypass the amplifier section. This revised signal path is shown in Figure A-1 by a heavy line.

Test Results

Twenty-five units were given thorough tests in the laboratory after modification; two units had been severely damaged by water seepage due to faulty seals. In general, few component failures were found with the exception of diodes D301-D304 and clamping diodes D55 and D56, designated S3, S5, and S6 in Figure 9 of the main report, which are quite sensitive to overdrive levels in the transmit mode. Two Darlington regulators and approximately five rf transistor amplifiers were replaced plus occasional low-power transistors in the top (control) unit and approximately 15 tubular electrolytic capacitors used in the top unit high voltage supply. With the exception of the two units mentioned, none showed evidence of loss of weather integrity. In addition to functional checks of power supply and control-pulse amplitudes and operation of antenna switches and power monitor signal levels, quantitative tests were made on all 25 units to determine transfer functions for gain and phase in both receive and transmit. The results are described below.

The average of gain of the transmitter power amplifiers is shown in Figure A-2, measured with an input level of + 15 dBm. The gain is seen to be flat to within ± 1 dB over the band from 2 to 25 MHz. The variations from unit to unit were found; standard deviation was approximately 5 dB. Input leveling pads, originally installed in the units, were removed in the reservice.

The phase shifts of the power amplifiers were measured for all units; these results are shown in Figure A-3. In this figure, the circled points are the average value for all 25 units, and the bars indicate the standard deviation. In making the phase shift measurement, a dual-beam oscilliscope was used to compare the relative phase of the input and output signals. To achieve accuracy in the comparison, input frequency was adjusted to values where exactly 180° of phase shift was indicated. Accordingly, the standard deviation is shown in the frequency coordinate. These measurements were made with a calibrated dummy load/voltage divider connected to the unit (antenna connection) output. The characteristics of this load are shown in Figure A-4.

The amplitude transfer characteristics of the receiver front-end are shown in Figure A-5 in which the power loss from antenna terminal to the phase terminal connection is plotted as a function of frequency. The values plotted are the average of 25 units.

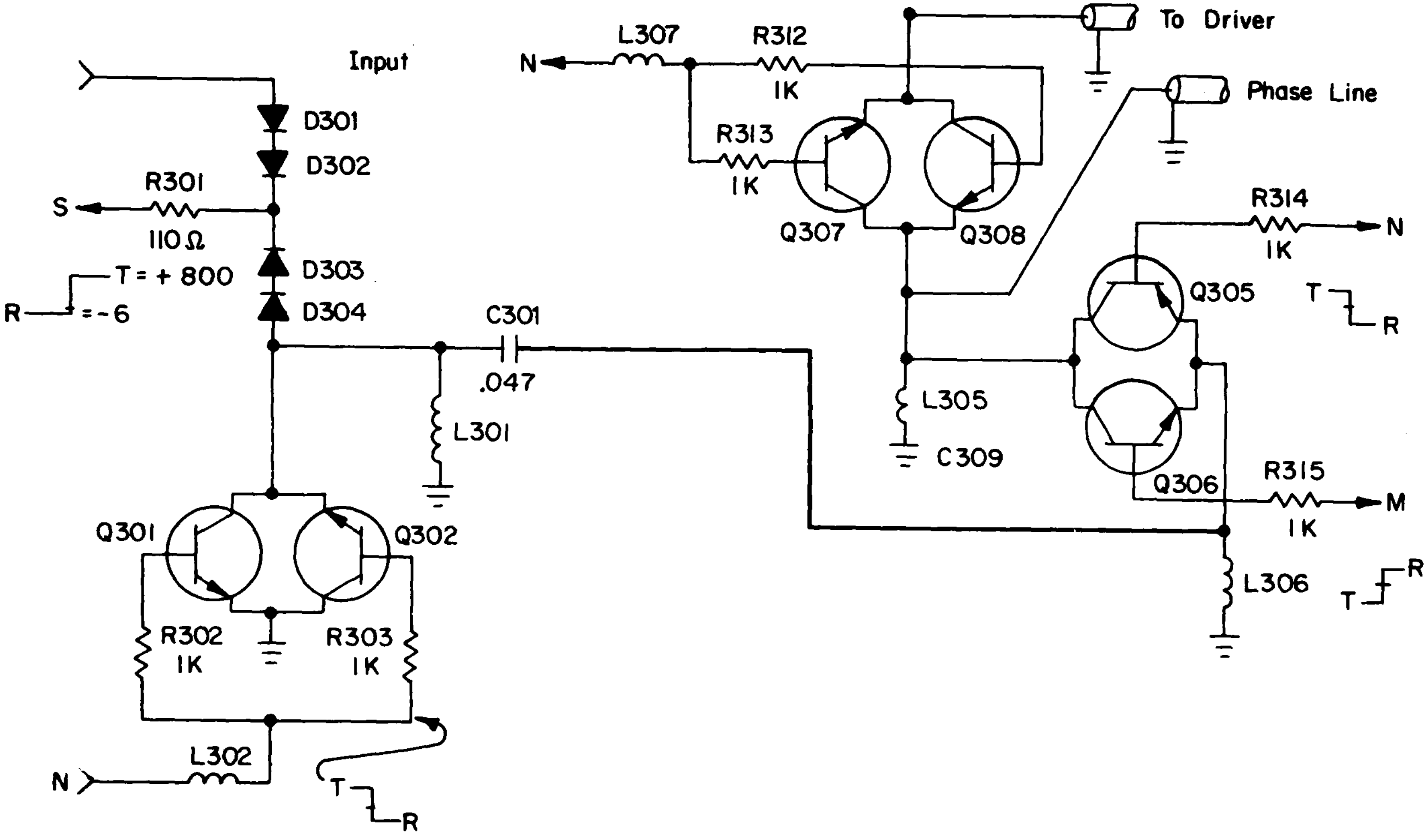


Figure A-1. Schematic of modified front end.

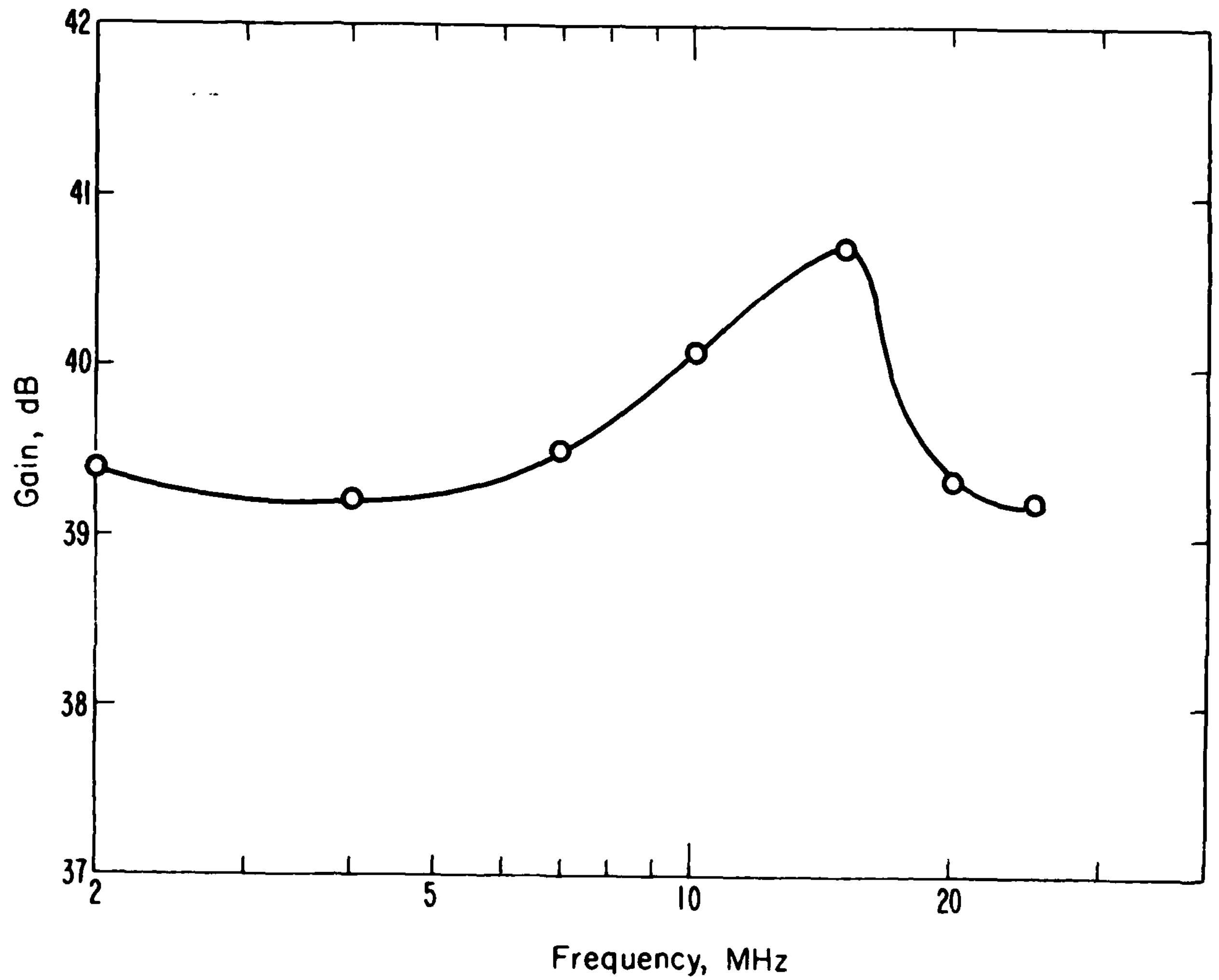


Figure A-2. Frequency response of power amplifier (average of 25 units) with input power of +15 dbm.

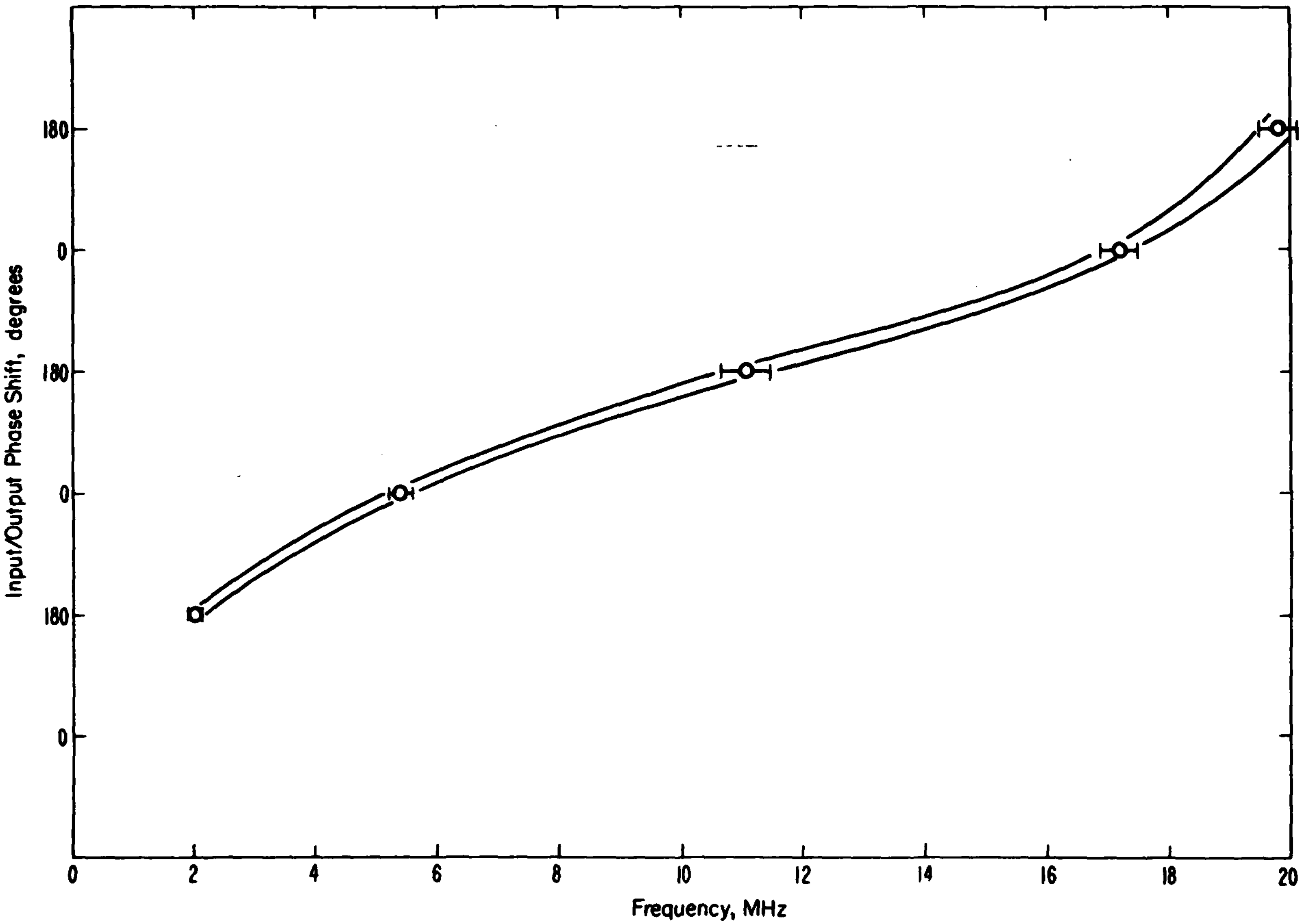


Figure A-3. Phase shift of power amplifier (average and standard deviation).

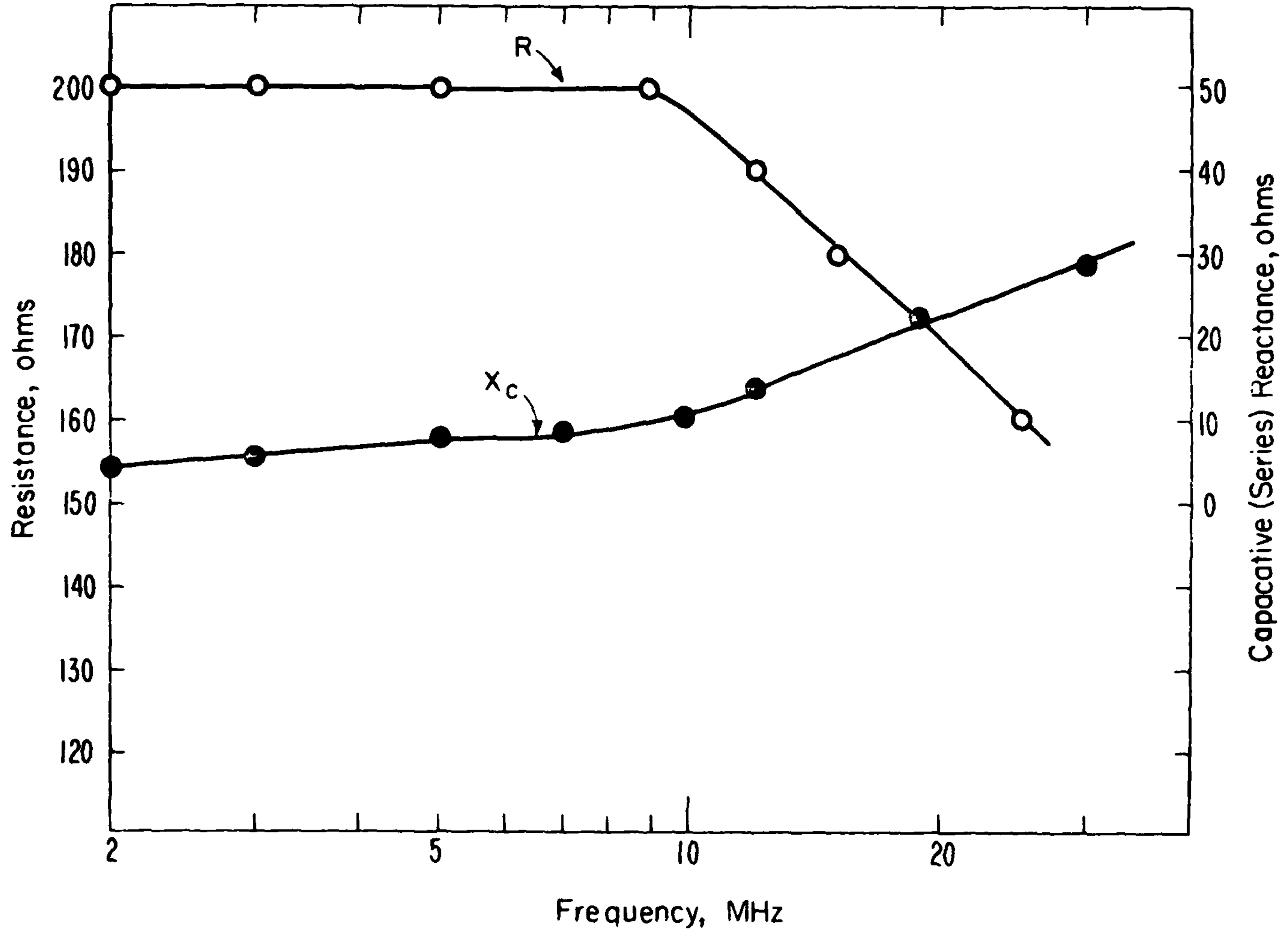


Figure A-4. Frequency characteristics of dummy load.

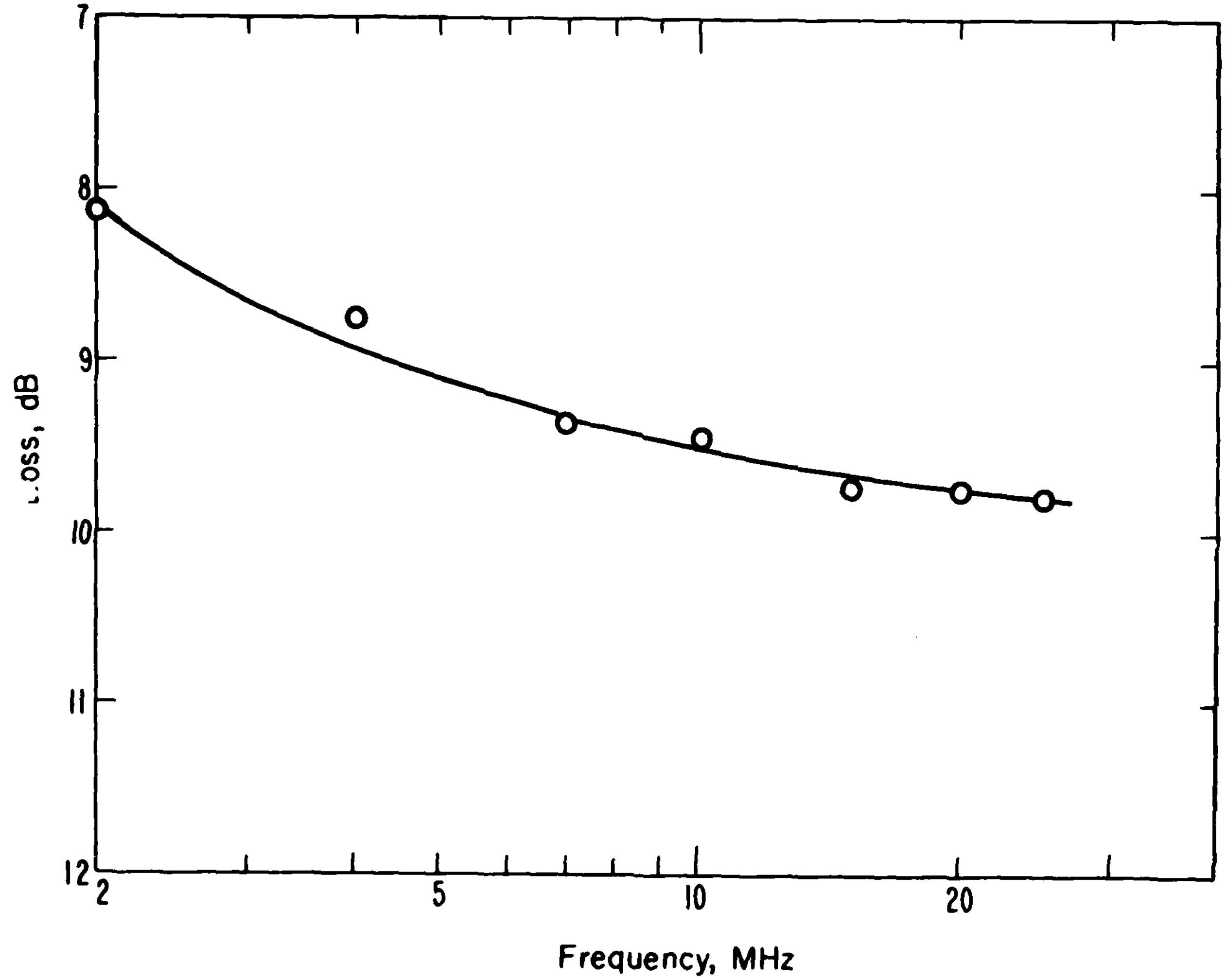


Figure A-5. Average input loss in receive mode for 25 units.

Similarly, the front-end phase shift is shown in Figure A-6. The phase shift values represent the results of measuring three units; no measurable difference was found among these samples. Since the modified front-end is a passive system, and, as can be seen, for frequencies above 4 MHz the phase is exactly linear with frequency; the other units were not measured. It can be assumed that the phase-shift shown, except at the low end of the spectrum, represents the time delay of the lead-lengths in the unit and test leads.

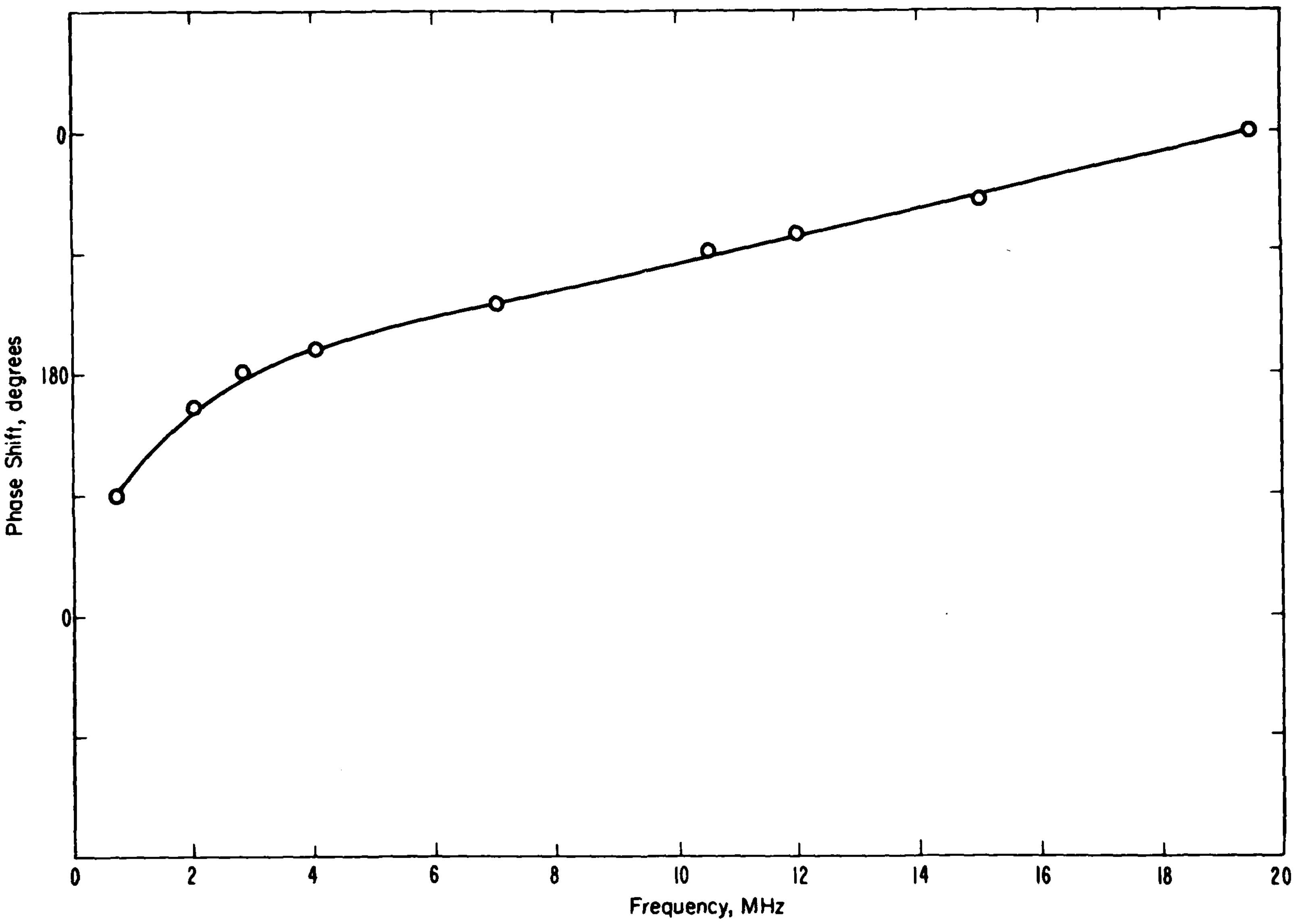


Figure A-6. Average input phase shift of modified receive units.

APPENDIX B. ANALYSIS OF TOROIDAL HYBRID COMBINERS

B.1. 2:1 Combiner/Splitter

When used as a combiner with inputs at R_3 and R_4 at zero degrees phase relation, the input currents flow as shown in Figure B-1. Current i_1 splits into i_5 and i_6. Current i_2 splits into i_3 and i_4. In the balanced condition, i_4 cancels the induced current i_6. Net current in the waster resistor R_1 and power dissipated is zero.

Currents i_5 and i_6 are in phase at the load resistor R_2.

The voltages E_1 and E_2 add. The output impedance is therefore

$$R_{out} = \frac{2E}{I} = 2\ R_{in}\ .$$

When one input is totally absent, half of the other input power is dissipated in the waster resistor R_1' and half in the load. The total loss by losing one input source is 6 dB.

A similar analysis can be done in the case of the input signals having a phase relation of 180°. The functions of R_1 and R_2 are exchanged with R_1 becoming the load and R_2 the waster termination.

The characteristic impedances of T_1 and T_2 are:

$$Z_o = \frac{E_{in}}{I_{in}} = Z_{in}\ .$$

Winding of the toroids is done as a complete assembly and then soldered into the circuit (see Figure B-2 for winding detail).

B.2. 9/16:1 Impedance Transformer

The input current (see Figure B-2) i_{in} splits into i_1 and i_2. The mirror current i_1' is induced in the second winding of T_1 and sums with i_1 producing $2i_1$. Current $2i_1$ is in series with and therefore must be equal to i_2' and i_2. Currents i_2' and i_2 sum at R_L producing the load current

$$i_L = 2i_2 = 4i_1.$$

Since

$$i_{in} = i_1 + i_2 = i_1 + 2i_1 = 3i_1,$$

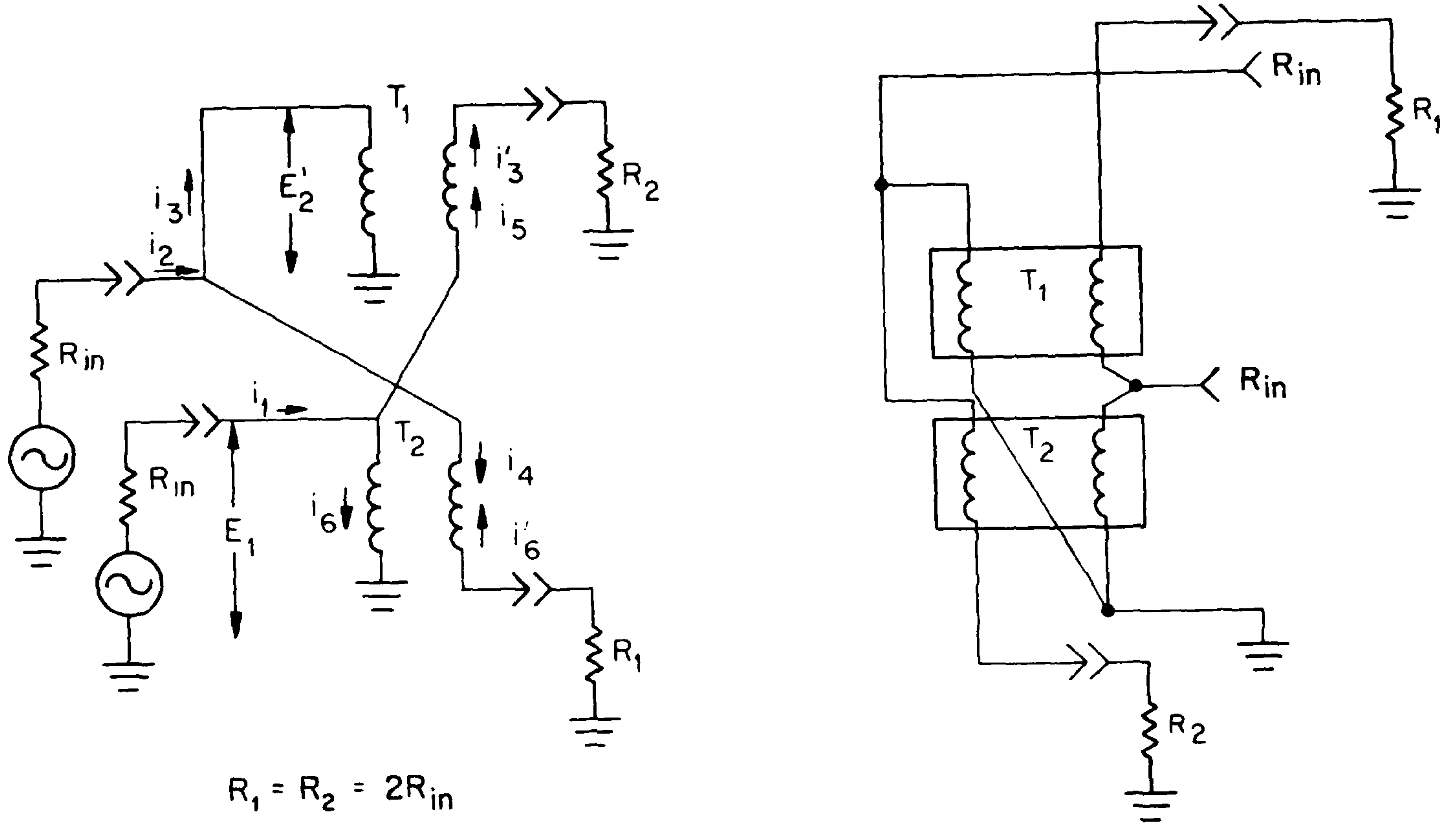


Figure B-1. 2:1 combiner.

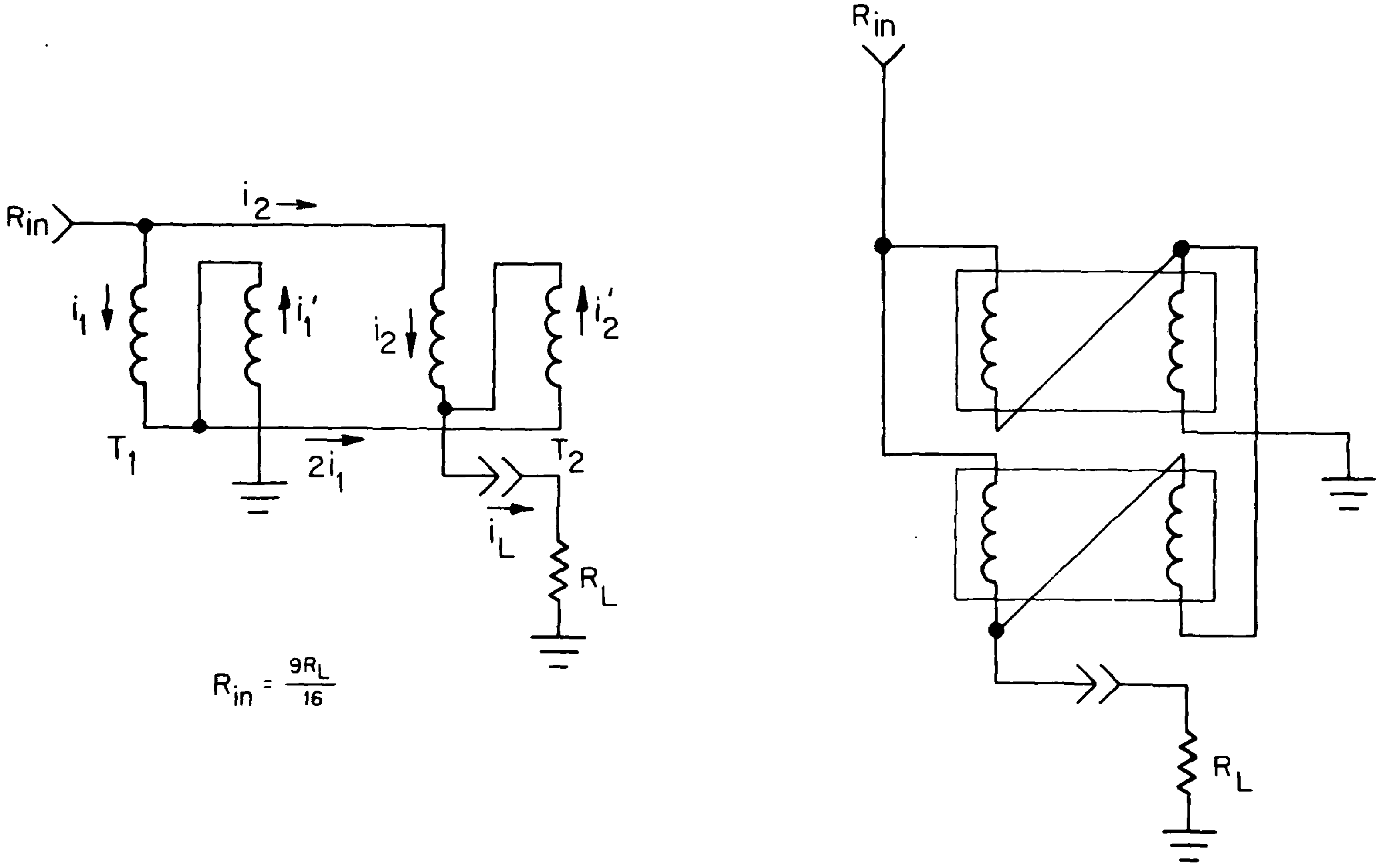


Figure B-2. 9/16:1 transformer.

the current transform ratio is

$$\frac{i_{out}}{i_{in}} = \frac{4i_1}{3i_1} = 4/3 \quad .$$

One-half of the input voltage appears across each winding of T_1. Likewise, each winding of T_2 has one-half the winding voltage of T_1 or one-fourth of the input voltage. The load voltage is therefore:

$$E_{load} = E_{in} - E_{WT_2} = E_{in} \frac{e_{in}}{4} = 3/4\ E_{in}$$

$$\frac{E_{out}}{E_{in}} = 3/4 \quad .$$

The impedance transform ratio therefore is:

$$Z = \frac{E}{I} = \frac{3/4}{4/3} = 9/16 \quad .$$

The characteristic impedances of T_1 and T_2 are given by:

$$Z_o = \frac{E_{in}}{2} \Big/ \frac{i_{in}}{3} = 3/2Z_{in} \quad .$$

B.3. 4:1 Transformer

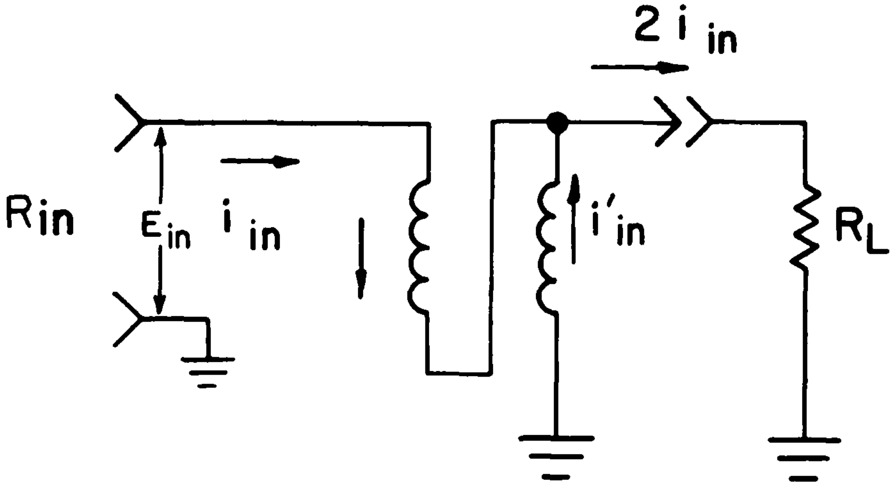
The 4:1 impedance transformer is treated by Ruthroff (Some Broadband Transformers, Ruthroff, 1959) but will be repeated here for reference. The analysis follows the same procedure as in B-2. (see Figure B-3).

B.4. 2:1 Combiner/Splitter

This combiner provides a summing of i_1 and i_2 in the transformer output (see Figure B-4). The output voltage for equal in-phase inputs is equal to E_{in}.

Therefore,

$$Z_{out} = \frac{E_{in}}{2I_{in}} = \frac{Z_{in}}{2} \ .$$



$$R_L = \frac{E_{in/2}}{2\,i'_{in}} = \frac{R_{in}}{4}$$

Figure B-3. 4:1 transformer.

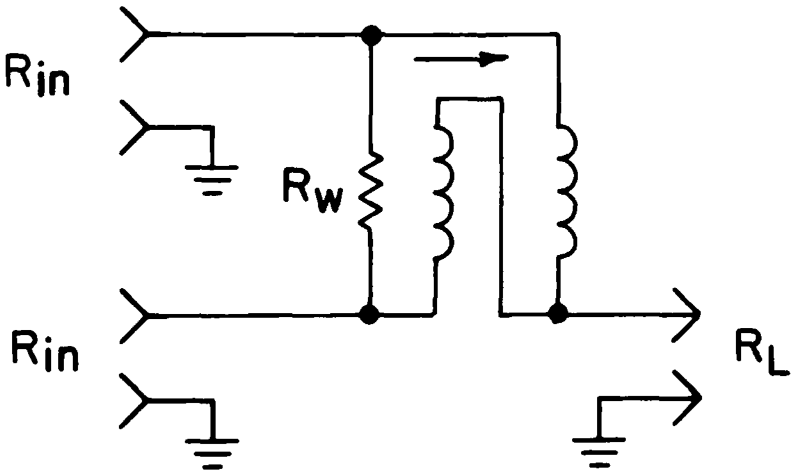


Figure B-4. 2:1 combiner.

This combiner is attractive since, in normal operation, no winding voltage drop exists, and hence no core flux. The losses of this type of combiner/splitter are extremely low.

The waster resistor value can be computed from the imbalance condition. The circuit then becomes a 4:1 impedance transformer and R_L is reflected to the active input as $4R_L$. The power source, however, requires an impedance of $2R_L$. A resistor must be added with a value of

$$R_W = 4R_L$$

to make the input look like the required $2R_L$.

The characteristic impedance of the winding can be seen from the imbalance case. When the winding must act as a 4:1 transformer, the Z_o must be $2R_L$ (from 4:1).

The characteristic impedance of this unit is, therefore,

$$Z_o = Z_{in}.$$

B.5. 3:1 Combiner/Splitter

This network, see Figure B-5, is similar to that of Figure B-1, the 2:1 combiner/splitter, but no description of this exact design has been found in the literature. One of the principles of balance of the circuit of B-1 is the cancellation of current in the secondary of T_2 as a result of the secondary voltage balancing the voltage at input #1. If the power and the impedance at input #1 are both doubled, the voltage at that input will be doubled. By adding a winding to T_2, twice the voltage of input #2 may be obtained which will balance the circuit. The input currents will be equal, and i_1 will be applied to R_L. If the power is to add in the load,

$$R_X = \frac{3S}{I^2} ,$$

$$I^2R_L = 3X , \qquad R_L = 3R .$$

Assume input #1 is open with no signal. The induced current i_2' will flow in the primary of T_2. The voltage on input #1 must generate a current in the secondary of T_2 to exactly neutralize the effect of i_2 at input #2. The resistance at R_W necessary to do this due to the 4:1 current transformer in T_2 is

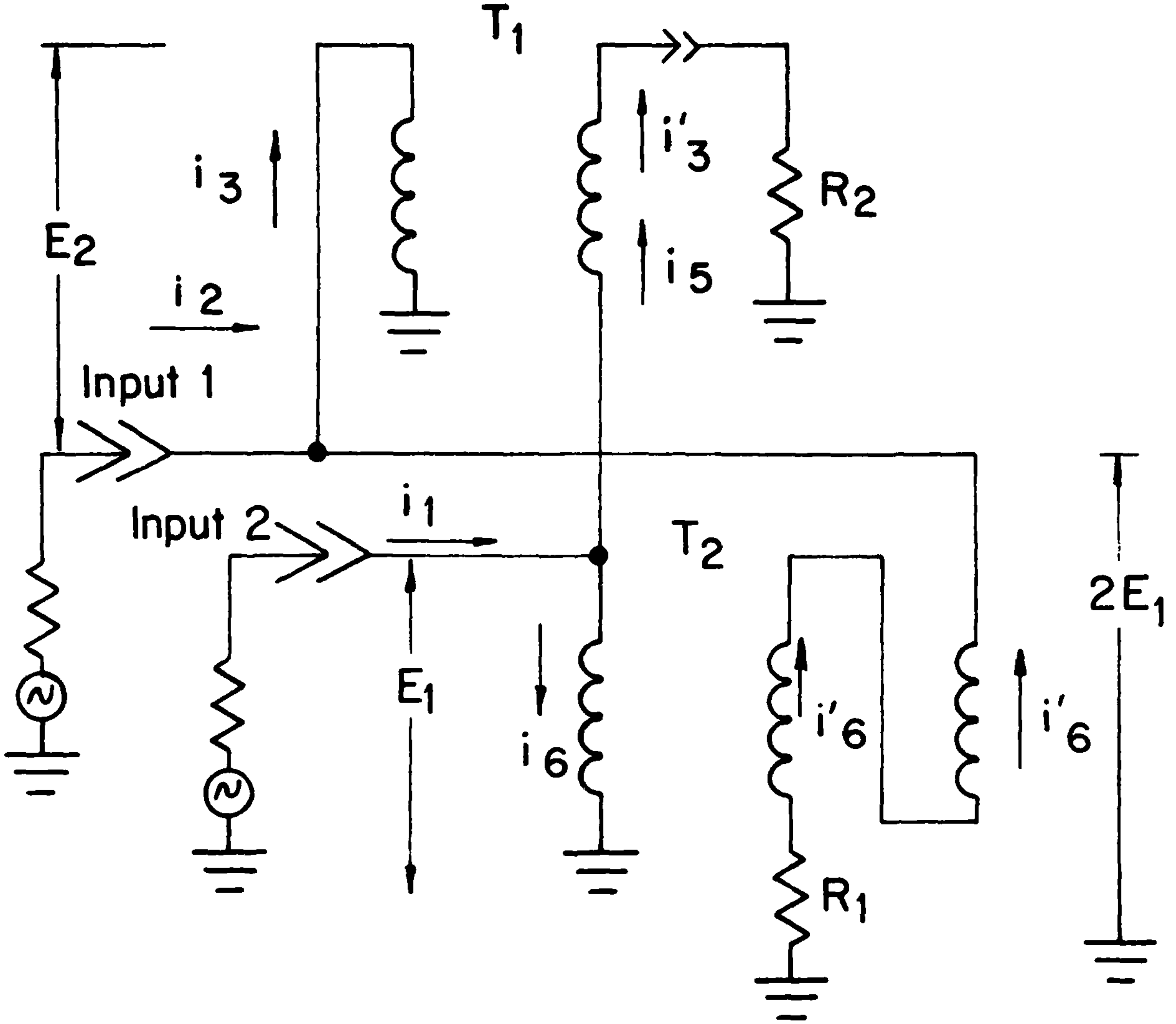


Figure B-5. Unequal power combiner for 3:1 combiner network.

$$\frac{i_1}{4} = \frac{E}{R} \quad ,$$

$$R_w = 4R \quad .$$

The application of the 3:1 combiner is shown in Figure B-6. It is used in conjunction with a 2:1 combiner as per Figure B-1 and a delay line to match the direct input to the delay of the 2:1 combiner.

With this system, three amplifier outputs can be combined or a single input can be split into three identical outputs.

Table B-1 is a tabulation of wire sizes versus wire twists for various impedances used in constructing the toroidal hybrid transformers described in this report (Kraus and Allen, 1973).

Table B-1. Wire Sizes Versus Twist* for Various Transformer Impedances (after Krause and Allen, 1973).

Wire Gauge	Insulation	Twists per cm	Z_o
14	Teflon .010"	1	80 Ω
14	Formvar	5/8	24 Ω
16	Teflon .01"	1	100 Ω
18	Formvar Formvar 2x2 twist	3/4 See Note 1 See Note 1	50 Ω
18	Formvar Double Wire	See Note 2 See Note 2	12-1/2 Ω
20	Formvar	3/2	33 Ω
20	Formvar	3	27 Ω
22	Teflon .008"	2	100 Ω
24	Formvar	4	50 Ω

Note 1: 2 wires are twisted to 6T/cm, then these pairs are twisted together to 1T/cm.

Note 2: 4 wires laid in parallel are twisted to 1T/cm. Two adjacent wires are then used per side of transmission line.

*Twist = 1/2 turn.

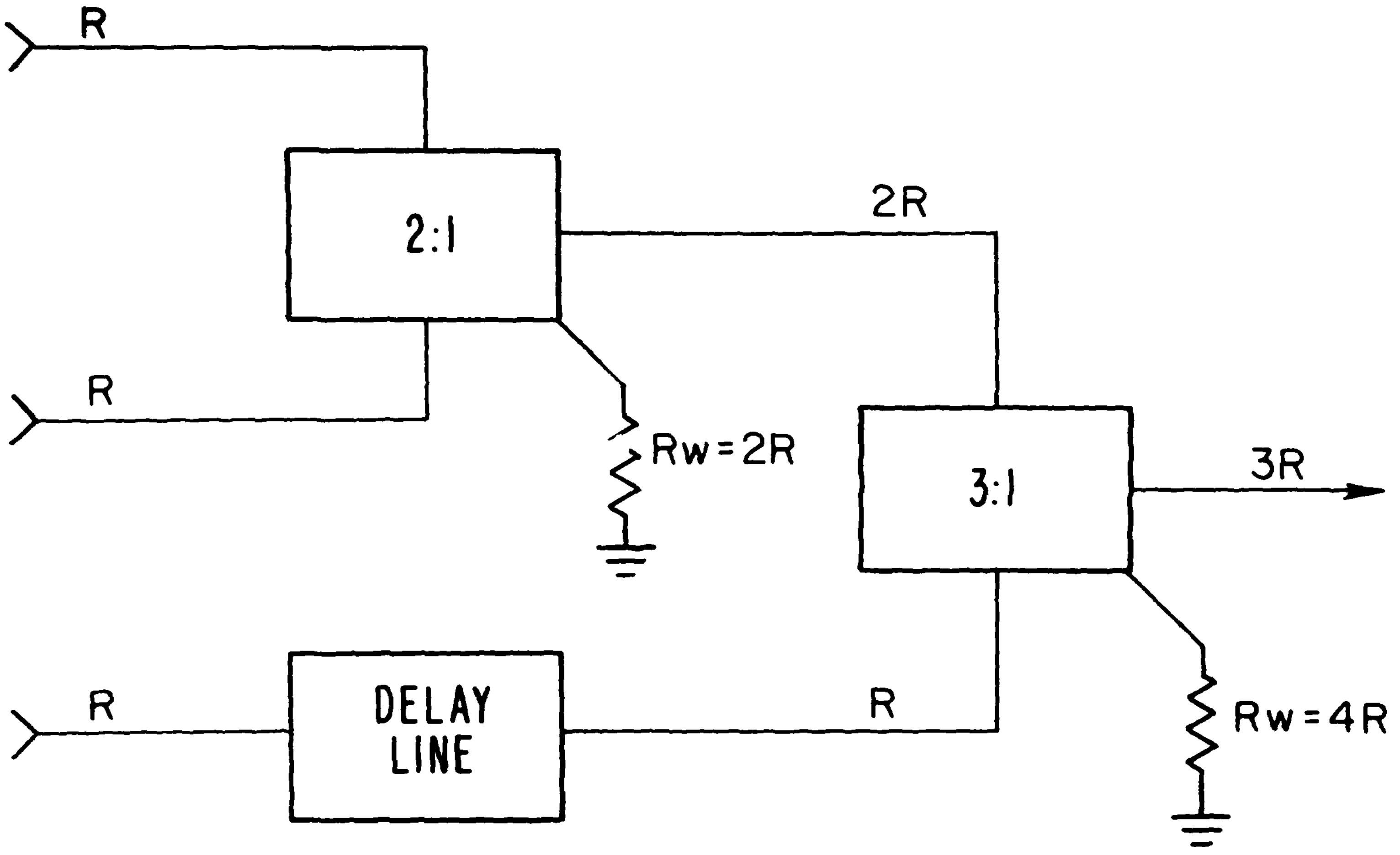


Figure B-6. Complete 3:1 power combiner.

APPENDIX B REFERENCES

Kraus, H. L., and Allen, C. W. (1973), Designing toroidal transformers to optimize wideband performance, Electronics, August, p. 113.

Ruthroff, C. L. (1959), Some broadband transformers, Proc. IRE 47, August, p. 1337.

APPENDIX C. TROUBLE SHOOTING

When a unit is to be repaired, the following routine checks should be made.

1. Main dc power supply is working.
2. Small power supplies for switching unit and receiver preamplifier are working.
3. T/R logic and associated switching are operating normally (including antenna relays).
4. The rf amplifier circuits are operating normally.
5. Receiver preamplifier is operating normally.

The test setup used for the T/R transmitter check is shown in Figure C1.

C.1. Main dc Power Supply is not Working

Figure C-2 is the schematic of the 35-volt, 50-ampere power supply. Check with an ohmmeter to determine if any shorts to ground exist from the + diode block. If a direct short to ground is found, remove the capacitor lead and bend up the copper buss to isolate these areas for the shorts check. The ohmmeter can be used to check the diodes to determine if any are shorted. To determine which diodes are at fault, however, they must be disconnected and checked individually.

Shorts in the Darlington regulator transistors will often be indicated by blown fuses. Shorted case to ground of the Darlington transistor pairs can be detected without removing regulator boards by measuring with an ohmmeter at the the small wire which protrudes at the center of the regulator board.

Short circuits on the amplifier modules may not be obvious at this point since the foldback current limiting will allow a short to exist without damaging either the regulator or the amplifier module. Voltage measurements should now be made to determine that all the required voltages are present.

In the absence of a voltage at one or more of the amplifier modules (rectangular pad), the T/R unit should be turned off and resistance measurements made at the voltage input pad to locate the short circuit (see Table C-1).

Figure C-3 is the voltage regulator schematic. Note that one section of the dual regulator feeds the common zener reference diode. Should this section be shorted, no voltage will appear on the companion section.

If all voltages are present at amplifier modules, proceed to test 2.

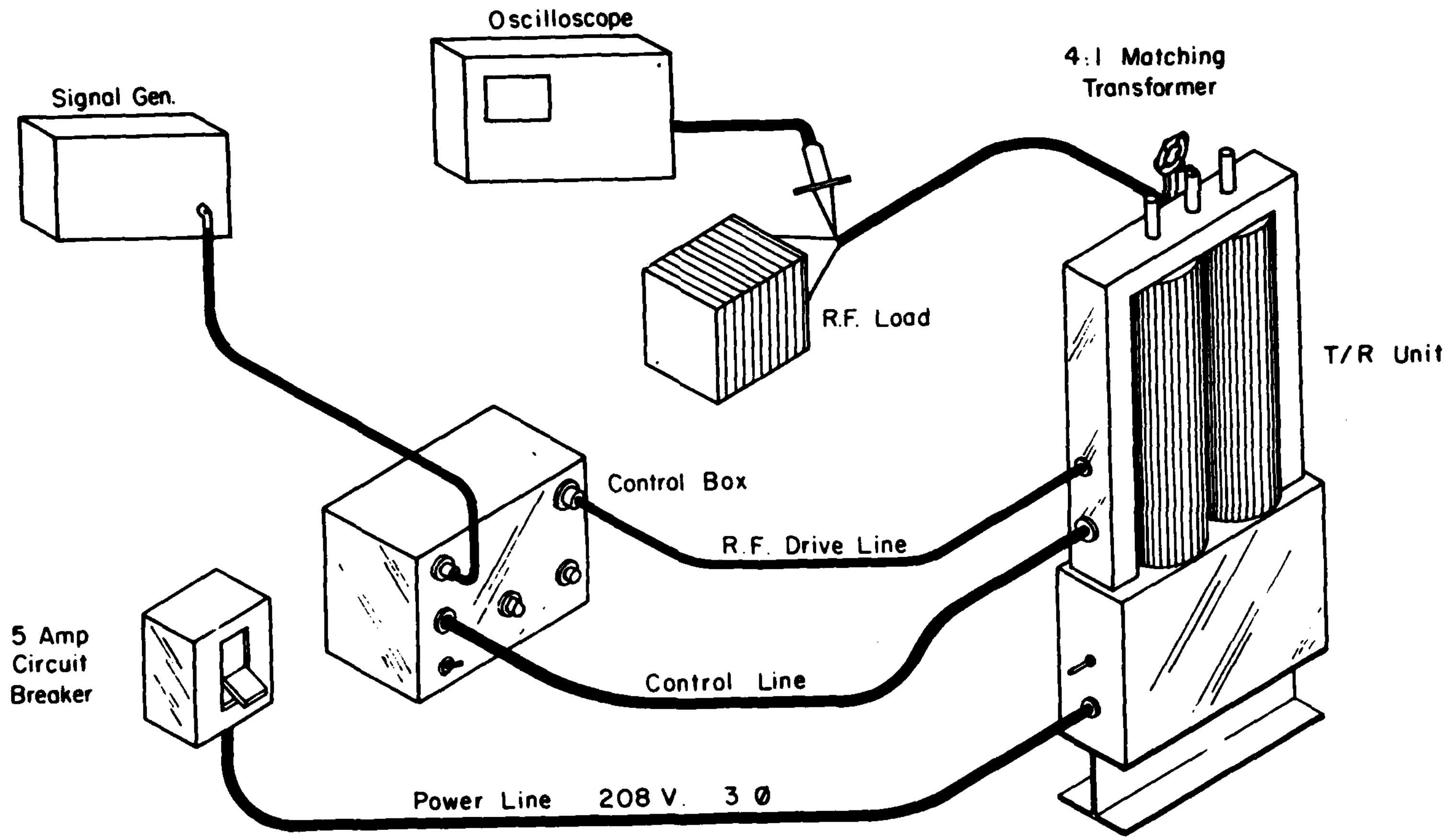


Figure C-1. Test setup for transmitter checks.

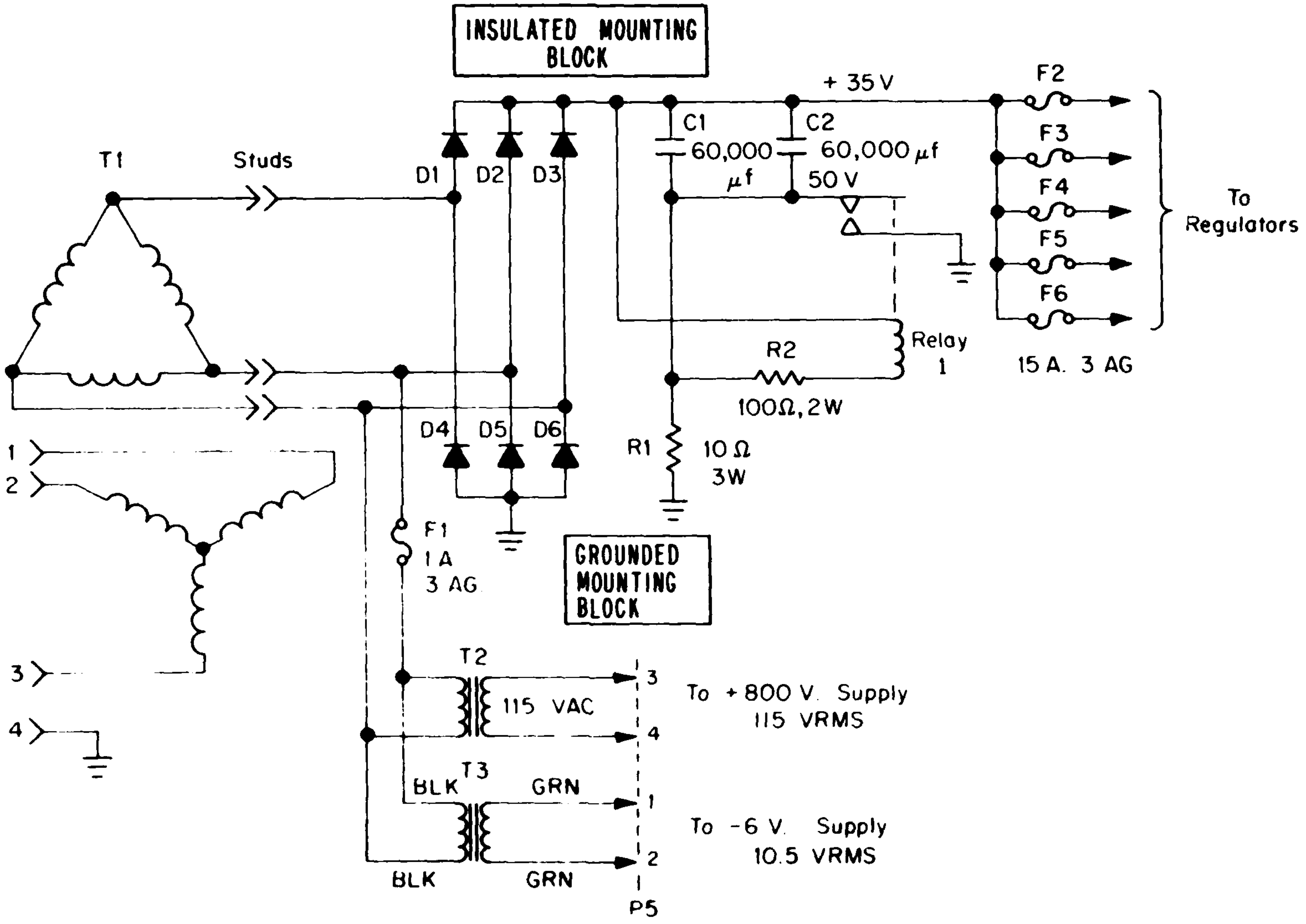


Figure C-2. Schematic diagram of main power supply.

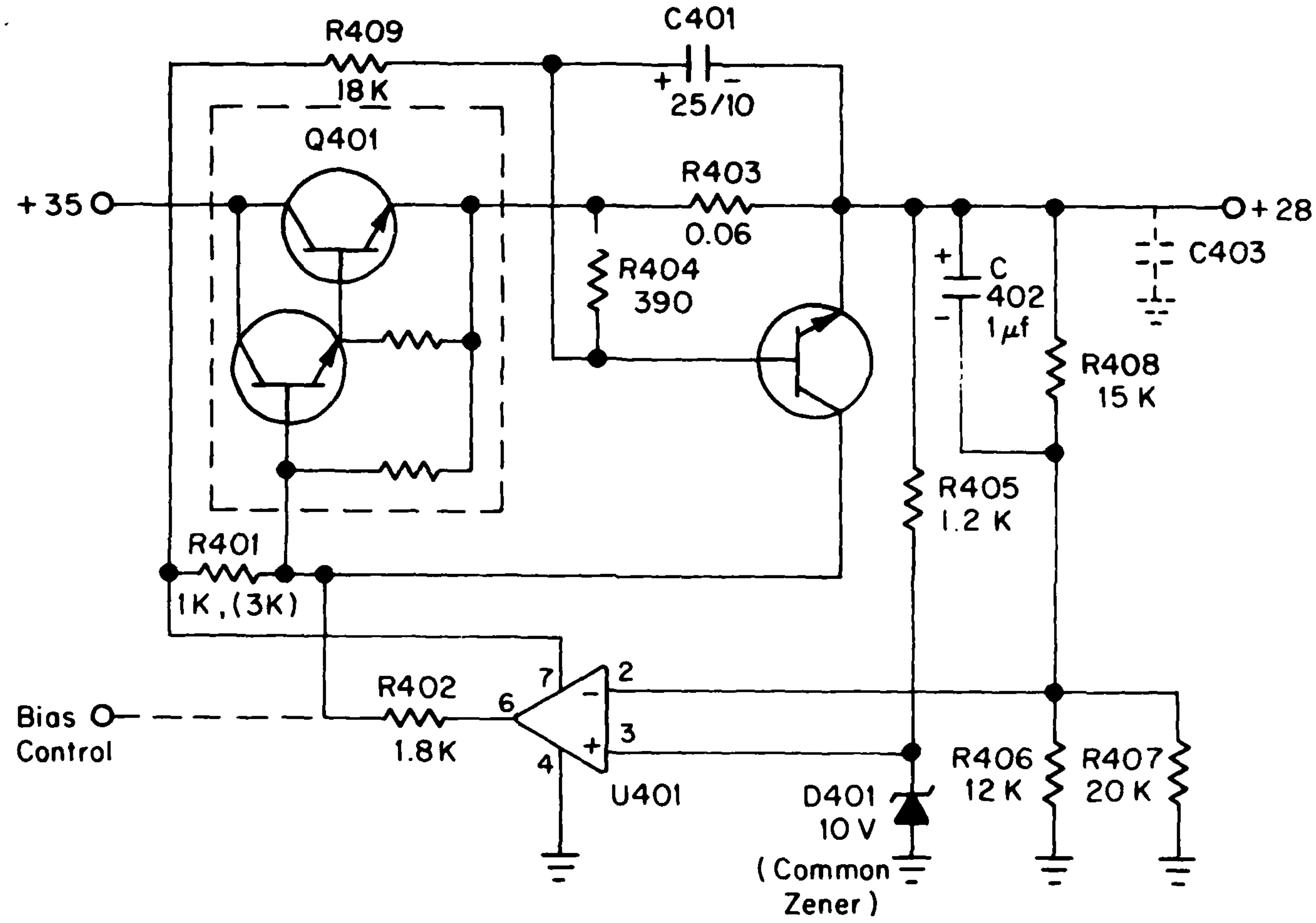


Figure C-3. Schematic diagram of 28 V regulator module.

C.2 Secondary Power Supplies Not Working

Refer to Figure C-4, which is the schematic diagram of the top unit power supplies.

The receiver power supply should have three voltages present: +15, -6, and +800. The power monitor board has a single +15 V supply. Both +15 V supplies are IC regulated from one of the +28 V module regulators.

The -6 V and +800 V supplies receive power from one phase of the 28 V rms main power transformer via step-up transformers, Figure C-2. The -6 V supply has 10 V rms applied to a diode bridge; the +800 V supply receives 115 V rms which is then stepped up to 155 V rms with an auto transformer mounted with the receiver board. A voltage quadrupler then provides +800 V-dc.

If both +15 V supplies are inoperative, check fuse F7. Generally a short circuit will blow the 1 A protective fuse. If only one of the two supplies is inoperative, check for shorts in the respective circuits. The IC regulators are protected against short circuits and may recover if the short is removed.

If no short circuits are found, proceed to check and replace faulty components.

C.3 T/R Logic and Associated Circuitry are Not Working

Figure C-4 is the schematic of the T/R logic with associated waveforms. Normal circuit and signal tracing techniques should locate faulty components.

C.4 The rf Amplifier Circuits are Not Operating Normally

If the rf amplifier output is zero this indicates trouble in one of two places:

1. bias regulator
2. driver module.

C.4.1 Pulsed bias regulator not working

This condition is detected by measuring the pulse at the output of the byistor in any of the amplifier modules or the driver module (i.e., the voltage at the 2.2 ohm byistor load resistors).

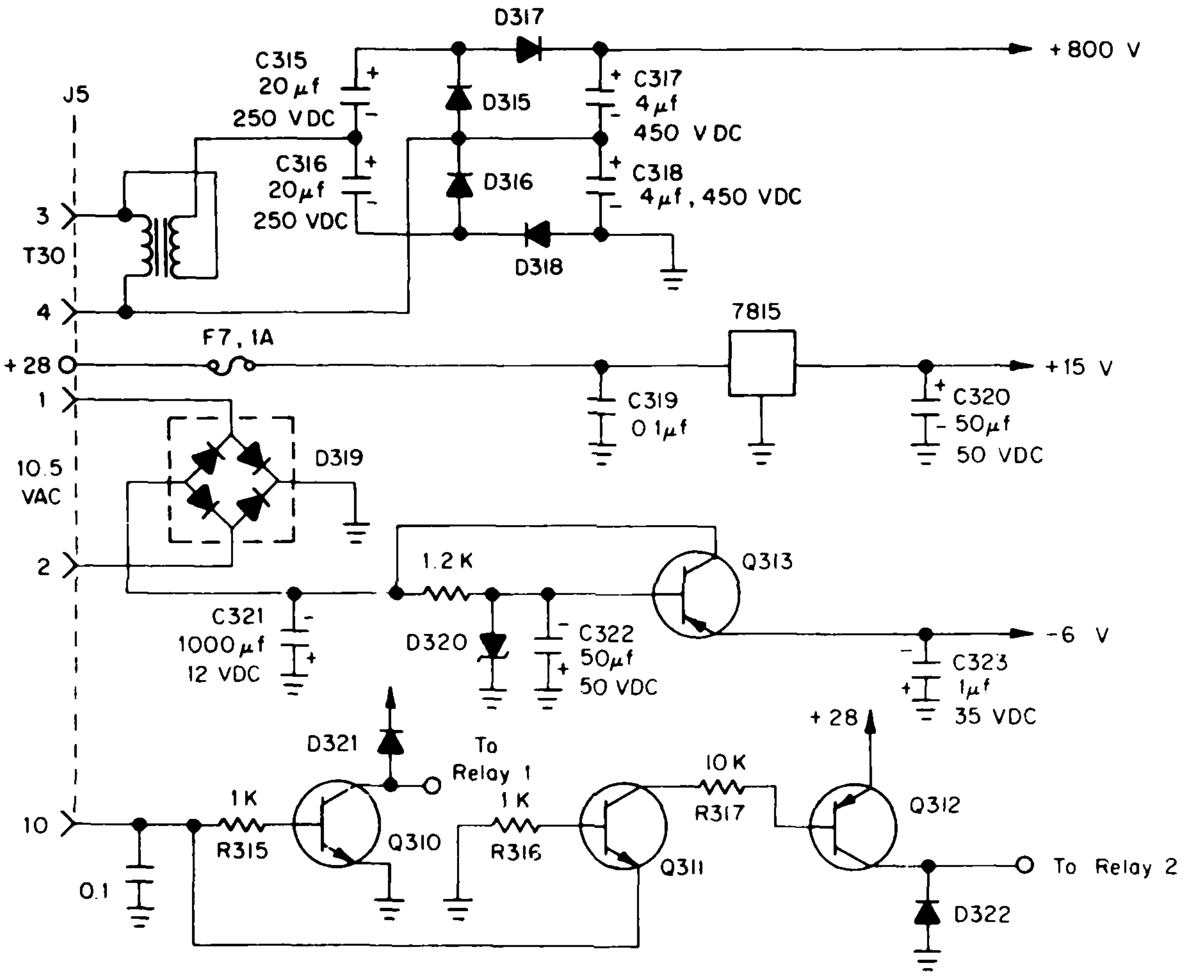


Figure C-4. Schematic diagram of top unit power supply and antenna relay driver circuits.

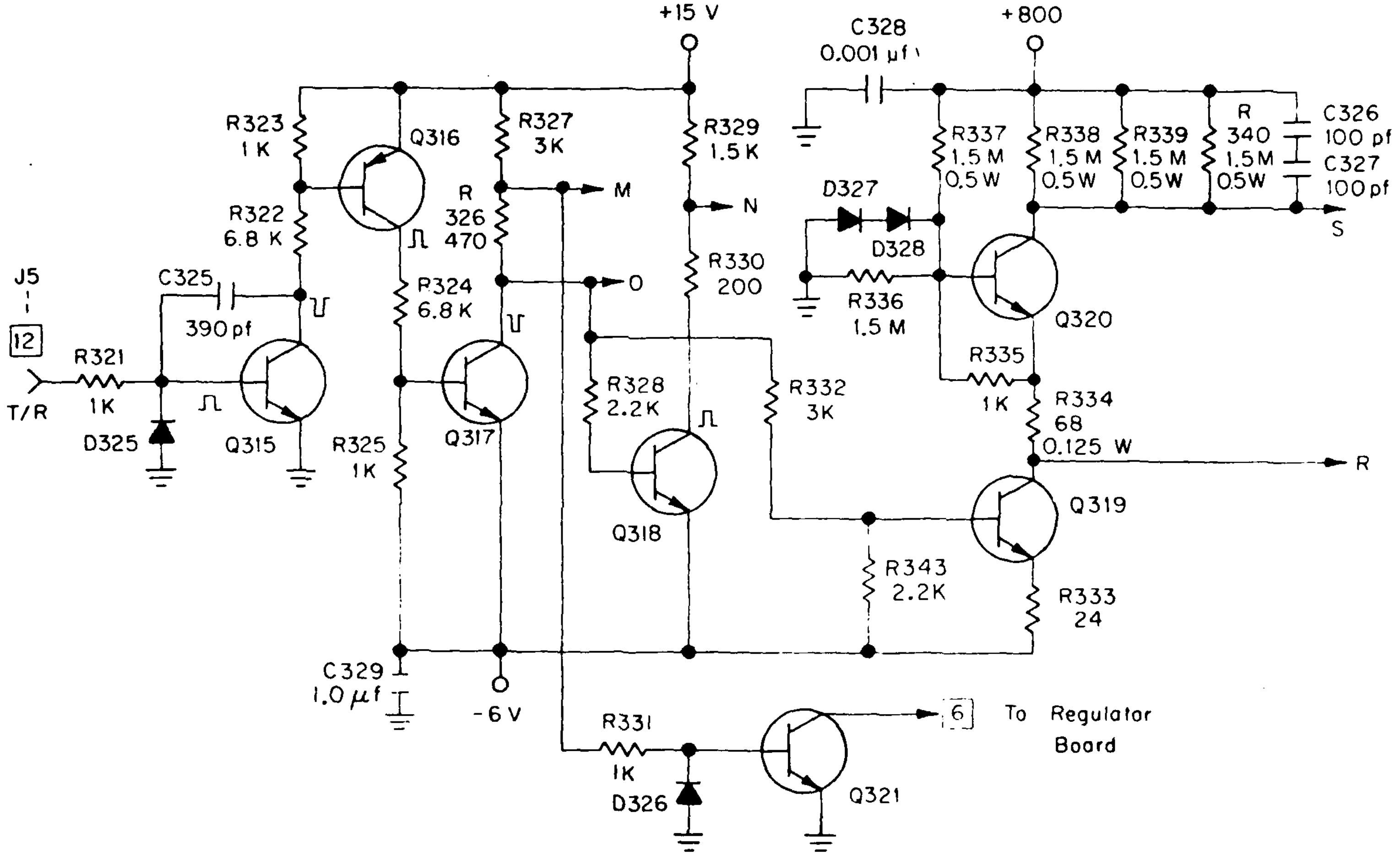


Figure C-5. Schematic diagram of T/R switching logic.

Figure C-6 is a partial diagram of the bias pulser and its interconnection to the T/R logic board.

C.4.2 Driver module not working

Figure C-7 depicts the signal flow from J1 through the rf switches and through the driver module.

Signal tracing through these circuits with an oscilloscope with a short ground lead on the probe should uncover the defective stage and component.

A check of overall transmitter performance and individual module operation may be made as follows:

1. Set the pulse width and pulse repetition frequency for a low duty factor. This will reduce the power dissipation in the waster resistors throughout the transmitter.
2. While observing the output rf envelope on the oscilloscope, short each module rf <u>input</u> to ground in turn with a small screwdriver. The drop in the output envelope should be equal for all modules.

Table C-1 is a table of resistance values which can be used to locate problem areas. The following procedures may be used to isolate faulty components.

<u>Procedure 1</u>

If the collector of an output-transistor indicates slightly higher than 4.2 ohm this may mean that one or both transistors are defective or one side of the output transformer is disconnected.

Desolder the transformer from the transistor collectors. The transformer may now be lifted slightly from contact with the transistors and the individual collectors may be checked for open circuits and resistance values.

<u>Procedure 2</u>

If the output-transistor collectors indicate a short circuit, it may be at one of several points which must be isolated.

Desolder the lead from the balancer toroid to the +28 V pad. If the collectors test normal, the short is in the power supply. Desolder each wire from the +28 V pad and test until the short is located.

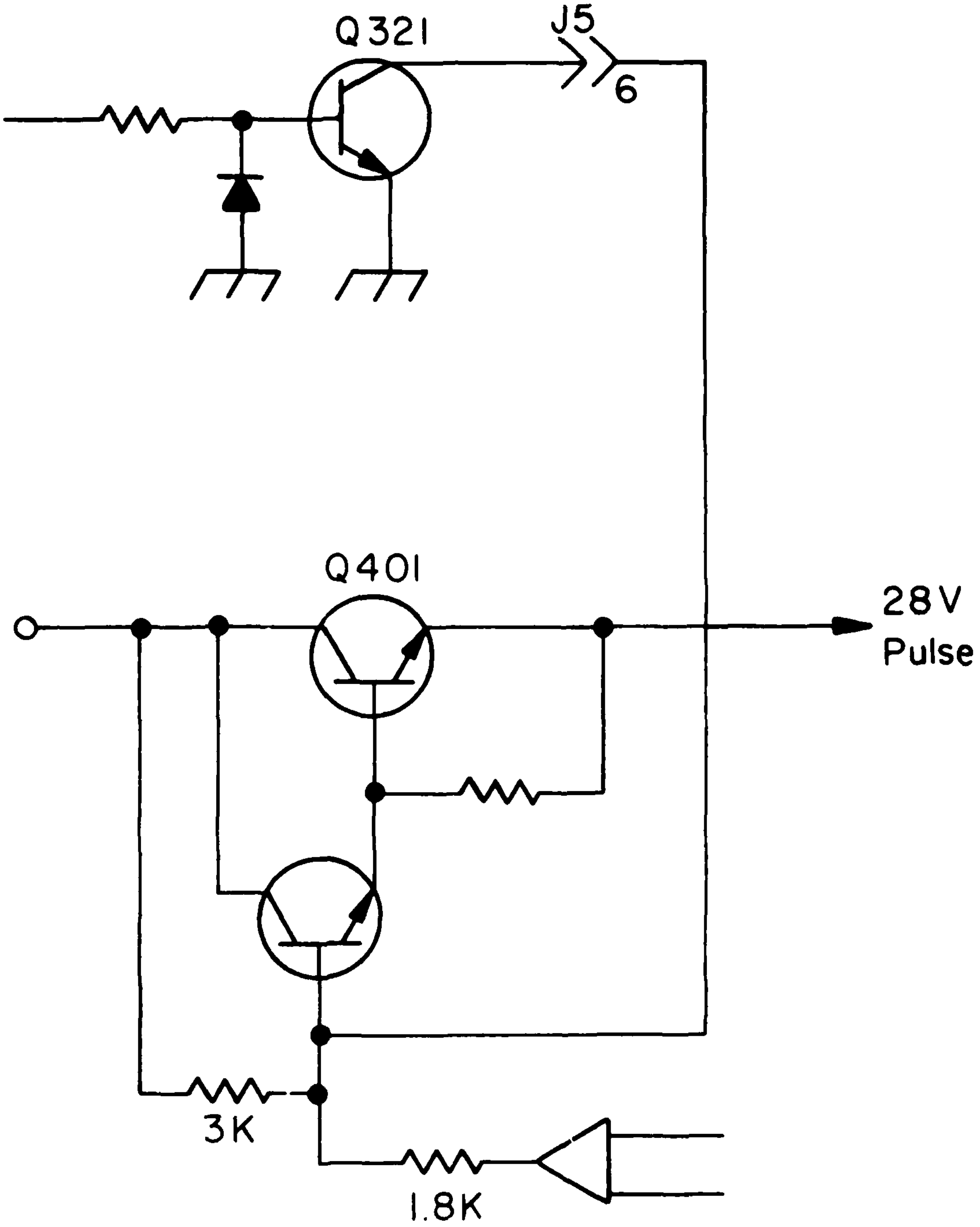


Figure C-6. Simplified schematic diagram of bias switching scheme.

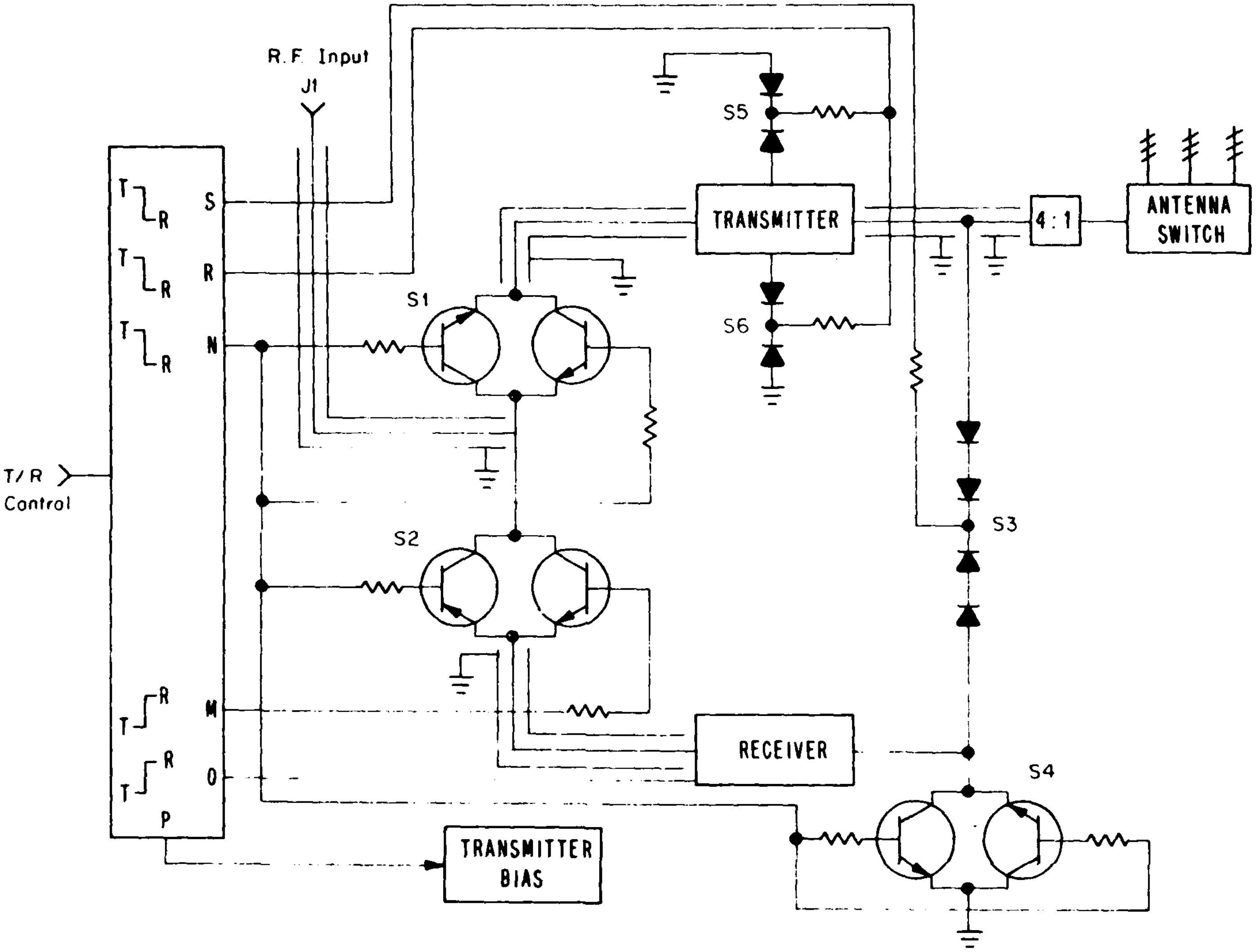


Figure C-7. Functional diagram of T/R switching.

Table C-1. Resistance Measurements for Trouble Shooting the rf Amplifier Modules

OHMS	TEST POINT	REMEDY
4	output transistor collectors	procedure #1 or #2
1.8	output transistor base	
15	output transistor base with rf choke removed	
10	input transformer secondary	
0	rf input terminal	
4.5	driver input transistor collector (isolated from output transistors)	procedure #3

If the short persists on the collectors, it is possible that the winding on the output transformer is shorted. Desolder the wires from the transformer output end and check the transistor collectors for shorts. If no short is detected, remove the wire from the transformer. Remove the transformer and inspect the pipe ends for burrs. Clean off any sharp edges, rewind the transfomer with new wire, being careful not to abuse the wire when pulling it through the pipes.

Procedure 3

If a short circuit is evident at the input transformer secondary, it is likely the wire is shorted. Proceed as per procedure 2, paragraph 3.

C.5. Receiver Pre-Amplifier Not Working

Figure C-8 shows the test setup for testing the operation of the receiver preamplifier.

With an rf signal applied at the antenna terminals of the T/R unit, use an oscilloscope for signal tracing.

One frequent problem is Q303 and Q304 shorted emitter to collector. This holds point O high and stops all switching of the several rf switches. The entire transmitter appears dead.

After repairs have been made, refer to Section 2.2 for final adjustment. The gain pattern of the preamplifier should be that shown in Figure B-6.

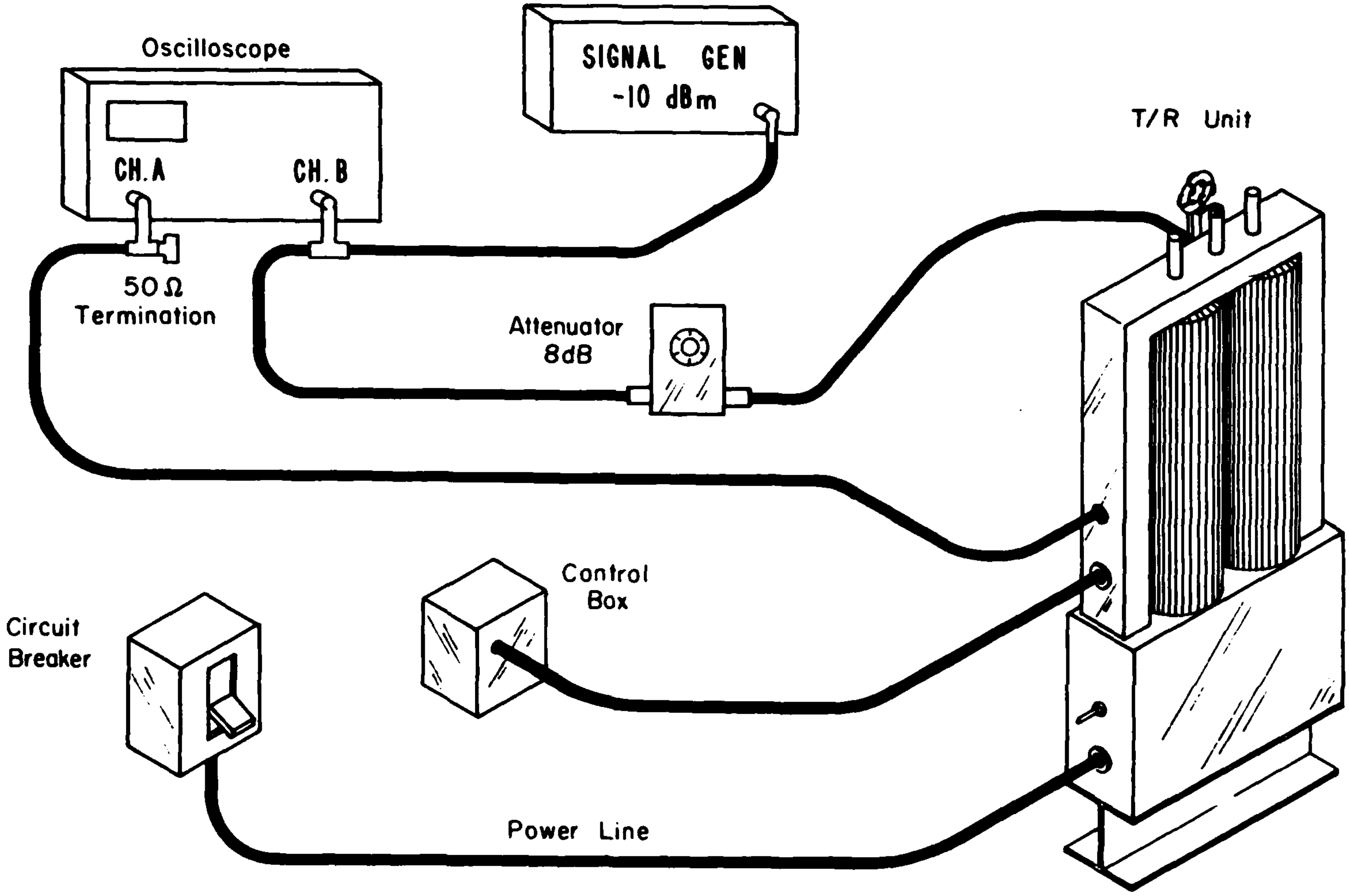


Figure C-8. Test setup for receiver amplifier checks.

APPENDIX D

This section describes the operation of each of two test sets provided for the testing and operation of the T/R unit in the service shop.

D.1 Top Unit Test Set

The test unit (see Figure D-1) contains circuits for testing and monitoring the following functions in the top unit:

1. power supplies to furnish the necessary operating voltage for the top unit;
2. pulse generator for driving the T/R control line, including a switch for manual slow-speed control;
3. a monitor circuit for checking the operation and levels of the +400 and +800 V circuits and the bias control circuits;
4. manual operation of the antenna transfer relays;
5. signal connectors for checking the operation of the low level rf switches.

D.1.1 Operation

Connect molex plug and blue, high-voltage lead from test unit to top unit.

Connect the red clip lead to one of the three 1.5 megohm 1/2 W resistors at the inside end toward the 110 ohm resistor.

Move RANGE switch to +800.

Move MODE switch on test unit to T (transmit) position.

Turn on power switch on side of test unit.

"HI" light should energize immediately, indicating the 800 V power supply is operating normally.

If HI light does not come on: Check circuit breaker on test unit. If breaker has opened, this indicates a short circuit in the +800 V power supply circuitry. If HI light indicates properly, move MODE switch on test to R position. The LO lamp now should be illuminated to full brilliance.

If LO lamp does not light, see appropriate trouble shooting section.

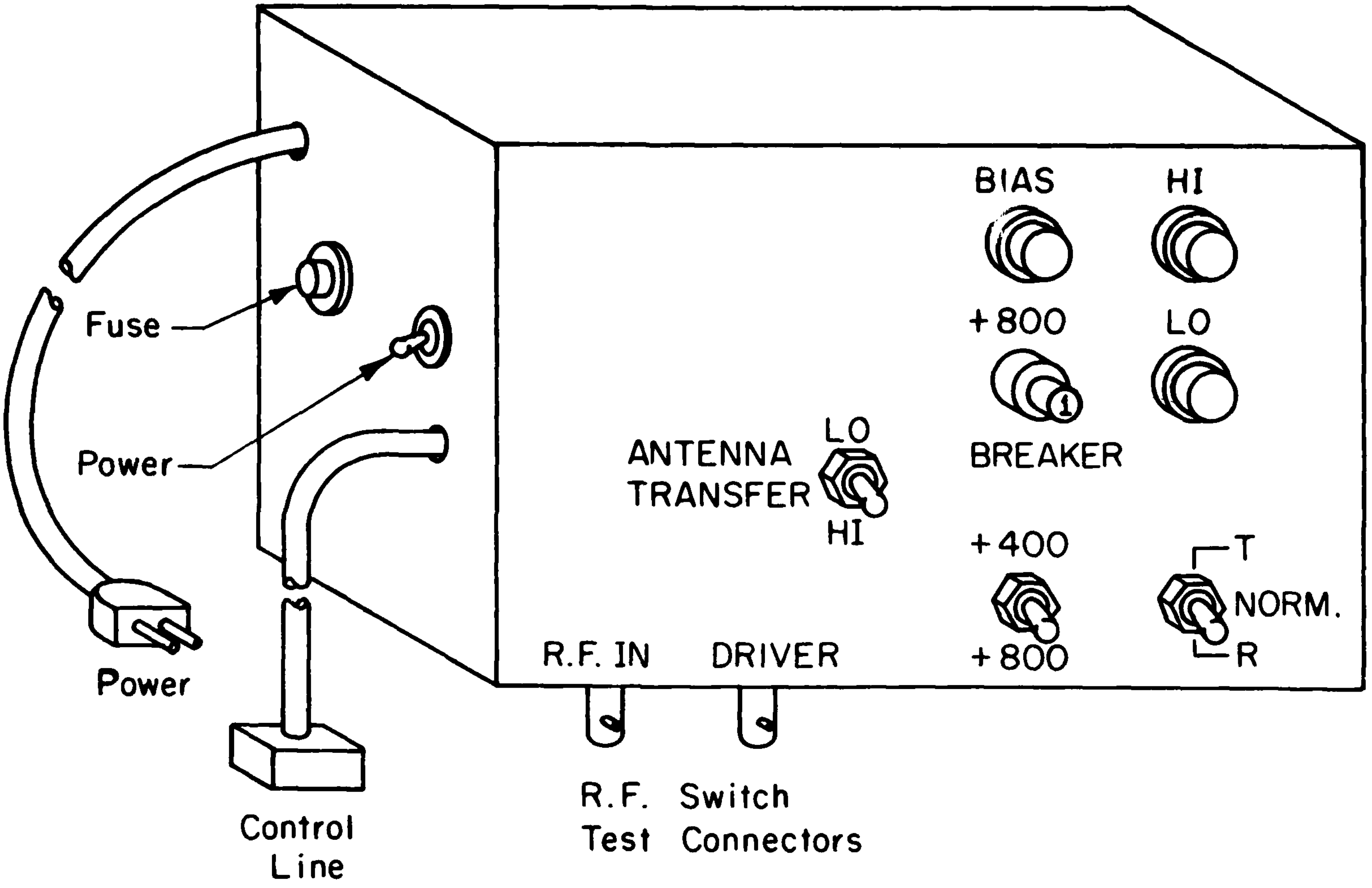


Figure D-1. Top unit test set.

D.2. T/R Unit Control Box

The control box (see Figure B-2 and B-3) contains circuits which perform the following functions:

1. pulse generator of variable pulse width and repetition frequency to drive the T/R control line (with provision for external triggering);
2. gating of the rf drive from a signal generator;
3. built-in delay between the T/R control transmit level and the pulsed rf signal.

The control box is to be used while completing the final checks on the T/R unit.

Figure D-4 depicts the setup for testing the transmitter section and Figure D-5 for receiver tests.

D.2.1 Testing procedure - transmitter

The rf input should be a controllable source with output capability of 2 V. The maximum usable with the units as set up for current operation is 1.7 V at 15 MHz.

Test procedure should be as follows:

1. Mount the test matching transformer on the top unit ground screw and to the center ceramic antenna terminal. Connect the coaxial cable from the coaxial connector to the 50 ohm dummy load and oscilloscope probe.
2. Assemble the equipment and cabling as depicted in Figure D-4.
3. Move the source switch to the neutral (center) position. This must be done to assure that switching does not occur in the diode switches while the rf is applied.
4. Turn on the 208 V three-phase circuit breaker. After three or four seconds, a small click will be heard, indicating the charging protective surge relay has closed and the unit is ready for operation.

If LO lamp illuminates normally, then move MODE switch to the center position. Both HI and LO lamps should now be illuminated. The LO lamp will be slightly brighter than the HI lamp because of the 33% duty factor of the driving circuit.

Move the RANGE switch to +400. All lamps should operate as in the +800 position.

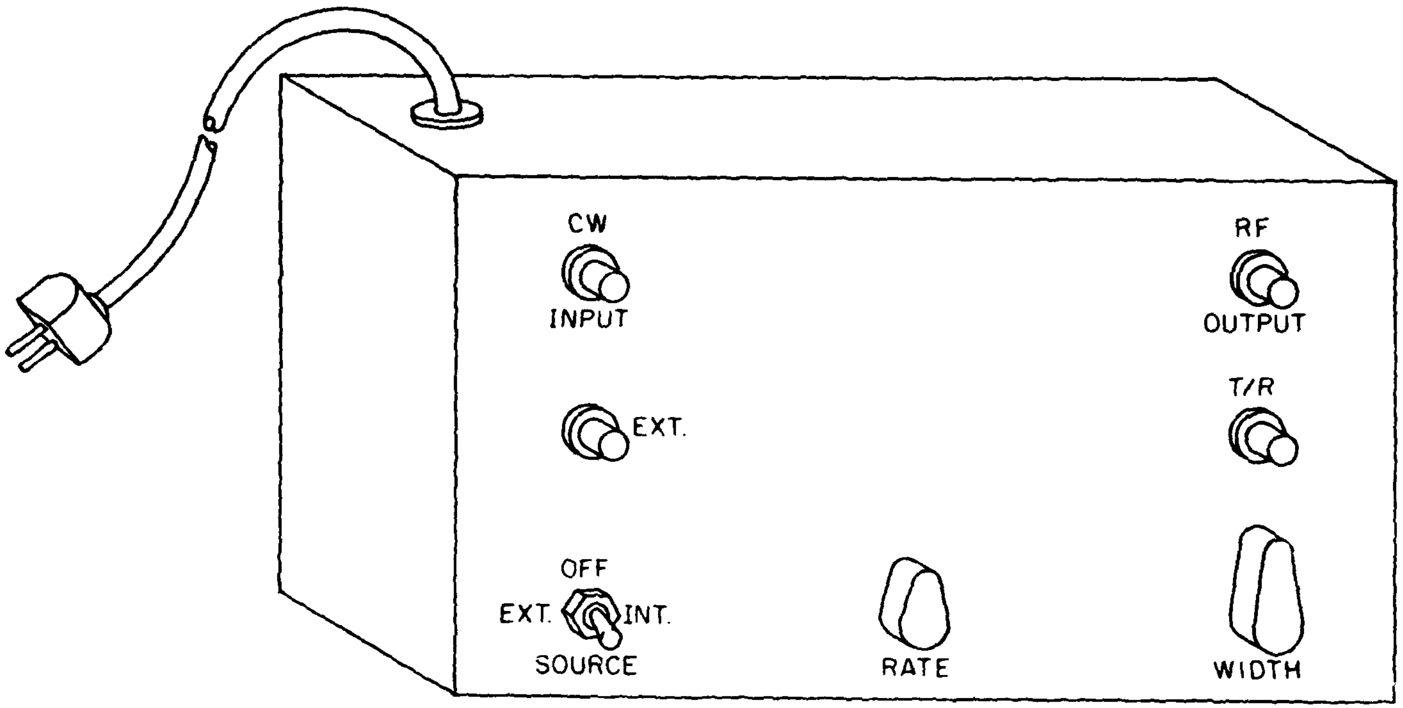


Figure D-2. T/R unit bench control box.

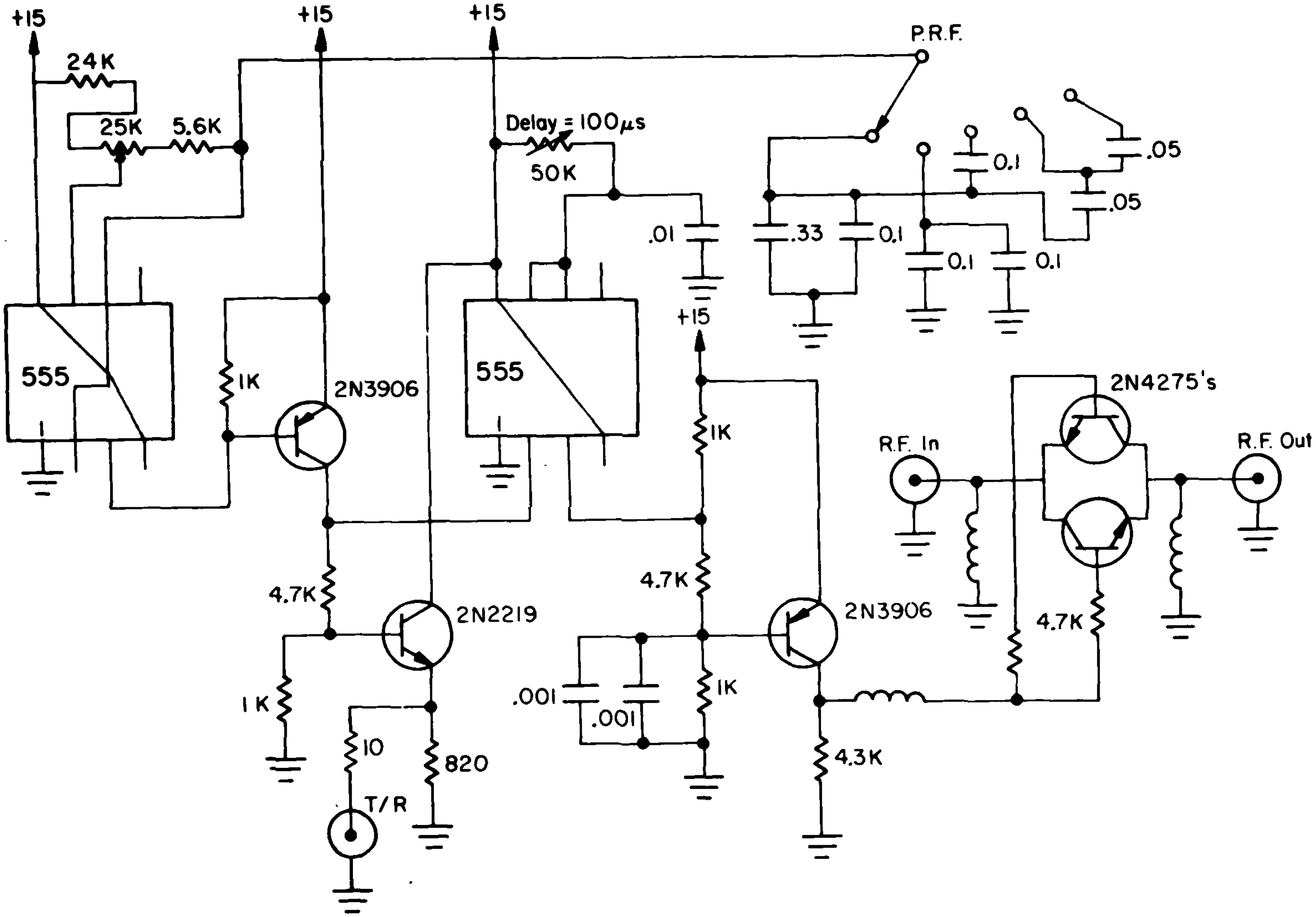


Figure D-3. Schematic diagram of T/R bench control box.

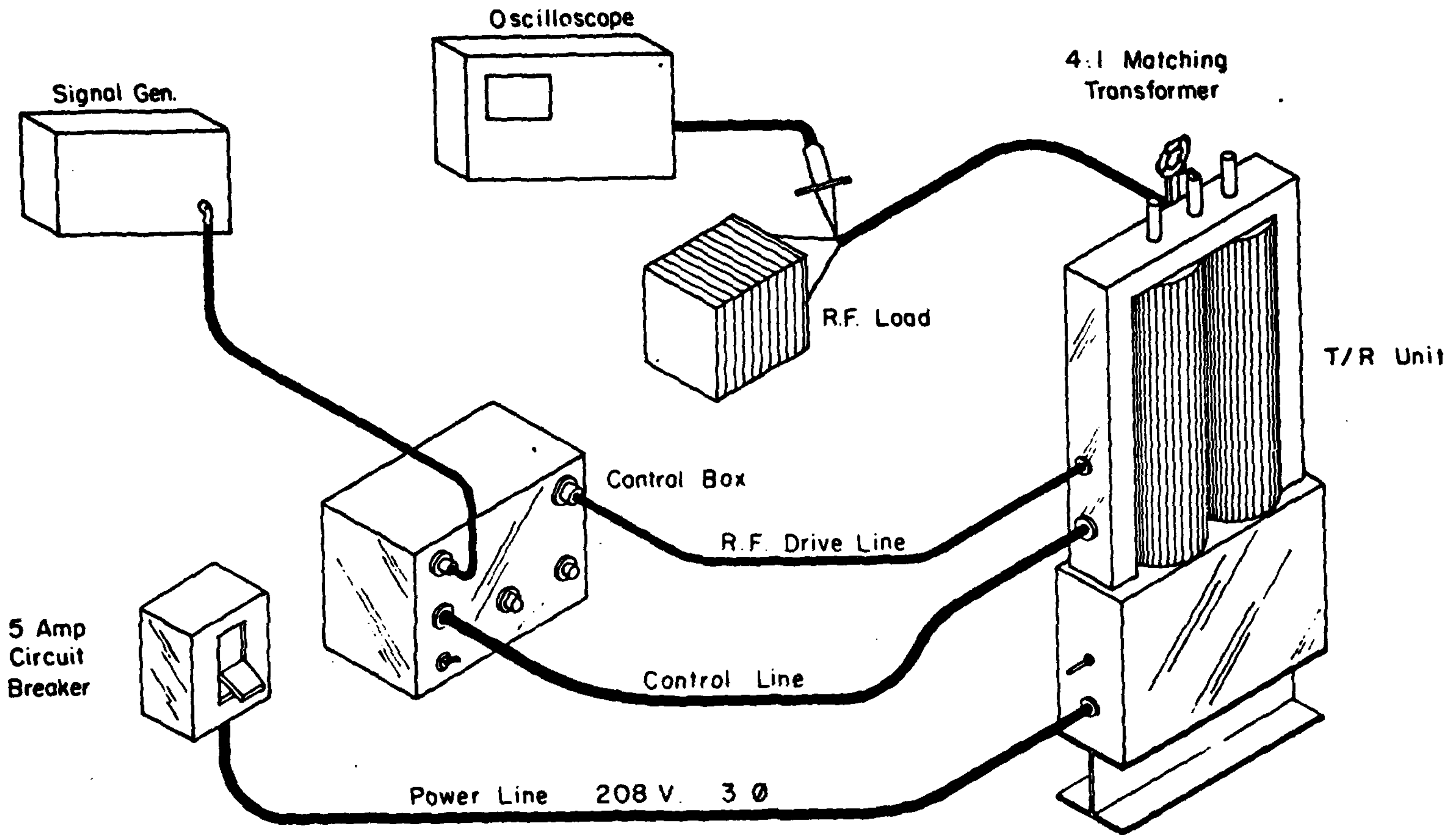
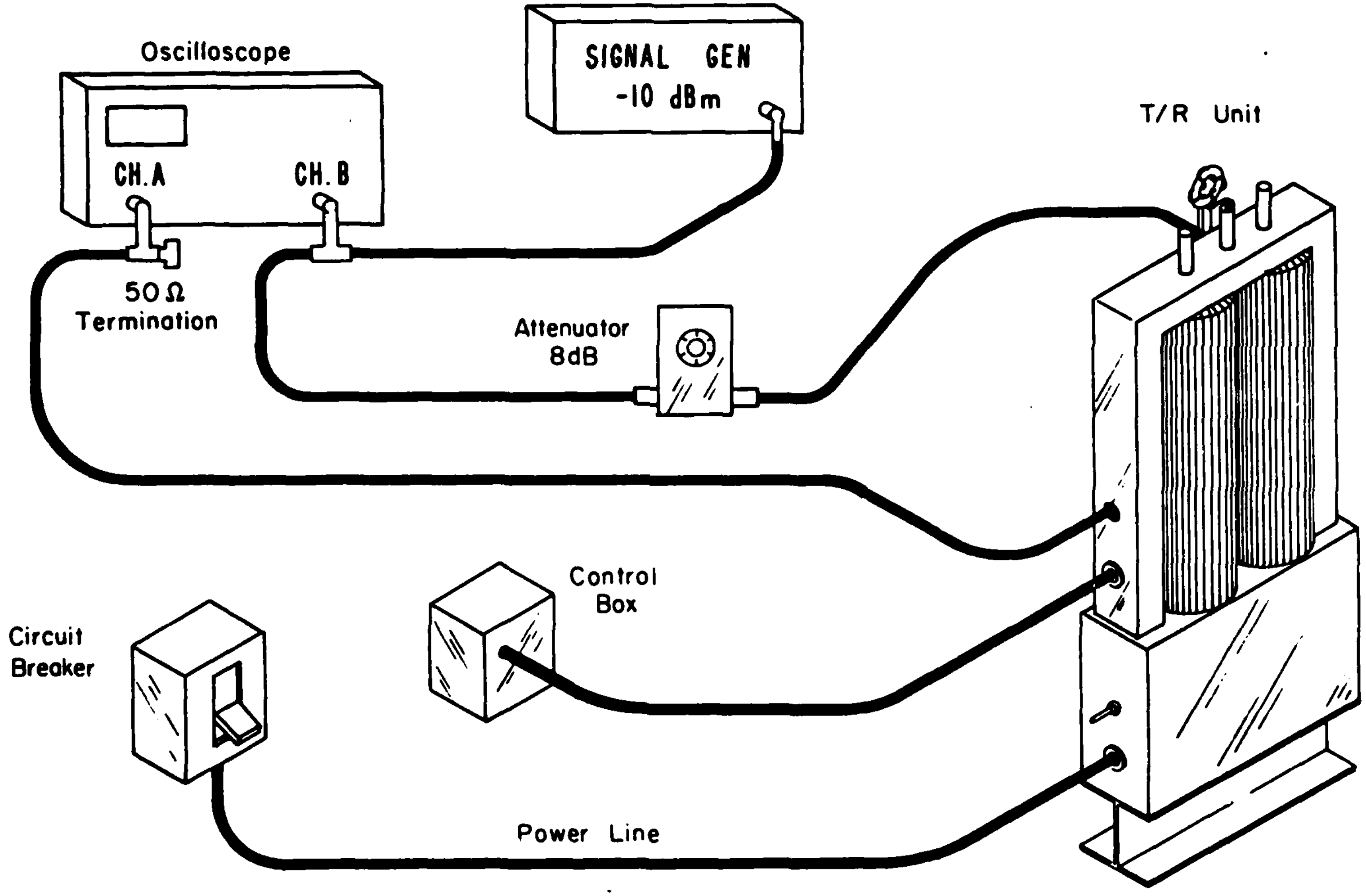


Figure D-4. Test setup for transmitter checks.



.Figure D-5. Test setup for receiver amplifier checks.

Observe the BIAS lamp while operating the MODE switch. Full brilliance should occur with the MODE switch in the T position, less brilliance (about 1/3) in the center or NORMAL position, and completely off in the R position.

Apply an rf signal to J_1 of the test unit and connect J_2 to a 50 ohm termination at an oscilloscope. Vary the frequency and amplitude of the driving rf while observing the oscilloscope wave form, which should be a pure sine wave with no significant distortion with driving signals up to 3 volts rms. Switching should be clean. The rf energy passing through the switch on the "off" cycle should be no greater than -55 dB relative to that for the "on" cycle.

Table D-1 shows common problems with possible remedies.

Table D-1. Top Unit Test Set, Lamp Indications and Probable Faults

	SYMPTOM	REMEDY
1.	HI lamp does not light, circuit breaker trips.	Check +800 volt power supply and switching circuits for shorts.
2.	HI lamp does not light, circuit breaker does not trip.	Excessive leakage or lack of cutoff in MJE340 transistors.
3.	LO lamp does not light, HI lamp stays on regardless of MODE switch position.	Bad MJE340 transistors (Replace lower one first). Lack of drive to lower MJE340.
4.	BIAS lamp stays on regardless of MODE switch position.	Shorted bias driver (Q321) in T/R logic board.
5.	BIAS lamp stays off regardless of MODE switch position.	Faulty bias driver (Q321) or lack of drive to bias driver.

5. Move the source switch to INT and increase the rf drive to 1.7 V rms. The oscilloscope should show an rf envelope of 768 V peak to peak, indicating peak envelope power output of 1400 W.

D.2.2 Testing procedure for receiver

Refer to Figure D-5 for the equipment assembly for the receiver test.

1. Adjust the signal generator to approximately -10 dBm with a sweeping mode or a single frequency generator at 9.0 MHz.
2. Set the attenuator to 8 dB.
3. Turn the main power on and wait for the click as per 2.1.4.

4. The two traces of the oscilloscope will display the input and output rf envelopes of the receiver. This setup lets the receiver amplify the signal that was initially reduced by the attenuator.
5. Adjust the variable resistor R308 so that input and output envelopes are equal. Vary the frequency, if a non-sweep generator is used, to ascertain that the passband is identical to Figure D-6.

Refer to the <u>troubleshooting</u> section for problems that may be encountered in the receiver and T/R logic board along with possible remedies.

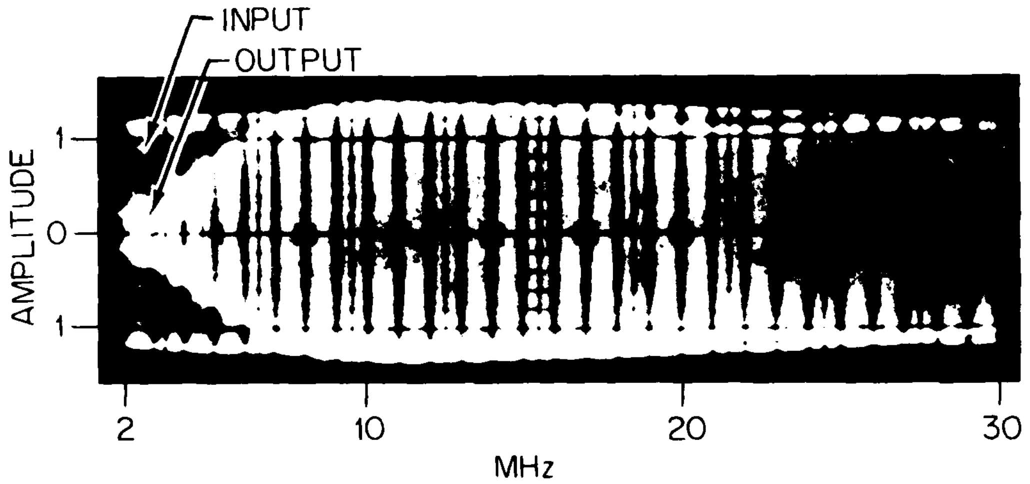


Figure D-6. Receiver passband adjustment using sweep frequency generator.

APPENDIX E. PARTS LIST

The following numerical designation has been assigned to parts to aid in their location:

0-99	Main frame and main power supply.
100-199	Power amplifier and driver amplier modules.
200-299	T/R logic.
300-399	Receiver preamp and power supply.
400-499	Regulators.
500-599	Power monitor.

All resistors are:

1/4 watt
5% tolerance
Carbon composition
(unless stated otherwise)

All capacitors are:

dipped mica
100 volt
(unless stated otherwise)

Main Frame and Power Supply:

C_1, C_2	60,000μF 50 volt electrolytic
D_1-D_3	1N 3209 diode
D_4-D_6	1N 3209R diode
D_7-D_{14}	A-10 P4 diode
F_1	3AG 1 ampere
F_2-F_6	3AG 15 ampere
F_7	3AG 1 ampere mounted on power monitor board
F_1	10Ω 3 watt wire wound mounted on Ry-1
R_2	100Ω 2 watt carbon composition mounted on Ry-1
R_3-R_{12}	50Ω 10 watt wire wound bias supply resistors mounted internally to heat sink with clamp and thermal epoxy
Ry-1	Surge relay mounted internally to heat sink. 28 volts dc
T_1	Main power transformer/208v 3 phase wye primary/28v 3 phase delta secondary mounted in support box. MFR-Lestronix Inc., Boulder, Colorado

T_2	28v RMS primary, 115v RMS secondary 7va mounted internally to heat sink (Chicago-Stancor P-8364)
T_3	28v RMS primary, 10.5 V Rms secondary 10va mounted internally to heat sink, MFR-Lestronix Inc., Boulder, Colorado

Power Amplifier Module:

C_{101}, C_{102}	3300 pf dipped Mica
C_{103}	1500 pf dipped Mica
C_{104}	50 μf 50 volt electrolytic
C_{105}, C_{108}	.1 μf 100 volt ceramic
C_{106}	3,000 μf. 50 volt electrolytic mounted internal to heat sink
C_{107}	1 μf. 50 volt electrolytic
L_{101}	4 turns #18 Tormvar on Fair Rite Products toriod #2643002401
L_{103}	10 turns bifilar wound of #18 Nyclad twisted 2 twists per cm.
Q_{101},Q_{102}	S80-28 transistor selected by code number CD2622
	Communications Transistor Corporation
Q_{103}	Byistor with flange mounting. Order by code number CD2091
R_{101}, R_{102}	2/30Ω 1/2 watt 5% carbon resistors in parallel
R_{103}	2/12Ω 1/2 watt 5% carbon resistors in parallel across secondary of T_{101}
R_{104}, R_{105}	16Ω 1/2 watt 5% carbon
R_{106}	2.2Ω 1/2 watt 5% carbon
R_{107}, R_{108}	51Ω 1/2 watt
T_{101}	Transformer, input, fabricated according to text (2.3) loaded with eight ferrite beads. (Fair Rite Products #2643002401)
T_{102}	Three turns #18 teflon insulated wire on primary output transformer, same as T_{101} with 12 ferrite beads two turns #18 teflon wire on secondary

Driver Amplifier:

C_{110}	120 pf dipped mica
C_{111}	820 pf dipped mica
C_{112},C_{114},	
C_{115},C_{125}	1 μf 50 volt ceramic
C_{113}, C_{117},	3900 pf dipped mica
C_{118}	3900 pf dipped mica
C_{114}, C_{120},	
C_{121}	50 pf dipped mica
C_{119}	2,000 pf dipped mica

C_{122}	50 µf. 50 volt electrolytic
C_{123}, C_{126}, C_{127}	.1 µf. ceramic
C_{124}	same as C_{106}
Q_{104}, Q_{105}	same as Q_{101}
Q_{106}, Q_{107}	same as Q_{103}
R_{109}	2/10 Ω 1/2 watt in parallel
R_{110}, R_{116}, R_{117}	same as R_{104}
R_{111}	220 Ω 1/2 watt
R_{112}, R_{113}	same as R_{101}
R_{114}, R_{115}	Not used
R_{116}, R_{117}	Same as R_{104}
R_{118}, R_{119}	Same as R_{107}
R_{120}	4.7 Ω
R_{121}	2.2 Ω 1/2 watt
T_{105}	Same as T_{101}, 3 turns of #22 teflon insulated wire on primary
T_{106}	Same as T_{101}, 2 turns of #22 teflon insulated wire on primary
T_{107}	Same as T_{102}

Receiver Preamplifier

D_{301}, D_{302}, D_{303}, D_{304}	A-14 1000 PIV 1 amp
D_{301}	1N5230 4.7V 1/2 watt Zener
C_{301}	.047 µf 50 volt ceramic
C_{302}	.1 µf 100 volt ceramic
C_{303}, C_{304},, C_{305}	.01 Disc ceramic
C_{306}	560 pf dipped mica
C_{307}	50 pf dipped mica
C_{308}	1 µf 25V cera,oc
C_{309}, C_{310}	1 µf 50 volt ceramic
L_{301}, L_{302}	

L_{307}	10 μh rf choke
L_{303}, L_{304}	Ferrite bead on lead of R_{310} and R_{311} respectively
L_{305}	5 turns #20 Formvar wound on Fair Rite Products #2643002401 bead
L_{306}	.68 μh rf choke
Q_{301}, Q_{302}	2N4275
Q_{303}, Q_{304}	2N4876 or 2N3866
Q_{305}	2N3906
Q_{306}	2N4275
Q_{307}, Q_{308}	2N4275
R_{301}	110 Ω
R_{302}, R_{303}	1,000 Ω
R_{304}	160 Ω
R_{305}	720 Ω
R_{306}, R_{207}	82 Ω
R_{308}	200 Ω variable, carbon
R_{309}	10 Ω
R_{310}, R_{311}	500 Ω
R_{312}, R_{313}, R_{314}, R_{315}	*1000 Ω*
T_{301}, T_{304}	7 turns bifilar wound #24 Formvar twisted 3 twists per cm. Wound on Indiana General F624-19 Q_1 material.
T_{302}, T_{303}	7 turns trifilar wound #22 Formvar twisted 3 twists per cm. Wound on core as per T_{301}

Receiver Power Supply

C_{315}, C_{316}	20 μfd 250 volt electrolytic
C_{317}, C_{318}	4 μfd 450 volt electrolytic
C_{319}, C_{324}	.1 μfd 100 volt ceramic
C_{320}, C_{322}	50 μfd 50 volt electrolytic
C_{321}	1,000 μf, 12 volt electrolytic
D_{315}-D_{318}	1N4007, 1,000 PIV, 1 amp
D_{319}	Diode bridge assy. 2 amp
D_{320}	1N5235 zener diode, 6.8 volt, 12 watt, 10%
D_{321}, D_{322}	1N4591
F_7	3AG 1 amp fuse
Q_{310}	2N2219

Q_{311}	2N4275
Q_{312}	2N2905
Q_{313}	2N3638
R_{315}	1k Ω
R_{317}	10 Ω
Ry_{301} Ry_{302}	Vacuum relay, HC-1 MFR Kilovac Corp., Santa Barbara, California
T_{301}	Transformer, 115 v/36v connected as auto transformer (Chicago Stancor, P8610)

T/R Logic board

C_{325}	390 pf
C_{326}, C_{327}	100 pf
C_{328}	.001 1 KV ceramic
C_{329}	1 μf. 25 volt
D_{325}, D_{326}	1N459
D_{327} D_{328}	1N4007
Q_{315}, Q_{317}, Q_{318}	2N4275
Q_{316}	2N3906
Q_{319}, Q_{320}	MJE 340
R_{321}, R_{323}, R_{325}, R_{331}, R_{335}	1k Ω
R_{326}	470
R_{327}, R_{332}	3k Ω
R_{328}	2.2k Ω
R_{329}	1.5k Ω
R_{330}	200 Ω
R_{333}	24 Ω
R_{334}	68 Ω
R_{336}	1.5 meg-MΩ
R_{337}	1.5 meg 1/2 watt
R_{338}, R_{339}, R_{340}	1.5 meg 1/2 watt

Module Regulator

C_{401}	25 μf 35 volt solid tantalium
C_{402}	.01 μf 100 volt ceramic on bias regulator

C_{403}	50 µf 50 volt electrolytic on drive regulator and bias regulator only.
D_{401}	1N5240, 10 volt Zener diode
Q_{401}	2N6282 20 ampere darlington transistor
R_{401}	1kΩ on PA and Driver regulator 3k on Bias switching regulator
R_{402}	1.8kΩ
R_{403}	.06 Ω nichrome resistor wire
R_{404}	390 Ω
R_{405}	1.2k Ω
R_{406}	12k Ω
R_{407}	20k Ω
R_{408}	15k Ω
R_{409}	18k Ω (not used on bias regulator)

Power Monitor

C_{501} C_{502}	Variable capacitor, 3-9 pf ceramic
C_{503} C_{504}	270 pf mica
C_{505}, C_{506}	.01 µfd ceramic
D_{501}, D_{502}	Diode, hot carrier, HP-28
J_{506}, J_{507}	Connector, BNC
L_{501}, L_{502}	RF choke, 220 µh
Q_{501}, Q_{502}	2N4275
Q_{503}	2N2905
R_{501}, R_{502}	10 Ω
R_{503}, R_{504}	1500 Ω variable resistor (model 3) (not used on earlier models)
R_{505}	506k Ω
R_{506}	1k Ω
R_{507}	2.2k Ω
R_{508}	220 Ω

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This report describes the design and fabrication of the broadband amplifier for the Sea Watch Radar on San Clemente Island. The amplifier is capable of 1400 watts peak output with a maximum duty cycle of 33%. Twenty-seven units were built with a typical amplitude deviation of 0.2 dB. Receiver pre-amplifiers are included in each unit to provide 8 dB of gain to overcome cable and phasing system losses. Each unit is self-cooling and sealed from the salty atmosphere.

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