

DECLASSIFIED

2027

NRL Report 5157

Copy No. [redacted]

# THE ALQ-H(X) COUNTERMEASURES SYSTEM

[UNCLASSIFIED TITLE]

DECLASSIFIED by NRL [redacted]

Declassification [redacted]

Date 11/27/2013

Authority [redacted]

Lynwood A. Cosby

Countermeasures Branch

Radio Division

[redacted]

# [redacted]

July 16, 1958

[redacted]



DISTRIBUTION STATEMENT A APPLIES

Further distribution authorized by

UNLIMITED

only

NAVAL RESEARCH LABORATORY

Washington, D.C.

DECLASSIFIED

DECLASSIFIED

NRL Report 5157

**THE ALQ-H(X) COUNTERMEASURES SYSTEM**

[UNCLASSIFIED TITLE]

**AN X-BAND COUNTERMEASURES  
DECEPTION REPEATER**

Lynwood A. Cosby

Countermeasures Branch  
Radio Division

July 16, 1958



**NAVAL RESEARCH LABORATORY  
Washington, D.C.**

DECLASSIFIED

CONTENTS

Abstract	ii
Problem Status	ii
Authorization	ii
INTRODUCTION	1
X-BAND RADAR CHARACTERISTICS	2
REPEATER-JAMMER SYSTEM REQUIREMENTS	3
RF Considerations	3
Video Considerations	9
DESCRIPTION OF TRAVELING-WAVE AMPLIFIER TUBES AVAILABLE FOR SYSTEM USE	10
ALQ-H(X) REPEATER DESIGN	13
FIELD EVALUATION	19
EQUIPMENT STATUS	21
CONCLUSIONS	25
REFERENCES	25

DECLASSIFIED

ABSTRACT

[REDACTED]

A 1-kw X-band broadband electronic deception repeater capable of destroying the angle coordinate tracking accuracy of operational types of conical scanning radars has been developed for installation in naval penetration-attack aircraft. Utilizing traveling-wave type rf power amplifiers, the system has, inherently, fast response, wide bandwidth, and multiple signal-handling capacity. This experimental equipment, designated the ALQ-H(X), has been subjected to field evaluation and has demonstrated an operationally useful technique. Flight tests utilizing a P2V aircraft and both ground-based and airborne radars have been conducted and are continuing.

While the present experimental equipment fulfills a major operational requirement of long standing and has great future potential, it is felt that major improvements in equipment performance and efficiency can be made with new tube design concepts. A set of permanent-magnet-focused traveling-wave tubes suitable for use in this system are presently under development and should be completed within a year. Integration of these tube types in the system will result in a reduction in size and weight and power requirements.

New approaches to the problem of reduction in system delay are being studied, and testing of the equipment under more severe signal environments is planned.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

NRL Problem R06-10  
Projects NA 442-002 and NE 071-200-1  
BuAer No. AV-42001  
BuShips No. S-1263

Manuscript submitted May 13, 1958

DECLASSIFIED

DECLASSIFIED

AN X-BAND COUNTERMEASURES DECEPTION REPEATER

[~~Secret~~ File]

INTRODUCTION

The requirement for an electronic radar countermeasure suitable for installation in penetration-attack naval aircraft has been long outstanding. Various equipments have been under continued development to fulfill this requirement; however, a universal disadvantage has been recognized: the capabilities of conventional systems which lie within the size and weight limitations imposed by naval aircraft installation are insufficient for the anticipated environment of modern electronic warfare. This impasse was the stimulus for the development of repeater types of active countermeasures. It was recognized that significant system advantages, such as power capability, response time, bandwidth, and security of operation existed as potentialities for the repeater-jammer. Conversely, it was also recognized that the repeater-jammer could not be considered as a "universal" jammer.

While it is not clear what the final capabilities of the various types of active electronic countermeasures systems under development will be, it is now certain that for specific modes of countermeasures action, the repeater-jammer described in this report offers an operational potential never available previously. An accurate assay of the usefulness of the technique remains as a task for the operations element. Toward this end, NRL has been asked for and is supplying six prototype equipments for technique evaluation purposes. Five of these equipments have been made available for operation in S band and one in X band.

The contemplated threat to naval aircraft exists in three basic enemy potentialities: manned interceptors with either rocket or conventional weapon attack, air-to-air guided missiles and surface-to-air missiles. Each of these methods of attack, because of the accuracy involved, requires a target tracking function. Techniques for target tracking utilizing a pulse radar with conical scanning are highly developed and in widespread operational use, both in this country as well as in other countries, hence its primary importance from a countermeasures point of view.

The basic technique of the repeater to be described is to deceive the angular tracking circuits in conical scanning radar. This technique has been described previously (1), but it is reviewed briefly here. As the radar pencil beam scans about the geometric axis of its antenna system, a cone in space is generated. At the target position, this appears as a point of maximum field intensity generating a circle in a plane normal to the radar beam axis. Only for perfect tracking is the target at the center of the circle; this condition exists only theoretically, since the error-sensing circuits in the radar can correct an error only after its development. The target reflects to the radar a signal proportional to the incident field strength. It is seen, then, that the reflected signal received at the radar varies during each scan, yielding a maximum when the target lies closest to the circle of maximum intensity and a minimum when it lies at the most remote position. The error signal so derived is used in the antenna servo system for angular tracking of the target. By generating and transmitting a larger false signal which is out of phase with this signal, the target can protect itself from attack, since in attempting to correct the tracking error, the radar servo system drives itself further off target, developing, ultimately, large errors and probable track break.

DECLASSIFIED

The feasibility of this technique of exploiting the basic vulnerability of all known operational conical scanning systems was demonstrated by the construction and exhaustive testing of an S-band repeater system at various testing facilities. An operational requirement for a similar system operating in X band was immediately apparent.

That the problem of extension upward in frequency was not trivial was fully appreciated. Many problems not encountered at S band had to be solved; among them was the basic problem of power traveling-wave amplifiers in this band. Solution of most of the other problems accompanying the shift in frequency is difficult, but relatively conventional; however, the traveling-wave-tube problems demonstrated that a significant tube-development program was required before successful completion of an equipment development program.

#### X-BAND RADAR CHARACTERISTICS

The undertaking of the X-band repeater development was based on information derived from a study of typical operational radars of two basic types: airborne intercept radar for either missile or rocket attack and ground-based tracking radar for either gun-laying or missile guidance. Pertinent characteristics of two of these radar types are shown in Table 1.

Table 1  
Pertinent Characteristics of Two Typical Radars

Typical Radar	Peak Pulse Power (kw)	PRF (pps)	Pulse Width ( $\mu$ sec)	Maximum Range (naut mi)	Minimum Tactical Range (yards)	Scan (cps)	Antenna Gain (db)
Airborne APQ-50	180	1200	0.5	15	1000	conical nutation 50	33
Ground-Based Tracking M-25, Mod 3	250	1350 $\pm 10\%$	0.25	25	3500	conical nutation 30	38

A review of the salient characteristics of these and many other tracking radars indicated that a sufficiently comprehensive set of characteristics for tracking radars was the following:

1. Pulse width: 0.1 - 0.5  $\mu$ sec
2. Scan frequency: 20 - 200 cps

3. PRF: 200 - 2000 pps
4. Frequency: 8400 - 9600 Mc
5.  $\frac{\text{Beam power}}{(\text{Min range})^2} \leq 2.5 \times 10^2 \text{ watts/meter}^2$
6.  $\frac{\text{Beam power}}{(\text{Max range})^2} \geq 1 \text{ watt/meter}^2$

To determine the basic repeater system parameters, these requirements were used as a guide.

### REPEATER-JAMMER SYSTEM REQUIREMENTS

#### RF Considerations

A fundamental rf requirement for the repeater is rapid response. In order that the repeater be effective, it is necessary that its reply arrive at the radar and fall within its range gate. Since the shortest anticipated pulse width is 0.1  $\mu\text{sec}$ , it follows that the shortest gate to be encountered may not be more than several times longer than this value. In addition, techniques of leading-edge discrimination could conceivably be applied against a sufficiently late pulse.

Three possible contributions to the repeater delay exist. The first, transmission-line delay from the antenna locations to the repeater installation point, can be significant. The velocity of propagation of a guided wave is given by

$$u = \frac{c\lambda}{\lambda_g} = c \sqrt{\epsilon - \frac{(\lambda)^2}{(\lambda c)^2}}$$

where

- u = velocity of propagation
- c = velocity of light
- $\lambda$  = free-space wavelength
- $\lambda c$  = guide cutoff wavelength
- $\lambda_g$  = guide wavelength
- $\epsilon$  = dielectric constant (-1 for free space).

This indicates that the group velocity can decrease considerably as the frequency approaches the guide cutoff (2). However, over the usually accepted bandwidth of the guide,  $u > 0.64c$ . Then the delay time is  $d/u$ , or less than  $d/0.64c$ , where  $d$  is the length of the transmission line. This implies that good installation practice prohibits long receiving and transmitting lines.

A second possible contribution to the delay problem is the electrical length of the traveling-wave-tube chain. An estimate of this delay time can be had from a calculation of the electron transit times of the cascaded traveling-wave-tube stages. This quantity is plotted in Fig. 1 as a function of the beam voltage for a family of circuit lengths which are typical for available tube types. This estimate should be accurate to within  $\pm C$ , the beam coupling factor (3), which lies between 0.01 and 0.1; that is, the estimate should be accurate to better than 1 to 10 percent, depending upon the coupling factor for the tube in question. As can be seen from the curves for the tube types available for equipment purposes which operate at voltages greater than 3 kv, the delay due to the electrical length of the amplifier chain is small, less than 0.02  $\mu\text{sec}$  for two stages of amplification.

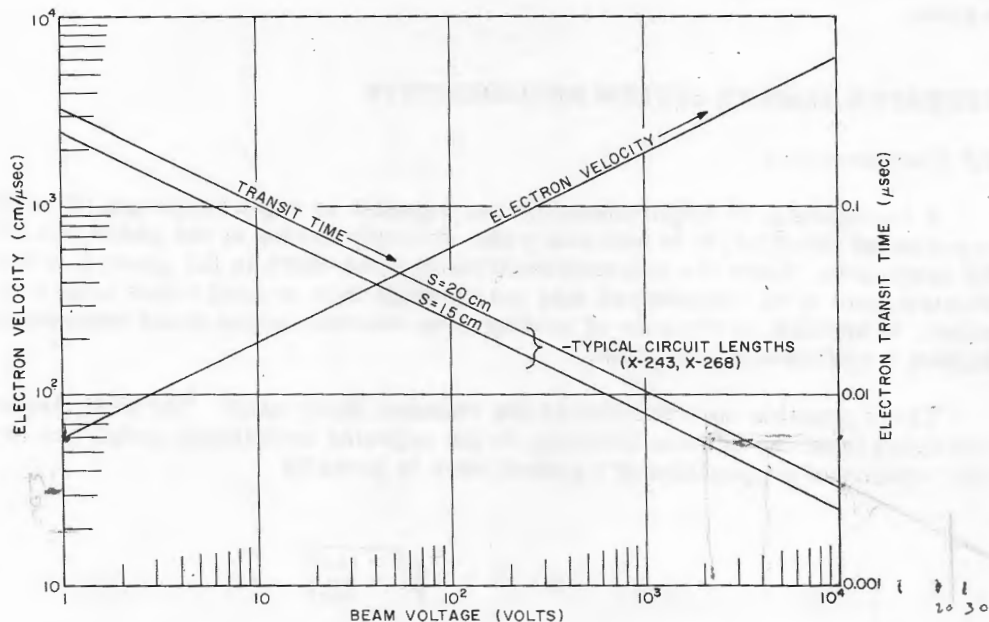


Fig. 1 - Electron velocity and transit time vs beam voltage for typical X-band TWT circuit lengths [Unclassified]

A third significant contribution to the delay is that resulting from video delay and rise time of the rf amplifier keying pulse. For the present system concept, this factor is significantly longer than the previous two contributions, where good installation procedures are followed. A discussion of the video delay problem is given in a later section.

It was indicated in the appendix to NRL Report 4811 (1) that a false-echo to true-echo ratio of 8.6 db is required to introduce a full half beamwidth of error. In terms of this ratio, the radar beam power, the minimum tactical radar range, and the target echoing area, the repeater maximum power output can be specified. The repeater output power  $P_T$  (on axis) is given by

$$P_T = P_R G_e G_T, \quad (1)$$

where

$P_R$  = the received power  
 $G_e$  = repeater electronic gain  
 $G_T$  = the output antenna gain.

Gain  $G_e G_T$  can be specified in terms of the echoing area  $\sigma$  of the target aircraft, the captive area  $A_R$  of the repeater receiving antenna, and the effectiveness ratio  $K$ .

$$G_e G_T = \frac{K\sigma}{A_R} \quad (2)$$

Then in terms of the radar parameters,

$$P_R = \frac{P_T' G_T' G_R \lambda^2}{(4\pi R)^2} \quad (3)$$

where

$P_T$  = radar transmitter power  
 $G_T$  = radar antenna gain  
 $\lambda$  = wavelength  
 $G_R$  = repeater receiving antenna gain  
 $R$  = slant range.

The above are the basic design relationships for the repeater.

Some typical calculations may be carried through to illustrate the design procedure. From above:

$$P_T = \left( \frac{P_T' G_T' G_R \lambda^2}{(4\pi R)^2} \right) \left( \frac{K\sigma}{A_R} \right),$$

or

$$P_T = \left( \frac{P_T' G_T'}{R^2} \right) \left( \frac{K\sigma}{4\pi} \right) \quad (4)$$

If

$$\frac{P_T' G_T'}{R^2} \leq 2.5 \times 10^2 \text{ watts/meter}^2$$

as noted above, then

$$P_T \leq 10^2 (2.5) \frac{K\sigma}{4\pi}$$

For a typical case, assume that  $\sigma = 25 \text{ meters}^2$  and  $K = 10$ , then

$$P_T \leq \frac{(2.5)(250)(10^2)}{4\pi} = 5.3 \text{ kw.}$$

With an antenna gain of 4, the repeater output is  $1/4 P_T$ . A graphical representation of Eq. (4) is given in Fig. 2.

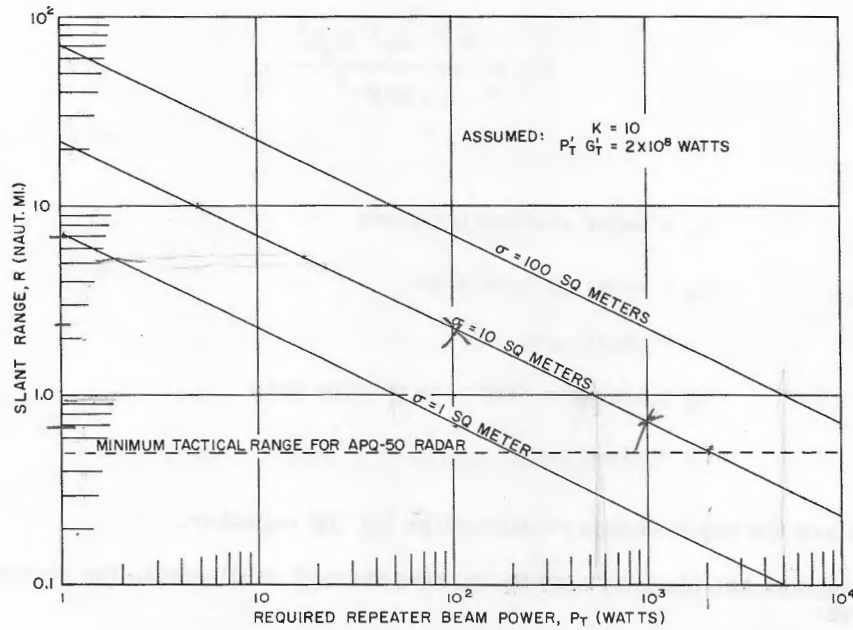


Fig. 2 - Required repeater beam power as a function of range for various aircraft echoing areas  $\sigma$

The required repeater gain is given by Eq. (2).

$$G_e G_T = \frac{K\sigma}{A_R}$$

and where

$$A_R = \frac{G_R \lambda^2}{4\pi}$$

$$G_e G_T = \frac{4\pi K\sigma}{G_R \lambda^2}$$

OR

$$G_e = \frac{4\pi K\sigma}{G_R G_T \lambda^2}$$

It is probable that  $G_R = G_T$ , SO

$$G_e = \frac{4\pi K\sigma}{G^2 \lambda^2} \quad (5)$$

This relationship is shown graphically in Fig. 3, where G is the antenna gain.

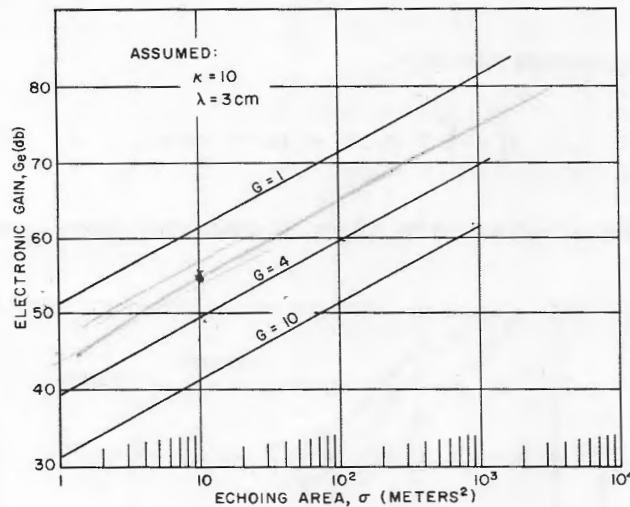


Fig. 3 - Required electronic gain vs aircraft echoing area for repeater antenna gains G [SECRET]

For the case above, i.e.,  $\sigma = 25$  meters<sup>2</sup>, and for an antenna gain of 4,

$$G_e = \frac{250\pi}{4\lambda^2} = \frac{196}{(0.03)^2} = 2.2 \times 10^5 = 53.4 \text{ db.}$$

The threshold sensitivity required of the repeater must be greater than the minimum signal level received at the greatest tactical range. Account must also be taken of the fact that as the radar develops error, the effective radar antenna gain in the direction of the target is decreased. If it is assumed that the repeater is to respond 20 db down on the radar beam skirt, then the computed sensitivity for the repeater must be increased by this amount. The minimum power calculation is made from Eq. (3)

$$P_R = \left( \frac{P_T' G_T'}{4\pi R^2} \right) \left( \frac{G_R \lambda^2}{4\pi} \right)$$

Figure 4 is a graphical representation of this relationship. If

$$\frac{P_T' G_T'}{R^2 (\text{max})} \geq 1 \text{ watt/meter}^2$$

then

$$P_R = \frac{1}{4\pi} \left( \frac{G_R \lambda^2}{4\pi} \right) = G_R \left( \frac{\lambda}{4\pi} \right)^2, \quad (6)$$

and for a receiving antenna gain of 4,

$$P_R = 4 \left( \frac{\lambda}{4\pi} \right)^2 = 0.25 \times 10^{-4} \text{ watts} = -16 \text{ dbm},$$

and when sensitivity is increased by 20 db, as discussed above, gives a requirement of -36 dbm.

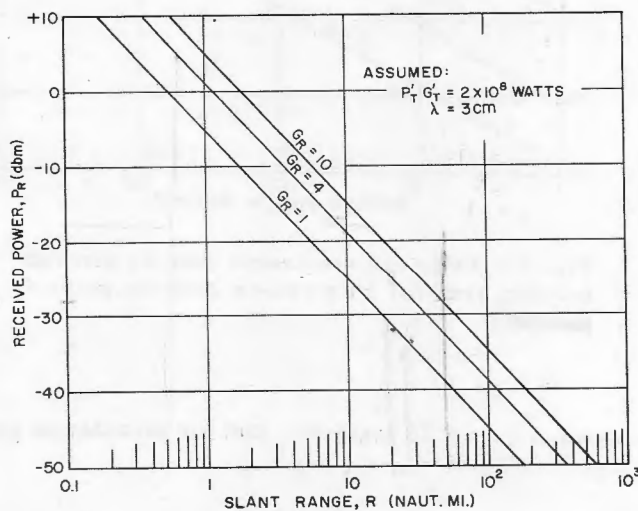


Fig. 4 - Received power vs slant range for receiver antenna gains  $G_R$

The important repeater characteristics can be seen to be a function of tactical considerations, victim radar characteristics, and repeater installation parameters. The maximum delay permitted is indirectly related to the minimum pulse width to be encountered and is about  $0.1 \mu\text{sec}$ . It should be noted that the power output requirement is a

direct function of target echoing area, radar beam power, and minimum slant range at which the repeater must perform, as well as the effectiveness parameter  $K$  and the repeater output antenna gain. A typical calculation indicates a repeater power output requirement of about 1 kw or greater. The gain required is a function also of the radar echoing area of the target aircraft, the antenna gains, and the effectiveness ratio  $K$ , and it is approximately 53 db for the chosen case. The threshold sensitivity requirement is determined by the radar beam power characteristics and the input repeater antenna gain and is, for the case considered, -16 dbm. Allowance must be made for a 20-db effective decrease in gain as radar error is developed. No allowance is made for transmission line losses between the repeater installation and the antenna locations. Because of the delay problem, these lines must be made short, hence only a slight increase in power and gain over that specified need be included.

The rf bandwidth required for the repeater should be as great or greater than the maximum frequency spread of the various radar systems. For the present, it is supposed that a bandwidth greater than 8400 - 9600 Mc would be necessary.

The antenna problem associated with the repeater installation is comparable to that involved in any active electronic countermeasures system, except for an additional constraint. The coverage problem is universal; just how it is to be solved has not been determined. The problem here involves both the tactical situation and the physical problem of installing antennas on high-performance aircraft, i.e., the determination of what sectors need protection, and in addition, once these sectors have been determined, how it is to be accomplished practically. The additional constraint peculiar to the repeater is that two well-isolated antennas are required. These are necessary, since the repeater must simultaneously transmit and receive. If the antennas are not well isolated, i.e., if isolation is not greater than the electronic gain, the system when keyed will oscillate at the most favorable frequency in the band, i.e., when the loop gain is greatest (greater than or equal to unity) and the phase shift is an integral multiple of  $2\pi$  radians. In practice, this requirement has been easily met, since isolations of the order required can be obtained at fairly close locations. Although this specific repeater antenna installation problem can be solved, it is significant that the general problem of active electronic countermeasures configurations of tactical aircraft has not been solved either for repeaters or for other active electronic countermeasures systems.

#### Video Considerations

A primary video requirement of the repeater is rapid response. Since a gated rf amplifier is utilized, the rf amplifier must be turned on almost instantaneously in order to reply for a large percentage of the pulse duration and return to the radar and fall within the range gate. Delay times less than  $0.1 \mu\text{sec}$  are desirable. This requirement has been difficult to meet in practice; however, it appears that an effective delay of  $0.12 \mu\text{sec}$  was attained in the present equipment.

The other basic video requirement of the repeater-jammer involves the deception function. Just what the optimum configuration here is, is not presently known. The function of the deception loop is to generate an effective deception modulation from an analysis of the detected video and to remodulate the rf output accordingly. A simple video strip followed by a second detector, phase inversion, and remodulation appears to be the best solution from the point of view of simplicity and suitability. However, problems exist for the case of the multiple-signal environment in which the signal levels and the scan frequencies may be quite different.

It is desirable that the repeater not respond to searchlighting search radar. An attempt to inhibit the repeater response under this condition was based on the fact that usually search radar does not scan conically. Only signals which were scan modulated were operated upon by the repeater. This was successful, at the expense of a somewhat lower demodulation sensitivity; i.e., the demodulation sensitivity was set at a level which might, in the case of extremely tight tracking, be mistaken by the repeater for a searchlighting search radar. Another technique utilized was to delay response for a time equivalent to the time a sweeping radar is on target.

An analysis of the various video functions reveals that the most serious problem, as far as the video functions are involved, is the delay time. The multiple-signal problem can be solved by assigning a priority on the basis of signal strength, or by replying to all the signals with the false scan of the strongest signal present on all signals. Again, components of the scan frequency of all signals present can be placed on the output pulse train by various means.

The video delay problem can be approached in a number of ways. The obvious solution is good video amplifier design. Experience with the design of conventional video amplifiers indicates that the rise time and delay time, which are not one and the same, are, however, functions of the same design parameters. Within limits, improvement of one yields an improvement of the other. Wideband design and compensation techniques should be employed. Another solution is the use of novel video amplifier techniques, such as secondary-emission electron multiplier tubes. Transit times for a decade amplifier can be as short as 20 millimicroseconds (4).

Yet another solution involves a different approach. The traveling-wave amplifier output tube can be operated in the "on" condition instead of being gated, as is presently done. It appears that the delays involved utilizing this technique can be made a minimum (the delay would be the rf delay of the traveling-wave tubes); however, the beam power required would be significantly increased. Traveling-wave tubes which would satisfy this system requirement are only now becoming available at lower power outputs.

#### DESCRIPTION OF TRAVELING-WAVE AMPLIFIER TUBES AVAILABLE FOR SYSTEM USE

In the last section, it was shown that a power output of about 1 kw is required for the most severe tactical consideration. Early in this development, an amplifier meeting this requirement was obtained from Federal Telecommunications Laboratories, Inc., for system evaluation. Designated the X-210, it was a classified (Confidential) tube developed under Air Force contract. It was reported to have a gain of about 30 db and a power output greater than 1 kw over the band 8500 to 9600 Mc. A photograph of this tube is shown in Fig. 5. The tube requires about 2000 gauss over the active region (about 6-1/2 in.). This field is provided by a liquid-cooled electromagnet of aluminum foil construction. The magnet requires about 1 kw of dc power, but it weighs less than 15 pounds. NRL tests have revealed a low-level oscillation in the tested sample, but otherwise fairly satisfactory performance was obtained. The beam voltage is 8 to 9 kv at a current of about 1 ampere. Since the tube was not constructed for grid pulsing, cathode pulsing was necessary. This caused a severe system problem in obtaining the required rise time of the voltage pulse. Table 2 gives the pertinent operating characteristics.

Because the gain of this tube fell somewhat short of the anticipated 30 db, it was felt necessary to utilize a nominal 10-watt driver tube in order to obtain the maximum power output and the required system gain. For this purpose, the Federal X-243G tube

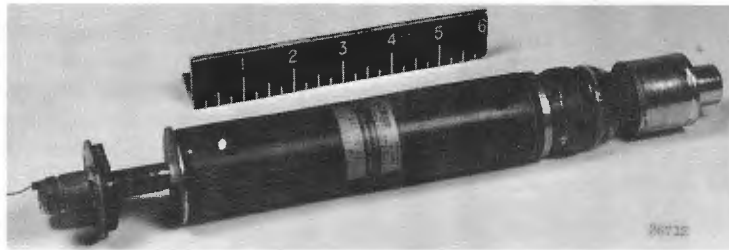


Fig. 5 - Federal X-210 1-kw X-band traveling-wave amplifier tube [Unclassified]

Table 2  
Typical Operating Conditions for  
Traveling-Wave Tube Type X-210\*

Circuit Parameter	Typical Value
Operating frequency	8500-9600 Mc
Heater voltage	6.3 v
Heater current	4.5 a
Beam voltage	7.8 kv peak
Beam current	1.35 a peak
Collector current	1.10 a peak
Pulse width	1.0 $\mu$ sec
Duty cycle	0.001
Solenoid field	1600 gauss
Power output	3.3 kw peak
Power gain	29 db
Small-Signal gain	35 db

\* From FTL Data Sheet for  
Tube #116

was evaluated (5). A photo of this tube is given in Fig. 6. The envelope size and appearance is quite similar to the X-210. The rf characteristics of the tubes evaluated revealed high gain, but not quite 10-watt output. The power obtained, however, was considered adequate to drive the X-210 to saturation. The operating characteristics of this tube are given in Table 3. A focusing field of 900 gauss is required and is provided by a liquid or forced-air-cooled electromagnet.

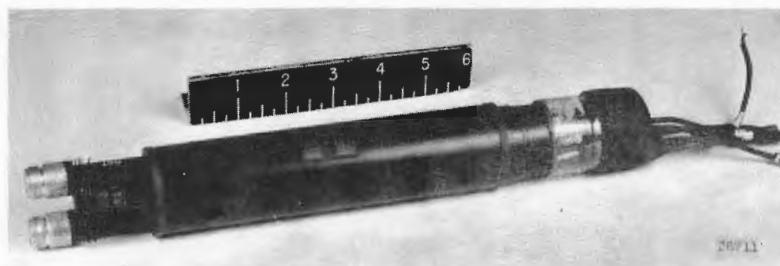


Fig. 6 - Federal X-243G 10-watt traveling-wave amplifier tube [Unclassified]

Table 3  
Typical Operating Conditions for  
Traveling-Wave Tube Type X-243G\*

Circuit Parameter	Typical Value
Operating frequency	8000-9600 Mc
Heater voltage	6.3 v
Heater current	2.3 a
Beam voltage	2800 v
Beam current	48 ma
Focus anode voltage	+10 v (resp. cathode)
Duty cycle	cw
Power output	10 w
Power gain	35 db
Small-Signal gain	42 db
Uniform focusing field	900 gauss

\* From FTL Data Sheet for  
Tube #230

Some time after the active design of the repeater system had begun, Federal made available the X-268 traveling-wave tube. Electrically this tube is similar to the X-210, except for the provision for grid pulsing. The grid operates at approximately +300 volts with respect to the cathode and biases to cutoff at less than -100 volts. The X-210 tube was replaced with this tube after its evaluation. Besides reducing the video drive requirements, some decrease in system delay was obtained by utilizing grid pulsing with this tube.

From a system point of view, the large focusing-field requirement for these X-band tubes is quite objectionable. The increased field requirement at X band over the S-band requirement is an inherent result of dimensional scaling of the helix circuit S-band designs to X band. Upon scaling, dimensions decrease inversely as the wavelength ratio. This results in a helix diameter about 1/3 of that at S band. Since the same or a larger beam power is required down the helix, it can be seen that the current density is greatly increased. This results in a greater space-charge factor, and hence larger focusing-field requirements to confine the beam to the smaller area.

It was considered necessary that a new approach to the X-band tube design be initiated. A basic design requirement should be a modest focusing-field power demand. This might be had at the expense of a lower bandwidth. This approach is a requirement of recent contracts with Litton Industries, Inc. (6), and Stanford University (7).

Subsequent to the planning of the NRL repeater system, Huggins Laboratories, Inc., has developed a 1-watt traveling-wave amplifier that operates in X band. Designated the HA-9, it requires a focusing field of only 600 gauss. Stanford University, under government sponsorship, has devised a method of periodic permanent-magnet focusing of this tube. These developments are of considerable interest to NRL.

Federal Telecommunications Laboratories, Inc., has developed a 100-watt tube design that requires a 2000-gauss field, but only over a very short interaction region (X-267). Tubes of this variety are being procured for evaluation purposes.

Because of the serious nature of the tube problem in this band, much effort is presently being devoted to this aspect of the system problem at NRL. Concurrent studies and tests of existing tube types have aided greatly in determining the proper approach to a new tube development program. It is considered that the lack of suitable traveling-wave-tube types is the most serious present obstacle to the development of the X-band repeater. Success or failure of the system effort will be a direct result of the present tube development program.

#### ALQ-H(X) REPEATER DESIGN

The ALQ-H(X) repeater (Fig. 7) is a direct implementation of the system concept arrived at to fulfill the requirements generated and outlined in this report. It utilizes a two-tube amplifier chain, the X-268 driven by the X-243G\*, and appropriate video and control circuitry. The system provides a nominal 60 db of rf gain with a power output of about 1 kw. The video circuitry was designed to yield a delay of less than 0.1  $\mu$ sec. The maximum pulse width that can be repeated is 1.0  $\mu$ sec, and the maximum duty cycle is 0.005. This provides for simultaneous response to as many as ten typical radars.

\* The production equivalents for the X-268 and the X-243G are respectively the D-95 and the 6996.

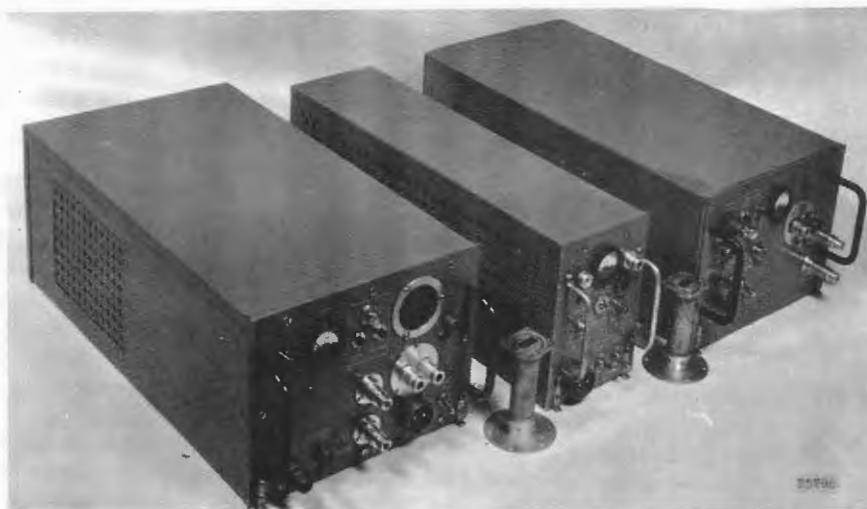


Fig. 7 - ALQ-H(X) repeater system flyable breadboard  
[Unclassified]

A block diagram of the system is shown in Fig. 8. It is basically similar to the S-band system previously reported, except for the video loop. Here, instead of having separate video channels, the limiting video for the gate and the agc video for scan demodulation, both functions are performed in one amplifier chain. The video is first subjected to agc action. This removes static input level differences resulting from the wide dynamic level at the input antenna. The demodulator input is taken from the output of this section. The video is then subjected to about 20 db of limiting action to remove any scan modulation that may be present in the video. This video is then fed to the modulator, which is gated from the rectangular wave generator voltage, synchronized with the audio signal from the demodulator. The result is similar to the action of the previous S-band system (1), except in the case of multiple signals. In the separate limiting amplifier scheme, all signals above threshold regardless of level arrive at the modulator, whereas in the present scheme only those signals which lie within a 20-db dynamic range will arrive at the modulator. Again, the modulation envelope on the strongest signal is applied to all the signals within the 20-db dynamic range.

In the present system, the video-signal input is detected from the rf, which is taken through a 30-db directional coupler at the junction between the driver and output rf stages. The amount of decoupling utilized was dictated by the noise figure of the driver amplifier. Close coupling to the driver stage yielded an insurmountable noise problem in the video amplifier. It is apparent that a maximum of about 10-db video gain advantage has been realized by dividing the power at the output of the driver stage rather than at the input. In addition, however, about 3 db more rf gain is available by utilizing this arrangement, since it would probably have been necessary to use a 3-db coupler at the input in order to obtain sufficient video sensitivity. The latter arrangement has the advantage of eliminating any possibility of saturation of the driver stage in strong signal environment, but it lacks the crystal burnout protection of the former.

The video amplifier shown in Fig. 9 was designed for approximately 8-Mc bandwidth. The delay and rise-time combination was intended to be less than 30 m $\mu$ sec. Peaking was utilized for optimum performance. The 6CL6's deliver an 80-volt pulse which is

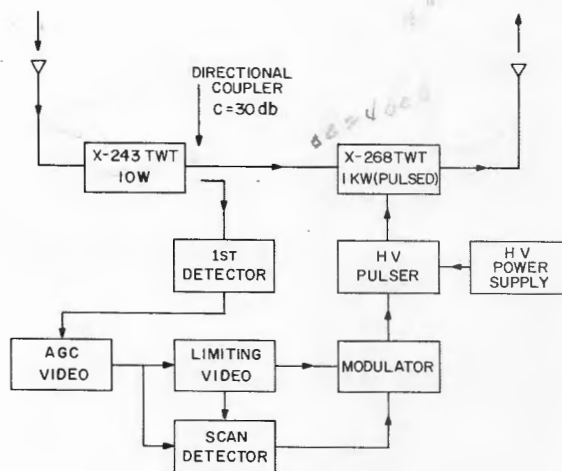


Fig. 8 - Repeater system block diagram

transmitted through a pulse transformer to a 180-ohm transmission line and to the pulser shown in Fig. 10. This consists of a transformer-coupled two-stage amplifier, two 4X250F's driving a 4PR60A. A revision of this circuit to accommodate the X-268 is shown in Fig. 11. Here the 400-volt pulse developed by the 4X250F's is cathode coupled to the X-268. The calculated delay time for the original pulser is less than 0.06  $\mu$ sec; in actuality it is somewhat less, due to additional grid limiting. The delay of the revised circuit using the X-268 was somewhat less.

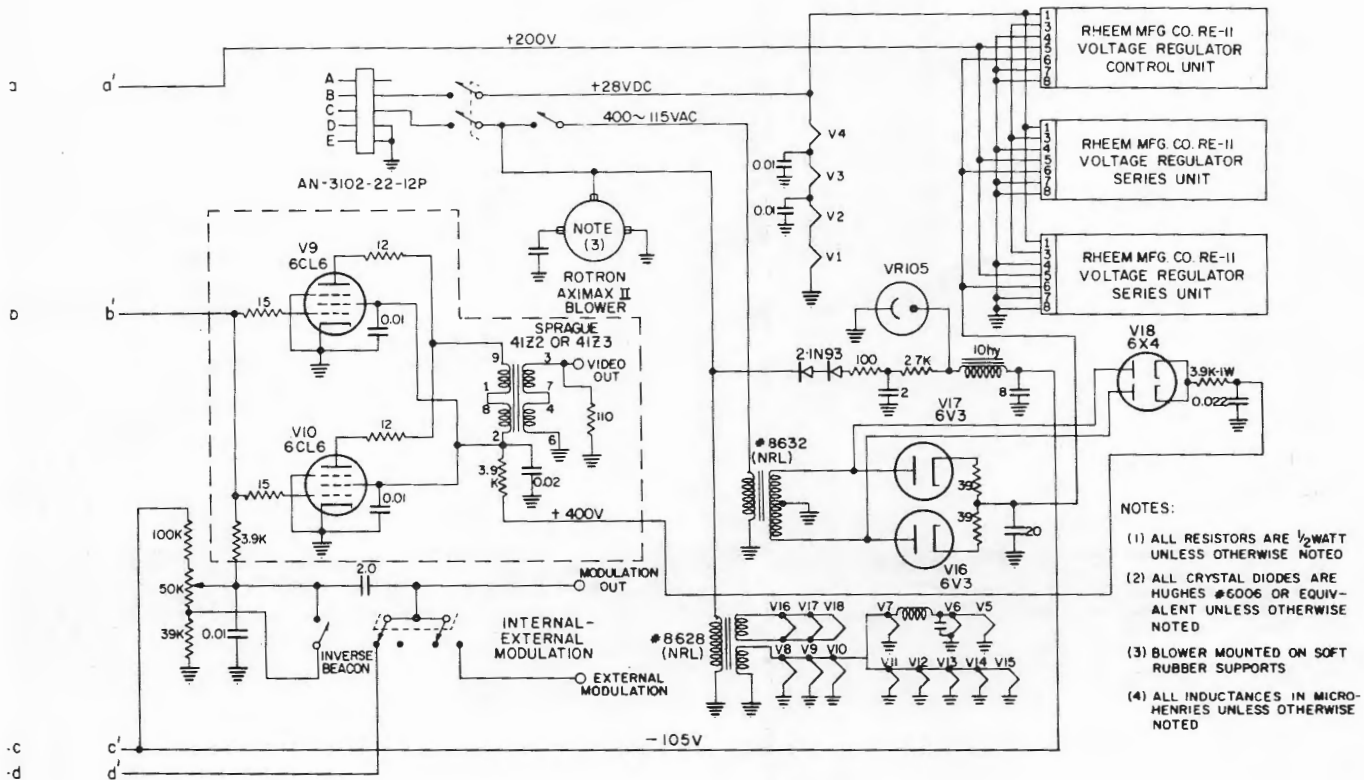
The high-voltage power supply is regulated, and a schematic is given as Fig. 12. It is capable of delivering 8 ma average current at 10.5 kv. This average current is required for the X-268 tube duty cycle.

The control circuitry shown in Fig. 11 is designed to provide sufficient safeguards to prevent damage to solenoid, tube, and high-voltage power supply in the event of coolant failure, defocusing, or overloading. A schematic of the driver amplifier is given as Fig. 13, and the circuitry is described in NRL Memo Report 685 (Ref. 5). Liquid cooling was originally utilized, which necessitated a heat exchanger for airborne installations. An APS-20 type heat exchanger proved satisfactory. Recent development of air-cooled solenoids has eliminated this requirement, however.

The antennas utilized were a pair of 60-degree-beamwidth, circularly polarized waveguide horns (Fig. 7) with the ALQ-H(X) equipment. Because long transmission lines between the antennas and equipment add both attenuation and delay, it is recommended that the installation of equipment be made as close to the antenna location as possible. In a P2V installation, these lengths were held to less than 5 ft.

The three basic units of the system are shown in Fig. 7. It is seen that there are two full ATR racks and one 1/2 ATR rack. The weight of the driver unit is 45 pounds, that of the video unit is 14 pounds, and the output stage 50 pounds. The primary power requirements are 1.5 kva, 115v/400cps/3 $\phi$  and 40a/28v dc. This does not include the power necessary for the heat exchanger, which required an additional 9a at 28v dc.





amplifier schematic [REDACTED]

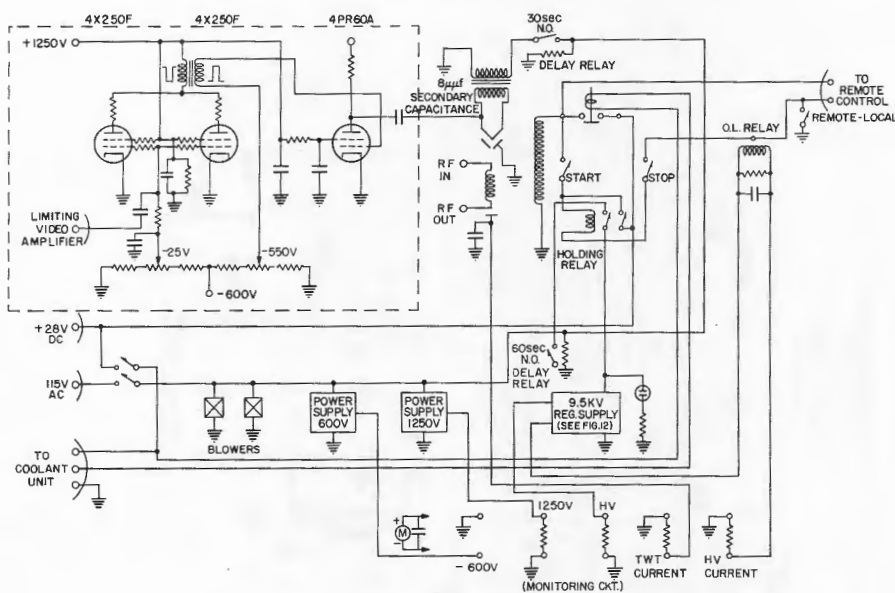


Fig. 10 - Output TWT stage utilizing X-210 tube [REDACTED]

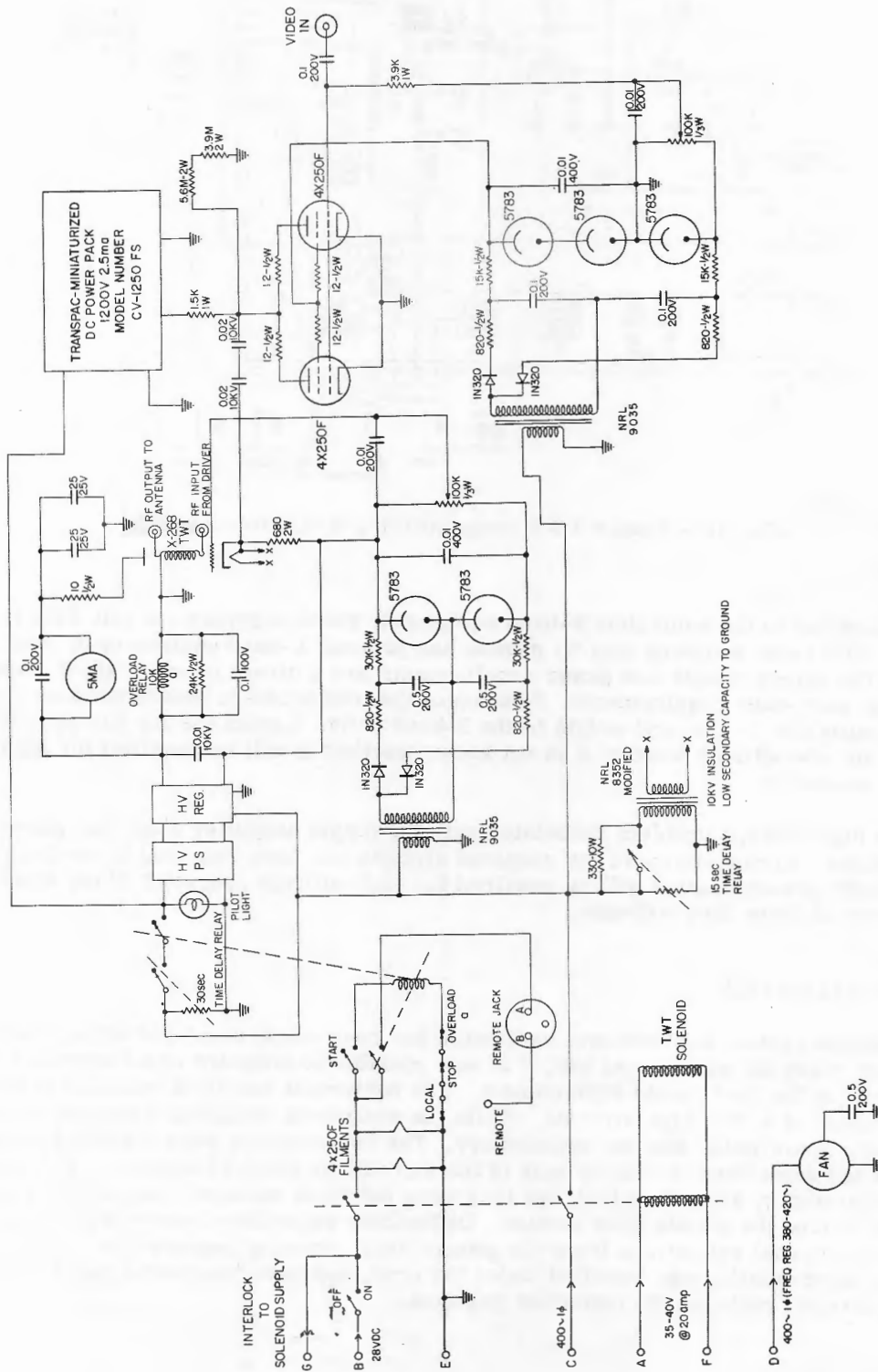
In contrast to the equivalent S-band equipment, which occupies one full ATR rack and one 1/2 ATR rack, weighing only 67 pounds, the present X-band equipment is large and heavy. The larger weight and power requirements are a direct result of the X-band traveling-wave-tube requirements. Solution of the tube problem should yield an equipment comparable in size and weight to the S-band units. Liquid cooling has proved undesirable for low-altitude testing; it is not known whether it will be required for high-altitude operation.

The high-voltage problem associated with the output amplifier stage has proved troublesome. Encapsulation of the required circuits has been resorted to successfully. Undoubtedly pressurization will be required for high-altitude operation of the traveling-wave tubes at these high voltages.

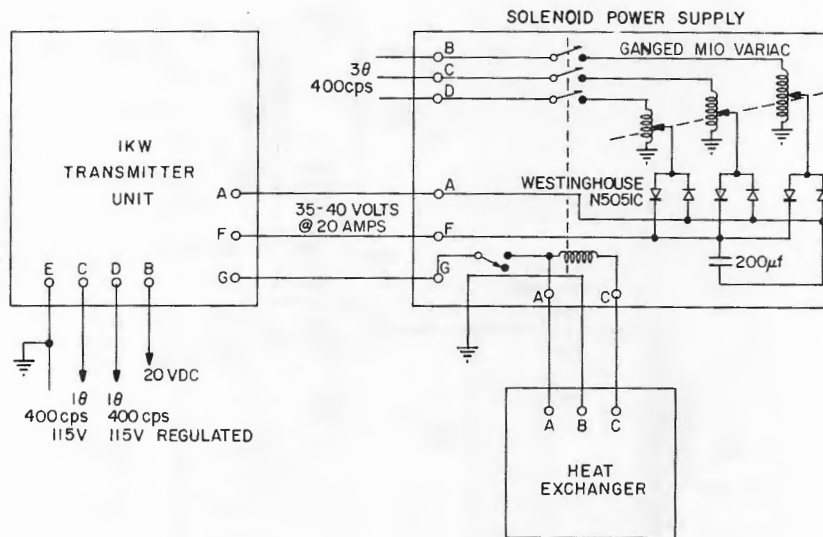
#### FIELD EVALUATION

A usable system for technique evaluation has been constructed and while it is certainly not ready for operational use, it is now possible to measure experimentally its usefulness in the operational environment. The equipment was first installed in the nose compartment of a P2V-type aircraft. While the equipment installation proved satisfactory, the antenna installation was not satisfactory. The two antennas were installed looking forward and down from the major axis of the aircraft by about 15 degrees. The antennas were separated by about four feet, but they were not flush mounted, instead, they were installed behind the plastic nose section. Difficulties experienced were apparently caused by internal reflections from the plastic itself, causing regeneration in the system. Later, a third antenna was installed under the nose, and omnidirectional receiving antenna. This apparently relieved the reflection problem.

*air ?*



(a) Circuit schematic [redacted] Fig. 11 - Output TWT stage utilizing X-268 tube



(b) Power distribution diagram [Unclassified]

Fig. 11 (Cont'd) - Output TWT stage utilizing X-268 tube

After an initial static testing of the equipment and installation, two flights were made, but equipment failures prevented any possibility of operation. Immediately after the second flight, the aircraft was diverted from this project.

The equipment was then installed on a 40-ft motor launch at the Chesapeake Bay Annex of NRL. Active testing of the equipment using the Mk 25 Mod 2 as a victim was completed. It was found that large radar tracking errors (of the order of  $\pm 1/2$  beam-width) were achieved, with occasional track break.

Installation of the equipment in a second P2V aircraft was completed. Tests involving 3 Mk 25's, a Mk 35, APQ-50, and APQ-51 airborne intercept radar types were conducted. These tests showed no unexpected results.

#### EQUIPMENT STATUS

A flyable breadboard X-band system has been designed, constructed, and subjected to field evaluation tests. During the course of this development program, the capabilities of the system have been continually brought up to the state of the art as related to the system components and techniques.

Experience in the design and testing stages provided first-hand information leading to important design concepts and requirements as well as component inadequacies, particularly of the available traveling-wave-amplifier types. System requirements were met by modification of existing tube designs; however, this approach was not considered the long-range solution. Consequently, a tube development program has been launched

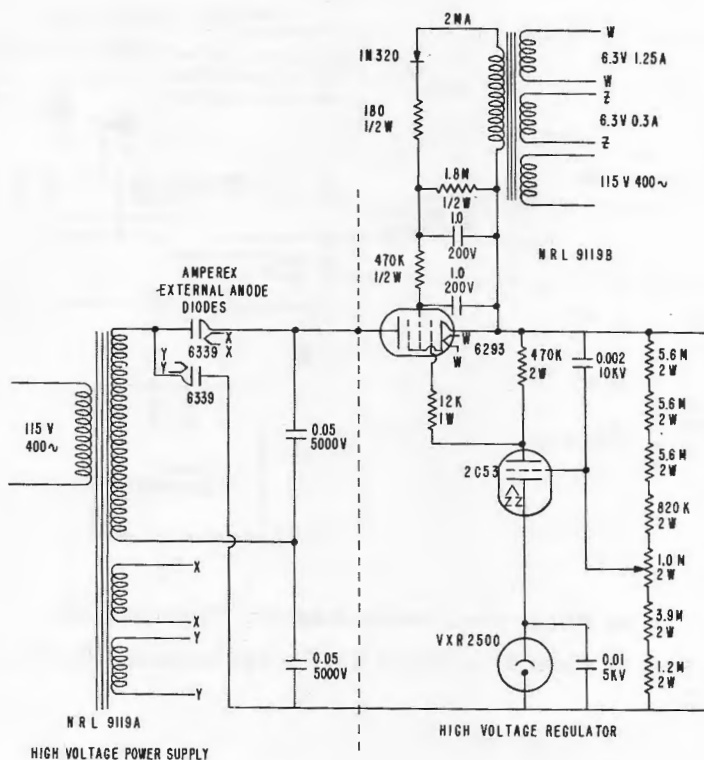


Fig. 12 - Regulated HV power supply [Unclassified]

which is expected to yield tube types which will satisfy the design requirements of the system. Within a year, it is anticipated that an amplifier chain utilizing permanent-magnet focusing will be available. This will allow a system design which will meet both the physical and electrical objectives of the original concept. Concurrently, a secondary-emission video amplifier tube development program capable of gating the output tube is being pursued. This program has as an objective reduction in system delay.

Serious consideration is being given to the concept of the continuous-beam technique. Tubes capable of this type of operation are being procured. At present, a system mockup is being constructed with an S-band tube (8). Results of these tests should give some indication of the problems to be encountered in this type of system development.

The requirement for maximum power output is being evaluated both theoretically and experimentally. There is a possibility that 100 watts of power will be sufficient for some small aircraft installations. Should this be so, the continuous-beam operation appears even more attractive.

The flight evaluation program is continuing; system changes and modifications as a result of these tests will be made where desirable. Recommendations made concerning system capability and requirements as a result of these tests will be useful in determining future program objectives.

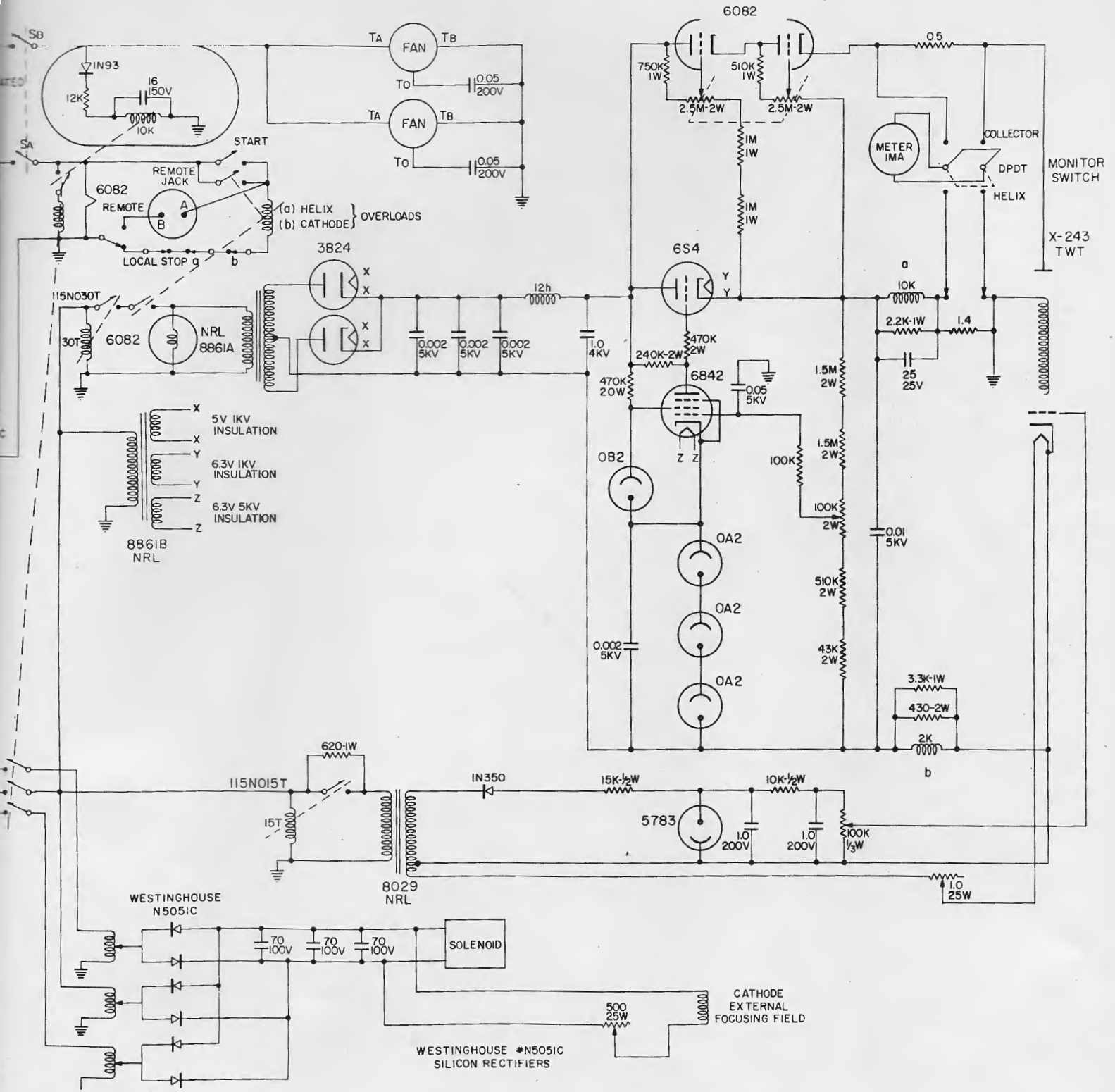


Fig. 13 - X-243 RF driver amplifier

## CONCLUSIONS

This report concludes the first phase of the X-band repeater development program. Equipment useful for technique evaluation has been developed and subjected to numerous tests. Certain equipment problems have been revealed. Foremost among them is the inefficiency of the total system as a result of the electromagnetic focusing of the traveling-wave tubes and the delay as a result of video amplifier deficiencies. In order to circumvent these difficulties, three major component programs are being pursued. The first involves a tube program to develop the required chain of traveling-wave amplifier tubes provided with nondissipative focusing techniques. The first phase of this program should reach fruition during Fiscal Year 1959. Concurrently, a new type of secondary-emission video amplifier tube capable of gating the final amplifier stage is being developed. This should materially reduce the delay of a system utilizing pulsed-beam traveling-wave amplifiers.

Another approach, i.e., utilization of continuous-beam type traveling-wave amplifier tubes to reduce the total delay to that of the rf circuit, is under investigation. The most serious shortcoming of this approach is the inherent inefficiency, since full beam power must be supplied continuously. Insufficient data are available to draw a valid conclusion as to the merits of this approach, but it is felt that it will be most useful for the case of small aircraft.

The flight program conducted by NRL was adequate to validate the equipment design concept; more data are required concerning the problems of utilizing this technique in the fleet environment. The experience and criticism by operational forces should prove valuable in that either the present design concepts will be proved, or a new set of objectives can be determined.

## REFERENCES

1. Brandenburg, R.L., "A Deception Repeater for Conical-Scan Automatic Tracking Radars," NRL Report 4811 [REDACTED], Sep. 27, 1956
2. "Reference Data for Radio Engineers," p. 621, New York:International Telephone and Telegraph, 1956
3. Pierce, J.R., "Traveling Wave Tubes," pp. 17-18, New York:D. Van Nostrand Co., Inc., 1950
4. Hastetler, W.E., "The Hy-Tramp, A Grid Controlled High Transconductance Electron Multiplier," paper given at IRE National Convention, 1956
5. Jesswein, A.J., Jr., "A Medium-Power Driven Amplifier for an X-Band Inverse-Gain Repeater Jammer," NRL Memo Report 685 [REDACTED], Mar. 25, 1957
6. Contract Number Nonr-2370(00), Litton Industries, Development of Type L-3190 Traveling Wave Tube
7. Contract Number Nonr-225(24), Stanford University, Stanford Electronics Laboratories, Electron Tube Research
8. Brandenburg, R.L., "High Beam Duty Operation of the RCA Type A-1084 Traveling-Wave Amplifier Tube," NRL Memo Report 681, Mar. 25, 1957

\* \* \*