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NRL REPORT 3899

AIRCRAFT X BAND JAMMER
AN/ALT-2 (XB-3)

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Naval Research Laboratory. Report 3899.
AIRBORNE X-BAND JAMMER AN/ALT-2 (XB-3), by
J. M. Miles. 21 pp. & figs., November 27, 1951.

A random-noise-modulated X-band transmitter tunable over a frequency range of 8875 to 9825 Mc has been developed at NRL. The output power is between 130 and 200 watts, and the gross input power is on the order of 1 kw. The unit, which is unusually compact and lightweight for equipment of this rating, incorporates the Laboratory's newly developed system of "slave look-through" which provides for a flexible utilization of complementary intercept equipment while jamming. The A1007 magnetron, which is the r-f power source, is unsatisfactory from the standpoint of its pushing factor and life, but it is otherwise well-suited (over)

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1. Radar jamming transmitters (X-band)

2. Radar jamming systems (Airborne)

- I. AN/ALT-2 (XB-3)

- II. Miles, J. M.

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AIRBORNE X-BAND JAMMER AN/ALT-2 (XB-3)

J. M. Miles

November 27, 1951

Approved by:

**H. O. Lorenzen, Head, Countermeasures Branch
L. A. Gebhard, Superintendent, Radio Division II**



NAVAL RESEARCH LABORATORY

**CAPTAIN F. R. FURTH, USN, DIRECTOR
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ABSTRACT

A random-noise-modulated X-band transmitter tunable over a frequency range of 8875 to 9825 Mc has been developed at NRL. The output power is between 130 and 200 watts, and the gross input power is on the order of 1 kw. The unit, which is unusually compact and lightweight for equipment of this rating, incorporates the Laboratory's newly developed system of "slave look-through" which provides for a flexible utilization of complementary intercept equipment while jamming. The A1007 magnetron, which is the r-f power source, is unsatisfactory from the standpoint of its pushing factor and life, but it is otherwise well-suited for this service and is at present the only medium power source available in X-band for aircraft use.

PROBLEM STATUS

This is a final report on the development phase of the problem; consultative work continues.

AUTHORIZATION

NRL Problem 39R06-41
RDB Project NL 460-052
BuAer Project NRL-EL-9A-361

Manuscript submitted October 3, 1951

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AIRBORNE X-BAND JAMMER
AN/ALT-2 (XB-3)

INTRODUCTION

Intensive development of microwave radar and allied equipment during the last war resulted in demand for effective jamming equipment for the microwave frequencies. But an adequate program for such a development could not be realized without available microwave cw sources of considerable power capable of being tuned over a relatively wide band of frequencies. Since, however, emphasis was on the development of magnetrons for radar and other types of pulsed equipment, the development of microwave cw power sources lagged behind.

Toward the end of the war, some jamming equipment, notably the TDY-1A and the APT-10, was available in the S-band region. There was none in the X-band. As a beginning, NDRC had placed a contract with RCA for a 200-w, tunable, X-band magnetron. Upon termination of this activity in 1945, the Bureau of Ships assumed responsibility for this contract and requested the Naval Research Laboratory to evaluate the tube in its experimental stages. Development of equipment and techniques which could be applied in a jamming transmitter were also undertaken.

An interim report¹, published in November 1948, described the Laboratory's evaluation of the tube then known as the A136 and covered the basic modulator and noise-source circuits developed at NRL.

These investigations resulted in the A1007, an improved tube, which was considered suitable for use in service equipment. Having urgent need for an airborne jammer in this range, the Bureau of Aeronautics established a project here to develop such equipment.

The prototype of an airborne X-band jamming transmitter, the AN/ALT-2 (XB-3), has now been completed. Hereafter, the subject transmitter will be referred to as the ALT-2.

CHARACTERISTICS OF THE A1007 MAGNETRON

The A1007 tube (Figures 1, 2) is a late model of the first tunable magnetron operating between nine- and ten-thousand megacycles to produce a relatively high-power, continuous-wave output; it is still the only source of X-band power adaptable to aircraft service. Evaluation during the developmental period made it possible to recommend improved specifications

¹ Miles, J. M., "Experimental Jamming Transmitter Using a 200-w CW X-Band Developmental Magnetron," NRL Report R-3384 (Confidential), 17 November 1948

for the tube. Continuous collaboration with the manufacturer resulted in a tube mechanically well adapted to the requirements of aircraft service and represents a fair compromise between the various electrical factors governing the design of magnetrons. The following characteristics of the proposed A1007A magnetron, electrically identical to the A1007, but somewhat changed mechanically, were taken largely from BuShips Tentative Electron Tube Specification of December 1, 1950:

Tuning Range	- 8875 to 9825 Mc
Power Output	- 130 w (min)
Power Input	- 550 w
Plate Voltage	- 2600 v
Heater Current	- 30 amp
Heater Voltage	- 1.5 v
Dynamic Impedance	- Unspecified (NRL Test Data - 400 ohms)
Pushing Factor	- Unspecified
Magnetic Field	- Permanent magnet supplied as part of the tube

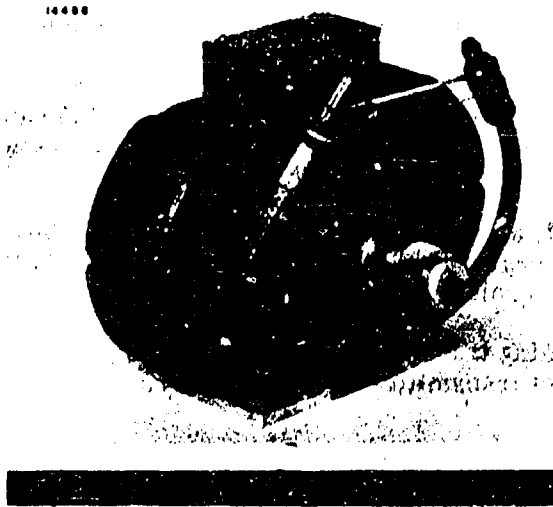


Figure 1 - A1007 magnetron
(front view)

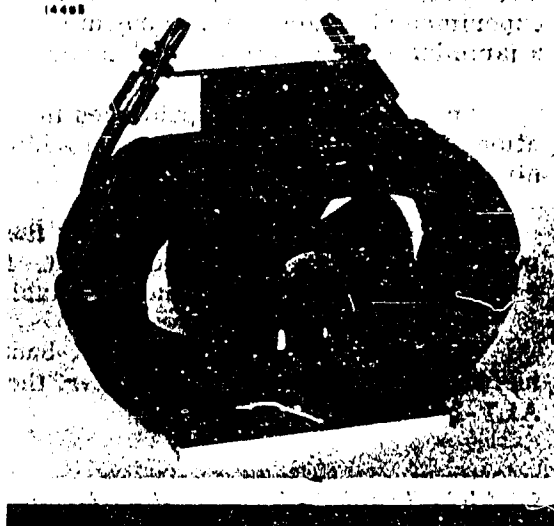


Figure 2 - A1007 magnetron
(rear view)

The rating, 130 w of output power, is the minimum allowed at any frequency in the tuning range, but in general, most A1007 types have higher power output, especially near 9850 Mc. At this frequency, the output is on the order of 200 w for a plate current of 200 ma. The plate power input is somewhat lower than specified, being more on the order of 460 w, so that the efficiency under the more favorable conditions is better than forty percent.

Adversely, the life of the tube is short, the maximum variation lying between one lasting 35 minutes and another lasting 160 hours. The average life is less than 100 hours. In general, erratic performance may be expected prior to failure, and those tubes which exhibit marked variation in dc current or unstable carrier amplitude and frequency can be expected to fail early.

The most prevalent cause of tube failure is looseness in the cathode structure which in the A1007 is a force-fitted thorla dispenser. Another cause is gassiness. The A1007A will utilize an improved dispenser; it is hoped the tube will be otherwise improved. Since the manufacturer could not always furnish experimental tubes as needed, frequent failures retarded development. An insufficient supply has meant that the circuitry in the ALT-2 has been developed around specific rather than average tube characteristics. Neither the dynamic impedance nor the pushing factor is specified for the A1007 or the A1007A; for complete correlation between transmitter and tube, these factors should be included in any specifications covering future development.

TECHNIQUES FOR MODULATING THE R-F POWER SOURCE

Modulator Design

The dynamic impedance of a magnetron is the ratio of ac changes in plate voltage to the resulting changes in plate current which occur when the magnetron is plate modulated. The character of this impedance is illustrated by the Voltage-Current (V-I) characteristics of a magnetron (Figure 3). As indicated, a relatively high voltage is required for an appreciable magnetron current. Thereafter, small increases cause large increases in plate current, and a small voltage change, ΔV , causes a large change in plate current, ΔI . The dynamic impedance is

$$R_d = \frac{\Delta V}{\Delta I}, \quad (1)$$

and for practical purposes, R_d can be considered resistive and constant within the operating limits. Obviously, the value of R_d is much less than the dc resistance of the magnetron, so if the magnetron current is modulated, the total voltage swing supplied by the modulating tube is small compared to the dc voltage across the magnetron; the modulation power requirement is therefore small. Since the magnetron anode is part of the tube structure (i.e., ground), the modulator output must be coupled to the cathode through a condenser, C_c , (Figure 4a) or applied directly (Figure 4b). In the latter case, the modulator must be on the high side of the power supply from ground. When the coupling condenser, C_c , is large enough to pass all the low-frequency components, the two circuits are equivalent. Resistors R'_c and R''_c (Figure 4a) are the dc supply elements for a magnetron and its modulator using conventional capacity coupling. When C_c has sufficient capacity to pass all low-frequency components in the modulating signal, R'_c , R''_c , and R_d , the dynamic impedance of the magnetron, are each effectively shunted across the modulator and can be represented by one equivalent resistor, R_L (Figure 4c). For direct coupling (Figure 4b), the same equivalent circuit applies, but in this network, R'_c and R''_c are normally not required because the dc current flows directly through both the magnetron and its modulator. If, however, additional loading is needed, a resistor, R'_c , could be shunted across the modulator. Additional current would be required through R'_c if 100-percent modulation were desired. Likewise, if additional loading is required for the circuit of Figure 4a, R'_c can be made any desired value, but more modulator current is necessary.

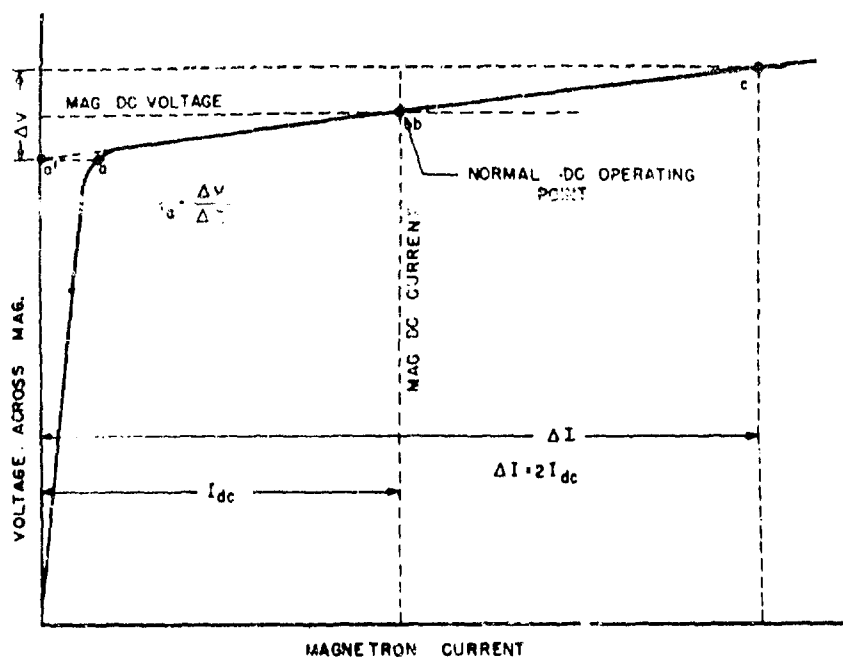


Figure 3 - Magnetron V-I characteristic

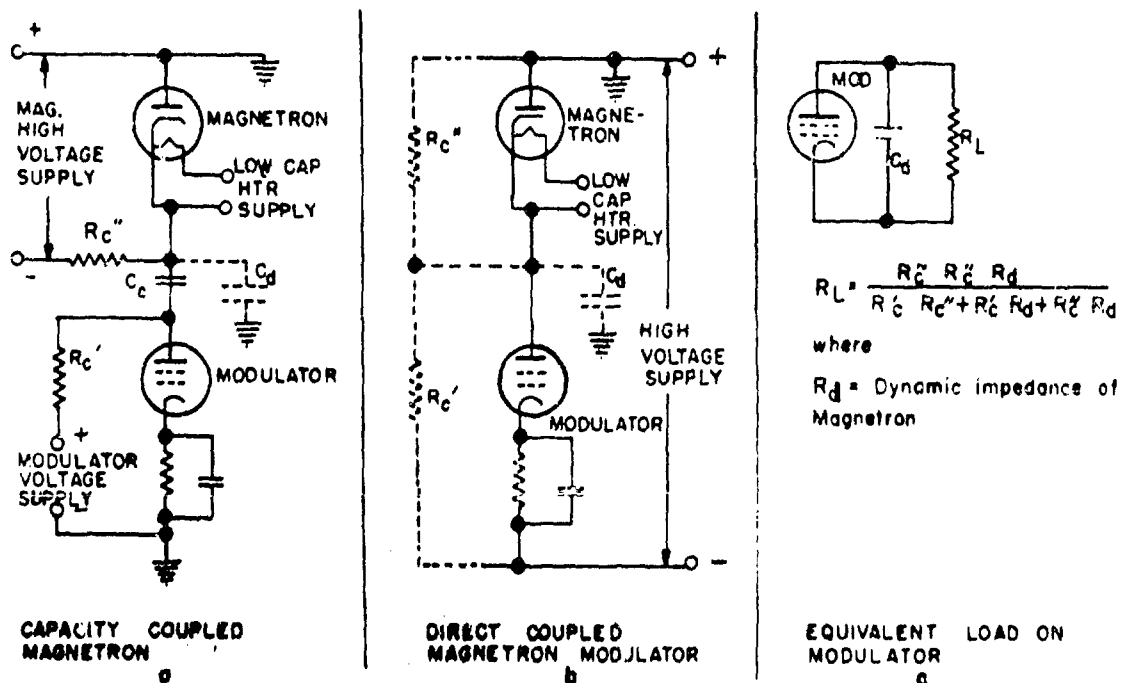


Figure 4 - Magnetron modulators

Since the 3-db cutoff frequency for the configuration of Figure 4c is

$$f_c = \frac{1}{2\pi R_L C_d} ,$$

the modulator design depends upon C_d , the total distributed capacity, and upon R_L , the total load shunted across the modulator. In general, it is a fortunate circumstance when the absolute value of the dynamic impedance R_d is less than the reactance of C_d at the highest desired modulating frequency. Then R_L may be effectively equal to R_d whence resistors R'_c and R''_c (Figure 4a) may be high or may be replaced with inductive reactances. In the series circuit (Figure 4b), these elements will not be required at all. In either case, the cutoff frequency will be

$$f_c = \frac{1}{2\pi R_d C_d} , \quad (2)$$

and the available spectrum will be greater than required when the absolute value of the capacitive reactance is greater than R_d at the highest modulating frequency. When Equation (2) holds, the current in directly coupled modulators (Figure 4b) is identical with that through the magnetron, and current variations caused by modulation are similarly identical. The same holds for the capacity coupling (Figure 4b), except that the modulated dc current can be greater, but cannot be less than the current through the magnetron if 100-percent modulation is assumed. For simplicity, consider the normalized V-I characteristic (Figure 3) made by extending the upper linear portion of the characteristic to the vertical ordinate at a' . Assuming 100-percent modulation for a voltage change of ΔV , the average dc voltage across the modulator cannot be less than

$$\begin{aligned} E_{\text{mod}} &= \frac{\Delta V}{2} \\ &= \frac{\Delta I R_d}{2} , \end{aligned}$$

Since from the V-I characteristic,

$$\frac{\Delta I}{2} = I_{\text{dc}} ,$$

then

$$E_{\text{mod}} = I_{\text{dc}} R_d . \quad (3)$$

Since the current through the modulator cannot be less than the magnetron current, I_{dc} , the dc power to the modulator must exceed

$$P_{\text{mod}} = I_{\text{dc}}^2 R_d . \quad (4)$$

When R_d is less than the capacitive reactance at the desired cutoff frequency, Equation (4) is the expression for the minimum dc power to the modulator. Accordingly, for the A1007, the dc-power requirement for the modulator cannot be less than 16 w for a plate current of

200 ma. From a practical standpoint, the modulator tube should be operated with more than the minimum dc plate voltage to reduce distortion. Operating with 150 v on the plate, the power input to the modulator is 30 w, still less than ten percent of the power to the magnetron. The bandpass in the plate circuit of the modulator, according to Equation (2), is about 6.25 Mc when the total shunting capacity is $84 \mu\mu\text{f}$. It is considered that for proper distribution of jamming energy around the carrier frequency, the modulation spectrum should extend out to 5 Mc. This spectrum is less than the available bandpass, i.e., the absolute value of the capacitive reactance at 5 Mc is greater than the dynamic impedance of the magnetron, the qualifying factor for operating with no additional loading other than the dynamic impedance of the magnetron.

For comparison, assume the use of a magnetron identical to the A1007 except that its dynamic impedance is around 1600 ohms, a typical value for some other magnetrons. Now, if the dc supply elements R_c' and R_c'' are maintained high compared to R_d , the cutoff frequency is only about 1.5 Mc. Peaking networks and transformer coupling have been used to extend the spectrum of such circuits, but have limited value. In addition, they are somewhat tricky to adjust and are not easily adapted to the series-modulation circuit (Figure 4b), used for the specific requirements of the ALT-2. For general purposes, shunt loading is the most straightforward method of increasing the spectrum, and because of simplicity, it will be used for comparison. To extend the spectrum by shunt loading, resistor R_c' must be decreased until R_L is equal to the capacitive reactance at the desired cutoff frequency. But the modulator must still provide the same voltage swing, ΔV , and since R_L is lower, the current swing is increased by the ratio

$$\frac{R_d}{X_c},$$

where

$$X_c = \frac{1}{2\pi f_c C_d};$$

R_L is inversely proportional to this ratio. Therefore, substituting in Equation (4), the total dc power required for the modulator when $X_c < R_d$ must be at least

$$\begin{aligned} P_{dc} &= \left(I_{dc} \frac{R_d}{X_c} \right)^2 \cdot R_d \left(\frac{X_c}{R_d} \right) \\ &= \frac{I_{dc}^2 R_d^2}{X_c} \\ &= 2\pi f_c C_d I_{dc}^2 R_d^2. \end{aligned} \quad (5)$$

For the magnetron identical with the A1007 except for its 1600-ohm dynamic impedance, the minimum dc power to the modulator is 200 w, an increase of 12.5 times for an increase of 4 times in the dynamic impedance.

Such severe power losses can be partially offset by peaking the high-frequency end of the spectrum ahead of the modulator, a method somewhat similar to stagger tuning if the modulator is considered to be peaked at zero frequency and the preceding stage or stages are peaked at the required high frequency. The rise in the high-frequency components ahead

of the modulator must be sufficient to offset the attenuation caused by C_d . Although shunt loading is not required, the modulator tube must pass sufficient current to provide for the required voltage swing across R_d and C_d ; this is still a relatively rigorous requirement. All in all, a high premium is paid for wide bandpass when the dynamic impedance is greater than the capacitive reactance at cutoff. In fact, the price is prohibitive with the circuit of Figure 4b because of the excessive loss in power through R_c which is necessary to supply the additional current to the modulator. This situation becomes really serious when the design must include high-power magnetrons of the 1-kw-output variety which draw on the order of 1 amp of dc current and have a dynamic impedance greater than 1000 ohms. When the total loading capacity is 100 μf and a 5-Mc spectrum is desired, the modulator alone will require better than 3000 w of dc power. Some compromise would seem in order, and limitation of the modulator spectrum to the natural cutoff frequency of the circuit is suggested. For this energy distribution, R_d is the only effective load on the modulator, and the spectrum limit is

$$f_c = \frac{1}{2\pi R_d C_d}$$

Although the result may be some degradation in the fineness of the noise structure on an "A" scope, this may not be too serious and might even be an advantage. The effectiveness of various types of noise is being investigated at NRL, and a subsequent report is to be published. One finding is the probability of an optimum noise spectrum for jamming a specific pulse. For example, when jamming a 1- μsec pulse in a receiver with a bandpass of 5 Mc, 1-Mc noise has been found more effective than 5-Mc noise. This was true even though the leading and trailing edges of the pulse were steep and represented frequency components considerably higher than 1 Mc. Such facts would indicate that in a general purpose jammer video coverage might well be compromised in favor of greater jamming energy for a given primary power.

Magnetron Pushing Effect

When pure amplitude modulation is assumed, an argument against compromising the noise spectrum exists because sideband energy in the r-f spectrum is limited to a narrow band of frequencies, and when this spectrum is much less than the receiver bandpass, the "victim" receiver can evade the jammer more easily. This argument is no doubt valid on the assumption that pure AM exists because a given noise spectrum would provide the carrier with sidebands grouped around the carrier by only plus and minus the frequencies of the video spectrum. The objection is less valid for plate-modulated magnetrons, all of which suffer to some degree from a characteristic known as "pushing," which refers to variations in the output frequency produced by changes in the dc voltage supplied to the tube. Thus, when a magnetron is modulated conventionally, FM will occur along with the desired AM. Until the frequency shift exceeds the order of the modulating frequency,² energy distribution is restricted to a narrower band.³ Beyond this, the spectrum will broaden and can exceed that obtained with pure AM. For narrow-band noise, the expanded spectrum will exist because for 100-percent modulation the frequency shift of most microwave magnetrons will be considerably larger than the value of the modulation frequency (i.e., $\beta > 0.2$). For example, the 25-Mc frequency shift of the A1007 is large when compared to the 5-Mc noise spectrum used in the ALT-2. These facts nullify the argument that narrow-band modulation of magnetrons will limit the r-f spectrum.

² The frequency modulation index is $\beta > 0.2$

³ Hund, August, "Frequency Modulation," New York: McGraw-Hill Book Co., 1942

Conversely, excessive FM presents a problem. Superficially, it would seem that sideband energy obtained by FM would be just as effective as any other distribution so long as random noise is produced within the bandpass of the victim receiver. This is generally true only when the bandpass of the receiver is sufficiently wide and is tuned to include the full noise spectrum.⁴ It is not true otherwise, because when part of the frequency swing falls outside the bandpass of the victim receiver, power is not only wasted, but a flattening of the noise presentation known as "clipping" results. The NRL noise-study report will show that when the degree of clipping is such that the noise peaks are limited to less than approximately three times the rms value of the noise amplitude, its jamming effectiveness on an "A" scope is likewise limited. Hence, when the pushing factor in a magnetron is sufficient to cause frequency swings beyond the bandpass of a victim receiver, less effective jamming can result. This could be an additional argument against the use of narrow-band modulation which depends on pushing to supply the necessary sideband coverage. It should be recalled, however, that the frequency swing is a plate-voltage function and will be unchanged by other variables. In other words, if narrow-band modulation produces excessive FM from a magnetron, then broadband modulation will produce the same frequency swing with like results. So if the chief purpose is to obtain a wide r-f distribution, there is still no good argument in favor of broadband modulation of microwave magnetrons for general purpose jamming.

Because clipping may result, excessive pushing is a distinct disadvantage. Unfortunately, with progressively higher carrier frequencies, the situation gets worse, and the small phase-shift produced by pushing, relatively unimportant at lower frequencies, may represent a frequency shift of many megacycles at X-band. From examination of typical Rieke characteristics of magnetrons, it is evident that a reduced pushing factor is obtained only at the expense of output power and efficiency, and at best, a compromise between a low-pushing factor and power output is probably necessary. At present, insufficient evidence prevents exact recommendations for such a compromise but the NRL noise study includes an investigation of the jamming capabilities of a noise-modulated carrier; the modulation comprises various combinations of FM and AM. The results should shed some light on this subject and will aid tube manufacturers and other interested agencies in assessing additional factors that have been largely overlooked as a result of the emphasis placed on maximizing cw output power and efficiency.

The pushing factor in the A1007 magnetron varies from tube to tube. An average of NRL test data indicates a 25-Mc total swing for approximately 100-percent amplitude modulation of plate current when the dc value of plate current is 200 ma. Fortunately, the greatest frequency change occurs when the current is near cutoff, and FM can be reduced if the negative peaks do not extend into this region. Accordingly, the normal 100-percent modulation, i.e., 0 to 400 ma centered at 200 ma, is altered so that the current swings from 66 to 400 ma, but is still centered at 200 ma. By such unsymmetrical modulation, the frequency swing is limited to approximately 15 Mc, and the loss in sideband power is small.

By operating the tube under a more highly stabilized condition, further reduction of incidental FM in magnetrons can be secured. A small, properly phased mismatch at the output tube gives the desired result of decoupling the magnetron from its load which causes it to operate at a more stable point on its Rieke characteristic. For this purpose, a control on the front panel of the ALT-2 adjusts a probe lengthwise along the waveguide connected to the tube output. The probe, fixed in penetration depth so as to cause a voltage standing-wave ratio (VSWR) of 1.2 at 9300 Mc, changes less than ten percent over the tuning range of the A1007. The adjustment, which changes the phase of this mismatch, is made while observing the panoramic presentation on the scope of complementary receiving equipment

⁴ Roder, Hans, "Amplitude, Phase and Frequency Modulation," IRE, Proc., 19, 2145-2176, 1931

such as the AN/APR-9 receiver. Minimum FM is recognized when the least spread of the jamming spectrum occurs across the scope. When the antenna and transmission line present a 1:1 VSWR, this adjustment and the aforementioned dissymmetry will limit the frequency swing of the ALT-2 to approximately 10 Mc.

Several questions arise concerning the advisability of using this second method for FM reduction. First, does operation with reduced coupling cause an unwarranted power loss? Second, is it possible to adjust the phase of the mismatch to combine with an improperly matched antenna system and cause instability whence moding will result in damage to the tube? To answer these questions, the tube was operated both modulated and unmodulated into a 2:1 mismatch. Keeping the mismatch constant, the phase was adjusted for the least FM. Power output was found to be reduced about 2 db from that measured when the VSWR was 1:1. When the phase was adjusted for maximum FM under modulation, the power increased approximately 2.5 db. Frequency swing was on the order of 40 Mc, but otherwise, tube operation was normal. A 2:1 VSWR is considerably larger than that produced by the probe, and if the mismatch from an antenna were bad enough to be really serious, the effect of the probe itself would be negligible in comparison. The power loss, which would be considerably less than the 2 db accompanying a 2:1 mismatch, would seem to be inconsequential. Of course, additional loss in sideband power occurs because of unsymmetrical modulation. This, too, is small, and the fact that the frequency swing is considerably reduced clearly justifies the means since the noise spectrum will more nearly match that of current X-band radar receiver and will give more effective power with less clipping.

ADDITIONAL MAGNETRON PROBLEMS

An interesting feature of the A1007 is that during oscillation back bombardment of the cathode supplies sufficient energy to maintain the cathode at the correct operating temperature, and an external source of heater current is necessary only for starting. In fact, if the heater current is not cut off or reduced considerably when the tube is in operation, damage will result. The tubes will oscillate readily if the plate power is applied by a quick switching action, and provision is made for automatically cutting off the heater current when the plate current exceeds 100 ma. Prior to the development of this sequence, a system of two variacs was used, one to adjust the plate current and the other to regulate the heater current. Plate power was increased until the plate current started. Thereafter, the heater current was gradually reduced as the plate current was increased until the plate current was 150 ma and the heater current was zero. When started in this manner, some tubes had a tendency to be unstable at low plate current, starting and remaining in the wrong mode until restarted. By adjusting the controls gingerly, proper operation could be obtained, but this required undue care. In fact all tubes that were started in this manner easily dropped out of oscillation if the heater current were reduced too rapidly. In all, such a starting procedure would not be appropriate for tactical service.

One tube became so hard to start that it was almost impossible to prevent it from starting in the wrong mode. As a last resort, the plate variac was adjusted so that when the power was applied the correct operating current would be obtained. When power was switched on, the tube started and operated normally. The same procedure has been used with consistently reliable results for all tubes subsequently available. Utilizing this system the ALT-2 is provided with a ten-tap switch to adjust the plate current. The first tap after the off position connects the line to the maximum primary turns on the power transformer and starts the tube with a plate current between 50 and 100 ma. Subsequent taps progressively increase transformer output which is adjusted for a magnetron current of approximately 200 ma. When the plate current exceeds 100 ma, a relay in series with the dc output of the high-voltage

supply automatically switches off the heater power. This simplified starting system is partly responsible for the relatively small size of the ALT-2 as compared to early experimental models.

TRANSMITTER FEATURES

The AN/ALT-2 (XB-3) jamming transmitter (Figure 5) is an airborne noise-modulated jammer intended for use against pulsed radars for fire and missile control. With a nominal output of 130 to 200 w, the transmitter covers a frequency range of 8875 to 9825 Mc. The complete equipment including r-f unit, modulator, and power supply is housed in a single C1-D aircraft rack weighing 76 pounds. The ac input power is approximately 0.75 kw at 115 v, 320 to 1760 cycles; 0.25 kw of dc power is required. The output terminates in X-band waveguide, and the associated antenna is a 60° circularly polarized horn, type AT-242/AL.⁵ The modulating circuits, providing for "time-sharing slave look-through," will automatically repeat a triggering pulse received from a complementary look-through unit developed as an auxiliary control for an intercept receiver. The repeated pulse quenches the magnetron during the pulse period. The development project included the design of r-f circuitry around the A1007 magnetron, a suitable modulator, an aircraft-type power supply, and control and indicator circuits all packaged into a compact unit and designed with consideration toward meeting general naval aircraft requirements.

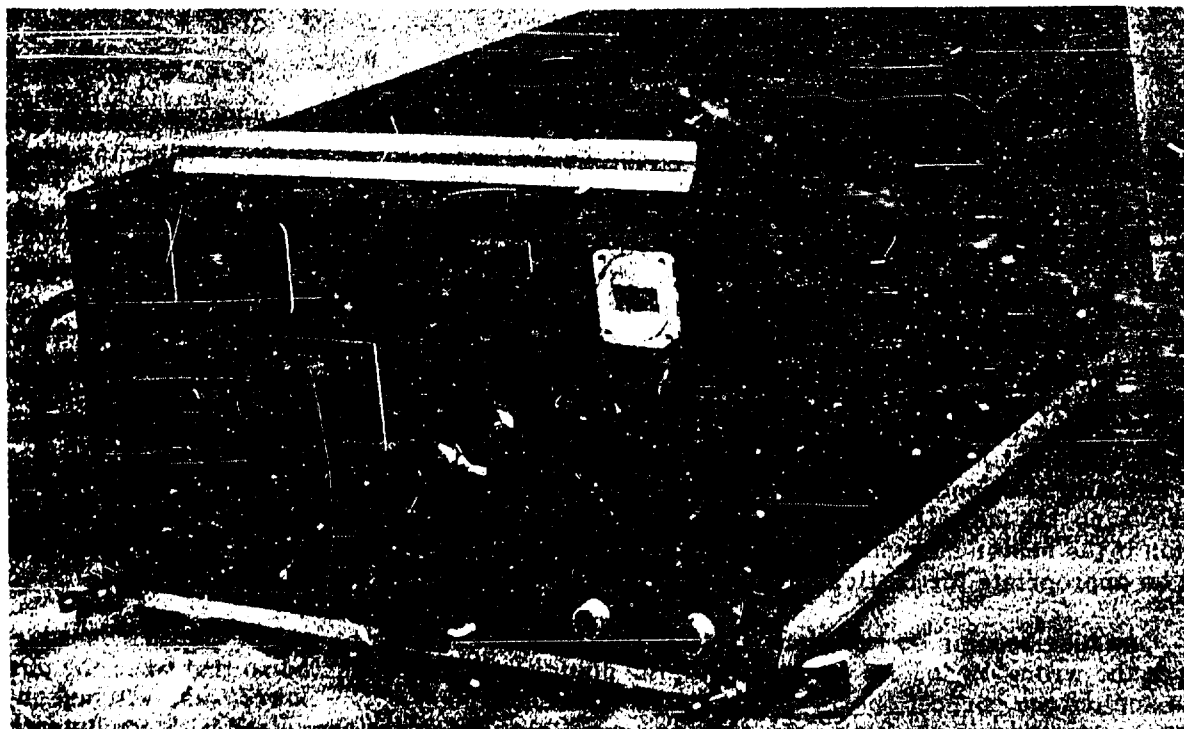


Figure 5 - AN/ALT-2 (XB-3) (complete)

⁵ Bewig, K. W., "X-Band Antenna for AN/APQ-33 (XB) Jam System," NRL Report R-3173 (Confidential), 21 July 1947

Modulation Circuits

In developing the modulation circuits for this transmitter, emphasis has been on the design of an airborne random-noise jammer with look-through. Because of the low dynamic impedance of the magnetron, the problem of noise modulation is relatively simple. The basic circuits were described in detail in NRL Report No. 3384, and the schematics of those circuits are reproduced in Figures 6 and 7. The noise, produced by the familiar 6D4 gas thyatron in a 375-gauss magnetic field (Figure 6), is appropriately filtered to provide a video spectrum flat to within six db out to five megacycles, and it is amplified sufficiently to drive the stage modulating the magnetron. To pass the 200-ma magnetron current, four sections of two 829B tubes are required for this stage (Figure 7), but because of the low dynamic impedance of the magnetron, the dissipation is only about 30 w.⁶ Series modulation originally used for current regulation now provides the long time-constant coupling-arrangement required for time-sharing look-through. Although all modulating components in the ALT-2 are at high potential, this does not imply that these components themselves are subject to high-voltage requirements. In fact, the circuit actually reduces the requirements in this respect because the large high-voltage coupling capacitors C_1 and C_2 (Figure 10a) are eliminated. The only high-voltage condenser required is the small 1000- $\mu\mu\text{f}$ condenser which couples into the multivibrator from the trigger input (Figure 8).

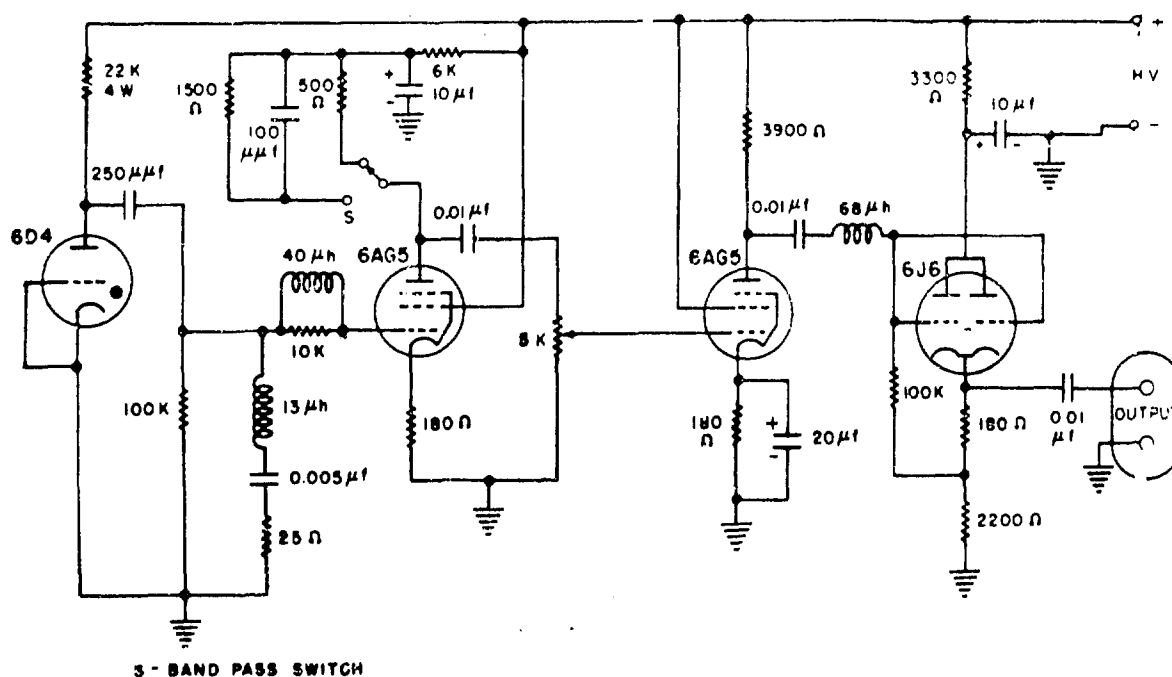


Figure 6 - Noise source and preamplifier for Al16 magnetron

⁶ See page 3 for this discussion

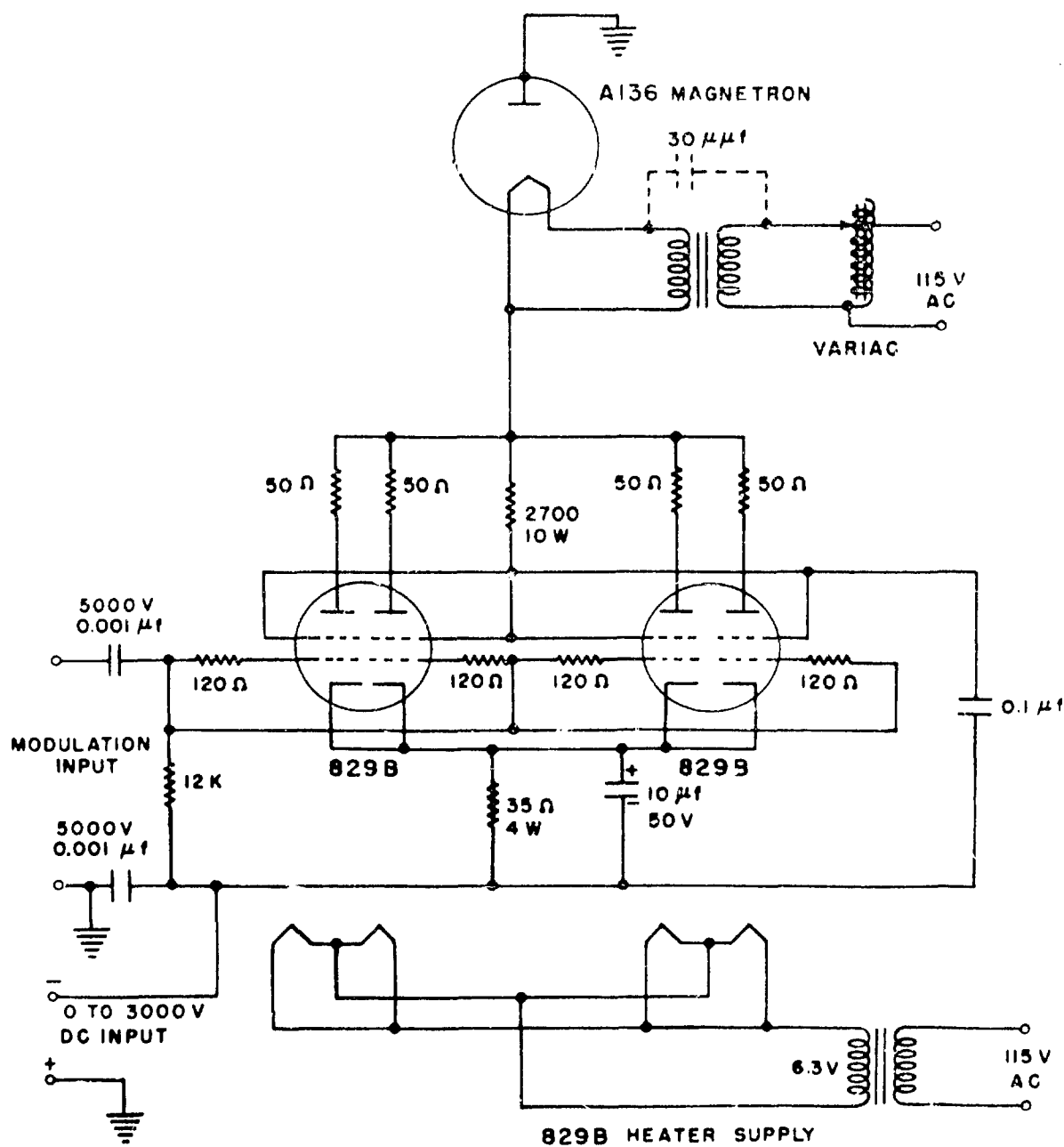


Figure 7 - A136 magnetron and modulator

The schematic of the circuits in the ALT-2 (Figure 8) show that the magnetron and modulator circuit, comprising tubes V5, V6, and V7, is basically unchanged from that of Figure 7, except that the screen grids of the 829B's are now shunt-fed from the positive or ground side of the power supply. Tubes V9, V10, and V13, series-fed for their dc supply, are on the high-voltage side of the power supply from ground. As a result, these tubes and associated circuits must be well-isolated from the chassis and other low-voltage elements, and covers must be provided for protection against high voltage.

One or two changes in the noise source and preamplifier should be noted. In the original transmitter, a separate case housed these two units and a cathode follower was used to couple the 5-Mc noise spectrum into the transmitter at low impedance. This stage and its 6AG5 driver have been replaced with a 6AQ5 tube, V11, directly coupled to the 829B grids. Unsymmetrical modulation⁷ is accomplished by biasing V10 so that the grid swing is over a more curved portion of its characteristic whence the magnetron current swings approximately from 66 to 400 ma around its dc value of 200 ma. Noise-filter values have been modified slightly to accommodate changes in circuit components; the noise spectrum is flat within 6 db from 50 kc to 5 Mc. To conserve space, the 375-gauss magnetic field for the 6D4 is obtained by placing this thyatron within the magnetic field of the magnetron, thereby eliminating the need for a separate magnet. The 6D4 is the horizontally mounted tube at the lower right of Figure 9.

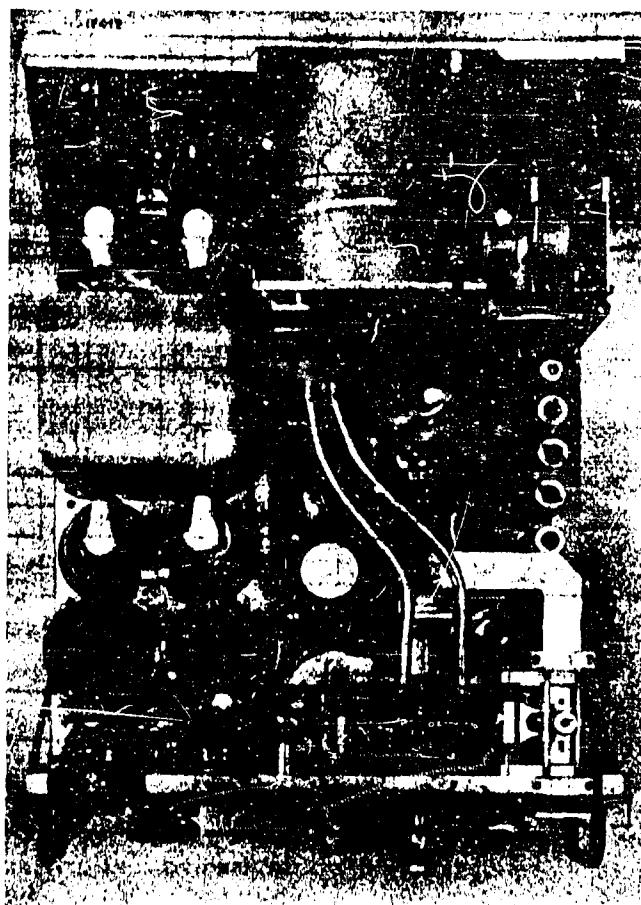


Figure 9 - AN/ALT-2 (XB-3)
(top view)

⁷ See page 8 for this discussion

Time-Sharing Slave Look-Through

When a receiver is physically near a jamming transmitter and both are operating on the same frequency, the receiver will be completely saturated by local jamming, and observation of the victim signal will be impossible. The term look-through refers to that process whereby the intercept gear can be made usable while the jamming transmitter is in operation. There are two general methods of look-through. The first, continuous look-through, attempts to observe the victim signal in the receiver by minimizing the jamming pickup. This is generally accomplished by a high degree of shielding between transmitter and receiver and by bucking the unwanted jamming with an out-of-phase signal inserted directly into the receiving system. The second method, used in the ALT-2 and called time-sharing look-through, is obtained by momentarily extinguishing the jamming signal while the intercept gear functions. To reduce the chance that the enemy can also utilize the look-through interval, the pulse is made to take place at random intervals so the victim cannot predict its occurrence; the interval is only long enough to obtain the desired information. The pulse producing circuits, a part of the intercept receiving gear, are described in another report.⁸ The look-through pulse from such equipment is supplied to the transmitter, and it is desirable to have the look-through interval of the transmitter coincide with that of the intercept gear. In other words, the leading edge of the pulse should extinguish the jamming signal, and the trailing edge should reinitiate it. Experience indicates that the pulse length must be variable between 10 and 50 ms. Accordingly, a variable look-through interval is provided by the intercept equipment, and the transmitter must automatically adjust its look-through to coincide. The transmitter may then be said to provide time-sharing slave look-through for use with its complementary intercept equipment.

To extinguish the jamming signal is fundamentally a problem of modulation, because the plate voltage across the magnetron must be lowered until oscillation no longer occurs. The problem is difficult because of the relatively long time that the magnetron must remain off. When pulses of the order of 50 ms are conventionally coupled between high-voltage points and when the load looks like a low resistance, condensers of a prohibitive physical size are required. Consider the conventional magnetron circuit (Figure 10a) and assume that condenser C_2 must couple a 50-ms pulse into a magnetron having a dynamic impedance of 400 ohms. If the pulse is to maintain a flat top within 90 percent of maximum amplitude, the capacitance must be $1200\mu\text{f}$. Or consider Figure 10b, an intermediate development of the present transmitter using the circuits shown in Figures 6 and 7. Although condenser C_2 is eliminated, C_1 is still necessary to couple into the modulator grids which are at high potential and have a grid leak of 12,000 ohms. This condenser must be $96\mu\text{f}$ and must be rated for 3000 v, which is out of the question for aircraft service. The solution uses direct coupling between the preamplifier circuits and the magnetron, and all the modulating circuitry is on the high voltage side of the magnetron which eliminates both condensers (Figure 10c). A positive look-through pulse from the intercept gear is applied at "TRIG-IN" (Figure 8) through the $1000\mu\text{f}$ condenser to the grid of the normally off section of the multivibrator, V12. Since the 10,000-ohm load in the screen of V13 is effectively in shunt with the grid of V12, the pulse is differentiated. The result is a positive trigger produced by its leading edge which initiates the multivibrator action and a negative trigger produced by its trailing edge which terminates the action. The original pulse is then reproduced by the multivibrator, and the net result is an effective means of coupling the lengthy look-through pulse into the circuits through a small high-voltage condenser. The multivibrator constants are chosen somewhat longer than the maximum look-through interval; should the negative trigger fail, the multivibrator will return to normal of its own accord. The plates of V11 and V12 are connected together so that the look-through pulse is applied to

⁸ Williams, J. R., "Random Look-Through for Jamming Transmitters," NRL Report 3817 (Confidential), 13 June 1951

the 829B grids directly along with the noise signal. The pulse, negative and of sufficient amplitude to drive the 829B's nearly to cutoff, reduces the magnetron current to a value where oscillation cannot occur.

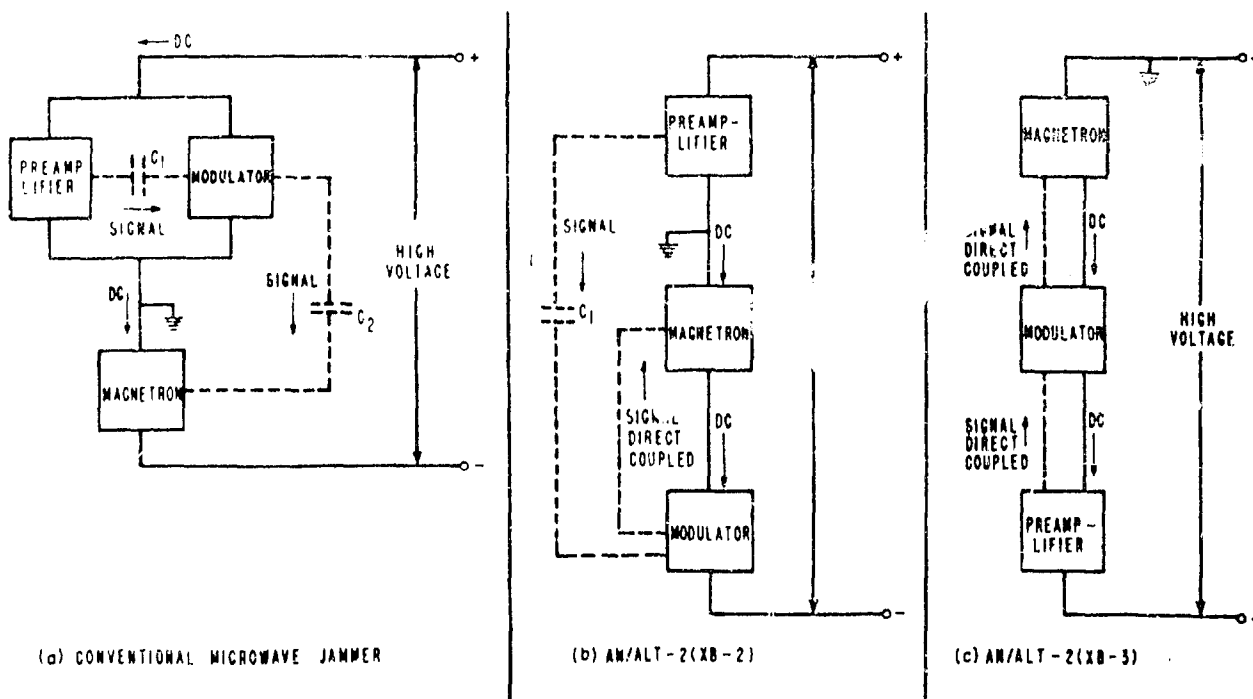


Figure 10 - Types of coupling for magnetron jammers

This effectively solves the first big look-through problem, namely, that of coupling circuits for the relatively long look-through pulse. The second difficulty is the stabilization of the dc voltage across the power supply and at other critical points in the circuit. The filter in the high-voltage power supply is designed to adequately attenuate ripple and modulation components. If, however, the supply is unloaded during the look-through period, the output filter condenser would have to be on the order of 100 μ f for proper regulation during the off period. Further, the screen grids of the 829B tubes would require a large capacity, and worse yet, there would be no current to maintain the voltage across the multivibrator circuit. All these problems are solved by the simple expedient of substituting an alternate load to replace the magnetron and the 829B tubes during the look-through pulse. Since the look-through pulses will be relatively infrequent, at most one every few seconds, the duty cycle of the alternate load will be low and need only stand the high voltage and carry the relatively high current for the look-through interval. The 3D21A tube, V8 (Figure 8), is well-suited for this service. The plate of this tube and its 8200-ohm plate load will shunt the modulator and magnetron while the screen shunts the screens of the 829B tubes. When the transmitter is functioning normally, the grid of the 3D21A is biased to cutoff by the voltage developed across the plate load of the normally "on" section of the multivibrator. During look-through, this bias drops to zero so that the 3D21A plate current replaces the magnetron current and its screen current replaces the 829B screen current. There is then a reasonably constant load on the power supply and a regulated voltage on the screen grids of the modulator. In addition, the current to the preamplifier and multivibrator is stabilized.

Using the circuits described, exceptionally long periods of look-through are possible. Theoretically, the only two factors that limit the length of the look-through interval are (a) cooling of the magnetron heater because of insufficient back heating and (b) the limit of the time that the 3D21A can stand the large plate dissipation. The multivibrator constants would also limit the interval, but since the condensers are low-voltage units, considerable capacity can be used without exceeding space limitations.

Corollary Circuits

Additional circuits for the transmitter are generally conventional. The dc power supply, a bridge-type rectifier, normally delivers 220 ma at about 2700 v and has a maximum rating of 250 ma at 3000 v. The two-section filter reduces ripple to less than 1.5 v. Total input including power for heaters, controls, and blower is on the order of 1 kw. Appropriate automatic controls and thermal switches reduce manual manipulation and provide for the necessary safety features.

Physical Characteristics

Physically, emphasis has been placed on the reduction in size and weight of the transmitter. Figure 11 shows an early X-band jammer using the 50-w A131 and later the A136 without permanent magnets (note the heavy electromagnetic structure). This equipment occupied about 20 cubic feet and weighed nearly 350 pounds. The AN/ALT-2 (XB-2) (Figure 11), the forerunner of the subject transmitter, weighed 150 pounds and was housed in two extra high, one and a half C2-D cabinets. Look-through was not provided, and the variac method of starting contributed to its bulk. In April of 1950, NRL accepted the problem of redesigning this equipment to meet aircraft specifications and to incorporate the present model of the tube. The result, the AN/ALT-2 (XB-3) (Figure 13), is housed in a standard one and a half C1-D cabinet (Figure 5) 7-1/2 inches high by 15 inches wide and 19 inches deep. It weighs 76 pounds.

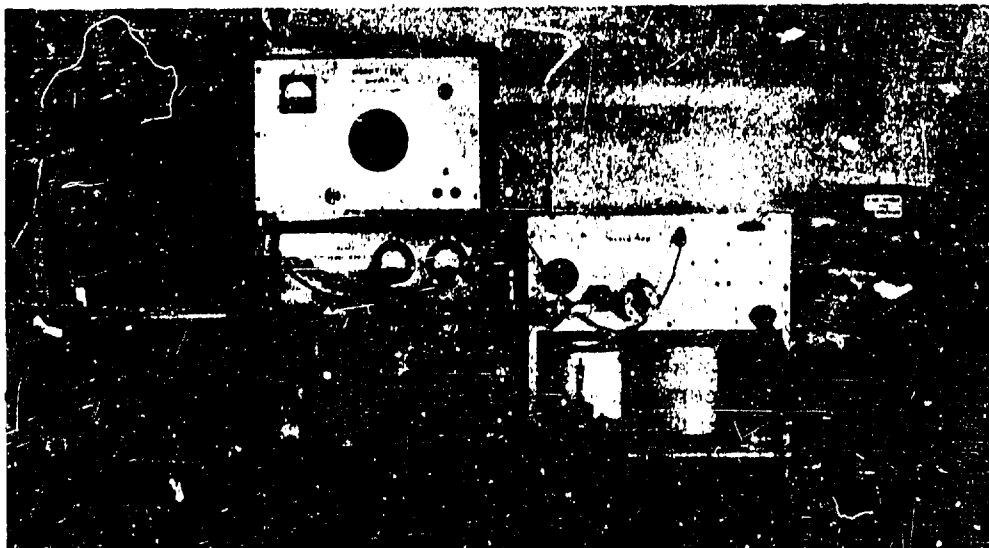


Figure 11 - X-band jammer using A136 magnetron

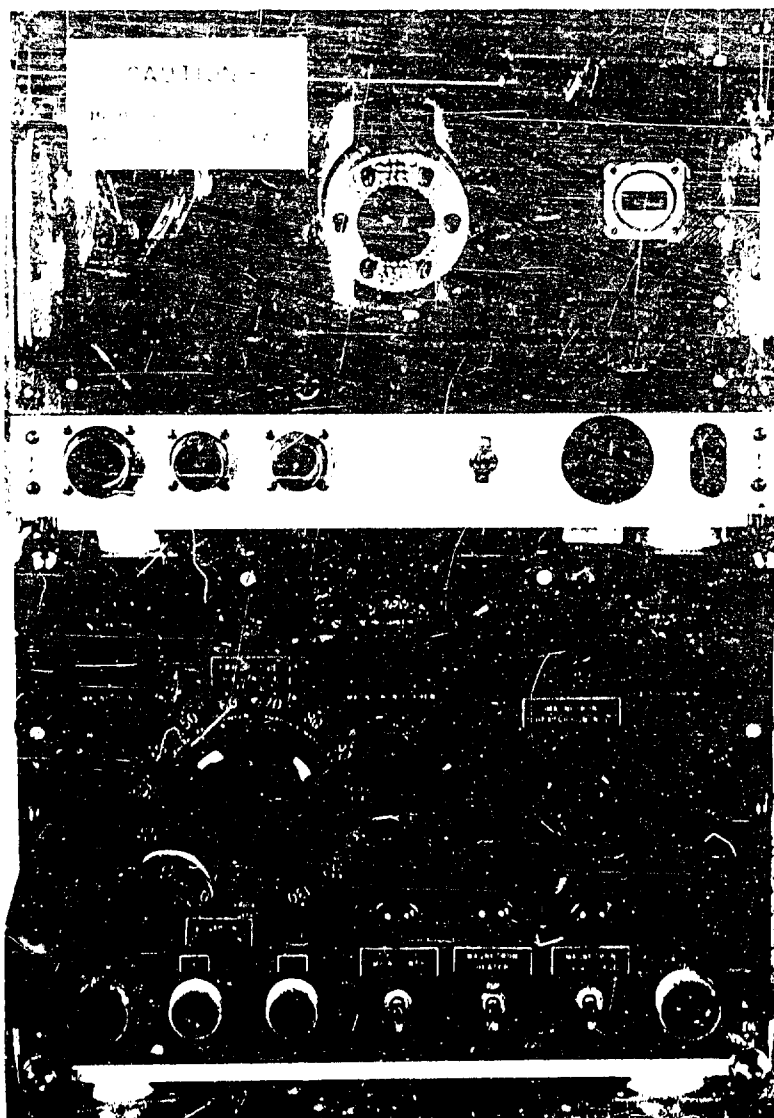


Figure 12 - Airborne jammer using Al36 magnetron
with permanent magnet

Cooling

Because high-altitude operation was specified, considerable thought was given to the problem of cooling, and since pressurization and liquid cooling are complicated, an additional heat interchanger is needed to transfer the heat outside the cabinet. Conversely, because it seemed feasible to isolate the high-voltage components against arc-over without undue insulation problems, pressurization was abandoned, and calculated on the basis of constant pounds of air per minute for all altitudes, 200 cfm of cooling air was found necessary. Circulation of this air through the cooling fins on the tube end and through the cabinet requires static pressure on the order of 3.5 inches of water. A compact commercial blower conforming to these specifications was located and may be seen at the rear center of the

ALT-2 (Figure 13). Note also the securely mounted and well-insulated arrangement of the modulator and amplifier circuits located between the blower and the magnetron.

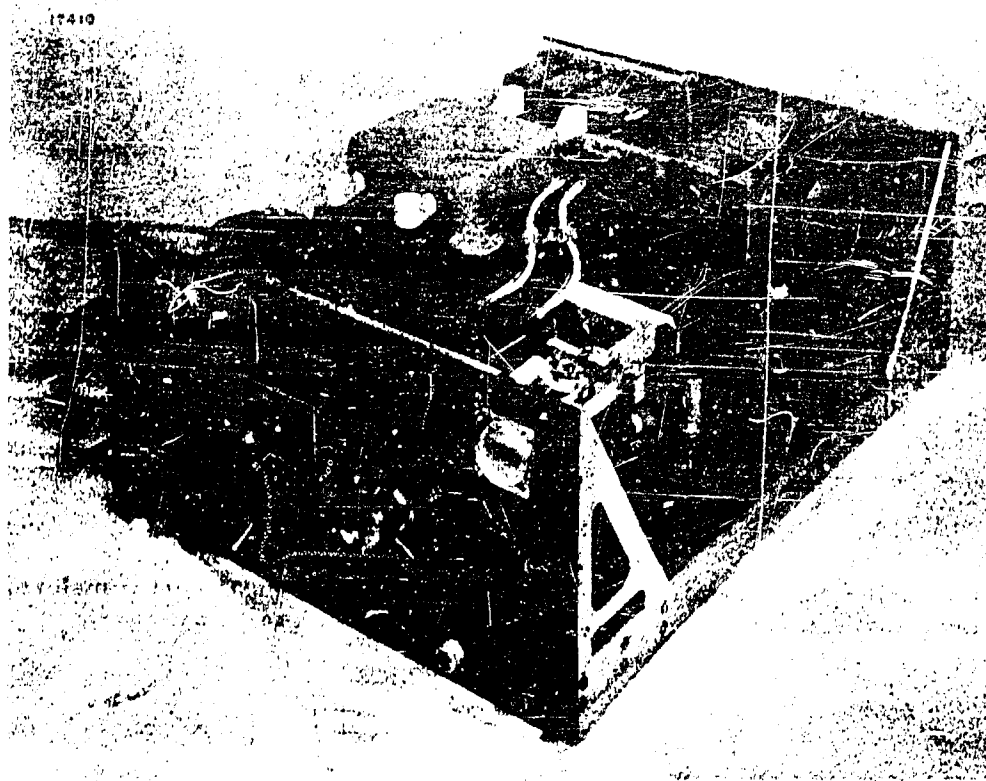


Figure 13 - AN/ALT-2 (XB-3) (uncased)

High-Voltage Problems

Transformer and choke terminal bushings were an additional source of concern because of the high voltage on these points. Normally, a relatively large terminal is required at high altitude for potentials of the order of 3000 v, and when it is necessary to use up to six such terminals on one transformer, the size of the unit becomes excessive. In collaboration with the Chemistry Division at NRL, a butyl rubber boot was developed to fit over a relatively small terminal (Figure 14). Under test, this terminal (Lundy No. 4762) with the boot withstood 5000 v, rms under an atmospheric pressure of 3.4 inches of mercury. Figure 15 shows the rectifier filament transformer with boots, and Figure 16 is a base view of the ALT-2 showing the boots and some chassis details.

Tuning

A knurled knob on the magnetron (Figure 1) projects through the front panel of the transmitter (Figure 13) and provides for manual tuning; a calibration chart is used in frequency determination ascertained by a micrometer-type indication on the side of the knob. Since a proposal has been made to furnish the tube with a built-on tuning mechanism adaptable to remote control, no elaboration of this timing device was attempted. The proposed tube,

which will be called the A1019, would be similar to the A1007 electrically. In view of this, it was not considered worthwhile to spend undue effort on tuning. When the new tube is made available, appropriate steps can be taken for improved tuning or remote control.

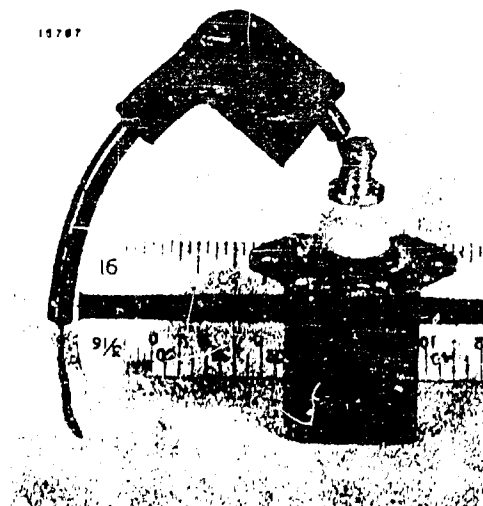


Figure 14 - Butyl rubber terminal cover and terminal

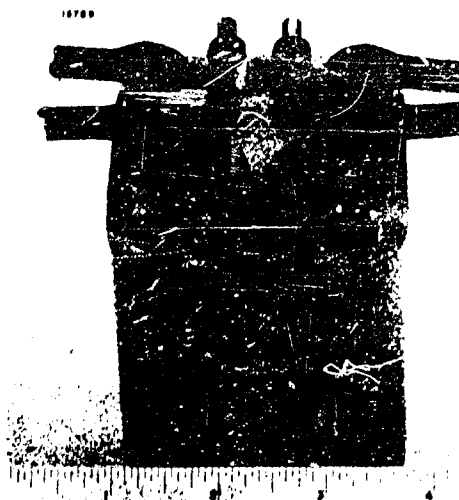


Figure 15 - Filament transformer with terminal covers

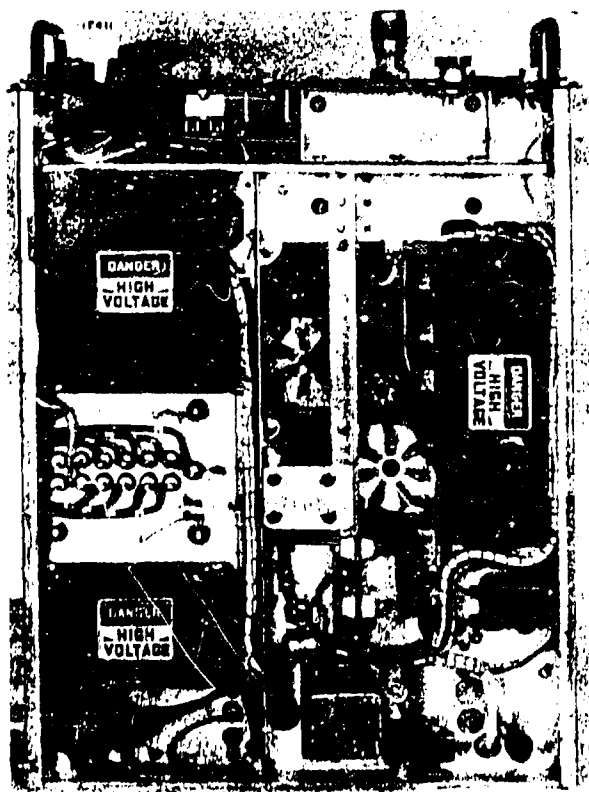


Figure 16 - X-band jammer AN/ALT-2 (XB-3) (base view)

SUMMARY

NRL has developed an airborne random-noise jammer that conforms closely to military specifications and has an output of 130 to 200 w. Occupying a standard one and a half C1-D rack and weighing 76 pounds, the unit is tunable over a range of 8875 to 9825 Mc. Automatic slave look-through provides for use of the intercept equipment during the jamming period. In volume and weight, this transmitter is believed to be smaller than any other microwave jammer of comparable power.

The unit is now at NATC, Patuxent, Maryland, for airborne evaluation tests; NRL has been requested to furnish personnel for test observation and to provide the necessary consultative service for implementation of the program. Results of these tests will form the basis for further work in the X-band jammer program.

The A1007, used as the X-band power source, would be well-suited to transmitting equipment that provides wide-band random-noise jamming except that it does have a high pushing factor and a short life. The pushing factor can be reduced at the expense of some power, and it is hoped that improved manufacturing techniques will produce more reliable tubes. The important fact, however, is that at present there are no other developed sources of X-band power suitable for aircraft use, and until such are available, a definite need for this tube exists.

ACKNOWLEDGMENTS

The author gratefully acknowledges the valuable technical assistance contributed by Mr. F. J. Hollweck, unit head in charge of this development. Credit for an unusually compact and lightweight transmitter is largely the result of the mechanical design work under the supervision of Mr. J. W. Burkert. Further valuable contributions were made by Mr. Ralph C. Taylor of the High Polymers Branch in the Chemistry Division of the Naval Research Laboratory, and by Mr. B. W. Graham and Mr. L. L. Thornton of the Countermeasures Branch.

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(NRL REPORT 3899)

AIRBORNE X-BAND JAMMER AN-ALT-2 (XB-3)

MILES, J.M. 27 NOV '51 21PP PHOTOS, DIAGRS

COUNTERMEASURES, ELECTRONIC

ELECTRONICS (3)

JAMMERS

STATIC AND INTERFERENCE (4)

TUBES, MAGNETRON^S

NOISE MODULATED

TRANSMITTERS, RADAR

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