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ASDE-2 TRANSMITTER MODIFICATIONS

Henry R. Guarino

Transportation Systems Center

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16. Abstract In October 1971, TSC was assigned the task of assessing the current ASDE-2 maintenance problems. After studying the available statistics, obtained from various airports, it was quickly concluded that the preponderance of ASDE-2 radar failures originated in the modulator-transmitter section where the low mean time between failures was controlled by the following inter-related factors: 1) An under-sized hydrogen thyratron driver for the power amplifier; 2) An inadequate trigger pulse amplifier output; 3) Poor operating conditions for the power amplifier tubes. The report analyzes these and other engineering inadaquacies and then describes in detail the modification of one channel of an ASDE radar, at TSC. To date the system has been operating for several months without any modulator failures. This is nearly fifty times longer than previous mean time between failures.

Details of illustrations in this document may be better studied on microfiche.

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PREFACE

In 1957, fourteen (14) airports in the United States were equipped with ground surveillance radars designated as ASDE-2. Around 1964 some of these radars were placed in a caretaker status because of high maintenance costs. For these reasons, TSC was asked to review existing ASDE-2 problems and recommend modifications to improve the radar. To this end one ASDE-2 radar channel was moved from Logan Airport in Boston, Mass. to TSC where it was modified and subjected to extended life tests. These tests have shown that the more frequent service problems can be eliminated. At this writing the modified radar has given more than 4400 hours of trouble-free operation.

The author wishes to thank Dr. Ralph Kodis for his considerable contribution in (1) obtaining the necessary authorization to transfer an ASDE-2 radar channel from Logan to TSC and (2) the preparation and writing of this report. The author also wishes to acknowledge the enthusiastic and able assistance received from Thomas Hayes during the various phases of modulator modification.

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TABLE OF CONTENTS

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LIST OF ILLUSTRATIONS

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LIST OF TABLES

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1.0 STATEMENT OF THE PROBLEM

A survey of a number of airport ASDE-2 radars (henceforth referred to as "radars") has revealed that they are subject to many breakdowns, most often occurring in the transmitter modulator and associated circuits. Diagrams of these circuits are shown in Figures 1 and 2. The main difficulty, as reported in this survey, is the short mean time between failures (MTBF) of the high power tubes. Typical MTBF's were given as follows:

TUBE	MTBF
Thyratron Driver (3C45)	60 hours
Power Amplifier (4PR60)	180 hours
Magnetron (BLM-006)	200 hours

Since these operating life-times are much less than the rated values given by manufacturers and in manuals, it was decided to study this transmitter section first and attempt to reduce the high modulator failure rate.

1.1 PULSE AMPLIFIER

It was quickly determined from the radar circuit diagrams that the root of the problem could not be attributed to the above tubes, but originated in the pulse amplifier (6AQ5) which delivers the pulse that fires a thyratron. This tube is a beam power tetrode, connected as a triode. In the original circuit it produces a negative pulse on its plate of about 150 volts at an impedance level of 2000 ohms. A transformer inverts and steps the pulse up 3 times, resulting in a positive output pulse of 450 volts at an impedance level of $2 \times 10^3 \times 3^2 = 18{,}000$ ohms.

1.2 THYRATRON GRID CIRCUIT (3C45)

The pulse source described above is connected to the grid of the thyratron driver (a 3C45 in the original circuit). When a voltage pulse triggers the thyratron, the source impedance should be less than 1500 ohms so that the grid is turned on with sufficient

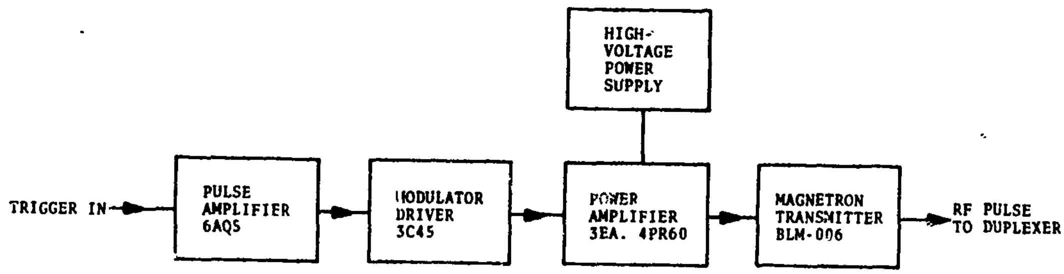
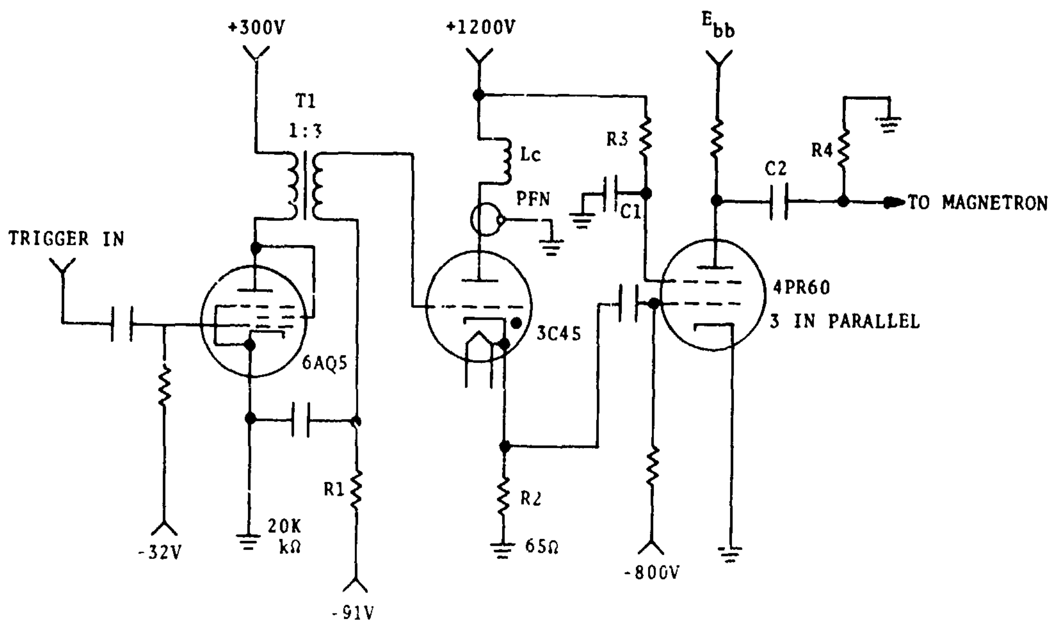


Figure 1. Modulator Block Diagram



Note: PFN is a pulse forming network. In this modulator it consists of a length of 50Ω coaxial cable.

Figure 2. Simplified Modulator Schematic

power. A driving source of 18,000 ohms cannot do this with the result that the trigger pulse is reduced to a value barely sufficient to maintain conduction. This condition leads to erratic firing.

1.3 THYRATRON DE-IONIZATION

When a hydrogen thyratron is pulsed at a high repetition rate (>10KHz), a negative voltage must be applied to the grid of the tube immediately after conduction ceases. This negative voltage removes ions from the grid region and makes it possible for the thyratron to deionize more rapidly. A leading manufacturer of hydrogen thyratrons recommends that the internal impedance of this voltage source be less than 5000 ohms in order to speed the ion clean-up. In the present circuit this impedance (R1) is about 20K ohms, at least 4 times too large, so that the thyratron is not quickly quenched, and may go into continuous conduction (another commonly listed cause of failure).

1.4 THYRATRON ANODE CIRCUIT

The hydrogen thyratron type 3C45 is a very poor choice for the modulator driver. Life tests on this tube have shown that it will not survive for long at high pulse rates.[1,2] In addition the radar circuit of which it is a part (Figure 2) is not well matched to its operating characteristics. For example, the stray capacitance that the 3C45 must charge during each pulse was measured and found to be 240 pico-farads, of which 80 pF is attributed to the filament transformer. The peak current required to charge this capacity is calculated to be about 24 amperes. The parallel load provided by the thyratron cathode resistor and the grid input circuit of the 4PR60 tubes is about 65 ohms at 1000 volts, leading to a resistive current component of 15 amperes. Thus, the 3C45 is required to deliver nearly 40 amperes peak when its rated maximum capacity is 35 amperes.

The average plate current of the tube is only 14 mA which is well within its specifications and may have been a factor in its choice. However, according to a prominent manufacturer, the most important thyratron parameter from the point of view of tube life is P_b, the plate dissipation factor, which is the product of the peak plate dissipation times the pulse repetition frequency. For the 3C45 the maximum safe value is $P_b = 3 \times 10^8$. In this application, the peak voltage is supplied through a resonant circuit so that

$$P_b = E_p \times I_p \times PRF$$

$$= (2 \times 10^3) \times (4 \times 10) \times (1.44 \times 10^4) = 1.15 \times 10^9$$

Thus the maximum rating is being exceeded by a factor of four, leading to short tube life in the best of circumstances.

1.5 OUTPUT (SWITCH TUBE) OPERATION

Another unexpected problem arises with the three paralleled 4PR60 power amplifier tubes. Under normal operating conditions these tubes should last a few thousand hours in contrast to the reported few hundred hours. Examination of the circuit showed that the 3C45 is incapable of driving the 4PR60's hard enough, i.e. the grid pulse is only about 1000 volts when the 3C45 is new and may be less than 800 volts after a few hours of operation. Thus, since the bias on the 4PR60's is -800 volts, the grid drive is too small and the tube dissipation is low so that the cathode is cool enough to become contaminated. This results in reduced emission due to cathode interface and very short tube life.

1.6 MAGNETRON OPERATION

Although the magnetron problems are reportedly less severe than those described above, some tubes showed shorter than expected life and/or a tendency to "double-pulse". This latter condition shows up as an intermittent secondary output pulse occurring between controlled main pulses of the magnetron.[3] To remedy these problems a long-life co-axial magnetron (SFD-315) was developed and installed in one ASDE-2 transmitter, but it operated rather poorly.[3] The lack of improvement was attributed to the modulator behavior which is discussed in a later section of this report. The new magnetron was therefore not adopted for the radar.

2.0 MODIFICATIONS

One of two identical radar units was borrowed from Logan and reconnected here at TSC. The transmitter circuits were checked extensively, and defective components were replaced. When the transmitter became fully operational, measurements were made to determine its operating characteristics. Circuit improvements were then designed and implemented.

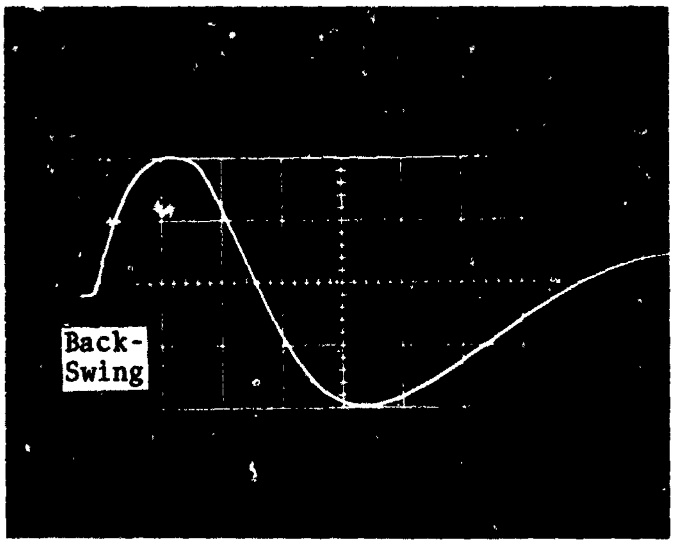
2.1 PULSE AMPLIFIER CIRCUIT CHANGES

Adequate pulse output for triggering the hydrogen thyratron was obtained by a related series of changes. First, the 6AQ5 circuit was changed from the original triode to a tetrode connection. This change increased the plate pulse to 250 volts. The plate impedance was reduced to 500 ohms by replacing the 6AQ5 with a 6DS5. Finally, a new pulse transformer with a ratio of 1 to 1.6 (originally, 1 to 3) was substituted for the original transformer, resulting in an unloaded pulse output of 400 volts with an internal impedance level of

$$R_p \times (1.6)^2 = 500 \times 2.5 = 1300 \text{ ohms.}$$

The old and new pulse amplifier outputs are shown in Figures 3 and 4. The two circuits compare as follows:

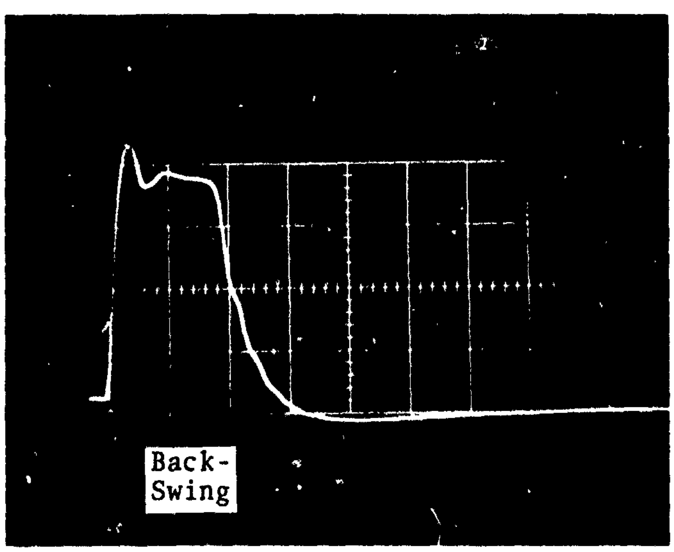
1. The old circuit could not trigger 3C45's reliably and could not trigger larger thyratrons at all.
2. The new amplifier will not only trigger larger thyratrons but will also fire used 3C45's without arcing. The same 3C45's could not be triggered by the old circuit without some of the tubes going into continuous conduction.
3. All of the component changes were made without chassis modifications, i.e. the new components fit the space occupied by the old parts. Thus, the modification can be made without drilling the chassis.



250 V/cm
0.5μs/cm

Note lack of pulse shape and excessive back swing

Present pulse amplifier output, 6AQ5



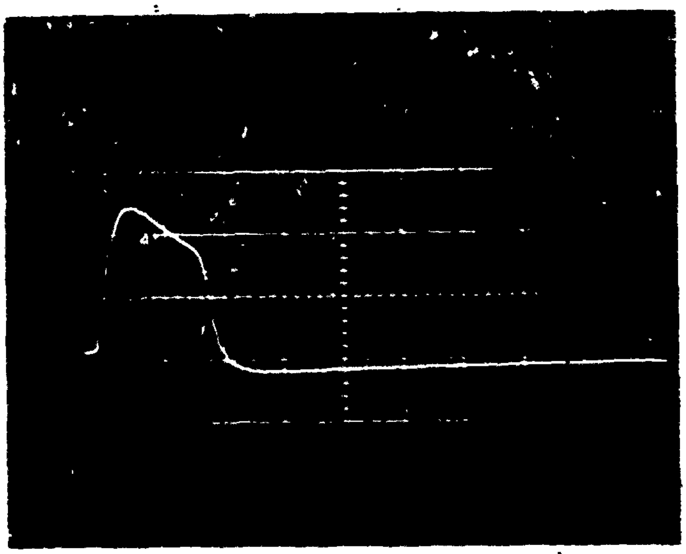
100 V/cm
0.5μs/cm

Unloaded pulse has very little back swing

Modified pulse amplifier output, 6DS5

3b

Figure 3. Comparison of Pulse Amplifier Outputs with Thyratron Removed.



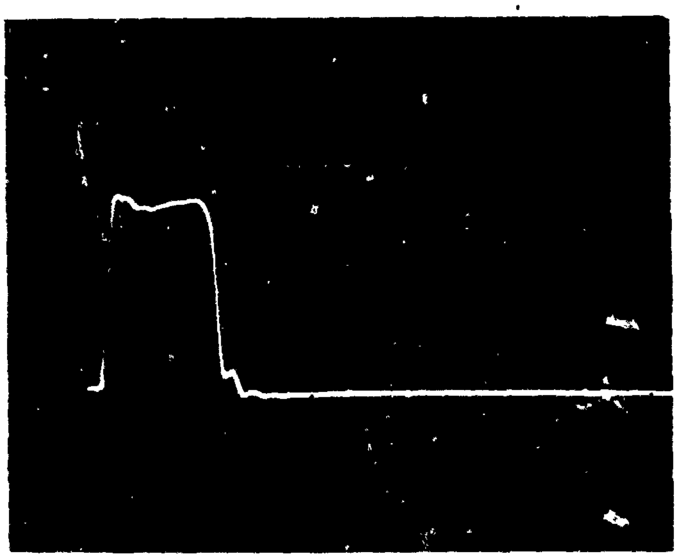
50 volts/cm

0.5μs/cm

The 125 volt pulse is inadequate for reliable thyratron triggering

Present pulse amplifier output, 6AQ5

4a



100 volts/cm

0.5μs/cm

Pulse output is ~ 300 volts which will provide excellent thyratron triggering

Modified pulse amplifier output, 6DS5

4b

Figure 4. Comparison of Pulse Amplifier Outputs with a 1500 ohm Load.

2.2 THYRATRON SUBSTITUTION TO 8765/KU-71Z

A larger thyratron with a ceramic envelope was substituted for the 3C45. The new tube is an 8765/KU-71Z which can deliver 350 amperes of pulse current and has a rated P_b factor of 4 x 10[illegible]. Both of these specifications are many times greater than required in ASDE-2. Furthermore, the tube is physically no larger than a 3C45, and uses the same tube socket. In order to trigger the 8765 (or a 3C45) in a reliable manner at 14,440 PPS the bias supply impedance was reduced. This was accomplished by ascertaining that the bias supply could deliver more current and then reducing the value of the bias resistors. The impedance is now less than 5000 ohms which conforms to the manufacturer's specifications.

2.3 8765/KU-71Z CIRCUIT REQUIREMENTS

Although the 8765/KU-71Z uses the same socket as a 3C45, the filament transformer had to be replaced with one of higher current capability. The replacement transformer was designed with a much lower distributed capacitance, although this was really not necessary because the 8765 is such a husky tube and could easily have supplied the extra current necessary to charge the capacitance.

2.4 THYRATRON LIFE TESTING

The 8765 was chosen as a replacement for the 3C45 after consulting with the manufacturer who predicted that the tube would operate properly for more than 5000 hours. Unfortunately, the first tube failed after 550 hours which is about 10 times less than predicted. This, none the less is 10 times longer than a 3C45 might last but much less than the 5000 hours minimum expected from the 8765. The tube manufacturer was consulted again, and the spent tube was returned and examined for the signs of early failure. The cathode proved to be contaminated (cathode interface) and the cause was determined to be "under use" of the tube and perhaps rapid cooling of the ceramic envelope.

2.4.1 Thyratron Cooling

The 3C45 had a thermal shield which snugly surrounded the glass in order to protect the tube from cooling air currents within the modulator compartment. Such operating conditions are not consistent with the manufacturer's specifications, and the shield was not used with the 8765. A careful study was made of the air flow in the modulator and as a result, an air shroud was placed around the tube. The shroud protects the ceramic enevelope from high velocity air currents, but allows natural convection of air to persist. This remedy took care of the excessive cooling. The "under use" problem was corrected by increasing the 8765 filament voltage to 6.7 volts, which is well within the specifications for the tube so that a minimum life of 5000 hours is again expected. The second 8765/XU-71Z has been on life test for more than 3800 hours and is still operating perfectly.

2.4.2 Output Voltage and Impedance Matching

Attention is directed to Figure 2 and to the 65 ohm total resistance in the cathode of the 3C45. The reflected value of R_2 is now 50 ohms in the modified driver, which is a proper match for the pulse forming network made up of 8 feet of 50 ohm RG-8/U coaxial cable. An impedance match is most necessary if the output pulse is to return quickly to zero, a condition that is important when operating at a high PRR. The pulse appearing across the 50Ω resistance coupled to the 4PR60's is 1150 volts positive when the driver is an 8765 and only about 1050 volts with a new 3C45 (see Figure 5). Thus, the 8765 drives the 4PR60's 350 volts positive compared to 250 volts for a 3C45. Some of the latter tubes could not drive the 4PR60's into the positive grid region at all, which resulted in very short tube life due to cathode contamination.

2.5 SWITCH TUBE (4PR60) CHARACTERISTICS

When the radar was brought from Logan to TSC, we were given 12 used 4PR60's whose condition was unknown. These 12 tubes were tested one at a time in a bench circuit with a 1000 ohm resistive load. The plate voltage was set at 15kV and each tube was driven by a 3C45 thyratron. The pulse voltages measured across the load varied from 9kV to 12kV depending on the tube being tested. When the 4PR60's were driven with an 8765, the output pulse voltage of some tubes increased to 13kV, about the same as for a new tube. Some of these old tubes then showed a remarkable recovery from their cathode interface problem as indicated by the steady rise of the output pulse voltage to 13kV.

2.5.1 4PR60 Life Testing

One set of three new 4PR60's has been driving an ASDE-2 magnetron without trouble for more than 4400 hours and still appears to be in excellent condition.

2.5.2 4PR60 Pulse Current

The magnetron RF average current is 4mA when the driving pulse voltage is 18 nanoseconds long. The peak current required from the 4PR60's is then:

$$ip = \frac{I_{av}}{\text{duty ratio}} = \frac{4x10^{-3}}{2.6x10^{-4}} = 15.5 \text{ amperes.}$$

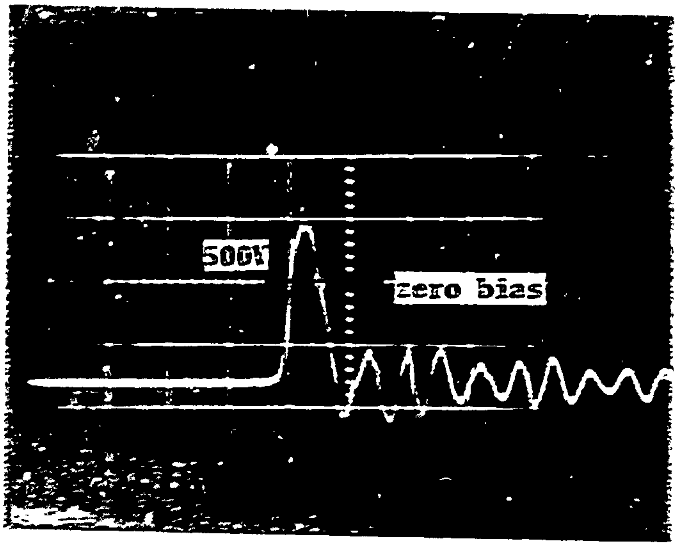
Since one 4PR60 is capable of delivering 20 amperes, a first thought is, why use 3 tubes in parallel when one will suffice. However, one tube will not supply enough current, because of the ever present distributed capacitance and also because of the current drawn by a 2000 ohm resistor (R4 in Fig. 2) which is required for recharging the magnetron coupling capacitor. The current through this resistor (if the inductance is neglected) is:

$$i_p = \frac{12x10^3}{2x10^3} = 6.0 \text{ amperes.}$$

Also the current due to the 20pf distributed capacitance is:

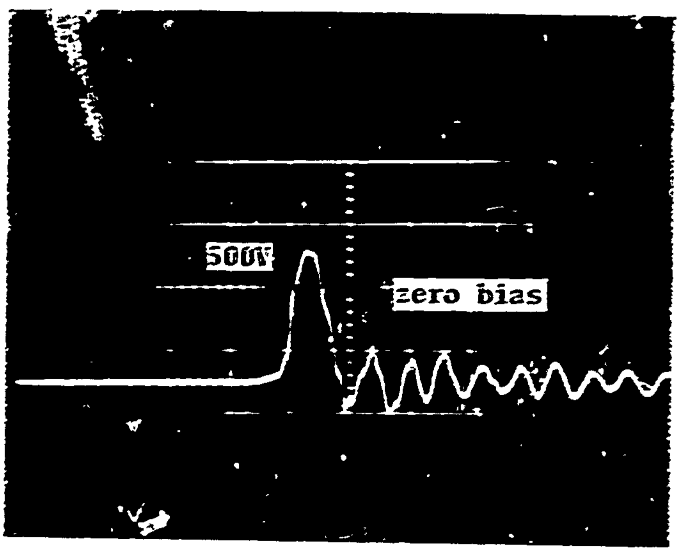
$$i_p = c\frac{dv}{dt} = 2x10^{-11} \text{ x } \frac{1.2x10^4}{10^{-8}} = 24 \text{ amperes,}$$

based on a nominal pulse rise time of 10 nanoseconds. The actual



4PR60's grid pulse delivered by 8765 thyratron. The portion of the pulse above the center line is the amount of grid drive and is about 350 volts

5a



The same pulse delivered by a 3C45 thyratron. The grid drive is less than 300 volts

5b

Sweep speed is 50ns/cm and the voltage calibration is 500 volts/cm. Both pictures were taken in a modified ASDE-2 modulator.

Figure 5. Pulse at Grids of 4PR60's

rise time of the output pulse may be observed in Figure 6. The sum of the three currents is 45.5 amperes, which is about twice the current that one 4PR60 can deliver. As a test, the magnetron was driven with two 4PR60's and the difference in operating parameters was hardly noticed. The magnetron average current went from 4mA down to 3.7mA but could be brought up to 4mA when the 4PR60's plate voltage was increased to 15kV from 14.0kV. The magnetron voltage pulse looked exactly as in Figure 6.

2.5.3 Normal Operation with Three 4PR60s

When the three 4PR60's were operating together all conditions were normal as shown in Table 1.

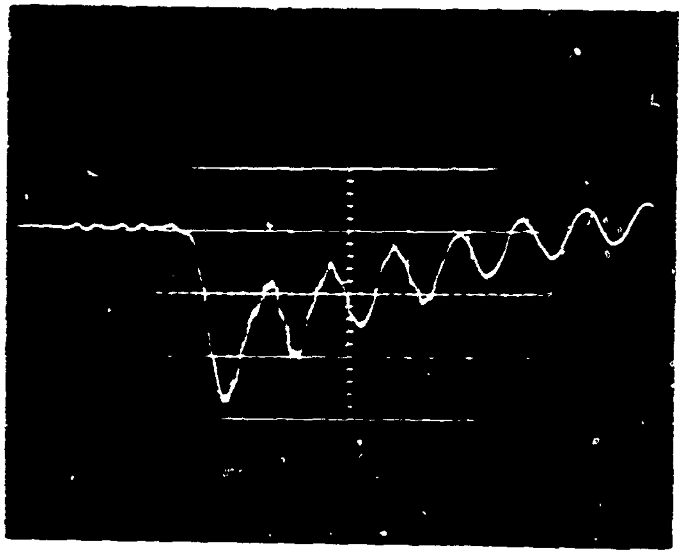
TABLE 1. MAGNETRON (BLM-006) AND MODULATOR (4PR-60) OPERATING PARAMETERS IN THE MODIFIED RADAR

1.	Pulse Duration, ns	18.0
2.	Pulse Repetition Rate, Hz	14400.0
3.	Duty Ratio	2.6×10^{-4}
4.	Power Output (Peak), kW	39.0
5.	Power Output (Average), W	11.3
6.	Magnetron Current (Average), mA	4.0
7.	Magnetron Current (Peak), A	15.4
8.	Modulator Current (Average), mA	16.5
9.	Modulator Plate Voltage, kV, DC	14.0
10.	Magnetron Voltage Pulse, KV	12.1

2.6 MAGNETRON CIRCUIT CHARACTERISTICS

Figure 7 shows a normal 20 nanosecond RF pulse envelope for a BLM-006 magnetron. Under some circumstances, however, magnetrons may not operate in this desired mode. For example, a magnetron may produce a double pulse, i.e. a second RF pulse appears about 50 ns after the first. This is an undesired condition and will be described below.

When the 4PR60's are driven positive, a negative pulse appears on their plates and is coupled to the magnetron by means of the 1000pF capacitor, C2. The magnetron is similar to a biased



Sweep 50ns/cm; Voltage 5000V/cm

The pulse was taken with the original coupling capacitor. Its value is 1000pF, and it has a series inductance of 2.0μH.

Figure 6. Magnetron Voltage Pulse

Notes:

1. Sweep - 10ns/cm
2. This is a sample RF pulse taken from a crystal rectifier mounted in the wave guide.
3. The magnetron peak power was 39kW.

Figure 7. Rectified Magnetron RF Pulse

diode because until a certain voltage threshold is reached, which may be 90% of the maximum voltage applied to the magnetron, current does not flow. At this point the magnetron begins to conduct and current flows until the trailing edge of the voltage pulse falls again to about 90% of its peak value. When the magnetron stops conducting, the load on the pulser is a 2000 ohm charging resistor. The decay of voltage pulse (and the recharging of the 1000 pF capacitor) depends on the magnitude of the charging resistor. The amount of energy removed from the capacitor is very small and is easily replenished in the time between pulses, which is 70 microseconds. However, the total distributed capacitance, including the magnetron capacitance, is 50pF and this must be recharged after each pulse. The time required to charge this capacitance is:

$$RC = 2x10^3 \times 5x10^{-11} = 10^{-7}$$

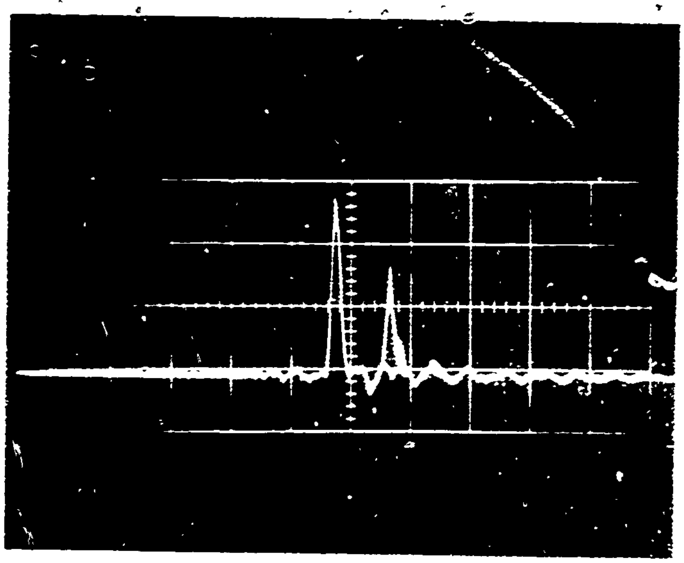
or 100 nanoseconds.

2.6.1 Magnetron Problems

This long time constant can be a serious problem for at least two reasons.[4] First, the magnetron may not turn off cleanly and the pulse spectrum may contain noise and cause interference with nearby targets. Secondly, the coupling capacitor may contain series inductance and result in transient oscillations of the magnetron voltage pulse during the re-charge portion of the cycle. While the spectrum noise does not appear to be serious, the ringing due to inductance is a potential problem with some magnetrons. Figure 6 shows this ringing clearly. The first crest after the main pulse may cause the magnetron to oscillate as shown in Figure 8, which should be compared to the single RF pulse shown in Figure 7.

2.6.2 Inductance in Series with Magnetron

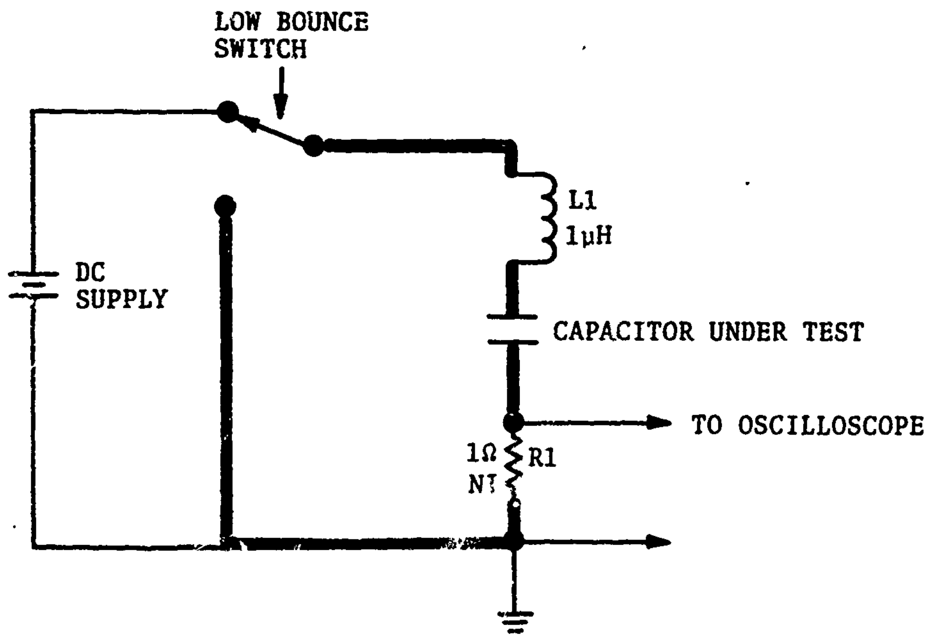
The coupling capacitor inductance was measured carefully by means of the circuit shown in Figure 9 and proved to be 2 microhenries. As stated earlier, the output capacitance was 50 pF, thus the ringing time is:



Sweep - 50ns/cm

Magnetron RF pulse (rectified) sample shows how double pulsing can occur when the magnetron voltage pulse shape is improper.

Figure 8. Magnetron Double Pulsing



$$L_S = \frac{T^2}{4\pi^2 C}$$

T IN SECONDS
C IN FARADS
L IN HENRIES

NOTES:

1. L1 SHOULD BE A PRECISION OR KNOWN INDUCTOR WHICH IS SOMETIMES REQUIRED TO BUILD UP ENOUGH VOLTAGE ACROSS R1. IF L1 IS USED SUBTRACT VALUE FROM L_S.
2. T IS OBSERVED ONLY DURING THE DISCHARGE OF THE CAPACITOR UNDER TEST.
3. THE HEAVY LINES SHOWN IN THE DISCHARGE CIRCUIT DENOTE LOW INDUCTANCE WIRING.

Figure 9. Circuit for Measuring Series Inductance (LS) in a Capacitor.

$$t = 2\pi \sqrt{LC}$$
$$= 6.28 \sqrt{2x10^{-6}x50x10^{-12}} = 6.28x10^{-8}$$

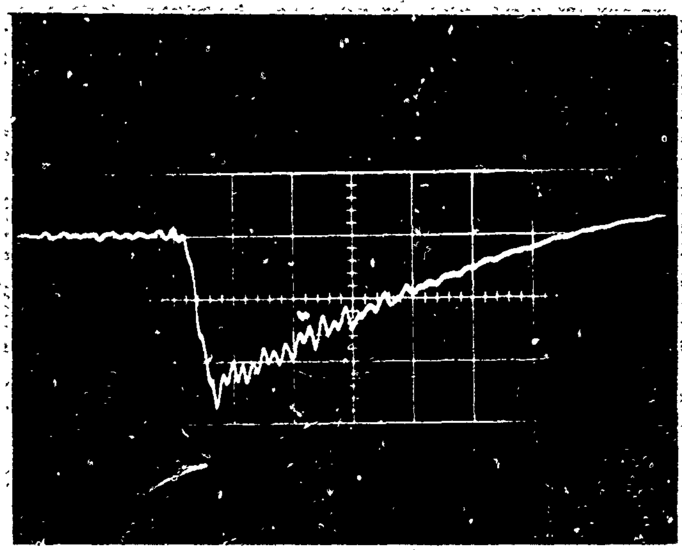
or 63 nanoseconds which agrees quite well with the time shown in Figure 6. Some or all of this problem could be eliminated by increasing the ringing time and the circuit damping. However, this could increase the "bleed" current from 6 to 24 amperes, and is really not a practical solution. For these reasons, other methods of preventing double pulsing were tried.

2.6.2 Inductance in Series with Magnetron

A low inductance capacitor (0.2μH) was installed with mixed results. The ringing frequency was increased accordingly and the double pulsing was reduced but not completely eliminated. Figure 10 shows the magnetron voltage pulse with a 2000pF, low-inductance capacitor. Double pulsing was produced simply by adjusting the magnetron voltage. Figure 11 shows the magnetron voltage pulse with a 5000pF, 32μH capacitor. Strangely enough, double pulsing could not be produced even though the second pulse is quite pronounced. This is due to the fact that the height of the second pulse is not sufficient to turn the magnetron on.

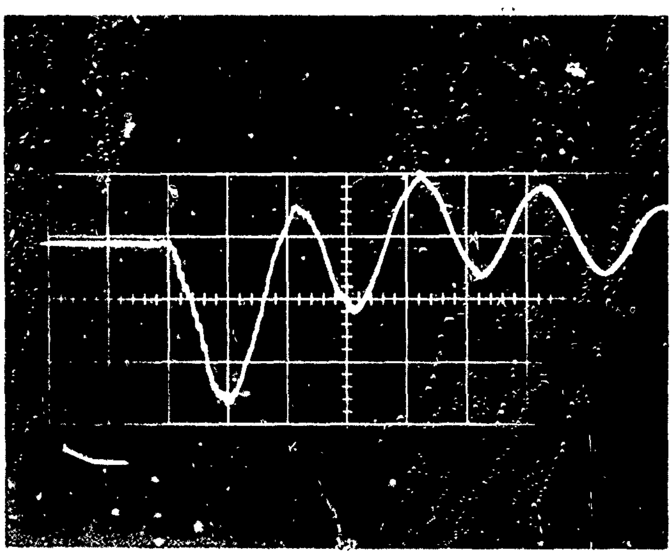
2.6.3 Adding Inductance in Magnetron Circuit

A high inductance capacitor would increase the ringing period and reduce the tendency to double pulse. How ver, the modulator high voltage would have to be increased considerably to produce any magnetron oscillations, again not a very practical solution. Alternatively one could use a high capacity, low inductance capacitor and add an external series inductance to increase the width of the main pulse and depress the first ringing crest below the required firing voltage. The results of such a change are shown in Figure 12. The value of series inductance was chosen empirically. The optimum value turned out to be 1.7μH for the following reasons:



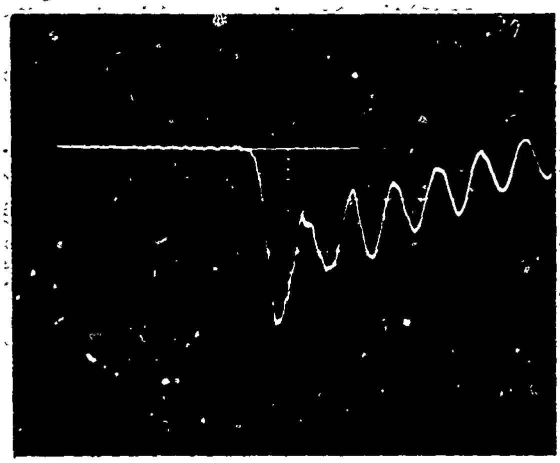
Sweep 50 ns/cm
Voltage 5kV/cm
$L_s = 0.2 \mu H$

Figure 10. Magnetron Voltage Pulse with a Very Low Inductance Capacitor



Sweep 100ns/cm
Voltage 5kV/cm
$L_s = 32 \mu H$

Figure 11. Magnetron Voltage Pulse with a Very High Inductance Capacitor.

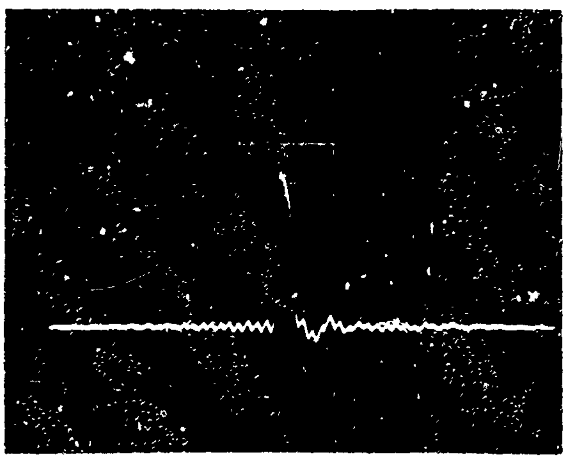


Sweep 50ns/cm

L_s=1.7µh total

Magnetron voltage pulse

12a



Sweep 50ns/cm

Magnetron rectified RF pulse

12b

Figure 12. Magnetron Pulses with a Low Inductance 2000pF Capacitor and a 1.7µH Inductor in Series.

1. The modulator dc voltage could be reduced without reducing the average magnetron current.

2. The main pulse is more than 20ns wide, producing an RF pulse somewhat broader than the 16ns previously observed.

3. Double pulsing could in no way be produced, even with the magnetron that was so easily double pulsed before.

2.6.4 Frequency of Magnetron Replacement

The magnetron is also a component that was replaced quite frequently. A check of some airports revealed that many magnetrons were replaced after as few as 180 working hours. A life test with a used magnetron has been underway at TSC for more than 4000 hours. This magnetron came installed in the radar when it was brought over from Logan. The magnetron had "NG" written on it, but it was decided to use it anyway after the modifications were made. When the pulse voltage was slowly applied to the magnetron, it did not oscillate at all, as indicated by the average current meter. A look at the circuit revealed that the magnetron filament voltage was reduced when the high voltage was applied to the 4PR60's. With the pulse voltage set to a 13.5kV, the magnetron filament voltage was raised to 5+ volts, and the magnetron immediately began to oscillate. The filament voltage was then reduced to 4.0 volts and the magnetron still oscillated.

A simple experiment was conducted in which the pulse voltage was slowly brought up to its operating value (12 to 13kV) on the magnetron with 4 volts fixed on the filament. This is normal operating voltage and is applied automatically with the modulator plate voltage "on" button. The magnetron would not oscillate with the filaments at 4 volts. The Modulator Off button was depressed which removes the pulse voltage and returns the magnetron filament voltage to 5 volts. The modulator control was set in a position that would immediately apply a 12.5kV pulse to the magnetron. After a 5 minute preheat time the modulator high voltage button was depressed (bringing the pulse voltage on full and simultaneously reducing the filament voltage), and the magnetron oscillated.

It is postualted that when the 3C45 thyratrons or 4PR60's were replaced in the field, the modulator pulse may have been applied slowly as described above, thereby creating the condition of a non-oscillating magnetron, which might also lead to the conclusion that the duplexer could be bad etc. The magnetron test was conducted with one other (used) magnetron and the same results were obtained. More experiments should be performed before any final conclusions are reached, but it does appear that some magnetrons and duplexers may have been scrapped prematurely.

3.0 OTHER RADAR AND MODULATOR PROBLEMS

The major problems have been covered above, but other modifications could be made to conform with good engineering practice. One of these is associated with the screen by-pass capacitor and the extremely long leads connected to the capacitor. The leads should be very short and direct so that the higher frequencies are effectively by-passed. Another beneficial change would be to replace the screen de-coupling resistors with higher wattage wire wound units. Although the power dissipation is less than one watt in the present two watt resistors, an important factor was overlooked. When a 4PR60 arcs from plate to screen, the screen voltage is momentarily lifted towards the plate voltage. Thus, the dissipation of the 2-watt screen resistor is exceeded and eventually shorts out or opens. Spark gaps are generally employed to prevent damage to the tubes and to the resistors from this effect.[2,4]

Another change that was actually made was to move the pulse forming network cable to the outside of the modulator cabinet wall. This increased the lead length about one-half inch, but the cable is now protected from the thyratron heat and is completely out of the way when the thyratron has to be changed. These are examples of minor changes that could be made even though they are not absolutely essential.

Other sections of the radar, in addition to the modulator-transmitter could be modified, but maintenance personnel at the various airports have not seriously complained about them, with two exceptions. These are the display tube brightness and the rotating yoke bearing failure. Both of these problems are being looked at by TSC personnel.

4.0 COMPARISON OF OLD AND MODIFIED MODULATOR

A comparison of the mean time between failures (MTBF) of the original and modified modulator is shown in Table 2. It is not clear from the records why so many components in the unmodified ASDE-2 have the same MTBF. A schematic diagram of the modified modulator is shown in Figure 13. Components that were changed or added are marked. A parts list is given in Table 3.

The parts required to make the change are shown in Figure 14 and can be procured at a cost of approximately $400.00. The modification can be accomplished in two days by one skilled technician. A photograph of the modified Logan transmitter is shown in Figure 15.

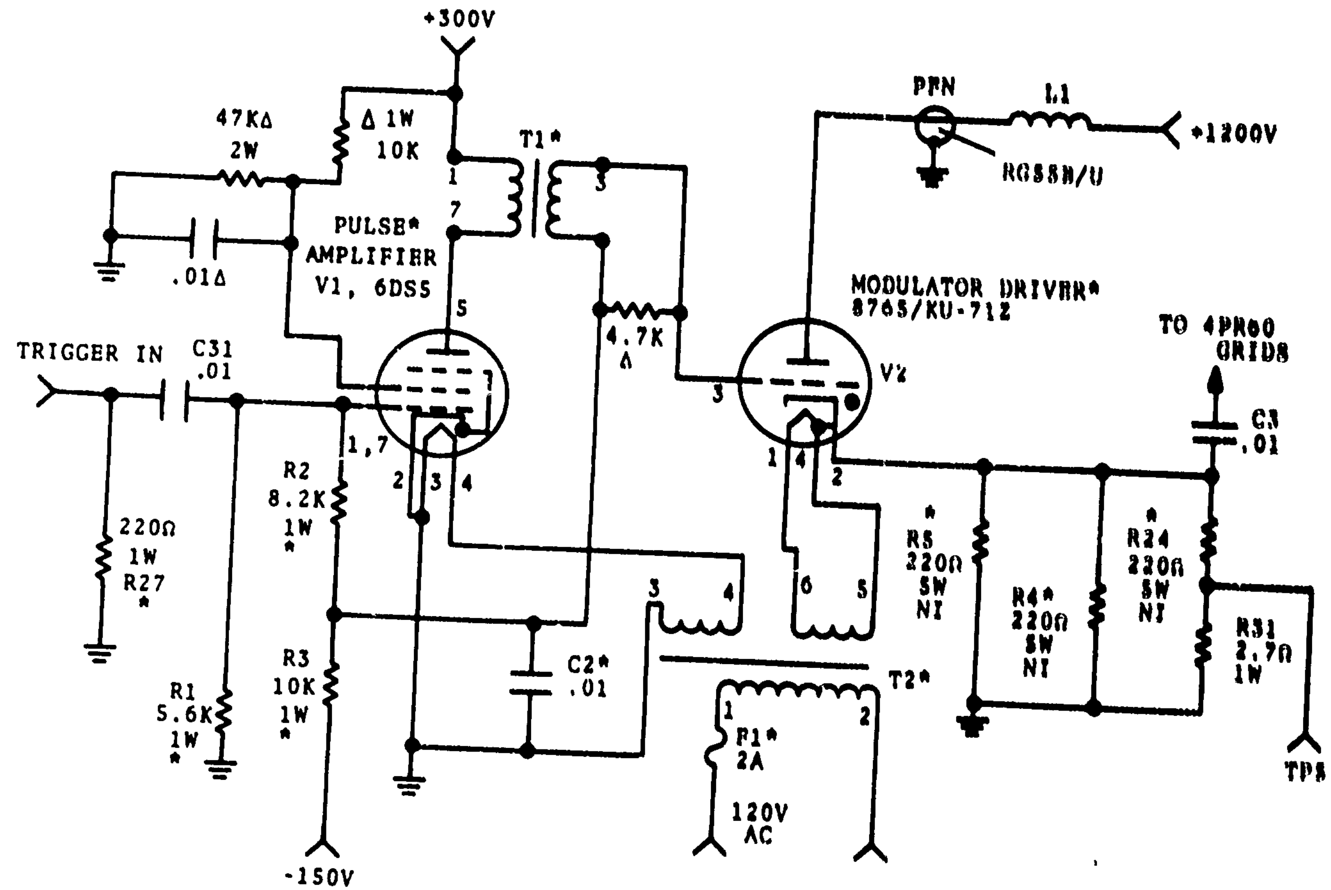
TABLE 2. COMPARISON OF ASDE-2 FAILURE RATE (MTBF)

Equipment	MTBF Original ASDE-2	MTBF Modified ASDE-2
1. 3C45 Modulator Driver	60 hrs.	200 hrs(1 tube)
2. 8765/KU-71Z Modulator Driver	not used	>3800 hrs.
3. 4PR60's Power Amplifier	180 hrs. each	>4400 hrs. each
4. BLM-006 Magnetron	200 hrs.	>4400 hrs.
5. BL-T-036 Duplexer	200 hrs.	>2444 hrs.
6. 1N26A Mixer Crystals	200 hrs.	1200 hrs.
7. 1N26AR Mixer Crystals	200 hrs.	1200 hrs.
8. 1N26 AFC Crystals	200 hrs.	1800 hrs.

Notes:

1. Equipment items 4 through 8 were probably changed unnecessarily as a result of the 3C45s and 4PR60s failing so often. This is the only real explanation of why MTBF is so much longer with the modified ASDE-2.

2. One 8765/KU-71Z failed at 550 hours and is not reflected in the MTBF hours. Since that failure, the engineering changes described on page 9 have been made.



NOTES:

1. * COMPONENT CHANGE
2. Δ COMPONENT ADDITION

Figure 13. Schematic of Modified Pulse Amplifier

TABLE 3. COMPONENT PARTS LIST FOR MODIFIED PULSE AMPLIFIER

COMPONENT NO.	OLD VALUE	NEW VALUE	REMARKS
R27	75Ω, 1W	220Ω, 1W	component changed
R1	18K, 1/2W	5.6K, 1W	component changed
R2	33K, 1/2W	8.2K, 1W	component changed
R3	33K, 1/2W	10.0K, 1W	component changed
R4	270Ω, 2W	220Ω, 5W, NI	component changed
R4, R6	220Ω, 2W	220Ω, 5W, NI	component changed
none	none	10K, 1W	component added
none	none	4.7K, 1W	component added
none	none	47.0K, 2W	component added
C2	.001, 600V	.01, 600V	component changed
none	none	.01, 600V	component added
V1	6AQ5	6DS5	tube changed
V2	3C45	8765/KU-71Z	tube changed
PFN	RG8/U	RG55B/U	8 ft. section

T_1 is a Polyphase pulse transformer ratio 1:3 and is changed to a Titan special ratio 1:1.6

T_2 is a Freed filament transformer pri. 120V 60∿; sec. 6.3V, .3A and 6.3V, 2.5A changed to a Titan special pri. 120V 60∿; sec. 6.3V, .8A and 6.7V, 7A.

V_1 Tube socket is a 7 pin vector with some new components mounted for ease in component changing.

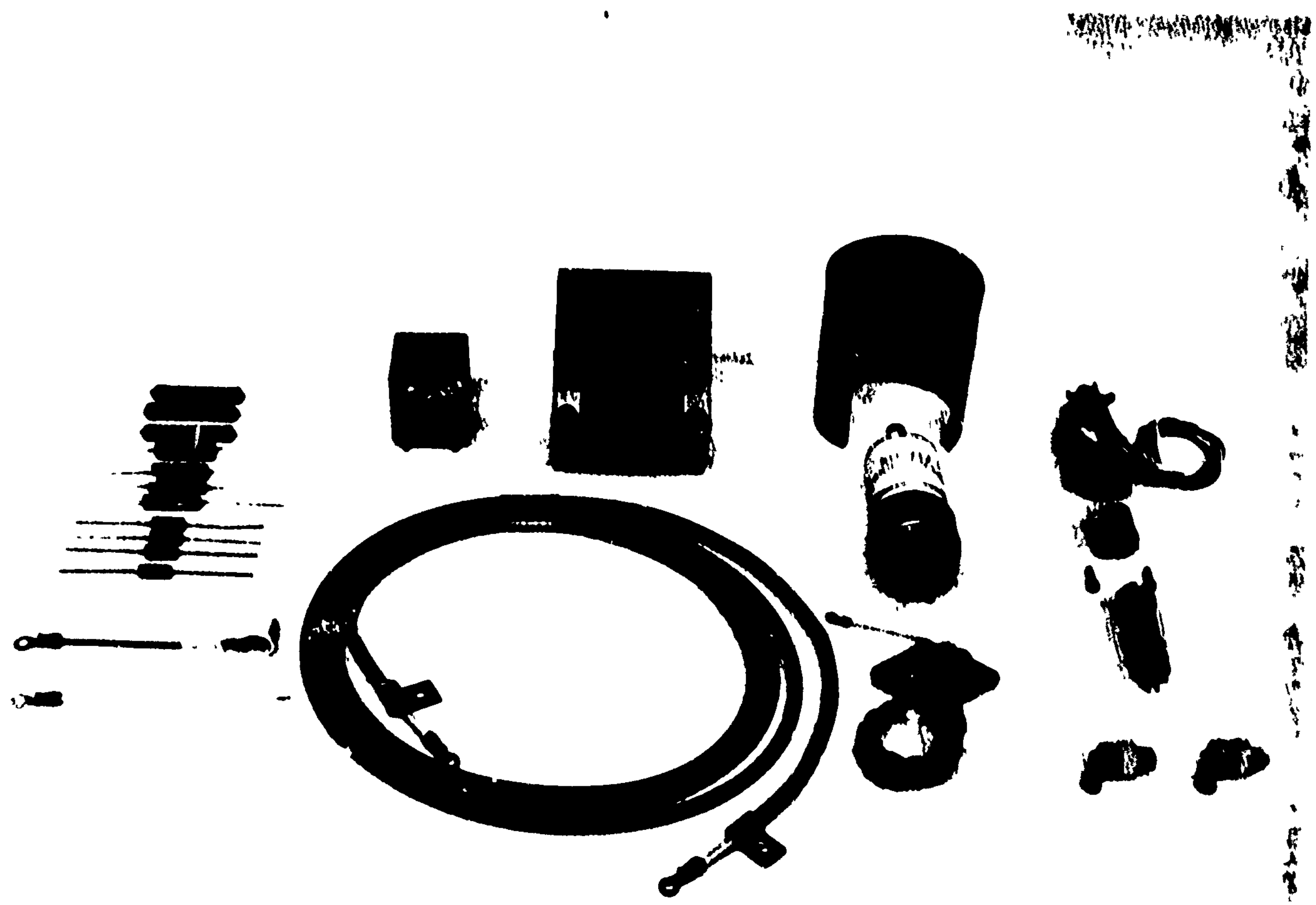


Figure 14. Photograph of New Components

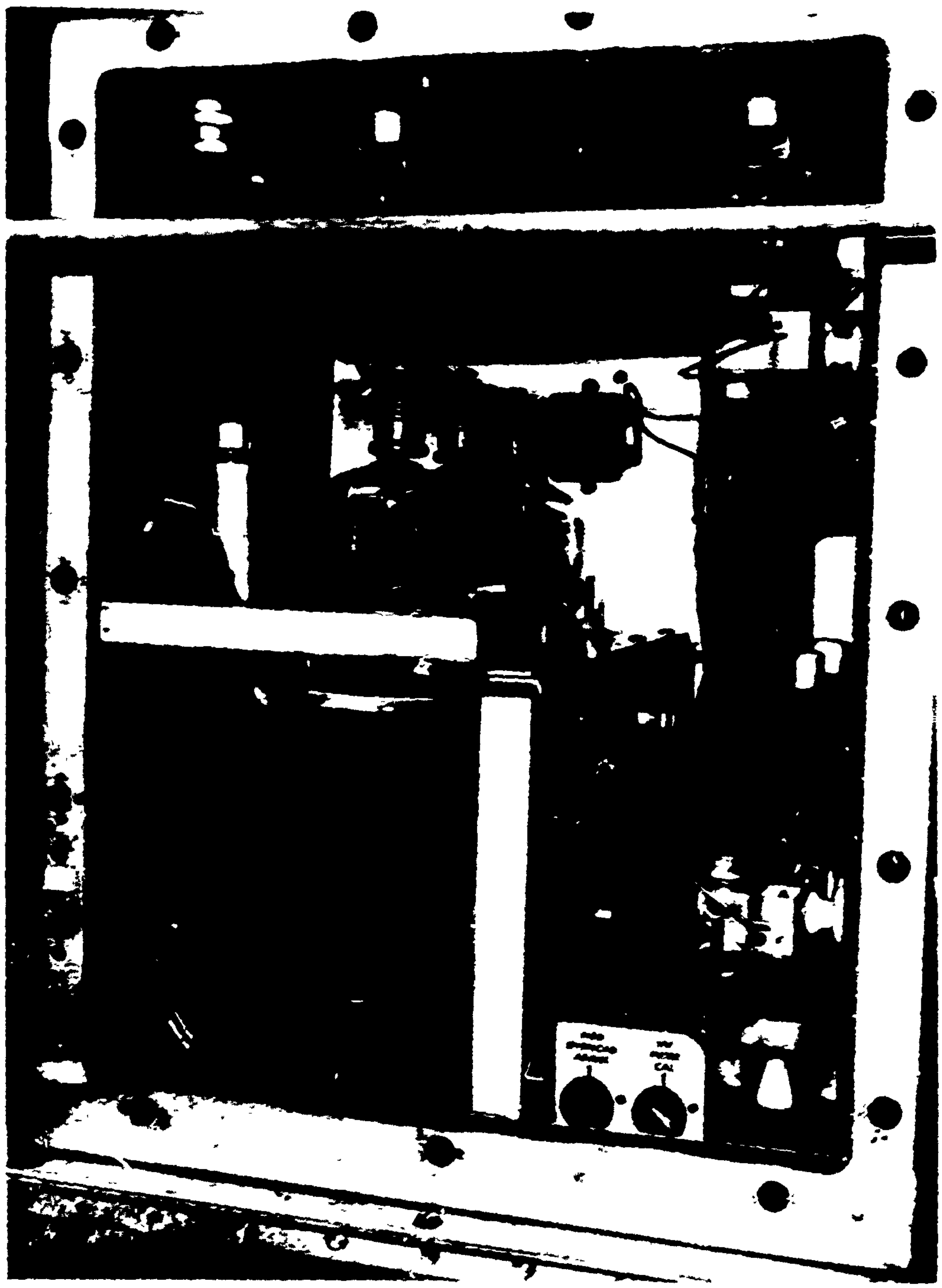


Figure 15. Photograph of Modified Logan Transmitter

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