[redacted]

[redacted]

NRL Report 4526

DECLASSIFIED

UNCLASSIFIED – [redacted]

Auth NRL ltr
Fp28-1723:HWO:dt
Ser 10435 dtd:
11/10/59

AN AIRBORNE INSTANTANEOUS MICROWAVE DIRECTION FINDER, THE (NL/ALD-A)

[redacted]

J.R. Gruber, A.J. Jesswein Jr.
and V.S. Rose

Countermeasures Branch
Radio Division

DECLASSIFIED by NRL Contract
Declassification Team
Date: 10 MAR 2017
Reviewer's name(s): [redacted]
Declassification authority: NAVY DECLASS
GUIDE/NAVY DECLASS MANUAL, 11 DEC 2012
08 SERIES

APPROVED FOR PUBLIC RELEASE
DISTRIBUTION UNLIMITED

May 3, 1955

[redacted]

DISTRIBUTION STATEMENT A APPLIES.
Further distribution authorized by
UNLIMITED only.

Naval Research Laboratory
Washington, D.C.

[redacted]

DECLASSIFIED

[redacted]

[redacted]

CONTENTS

[redacted]

[redacted]

ABSTRACT

[redacted]

An airborne wide-open direction finder which covers the frequency range of 2200 to 10,000 mc in two bands has been developed at the Naval Research Laboratory. The direction finder utilizes crystal-video detection and, being untuned, is capable of responding to all amplitude-modulated signals within the r-f band at any time. The system responds to signals of any polarization and presents bearings instantaneously on a 3-inch cathode-ray tube. It is designed primarily to detect radar signals from submarines and to give warning of the presence of potentially dangerous signals such as airborne intercept or ground-controlled intercept. The maximum instrumental bearing error of the direction finder is less than ±8 degrees and is generally less than ±6 degrees. The bearing errors of the system installed on an aircraft are appreciably greater because of the critical effect of the reflections from the aircraft surfaces upon the field at the antenna. The sensitivity is sufficient to provide line-of-sight or greater detection ranges against high-power shipborne or ground-based radars. Tests have shown that the direction finder is capable of handling a large number of near-simultaneous signals at one time and can be utilized very effectively in homing on intermittent radar signals. The power requirements of the system are moderate and the size and weight are small enough so that it can be installed in a carrier-type aircraft.

A possible method of determining signal frequency with a direction finder of this type is outlined. The method is essentially instantaneous in operation and requires only the addition of suitable r-f filters, one for each of the amplifier channels, plus a provision for switching the filters to insert or remove them.

PROBLEM STATUS

This is a final report; if the Laboratory is not otherwise notified by the Bureau, the problem will be considered closed 30 days after the mailing date of this report.

AUTHORIZATION

NRL Problem R06-14
Project No. NL 460-064
Bureau No. EL-9A-358

Manuscript submitted March 30, 1955

[redacted]

[redacted]

AN AIRBORNE INSTANTANEOUS MICROWAVE DIRECTION FINDER, THE NL/ALD-A

THE NL/ALD-A DIRECTION FINDER

An investigation has been carried out under Bureau of Aeronautics problem EL-9A-358 to devise techniques for providing means of detecting the presence and direction of microwave radars which may operate for very short periods. As a result of this investigation, an equipment, the NL/ALD-A—which incorporates some of these techniques—has been developed, and, as a result of laboratory and flight tests, it was shown to have a considerably higher intercept capability than previous microwave direction finders.

Direction finder NL/ALD-A is designed to detect and give bearings on radar-type signals and is intended for airborne service. Its primary purpose is to provide naval aircraft with equipment having a very high probability of intercept in the detection of radar-equipped submarines. The direction finder is a wide-open-type intercept system, utilizing crystal-video detection, which provides instantaneous bearing indication against amplitude-modulated signals. The bearing indication is in the form of a radial trace (unilateral) on a cathode-ray tube and, in addition, an audio output is provided for aural detection or monitoring. The direction finder, being wide-open in azimuth and frequency (i. e., untuned), will detect all amplitude-modulated signals of sufficient strength within the frequency band of the antenna system. The present antenna system, which responds to signals of any polarization, covers the frequency range of 2200 to 10,000 mc in two bands.

In addition to the primary function of submarine detection, this direction finder is an ideal warning device for protection of the aircraft against airborne or ground-based fire-control radar. Its utility for this purpose results from the fact that it is wide-open in both frequency and azimuth and presents intercepted bearings instantaneously.

The general characteristics of the d-f system are listed in Table 1.

TABLE 1
Direction Finder Characteristics
(XB-1 and XB-2)

Frequency Range:	Depends upon antenna used; 2200 - 10,000 mc with the two present antennas
Azimuth Coverage:	360 degrees
Polarization:	Omnipolarized
Bearing Indication:	Radial trace on 3-inch CRT
Bearing Accuracy:	Maximum instrumental error—±8 degrees
Intercept Range:	Line-of-sight range or greater against typical high-power radars
Power Required:	28 v dc, 2 amps 115 v ac, 200 - 1000 cps, 170 watts

[redacted]

[redacted]

The first model of the Direction Finder NL/ALD-A(XB-1) (Fig. 1) consists of an X-band antenna (Model C), an S-band antenna (Model B), the Control, the Indicator, the Amplifier-Mixer, and the Power Supply. In an actual installation only the Control and Indicator are required in front of the operator; the Amplifier-Mixer and Power Supply are mounted out of the way and do not require space near the operating position. The antennas are designed for mounting below the fuselage of the aircraft.

Fig. 1 - Direction Finder, NL/ALD-A(XB-1)

A second model of this direction finder, except for the antennas, has been completed recently and incorporates some mechanical and circuit changes. The principal changes incorporated in this model, the AN/ALD-A(XB-2) (Fig. 2), are a reduction of one-third in the size of the d-f indicator and the addition of an antenna selector switch which allows the operator to select any one or combination of d-f antennas, up to a total of three, for operation at any time. Thus, whereas the NL/ALD-A(XB-1) was designed to operate with just one antenna at a time, the NL/ALD-A(XB-2) will accommodate one, two, or three which can be operated either separately or simultaneously to cover a wide frequency range. The size and weight of each component of the NL/ALD-A(XB-2) are given in Table 2.

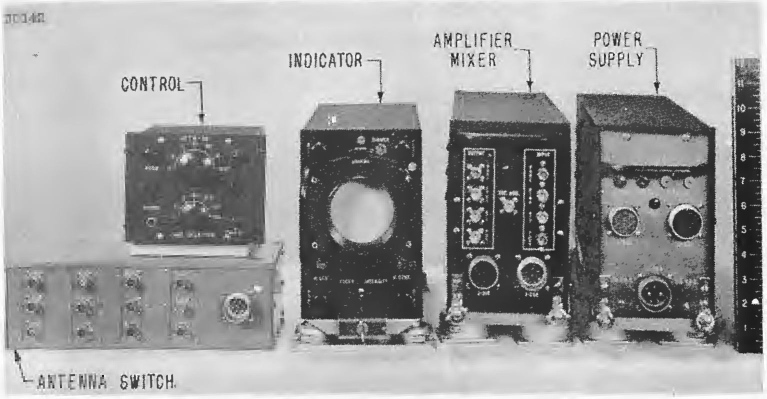


Fig. 2 - Direction Finder, NL/ALD-A(XB-2), less antennas

[redacted]

[redacted]

TABLE 2
NL/ALD-A(XB-2), Sizes, and Weights
(weights do not include shockmounts)

Unit	Size (in.)	Weight (lb)
Indicator	4.87 × 7.63 × 13	11.8
Amplifier-Mixer	4.87 × 7.63 × 19.5	13.0
Power Supply	4.87 × 7.63 × 19.5	26.5
Control	4.50 × 5.75 × 4.38	2.0
Antenna Switch	3.63 × 4.75 × 11.13	4.0
S-Band Antenna	13 D × 14 L	16.0
X-Band Antenna	13 D × 9 L	13.5
	Total	86.8

THEORY OF OPERATION

The four-channel direction finder is a system (Fig. 3) consisting of four separate and independent receivers, each with its own antenna suitably oriented so that the four antennas are equally spaced (90 degrees apart) in the azimuth plane, and with the output of each receiver applied to one of the deflection plates of a cathode-ray tube. When a signal is intercepted by the antenna it is immediately detected by the crystal detectors associated with the antenna elements. The detected voltages (video) are amplified by the video amplifiers and the bearing is presented as a radial trace on the face of the cathode-ray tube. The bearing is read by means of a moveable cursor and alidade which is symmetrically positioned over the cathode-ray tube face. A mixer circuit is utilized to provide a voltage, independent of the angle of arrival of the signal, to intensify the trace on the indicator and to energize the headphones.

The bearing presented on the d-f indicator will be accurate if the four channels of the direction finder have identical characteristics and the antenna patterns are of such shape as to introduce no error. The factors which affect the bearing accuracy, such as antenna pattern shape and channel mismatch, have been considered in detail in previous reports (1, 2, 3).

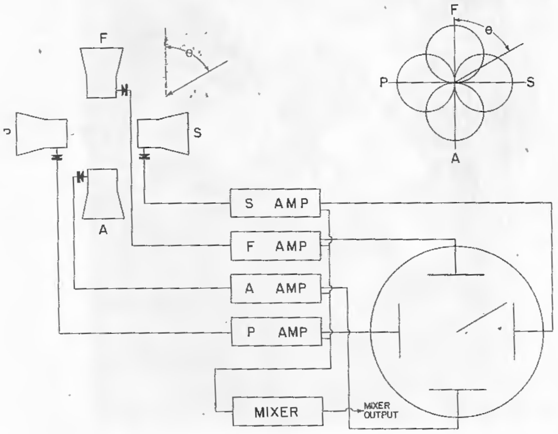


Fig. 3 - Diagram of four-channel direction finder

MAJOR UNITS

S-Band Antenna

The S-band (Model B) antenna (Figs. 4 and 5), which covers 2200 to 5000 mc, consists of four pairs of elements, each pair consisting of a dipole and a horn-fed slot,

[redacted]

mounted on a 13-inch-diameter conducting cylinder, 12 inches long. Each of the four horns and each of the four dipoles has its own crystal detector mounted integrally with the antenna element. The crystal mounts of the horns and dipoles can be seen in Fig. 4(c); the internal cabling and junction boxes for the element pairs in 4(b). The purpose of the junction boxes is to divide equally the dc bias currents applied to each crystal detector and to combine the video outputs of each element pair. It is this combination of the outputs of the horn and dipole pairs which results in an antenna system which will respond to all polarizations (omnipolarized).

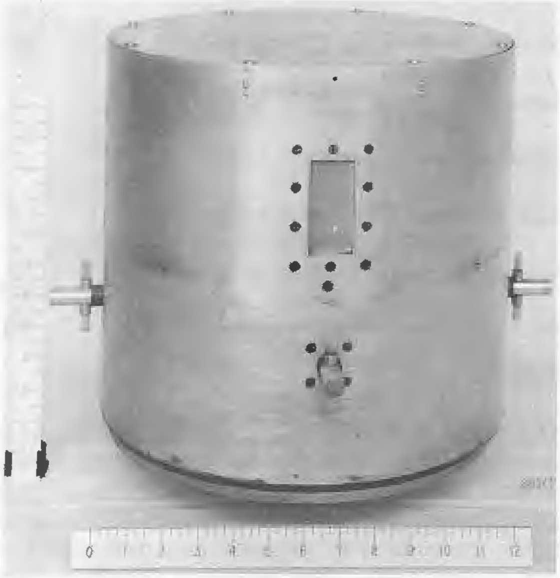


Fig. 4(a) - S-band antenna (external)

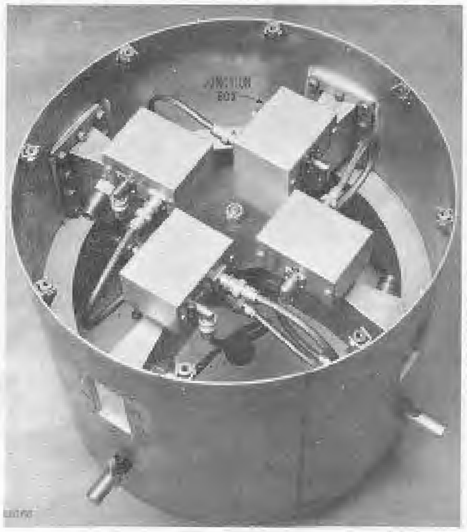


Fig. 4(b) - S-band antenna (internal, with cabling)

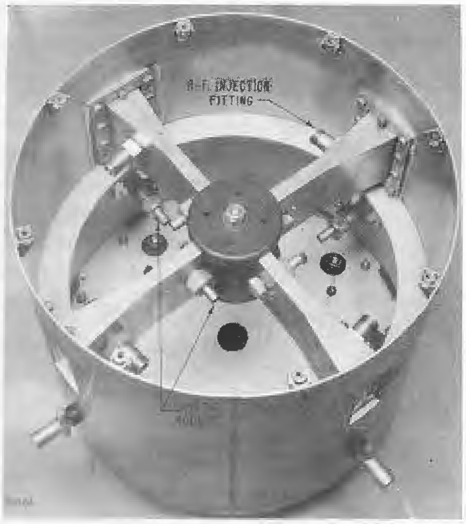
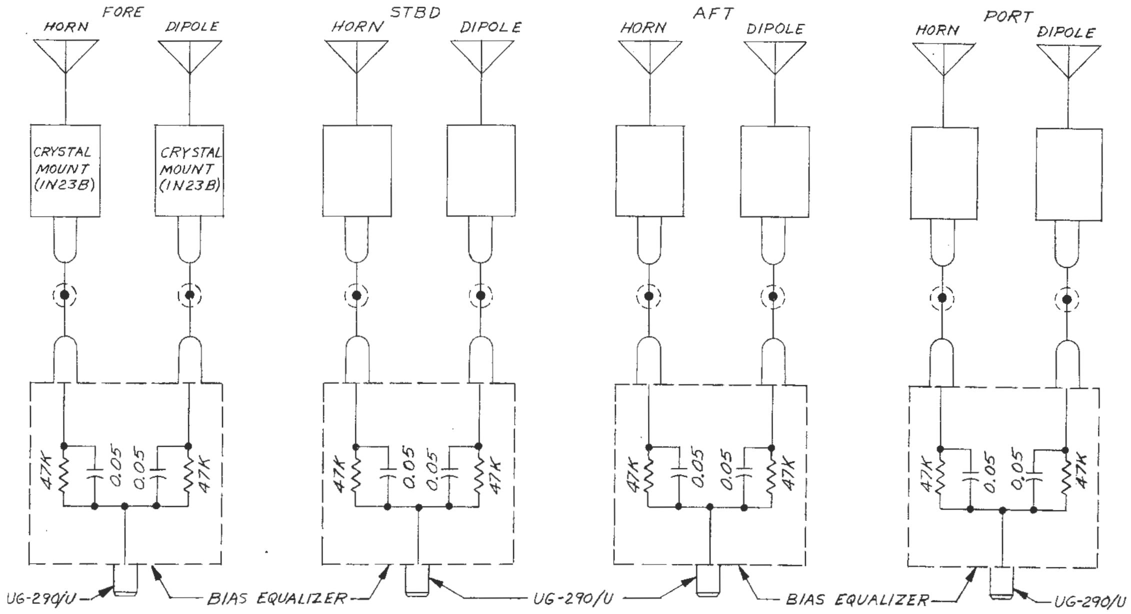


Fig. 4(c) - S-band antenna (internal, cabling removed)



NOTES
1. THIS DRAWING APPLIES TO ANTENNA ASSEMBLY OF ONE FREQUENCY BAND. ASSEMBLIES FOR OTHER BANDS ARE IDENTICAL.
2. ISOLATION IS REQUIRED BETWEEN FORE, STBD, AFT AND PORT CHANNELS.
3. SYMBOLS : —(•)— RG-71/U ⊏] UG-260/U

Fig. 5 - Antenna wiring schematic

A dc bias current of approximately 40 microamperes is applied to each crystal in order to reduce the variations in sensitivity from crystal to crystal, which makes it easier to match crystals, and to improve the sensitivity somewhat. The bias also reduces the video impedance of the crystals and makes it possible to connect the crystals directly to the video amplifiers via a long length of coaxial cable (RG-71/U) without the use of impedance-matching transformers. The effect of bias current upon the video impedance of crystal detectors is described in Ref. (4).

Each horn and dipole is separately insulated from the antenna cylinder in order to minimize pickup of low-frequency interference which is present in most aircraft. The insulation breaks the loop path which would otherwise exist for any low-frequency currents on the outer conductors of the video cables. Experience with several different crystal-video type installations in aircraft has proved that ac power-line hum and other types of annoying interference such as motor noise can be appreciably reduced by insulating the antenna elements from the airframe. The horns are insulated from the cylinder by thin Teflon sheets which also exclude dirt and moisture. Each dipole is insulated by a phenolic sleeve which surrounds the body and also positions the dipole the correct distance from the cylinder surface.

Each of the S-band horns contains an r-f injection fitting, about 1-1/2 inches from the aperture, which permits an r-f test signal to be introduced. By this means the crystal detector and video amplifier associated with each horn can be checked. The dipole elements could also have been provided with an injection fitting, but, because of the delay this would have imposed upon obtaining flight-test information, it was eliminated.

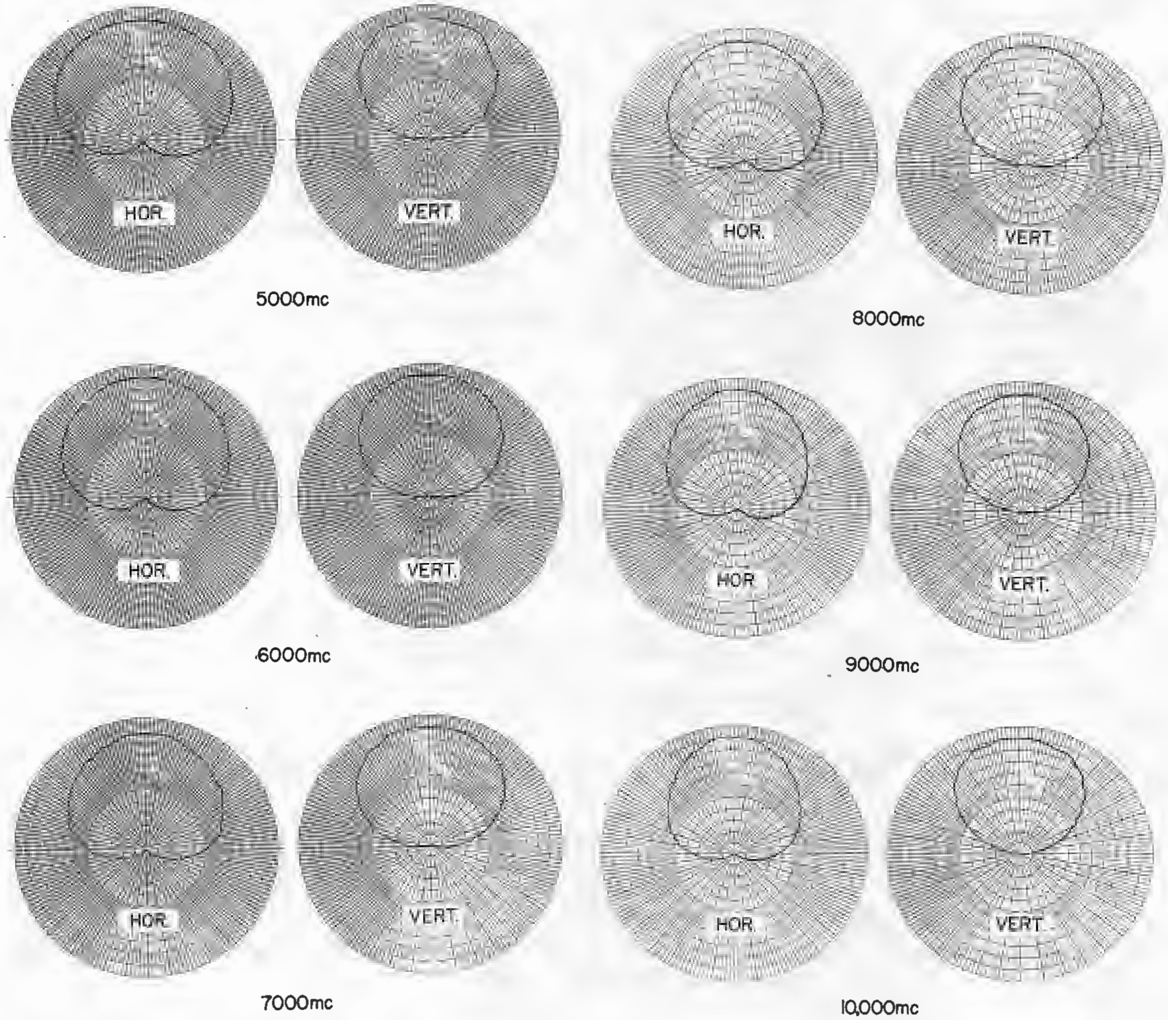


Fig. 7 - Azimuth plane patterns, X-band

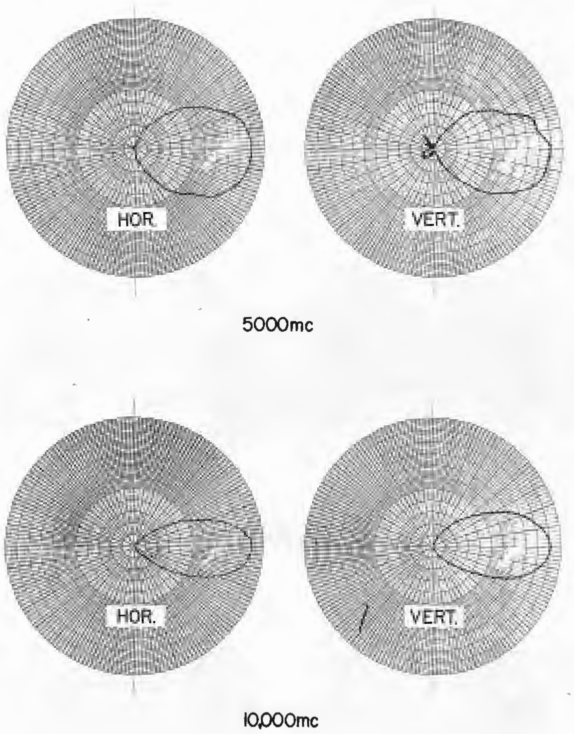


Fig. 8 - Elevation plane patterns, X-band

Each horn and dipole is separately insulated from the antenna cylinder for the same reasons as for the Model B antenna. The horn elements are insulated by a thin Teflon sheet placed between the waveguide flanges of the horn and crystal mount. The dipole elements are insulated by a single layer wrap of Teflon-Fiberglas tape.

The cylinder, the end-cover plate, the horns, and the mounting plate are made from aluminum alloy and the total weight is approximately 14 pounds. The mounting plate (Fig. 6(a)) is made exactly like that for the S-band antenna and was described above.

Amplifier-Mixer

The Amplifier-Mixer unit (Figs. 9 and 10) contains four identical video amplifiers, a circuit which mixes the outputs of these video amplifiers, an audio amplifier, and a video test signal generator. The mixer produces a common signal which is utilized to provide:

1. Intensification of the cathode-ray tube trace
2. An audio signal to the headphones
3. An output which is capable of being used for pulse analysis.

Each video amplifier contains two dual-triodes which are used as direct-coupled inverse-feedback pairs. The voltage gain of these two tubes is about 70 decibels. A precision video step-attenuator is placed between these two tubes to permit adjustment of the over-all gain of the video channel. These step-attenuators in the four amplifiers are matched and ganged mechanically so that the gains of the four channels are always changed by the same number of decibels whenever a change is made.

The output of the second dual triode, V202, is applied to the square-rooting circuit in the first half of dual-triode, V203. This circuit consists of the 1.8K and 10-ohm resistances, the 1N69 germanium diodes, and the triode feeding these circuit elements. A curve showing a measured output-vs.-input characteristic typical of the square-rooting circuit is shown in Fig. 11. As a result of measuring this characteristic over a wide range of operating temperatures, it was found that the slope of the characteristic changes somewhat with temperature. However, it was verified that these characteristics for all four channels change in a nearly identical manner and the amount of bearing error resulting from a change in temperature is very small.

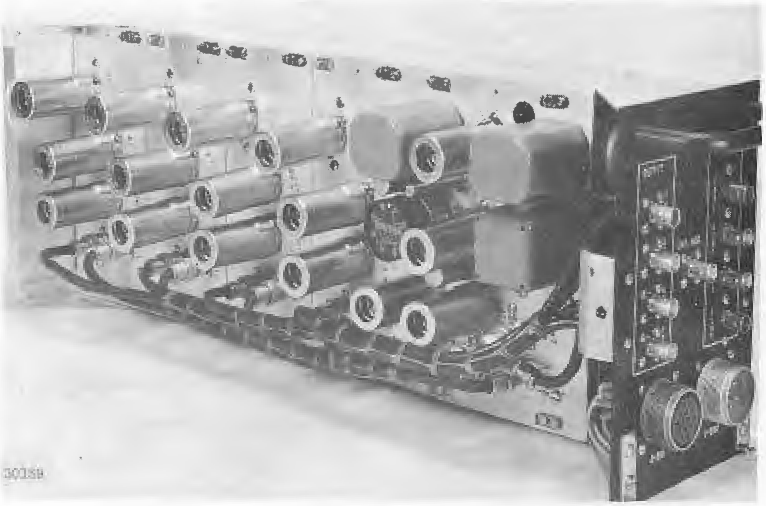


Fig. 9(a) - Amplifier-Mixer (left side)

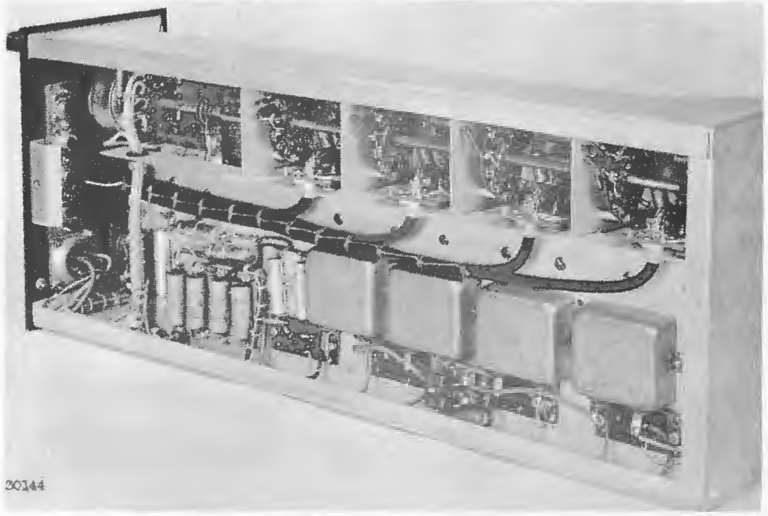
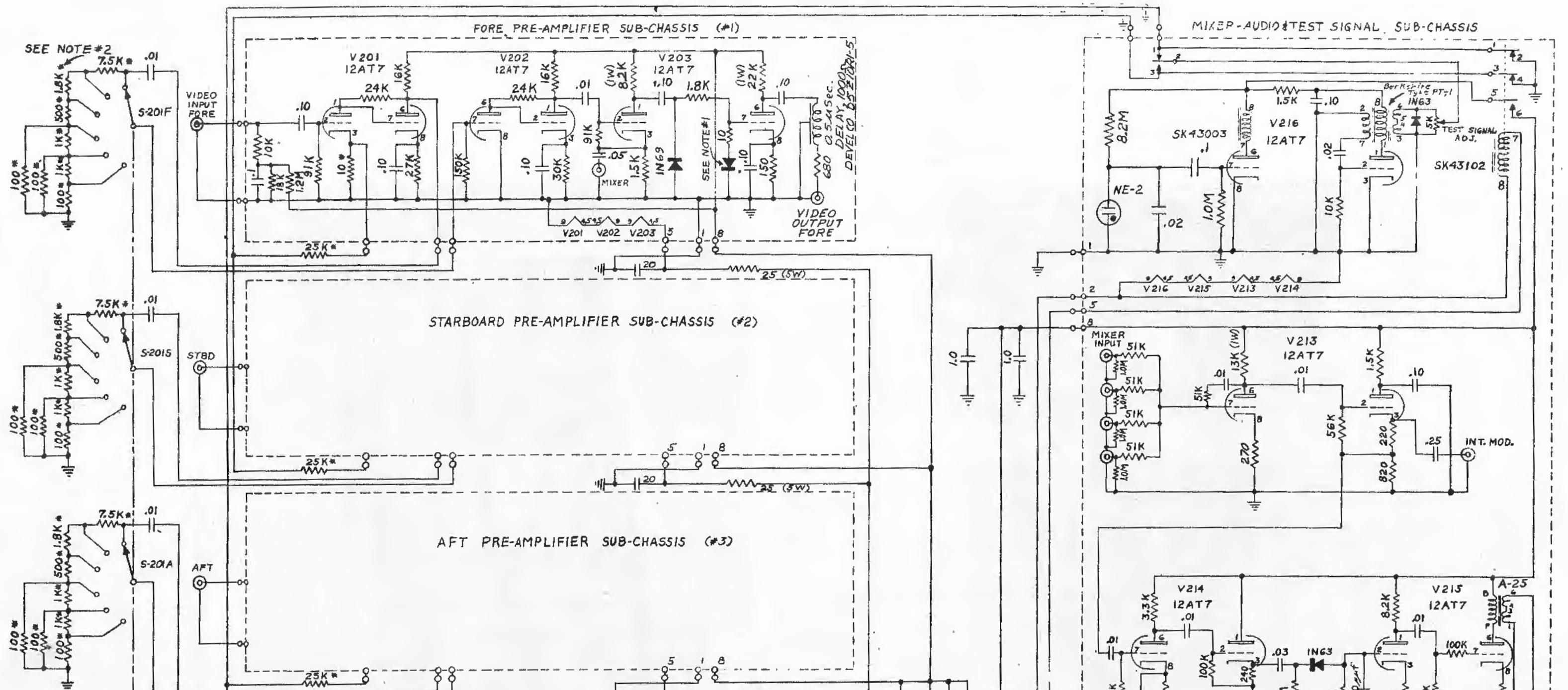


Fig. 9(b) - Amplifier-Mixer (right side)


FORE PRE-AMPLIFIER SUB-CHASSIS (#1)
SEE NOTE #2
7.5K*
.01
1.8K*
500*
1K*
100*
S-201F
VIDEO INPUT FORE
V201 12AT7
V202 12AT7
V203 12AT7
24K
16K
10K
18K
1.2M
91K
27K
150K
30K
.05
MIXER
1.5K
8.2K (1W)
1.8K
22K (1W)
IN69
SEE NOTE #1
150
680
0.5 μSec. DELAY 1000Ω DEVELCO D5Z10R1-5
VIDEO OUTPUT FORE
25K*
20
25 (5W)
STARBOARD PRE-AMPLIFIER SUB-CHASSIS (#2)
S-201S
STBD
AFT PRE-AMPLIFIER SUB-CHASSIS (#3)
S-201A
AFT
1.0
MIXER-AUDIO & TEST SIGNAL SUB-CHASSIS
8.2M
NE-2
.02
SK43003
1.0M
V216 12AT7
1.5K
.10
Berkshire Type PT-1
IN63
5K
TEST SIGNAL ADJ.
10K
SK43102
V216 V215 V213 V214
MIXER INPUT
51K
V213 12AT7
13K (1W)
56K
270
220
820
.25
INT. MOD.
V214 12AT7
3.3K
100K
240
.03
V215 12AT7
8.2K
A-25

The last triode stage in the video amplifier provides a signal to the deflection amplifier in the Indicator. A 0.5-μsec delay is inserted into each of the four directional channels at this point so that the intensifying pulse (which is undelayed) will intensify the leading edge of the directional pulse appearing on the cathode-ray tube.

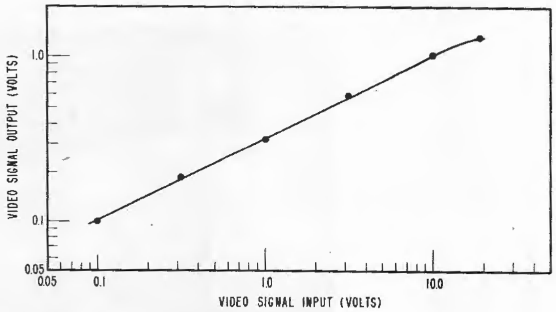


Fig. 11 - Square-rooting circuit characteristic

The voltage applied to the mixer circuit, V213, is obtained from the cathode of the first half of V203. The mixing in V213 is of the additive type. The over-all gain of the mixer, including both halves of V213, is approximately unity. The output is applied to the audio amplifier circuit consisting of V214 and V215. This circuit employs a conventional pulse-stretching circuit which has a fast charging time of about 0.5 μsec and a discharge time of about 80 μsec for a signal-to-noise ratio of 10 decibels. The output impedance of this amplifier is 600 ohms and at maximum setting of the video and audio gain controls it will deliver more than two milliwatts of noise power to a 600-ohm load.

A test circuit (V216) is provided to check the relative gains of the four video channels. This circuit generates a short, 3-μsec pulse at a pulse repetition frequency of about 2000 pulses per second and commutates this signal alternately between the fore and starboard channels with inputs paralleled and the port and aft channels with inputs paralleled. The pulsed signal is generated by the blocking oscillator utilizing the right-hand half of V216. The commutation is effected by means of relay SK 43003 (Clare) and the relaxation oscillator in the other half of V216. Because the commutation occurs at a rapid rate (30 cps), the test signal appears as a steady radial trace in the first and third quadrants of the cathode-ray tube. If the channel gains are all matched, the two traces will have the same length and will have angular positions of 45° and 225°. But if the channel gains are not matched, the test signal traces indicate the type and degree of gain adjustments needed. Channel gain controls for this purpose are located on the panel of the Indicator.

As seen in Figs. 12, 13, and 14 each of the subchassis is designed as a plug-in unit. No soldering or unsoldering is required to insert or remove a subchassis, each of which is held in place by means of aircraft-type snap-slide fasteners. The four video amplifier subchassis are identical physically as well as electrically so that, if trouble develops in one of these units, it can be replaced by a spare in less than one minute. The same holds true of the mixer subchassis which can easily be replaced if necessary.

The Amplifier-Mixer unit is housed in a standard A1D aircraft case, measuring approximately 5 ×7 ×19 inches, and the total weight is 13 pounds without shockmounts.

Indicator

The Indicator (Figs. 15, 16, and 17) contains four identical deflection amplifiers, an intensity modulation amplifier, a high-voltage power supply, and a 3-inch cathode-ray tube with alidade. The alidade, located in front of the CRT face, has a moveable cursor and azimuth scale from which the signal bearing is read. Both the cursor and azimuth scale are edge-lighted and a dimmer is provided for adjusting the level of illumination.

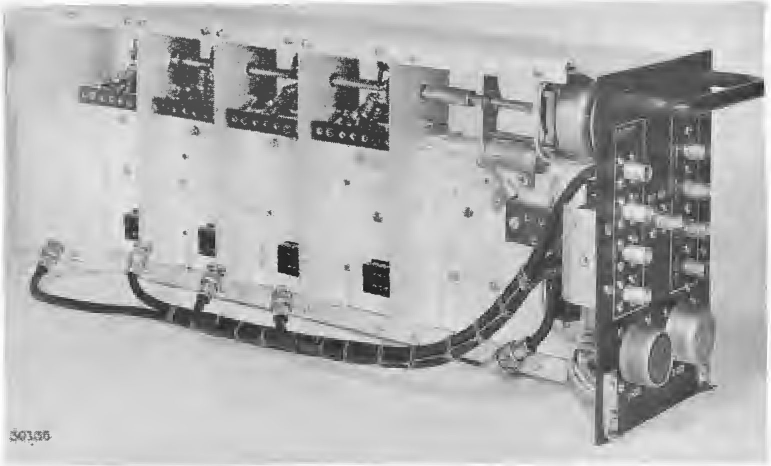


Fig. 12 - Amplifier-mixer, subchassis removed

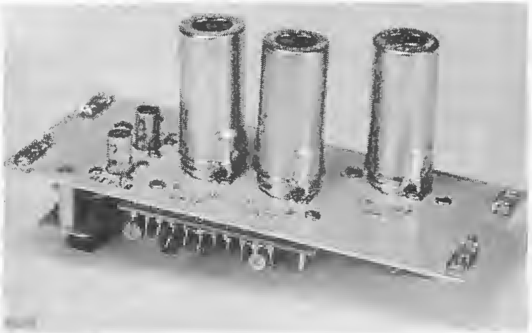


Fig. 13(a) - Amplifier subchassis (tube side)

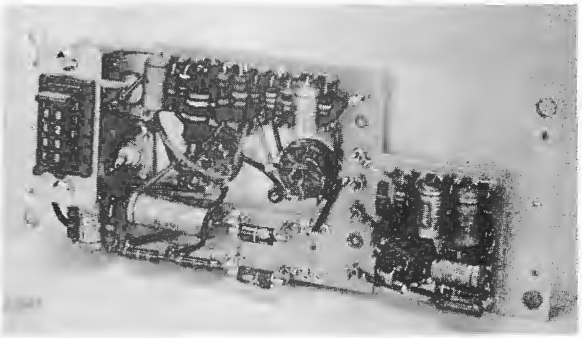


Fig. 13(b) - Amplifier subchassis (component side)

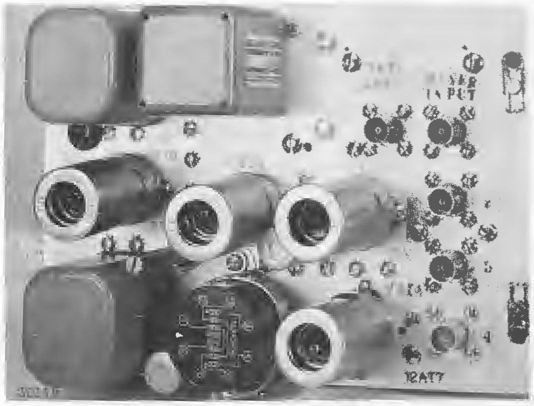


Fig. 14(a) - Mixer subchassis (tube side)

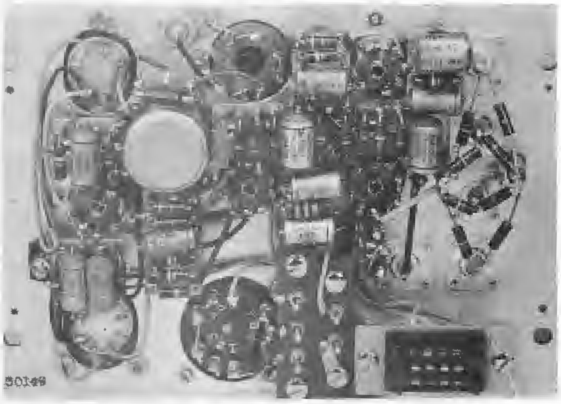


Fig. 14(b) - Mixer subchassis (component side)

[redacted]

Fig. 15 - Indicator, front panel

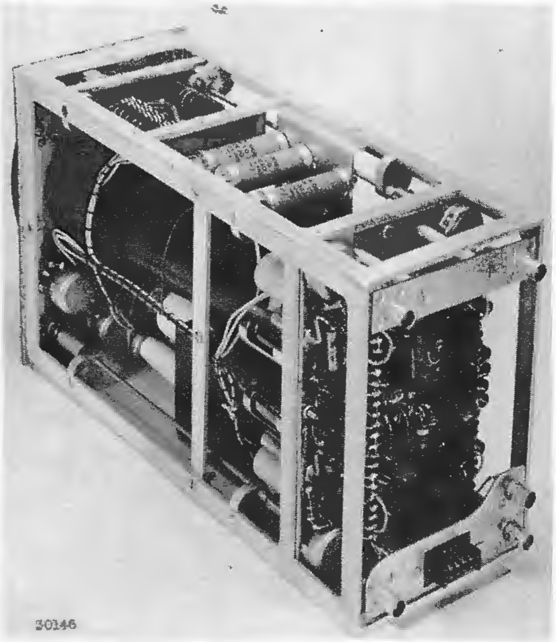
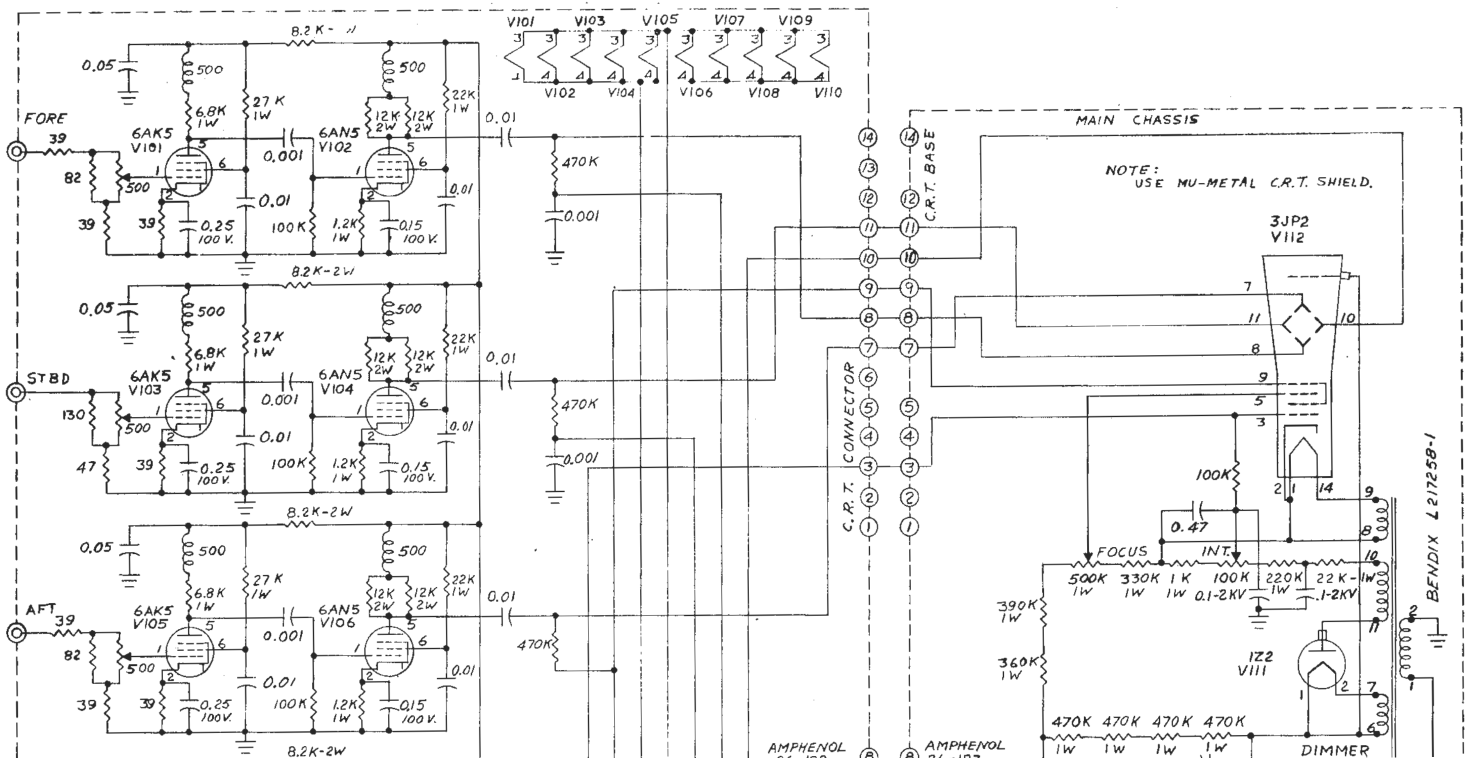


Fig. 16 - Indicator, internal

Shunt peaking coils are used in each of the video amplifiers to obtain bandwidths exceeding one megacycle. The voltage gain of the deflection amplifiers is about 56 db and the amplification is linear up to an output voltage of 200 volts, as measured on the deflectlion plate of the cathode-ray tube. A typical output-vs.-input characteristic for a deflection amplifier is given in Fig. 18. The deflection characteristic of the CRT is such that it requires a potential difference of about 133 volts on the D1 and D2 plates and about 100 volts on the D3 and D4 plates to obtain a spot deflection of one inch.

Figure 19 shows the output-vs.-input characteristic for the intensity-modulation amplifier. The amplifier was designed to limit at an output level of about 50 volts, which is adequate to achieve full brilliance from a 3JP2 cathode-ray tube operated as shown in Fig. 17. The display is not as satisfactory when a flat-face 3ACP2 tube is used under exactly the same conditions as the 3JP2. This results from the fact that the 3APC2 requires a considerably greater voltage change on the intensity grid to achieve a given change in light output as compared to the 3JP2. The 3ACP2 has the advantages of the flat-face screen and greater deflection plate alignment accuracy (±1 degree for the 3ACP2 and ±3 degrees for the 3JP2). It is believed that a more desirable indicator tube could be obtained by combining the preferred features of the 3JP2 and 3ACP2.


FORE
STBD
AFT
6AK5
V101
V103
V105
6AN5
V102
V104
V106
8.2K-2W
500
6.8K 1W
27K 1W
12K 2W
22K 1W
0.05
0.001
0.01
0.25 100V.
0.15 100V.
100K
1.2K 1W
39
82
130
47
470K
V107
V108
V109
V110
C.R.T. CONNECTOR
C.R.T. BASE
MAIN CHASSIS
NOTE: USE MU-METAL C.R.T. SHIELD.
3JP2
V112
FOCUS
INT.
500K 1W
330K 1W
1K 1W
100K 0.1-2KV
220K 1W
22K-1W .1-2KV
0.47
390K 1W
360K 1W
1Z2
V111
470K 1W
DIMMER
BENDIX L217258-1
AMPHENOL

[redacted]

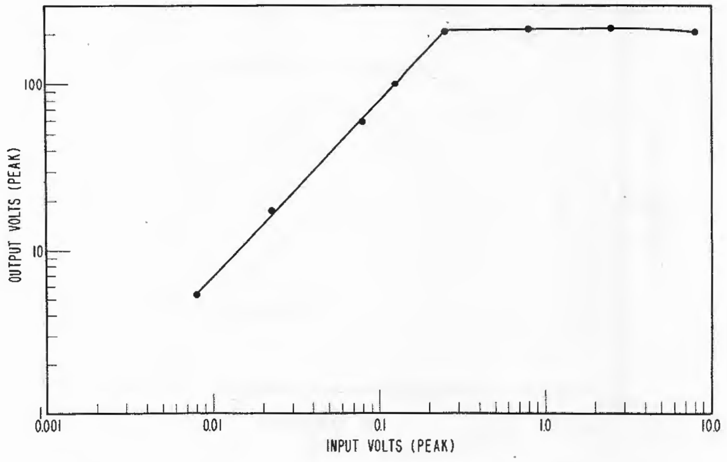


Fig. 18 - Deflection amplifier characteristic

The maximum accelerating voltage on the CRT is 2200 volts, which is considerably below the maximum voltage permissible. It is believed that a higher accelerating voltage is desirable in order to obtain a greater amount of light output on brief and low pulse-repetition-rate signals. Of course, the deflection sensitivity will be less at a higher accelerating voltage so that more drive will be required to produce a given amount of beam deflection.

The four channel gain controls are located in the grid circuits of tubes V101, V103, V105, and V107. These controls, which permit a total gain variation of about 10 db, are necessary to equalize the over-all channel gains. The control shafts are brought out to the front panel (Fig. 15) and are of the "push-to-turn" type so that accidental movement of the controls is not likely. The spot-centering controls and the alidade dimmer control are of the screwdriver type, accessible from the front panel. These controls should not require adjustment during flight.

The four deflection amplifiers and the intensity-modulation amplifier are mounted on a vertical plug-in-type subchassis which plugs in from the rear of the Indicator unit. The subchassis (Fig. 20) contains video and power connectors as well as the CRT socket. The filament voltage and the dc potentials on the focus and intensity grid electrodes are supplied via a thin (1/4 inch) intermediate connector which is permanently wired to the main chassis of the Indicator. This special connector, which has the same pin arrangement as the CRT socket, is positioned between the CRT socket and the base of the cathode-ray tube.

All external cable connections to the Indicator are made at the rear of the unit. The power connections are made via a receptacle which is permanently mounted at the back of the mounting base. The Indicator is housed in a standard S-2 size aircraft case measuring 4-7/8 × 7-5/8 × 13 inches and the weight, without shockmount, is 11.75 pounds.

[redacted]

[redacted]

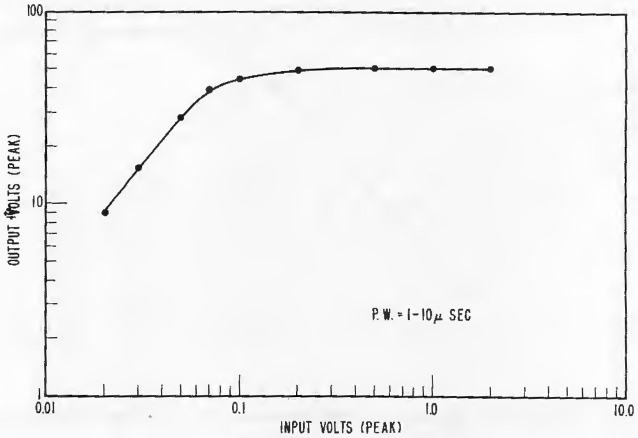


Fig. 19 - Intensity amplifier characteristic

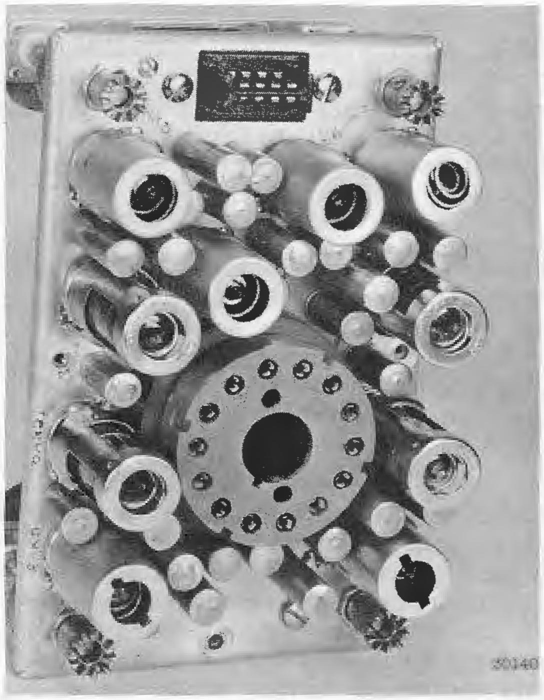


Fig. 20 - Indicator subchassis

Control Unit

The Control Unit (Figs. 21 and 22) contains the following:

1. Power switch
2. Video attenuator (gain control)
3. Audio gain control
4. Antenna switch

A phone jack also is available on the front panel.

The unit, which weighs two pounds and measures 5-3/4 × 4-1/2 × 5 inches, is designed in accordance with all applicable military specifications, including the panel fasteners by which it is mounted in an aircraft. The front panel is made of plastic, internally illuminated, and the control lettering is visible under all conditions of ambient light level from zero to direct sunlight.

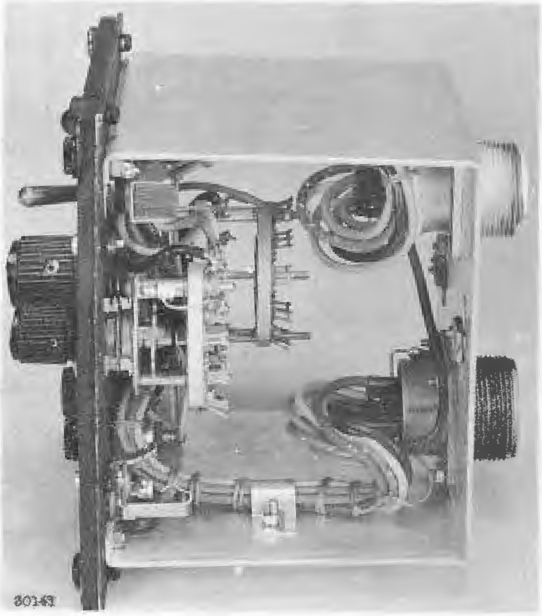
Antenna Switch

The Antenna Switch (Figs. 23 and 24) is required if it is desired to use more than one antenna (i. e., cover more than one frequency band) in a given installation. The unit permits the use of up to three separate d-f antennas which the operator can select individually or in any combination desired. If only one antenna is to be used on a given aircraft, the Antenna Switch may be eliminated from the installation since it is not required for operation of a single d-f antenna.

[redacted]

[redacted]

(a) Front panel



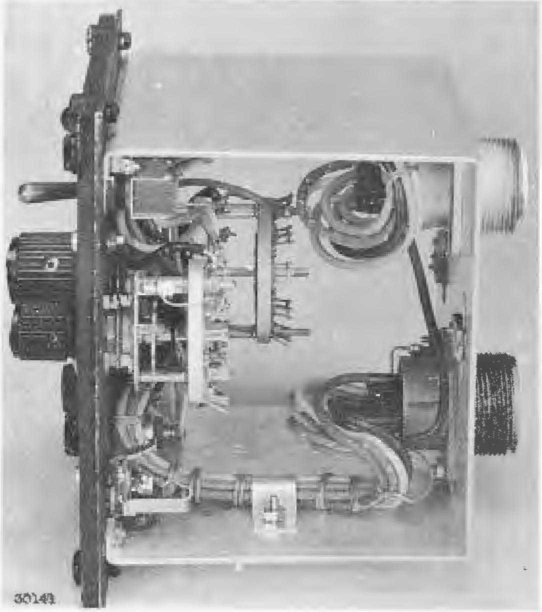
(b) cover removed

Fig. 21 - Control unit

[redacted]

[redacted]

(a) Front panel



(b) cover removed

Fig. 21 - Control unit

[redacted]

[redacted]

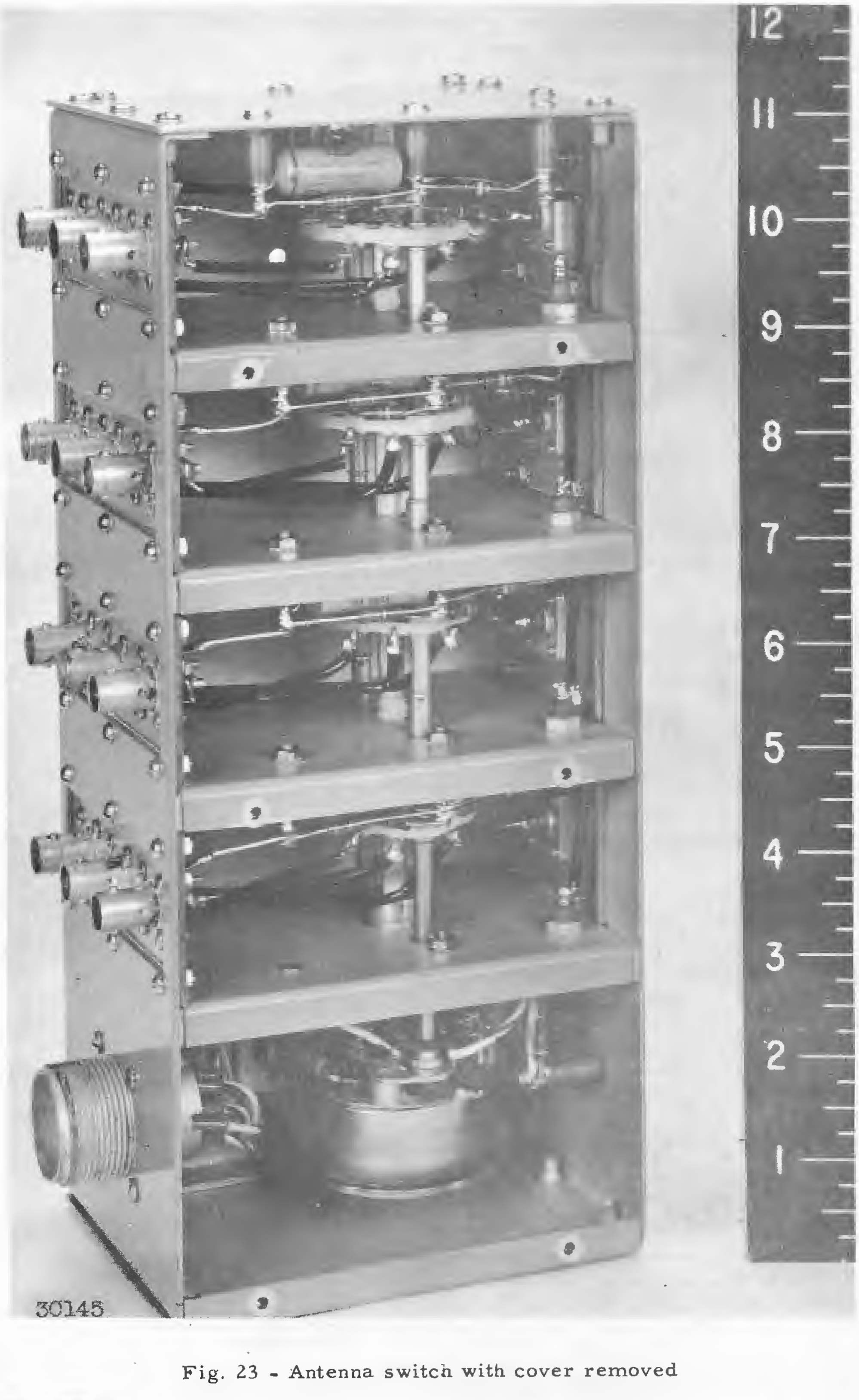
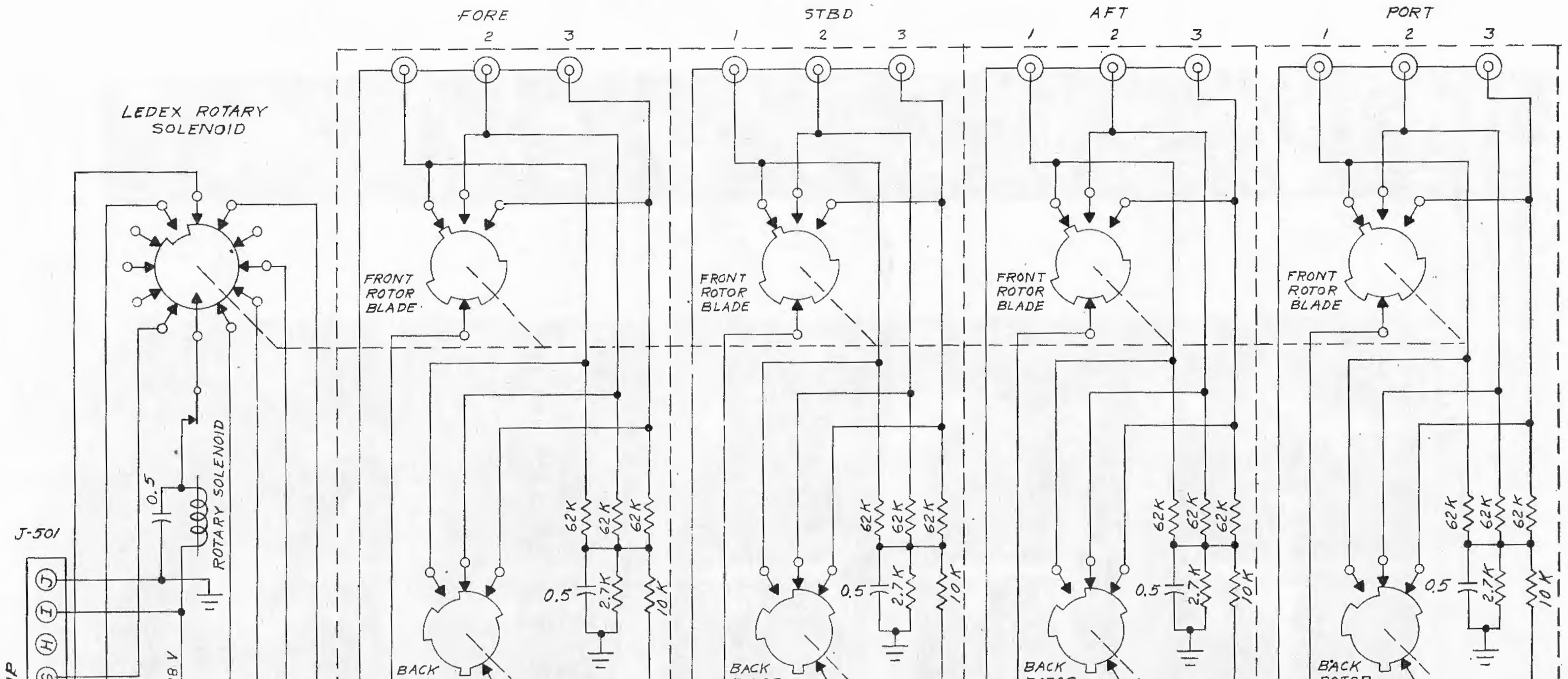


Fig. 23 - Antenna switch with cover removed

[redacted]


FORE
2
3
STBD
1
2
3
AFT
1
2
3
PORT
1
2
3
LEDEX ROTARY SOLENOID
FRONT ROTOR BLADE
FRONT ROTOR BLADE
FRONT ROTOR BLADE
FRONT ROTOR BLADE
ROTARY SOLENOID
0.5
J-501
J
I
H
62K
62K
62K
0.5
2.7K
10K
BACK
BACK
BACK
BACK ROTOR

This unit contains four separately shielded compartments, one for each channel of the direction finder. Each compartment contains three antenna input connectors and a single output connector which is connected by cable to the Amplifier-Mixer unit. All of the connectors are completely insulated from the box for the same reason that the separate antenna elements are insulated from the antenna cylinder. A crystal bias network is contained in each compartment so that all detector crystals are supplied with suitable dc bias (about 40 μamp per crystal). The bias current is obtained from the 28-volt dc supply with sufficient filtering to eliminate interference. The ganged selector switch is driven by a Ledex rotary solenoid which is remotely operated from the Control unit. The cross talk between any two of the three inputs to a given channel is down by greater than 50 db compared to the signal level with a direct connection.

The Antenna Switch measures 11-1/8 × 4-3/4 × 3-5/8 inches and weighs 4 pounds. It can be mounted directly to the airframe and preferably should be located near the antenna positions.

Power Supply

The Power Supply (Figs. 25 and 26) contains a source of filament power, a 250-volt regulated plate supply, and a 300-volt unregulated plate supply. The regulated B voltage is used primarily for the video amplifiers and other circuits of the Amplifier-Mixer unit while the 300-volt (unregulated) B voltage is used for the deflection amplifiers in the Indicator. It was found that a supply with very low internal impedance was needed for the video amplifiers in the Amplifier-Mixer, especially when the test-signal circuit was getting power from this same supply. An earlier attempt was made to use a conventional unregulated supply for the Amplifier-Mixer circuits, but this was not satisfactory because of the interaction which occurred between channels.

A power-line filter, housed in a mu-metal enclosure is located directly behind the power receptacle on the front panel. The purpose of this filter is to attenuate audio- and video-frequency interference which may be present on the power input cables. The filter consists of two pi-sections, one in series with the ac line and one in series with the dc line. The attenuation characteristics of the two sections are given in Fig. 27. It should be noted that the load on the output of each filter section was the actual power supply circuit normally fed by the power line.

SYSTEM PERFORMANCE

System performance of the NL/ALD-A(XB-2), as determined by a series of laboratory tests, is given in this section. The sensitivity data were measured by utilizing an accurately calibrated signal generator and transmitting horn antenna to establish a controlled level of power density at the receiving antenna.

In addition, special flight tests were made because the performance of the direction finder is influenced by proximity to and installation in an aircraft. These flight tests are described on page 27.

Sensitivity Versus Frequency

Figures 28 and 29 show system sensitivity vs. frequency for horizontally and vertically polarized signals, respectively. These graphs show the signal power-density required

[redacted]

at the d-f antenna to produce tangent-signal* sensitivity. The tangent-signal power level is about 3 db higher than a minimum discernible signal power level. The curves are given in terms of power-density rather than power because the entire system, consisting of crystals, amplifiers, and antennas, is thereby included. The actual power intercepted by the antennas is a direct function of the effective aperture area of the antennas at the frequency involved. This explains why the X-band antenna elements, which have smaller aperture areas, require a greater power-density than the S-band elements.

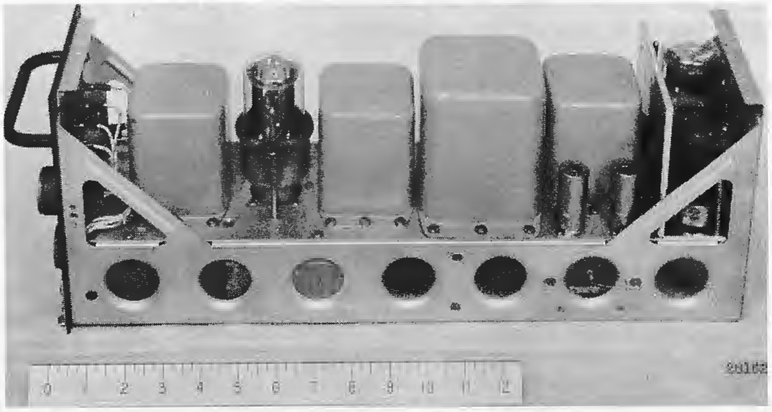


Fig. 25(a) - Power supply (side view)

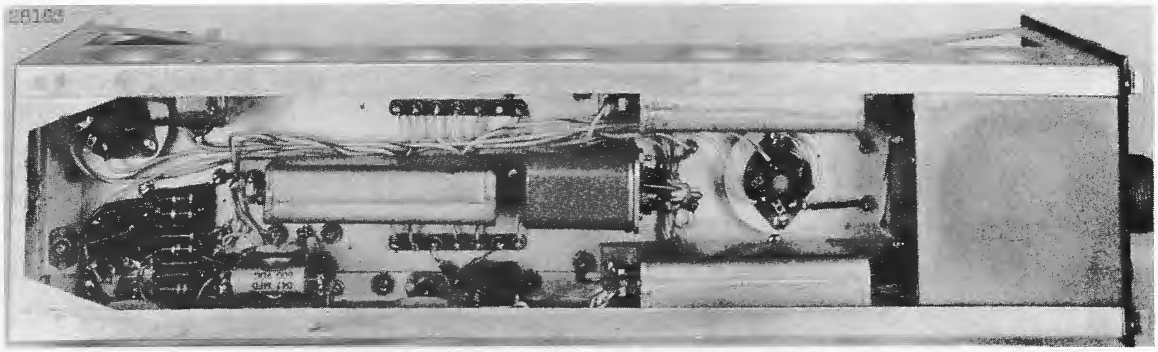


Fig. 25(b) - Power supply (under chassis view)

---

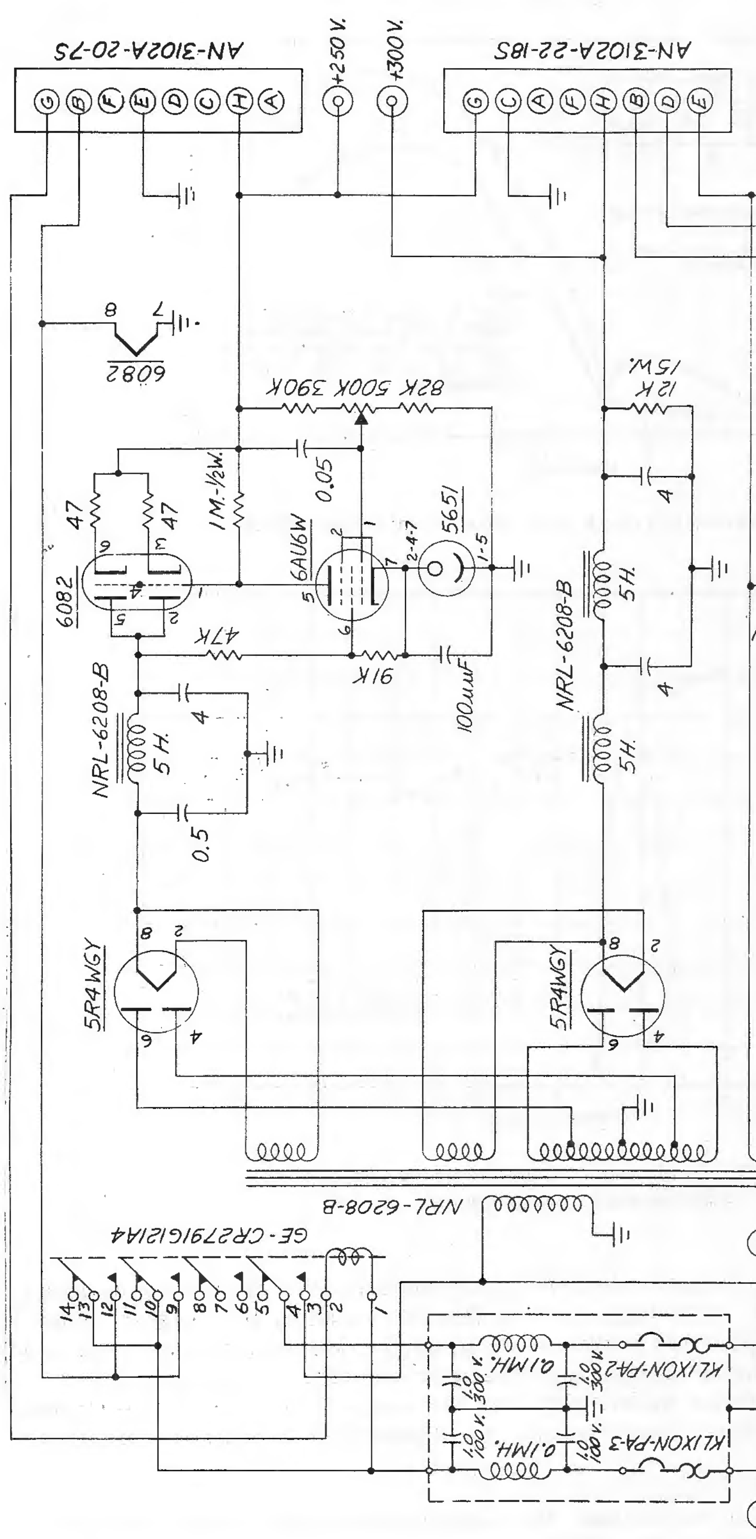
*Tangent-signal sensitivity for this type of system is defined as the r-f peak power (pulse modulation) required to produce a radial spot deflection on the CRT equal to twice the radial deflection produced by the noise alone.

[redacted]

DECLASSIFIED

[redacted]

NAVAL RESEARCH LABORAT



[redacted]

DECLASSIFIED

[redacted]

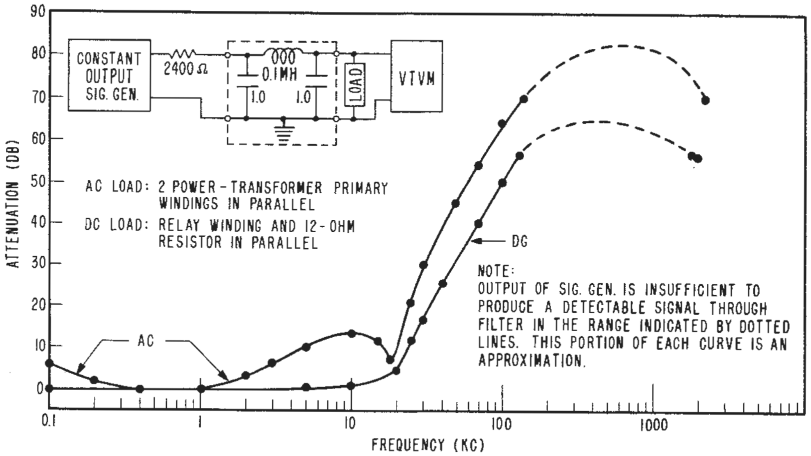


Fig. 27 - Characteristics of power supply line filter

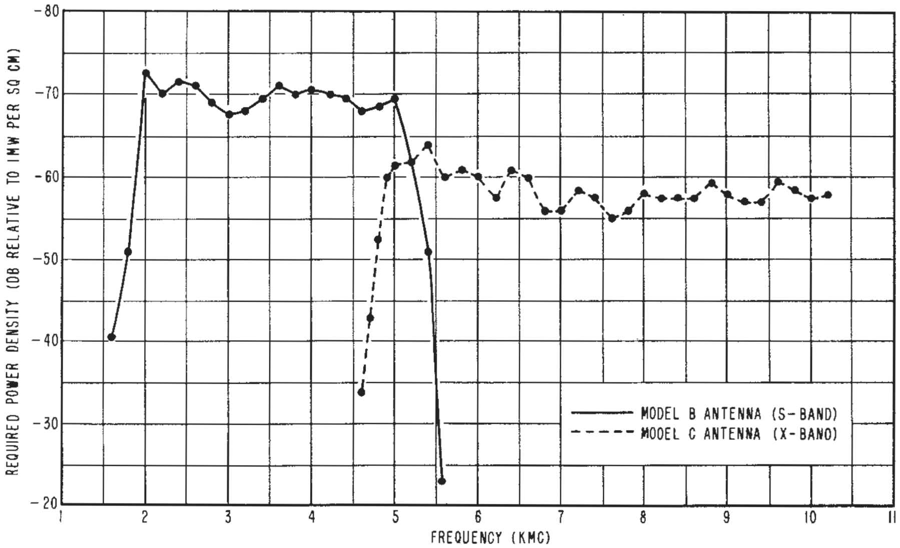


Fig. 28 - Tangent-signal sensitivity vs. frequency (horizontal polarization)

The sensitivity of the X-band dipole element is not uniform over its frequency range, but falls off, as seen in Fig. 29. It is believed that this is caused by the crystal holder used in the X-band dipole, and possible methods of remedying this situation are now under investigation. A recently developed dipole, fed from a waveguide, is very promising since it has better and more uniform sensitivity over the range of 5000 to 10,000 mc than the original dipole. The same type crystal mount, as is used with the horn element, can be used with this dipole.

In order to avoid confusion on the graphs, the sensitivities of the S-band horn and dipole elements have not been shown above 6000 mc. Actual tests have revealed that the

[redacted]

[redacted]

S-band horn and dipole elements will respond to signals at some frequencies higher than S-band. In fact, the sensitivities of the S-band elements are comparable to those of the X-band elements over the range of about 7500 to 9000 mc. Obviously, this situation is undesirable and needs to be ameliorated. The most direct method is to incorporate into the S-band elements a low-pass filter characteristic with a cut-off frequency slightly above 5000 mc. Some experimental work on low-pass filters for use with the S-band horn element has been carried out and a satisfactory filter was designed. But as yet, no filter has been designed for the S-band dipole or for the X-band horn and dipole. The filters are needed for the X-band as well as the S-band elements in order to restrict their response to the band over which they will operate satisfactorily.

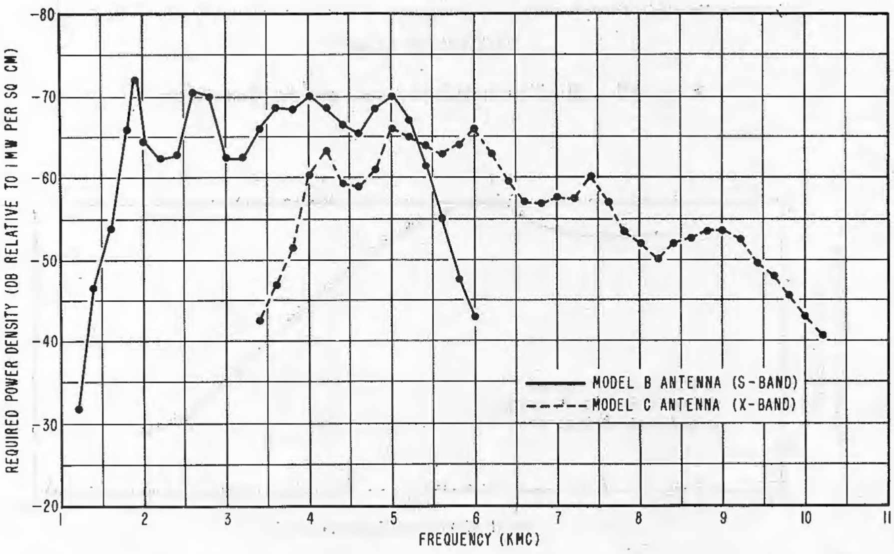


Fig. 29 - Tangent-signal sensitivity vs. frequency (vertical polarization)

Sensitivity Versus Pulse Duration

The manner in which the audio and video sensitivities vary with pulse duration of the r-f signal is displayed in Fig. 30. It is seen that the sensitivity, as measured at the cathode-ray tube of the Indicator, varies less than 2 db as the pulse duration is changed from 0.2 to 10 μsec. The variation in sensitivity as measured at the audio output is about 5 db when measured with a vacuum-tube voltmeter. When measured by ear, using a pair of AN/H3-ARR-3 headphones, a typical operator found a variation in r-f sensitivity of about 3 db for a change in pulse duration of 0.2 to 10 μsec.

Sensitivity Versus Pulse Repetition Frequency

Figure 31 gives the variation in audio sensitivity with pulse repetition frequency (prf), as measured with a vacuum-tube voltmeter. Actual subjective tests, in which the variation in sensitivity was measured using AN/H3-ARR-3 headphones, gave a typical variation of about 3 db in r-f sensitivity as the prf varied from 200 to 5000 pulses per second.

[redacted]

[redacted]

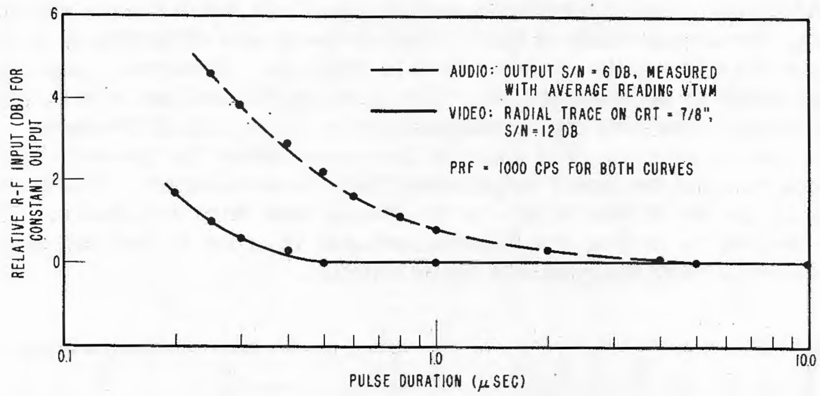


Fig. 30 - R-F sensitivity vs. pulse duration

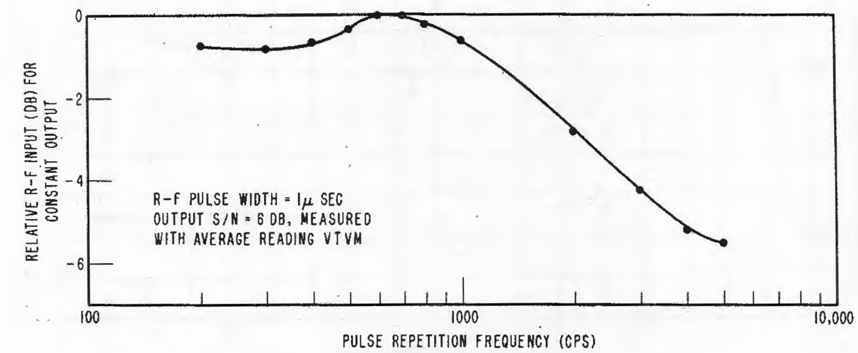


Fig. 31 - R-F sensitivity vs. pulse repetition frequency

Dynamic Range

The r-f dynamic range of the NL/ALD-A depends primarily upon the pulse duration and to a lesser extent upon the pulse repetition frequency. The variation of dynamic range with prf, measured ahead of the crystal detectors, is shown in Fig. 32. In this case the dynamic range represents the maximum change in r-f input signal level before any spurious trace (signal) is apparent on the CRT display.

Another method of defining the dynamic range is: the increase in r-f signal level above tangent-signal level which results in a 5-degree bearing shift. Based upon this definition, the dynamic range, measured at a prf of 1000 pulses per second, is 31 db for a 10-μsec pulse and is greater than 37 db for a 1.0-μsec pulse.

Instrumental Bearing Error

The instrumental bearing error of the complete direction finder was measured by placing the d-f antenna on a pedestal, clear of any reflecting objects, on the roof of an NRL building, then illuminating the antenna by an r-f signal from a horn antenna about

[redacted]

[redacted]

30 feet away. The rotation of the pedestal was controlled from the operating position near the transmitter and the angular positioning of the d-f antenna could be determined to within 0.1 degree.

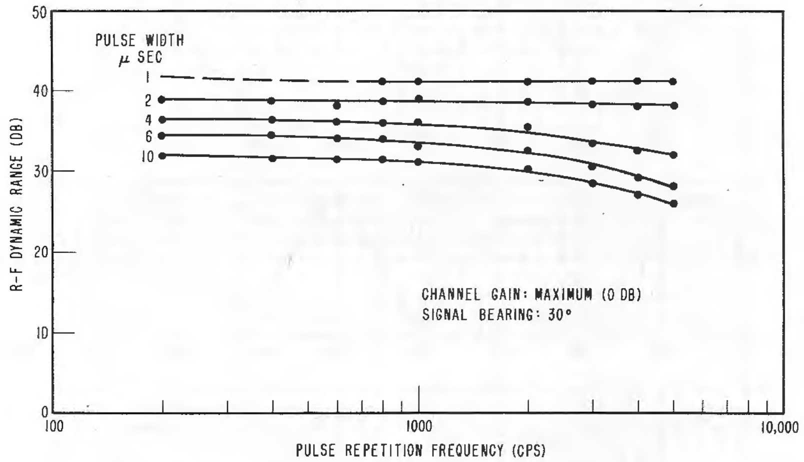


Fig. 32 - R-F dynamic range characteristics

The instrumental error curves of the direction finder for the frequency range of 5000 to 10,000 mc are shown in Figs. 33 and 34. In obtaining these data, the over-all gains of the four channels were matched at each frequency to within 5 percent. It is seen that the maximum bearing error obtained over this frequency range was less than ±8.0 degrees, at most frequencies less than ±6 degrees.

Instrumental error curves of the NL/ALD-A, measured over the frequency range of 2500 to 5000 mc, were given in Ref. (1) and will not be shown here. The maximum instrumental error determined by those S-band tests was ±7.5 degrees and this included the effects of crystal detectors which were not perfectly matched.

FLIGHT TEST PERFORMANCE

The NL/ALD-A(XB-1) with both the Model B and Model C antennas has been flight tested at the Naval Air Test Center, Patuxent, on a P2V and later on an R4D-6 type aircraft. Most of the flights were made with the R4D aircraft, and Naval Research Laboratory personnel participated in the majority of these flights. The position of the antenna, under a streamlined radome, can be seen below the R4D fuselage in Fig. 35, and a close-up of the installation is shown in Fig. 36. The X-band antenna was similarly installed when tests on it were carried out. Two reports describing the flight tests and some of the data obtained during these tests have been published by the Naval Air Test Center (5,6).

More than 30 separate test flights were made with the equipment installed in the R4D. The three principal types of tests carried out were:

1. Maximum range tests
2. Homing tests
3. Bearing error tests.

[redacted]

DECLASSIFIED

[redacted]

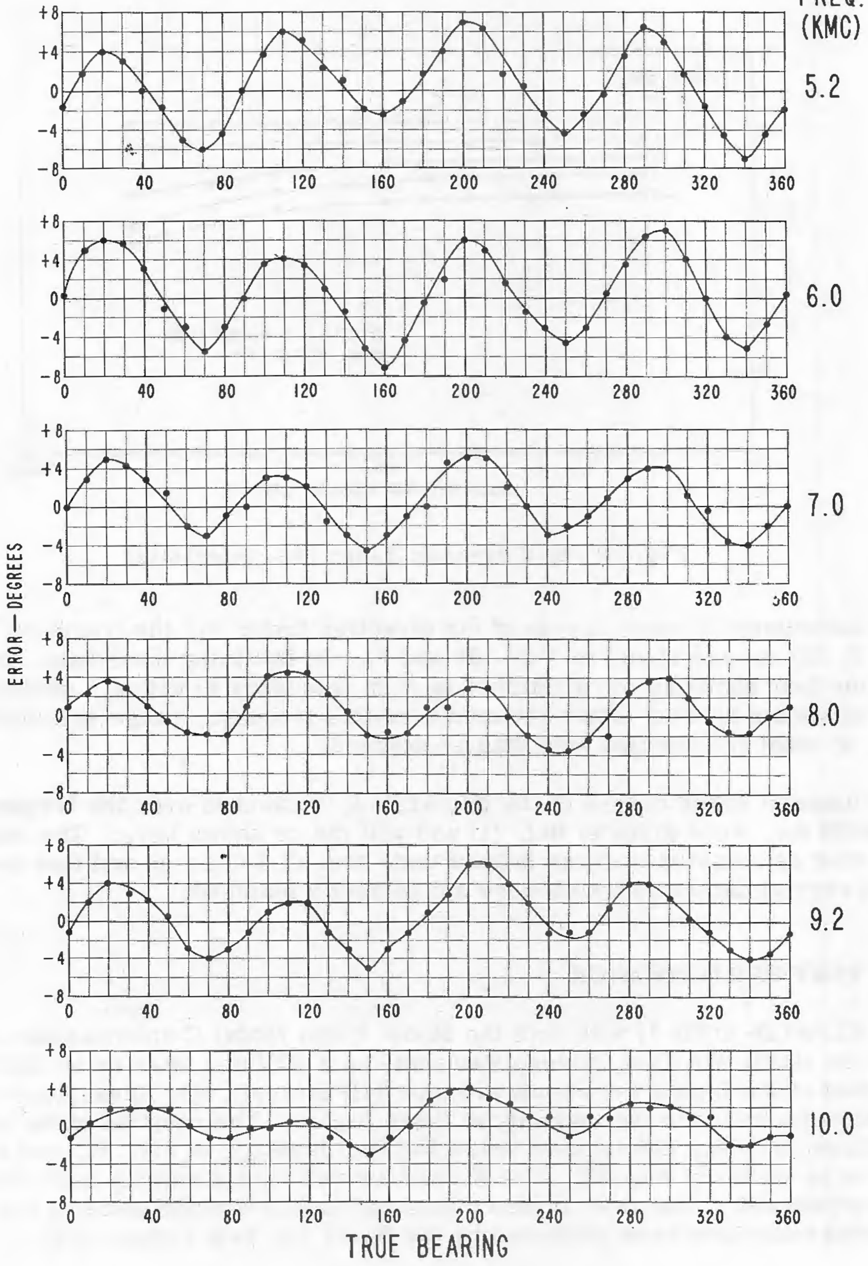


Fig. 33 - Instrumental bearing error (horizontal polarization)

[redacted]

DECLASSIFIED

DECLASSIFIED

[redacted]

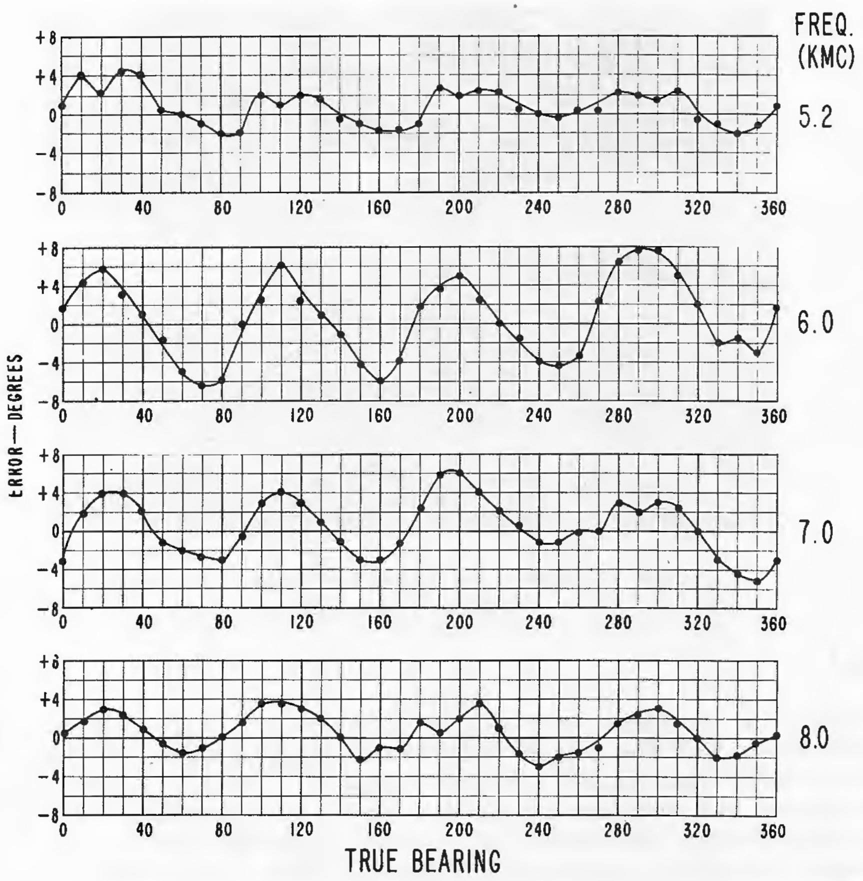


Fig. 34 - Instrumental bearing error (vertical polarization)

Fig. 35 - Antenna installation on R4D aircraft

[redacted]

DECLASSIFIED

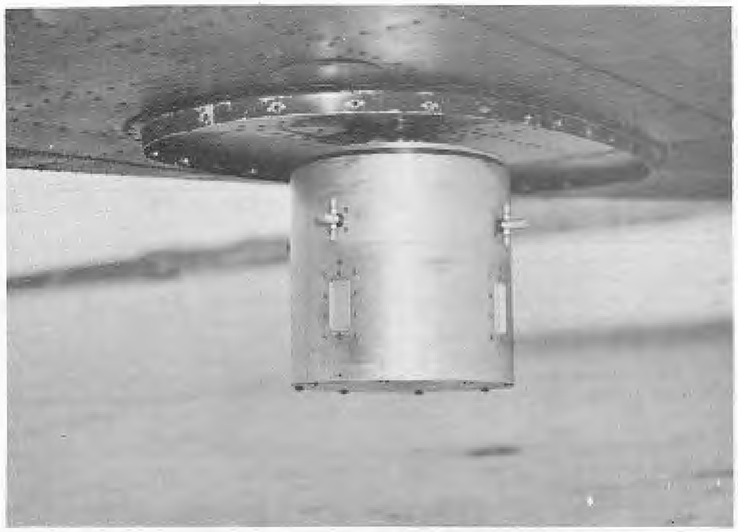


Fig. 36 - Close-up of S-band antenna installation (radome removed)

Range Tests

The results of the range tests are given in Table 3. Each of the source radars was ground-based, with the transmitting antenna located about 100 feet above ground. Where two different figures are given for range at a given altitude these figures represent inbound and outbound intercept ranges. As the range between aircraft and radar increased or decreased the received signal strength varied considerably going through successive maxima and minima. These fluctuations, caused by the interference between the direct ray from the radar and the gound-reflected ray, exceeded 20 db when flying over water. Because of these fluctuations, the signal was not intercepted on every sweep of the radar as the range approached the maximum values listed

TABLE 3
Maximum Intercept Range in Nautical Miles

Source	Frequency (mc)	Maximum Intercept Range (nautical miles)		
		Altitude 1000 ft	Altitude 5000 ft	Altitude 10, 000 ft
SX	2880	40-50	100	-
SG-3	3700	40-45	95	120
APS-44	5280	37	89-98	126-131
APS-44	9375	41	90	119-125

in Table 3. The dynamic range of the direction finder was adequate to accommodate the magnitude of these fluctuations without any difficulty.

Homing Tests

Several homing runs were made against both ground-based radars and against a radar-equipped submarine operating east of the Virginia Capes in the Atlantic. The submarine, Type SSR, was snorkeling at the time of the tests. In each of the homing tests, started about 20 to 30 miles from the radar, the pilot was given relative bearings by the operator of the NL/ALD-A. From these bearings, given at frequent intervals, the pilot determined his course and successfully homed in on the signal. During each test the radar antenna was rotating at a steady rate. As the aircraft approached the radar, the signal grew in intensity and even with the direction finder gain turned to a low level the d-f Indicator was virtually "filled" with signal when the plane approached to within a mile of the radar. The display on the Indicator was unmistakable as the plane flew over the radar and the bearing flopped over from 0 degrees to 180 degrees.

Bearing Error Tests

These tests were made under the following conditions whenever possible:

1. Altitude of aircraft was at some predetermined level between 2000 and 4000 feet.
2. Range between radar signal source and aircraft greater than 20 nautical miles.
3. At each test frequency, measurements were made against both vertical and horizontal polarization and both with and without a radome covering the d-f antenna.

A bearing-error run consisted of 24 separate d-f bearing measurements made approximately 15 degrees apart in azimuth. Most of these runs were made by the cloverleaf method wherein the plane flew a cloverleaf pattern about a fixed checkpoint on the ground. To complete such a pattern required the pilot to fly over the checkpoint 24 times, each time at a different heading (15 degrees apart). During the run the radar antenna, approximately 20 miles away, was beamed at the checkpoint. Each time the plane flew over the checkpoint the pilot signaled "mark," at which signal simultaneous readings of the d-f bearing and the magnetic compass were taken. Before calculating bearing errors from the flight data, the magnetic compass readings were corrected according to a compass calibration made on the ground.

In spite of normal precautions taken to perform the tests carefully, two factors existed which gave rise to some uncertainty in the determination of actual d-f bearing error. These were:

1. The inertia of the magnetic compass which made it difficult to obtain a precise reading.
2. The attitude of the aircraft at the moment when the d-f bearing was read from the Indicator.

The inertia of the magnetic compass was certainly detrimental to the accuracy of the tests; however, the error introduced by this factor is not known quantitatively. The attitude of the aircraft was critical because the d-f antenna, being located very close to the underside of the aircraft, was subject to a considerable amount of reflected energy from the nearby aircraft surfaces. At the frequencies involved these reflections from the aircraft structure can have considerable magnitude and do, in fact, cause the increase in bearing error observed with the equipment installed on an aircraft.

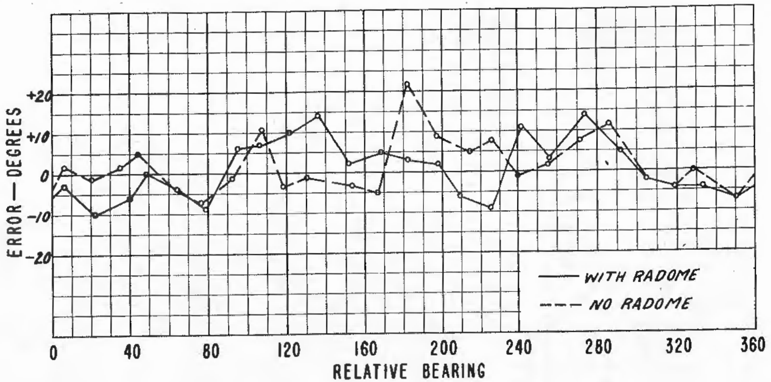
Bearing error curves for the Model B (S-band) antenna are given in Fig. 37. Three of the graphs show how the presence of a radome over the antenna affects the errors, and it is evident that the use of a radome does not materially increase the error. In one case, against horizontal polarization at 2800 mc, the errors are less when the radome is used. In general, though, the use of the radome increases the standard deviation by about 1.5 degrees at S-band (5). The fourth graph illustrates the repeatability of the error runs by giving the results of two runs made under identical conditions, that is, polarization horizontal and frequency 3500 mc.

Figure 38 shows bearing error data for the Model C antenna. As in the previous figure, three of the graphs show how the errors are affected by the use of a radome over the antenna, and the fourth graph illustrates the repeatability obtained in two runs made under the same conditions. Again it is evident that the use of a radome does not increase bearing errors very much. The standard deviation with the Model C antenna increases about 0.8 degree when a radome is employed. The d-f bearings were found to lack precise repeatability, similar to that noted at S-band. The lack of good repeatability is due to the reasons noted earlier, namely, the difficulty in making precise readings of the magnetic compass and the critical effect of the airplane's attitude upon the d-f bearing. For these reasons it is believed that an accurate calibration of the direction finder, installed in the manner described, is not possible.

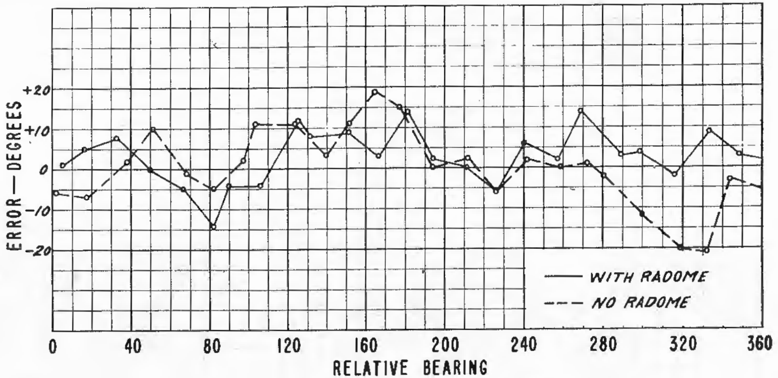
That the antenna system will operate satisfactorily against circularly polarized signals is seen from Fig. 39. When this type of signal is being received, part of the detected energy is supplied by the horn elements and part by the dipole elements. The display on the cathode-ray tube is essentially the same as that for a linearly polarized signal.

On a number of occasions during the flight tests it was noticed that the d-f antenna was "shadowed" by the aircraft structure. This shadowing was produced primarily by the engine nacelles and the landing gear which does not fully retract into the airframe on the R4D-6. This effect was most pronounced at the low end of the X-band frequency range and resulted in a very weak signal or no signal over narrow sectors of azimuth centered at 20 degrees and 340 degrees relative to the nose of the plane. The width of these shadowed sectors was about 15 to 20 degrees. Some effect upon the bearing accuracy was also produced by the tail wheel which does not retract and hangs down in view of the d-f antenna during flight.

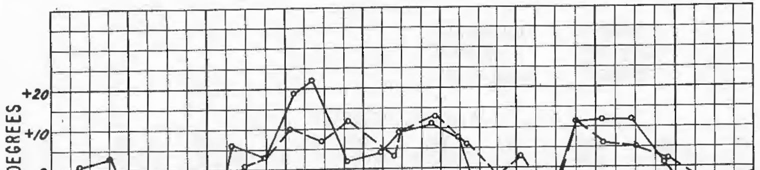
As reported by Patuxent (5,6), the results of all bearing error tests made in flight are as listed in Table 4. These figures include the data measured at all the test frequencies and for both horizontal and vertical polarization. There is no significant difference in the bearing accuracy for signals polarized either horizontally or vertically. If it is assumed that the bearing errors are normally distributed (i.e., Gaussian) about zero error, then 68 percent of the bearing errors will be less than the standard deviation in degrees. The Patuxent reports show that the bearing errors, measured in flight, exhibit a distribution very close to a normal distribution.

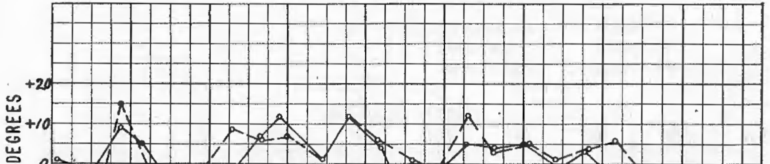


SIGNAL SOURCE SX
FREQUENCY 2880 Mc
POLARIZATION VERT.



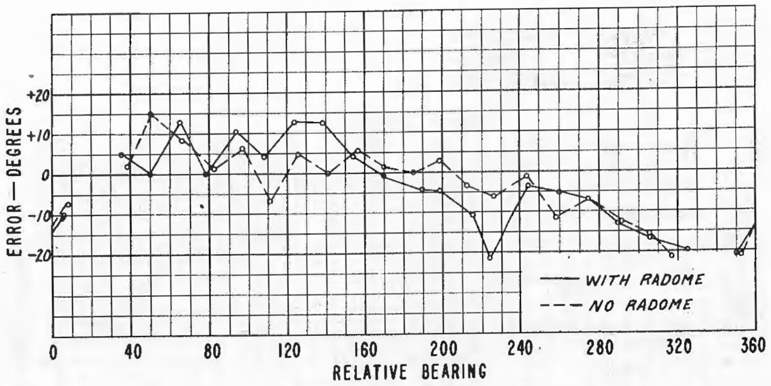
SIGNAL SOURCE SP
FREQUENCY 2800 Mc
POLARIZATION HOR.



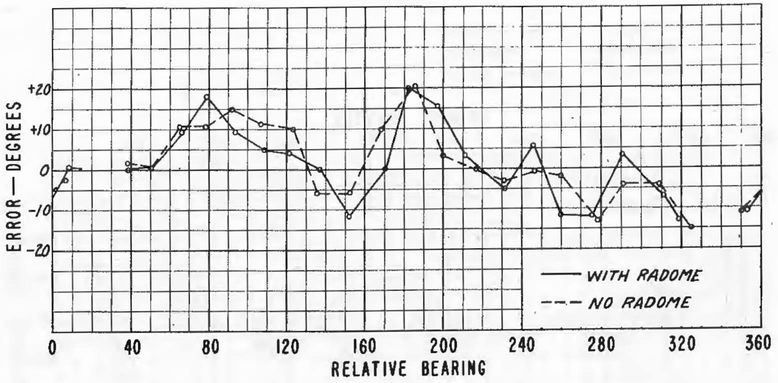


DECLASSIFIED

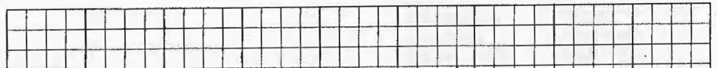
NAVAL RESEARCH LABO



SIGNAL SOURCE SG-6
FREQUENCY 6500 Mc
POLARIZATION VERT.



SIGNAL SOURCE AN/APS-44
FREQUENCY 5280 Mc
POLARIZATION HOR.



[redacted]

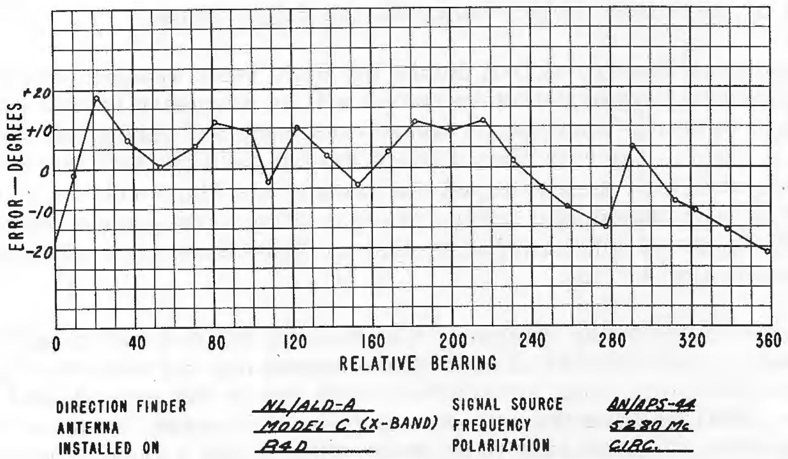


Fig. 39 - Error curve for circular polarization

TABLE 4
Standard Deviation of D-F Bearings

Antenna	Standard Deviation (degrees)	
	With Radome	No Radome
S-Band	10.7	9.2
X-Band	10.85	10.0

As pointed out earlier, one reason the bearing errors which occur in flight are appreciably greater than the instrumental bearing errors of the direction finder is that the aircraft surfaces reflect a considerable amount of signal energy into the d-f antenna. In order to reduce the bearing errors in flight, the following suggestions are listed as possible remedies:

1. Locate the d-f antenna on the aircraft at a position where the reflections and shadowing are a minimum. The antenna elements might be separated and located at the extremities of the wings or fuselage.
2. Design the antenna so that it "looks" away from the aircraft surfaces, e.g., the antenna beams can be tilted downward somewhat.
3. Provide the offending aircraft surfaces with an antireflective coating to reduce the magnitude of the reflections.

These suggestions are fairly obvious, but it would be necessary to carry out additional experimental work to determine their feasibility and effectiveness. For example, by separating the antenna elements and mounting them flush with the skin at suitable locations on the aircraft it might be possible to reduce bearing errors. The third suggestion, involving antireflective coatings, would have to be compatible with modern high-speed aircraft in order to be acceptable.

[redacted]

DECLASSIFIED

Observations on Equipment Performance During Flight Tests

The operation of the NL/ALD-A during the flight tests was practically trouble-free. With the exception of crystal detectors (which will be discussed below) and two tubes, no components had to be replaced and no breakdowns occurred during the more than 100 hours of operation in flight. The only circuit which did not perform satisfactorily at all times was the video test circuit used to adjust the gains of the four video amplifiers. The trouble with this circuit was caused by a faulty switching relay arrangement which has since been corrected. It was noted with satisfaction that no difficulties were experienced due to microphonics, interference, or hum.

The dynamic range of the equipment was found to be good and the ability of the system to accommodate a large number of near-simultaneous signals was excellent. As many as 5 or 6 radar signals were often intercepted within one or two seconds and each appeared as a separate radial trace on the cathode-ray tube. Of course, in areas of high signal density the operator finds his task to be more difficult and a greater effort is required of him to sort out and record the information being presented by the direction finder.

Some typical bearing displays were photographed during flight and are reproduced in Fig. 40. They illustrate how the indicator appears when signal activity is fairly high. Three separate signals are seen in (a) and (d) and four in (b) and (c). The spreading out of the display in (c) is caused by reflections and/or shadowing and was described earlier. The possibility of resolving two signals which lie almost on top of one another is illustrated in (d).

Crystal Detector Deterioration

The 1N23B crystals used in the NL/ALD-A during flight tests were selected in matched sets of four. The crystals were matched as to video output voltage for an r-f signal input about 10 db above tangent-signal level. The S-band sets were matched at four equally spaced frequencies within the band and the X-band sets were matched at five frequencies within the band. After periods of operation of about one month, the crystals were removed from the antenna on the aircraft and rechecked. It was found twice that the sets used in the S-band antenna were no longer matched, but that one of the four crystals in a set had deteriorated. In each case the video output of the degraded crystal was about one-half that of the other three, whereas it had initially matched the others within ±6 percent.

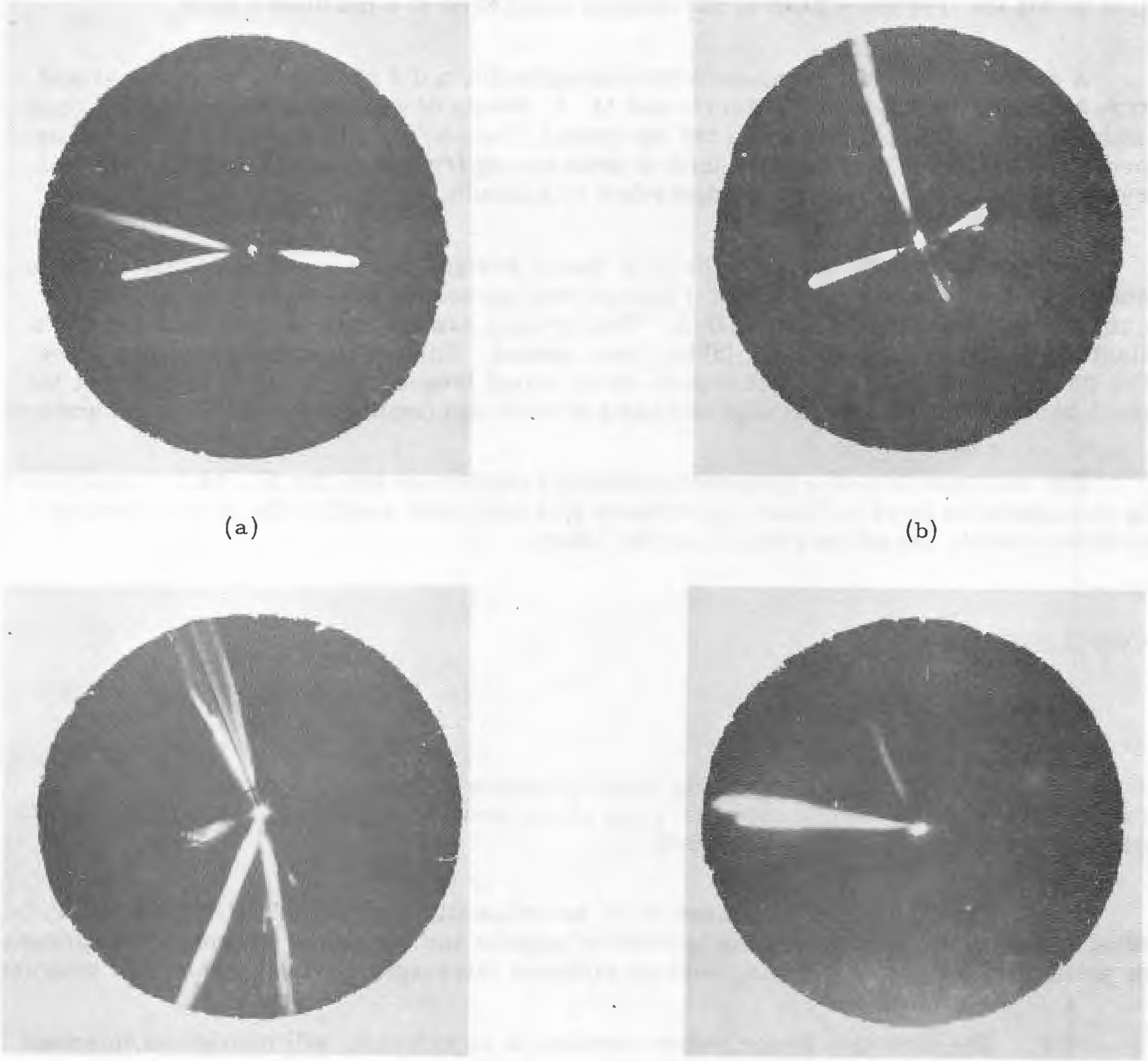
The two matched sets of crystals used in the X-band antenna were used for a period of about five weeks and at the end of this period a recheck showed that no significant change in sensitivity had occurred.

It is believed that the deterioration in crystal sensitivity was caused by the proximity of high-power radars (mainly S-band) to the aircraft during take-off and landing and even while the plane was parked near its hangar. The deterioration of crystal sensitivity is a serious matter since it can cause large bearing errors, and an effort is being made to determine the major cause of such deterioration. This effort involves tests of crystals for burnout and for loss in sensitivity under conditions of controlled impact and vibration.

It is considered essential to provide some means of protecting the crystals against high-power r-f fields, particularly during landing and take-off. Such protection might be afforded by a suitable switch or shutter associated with each antenna element and arranged so as to be effective whenever the direction finder power is off.

DECLASSIFIED

DECLASSIFIED



(a) (b)

(c) (d)

Fig. 40 - Typical bearing displays photographed during flight (exposures: 2 to 3 seconds)

DECLASSIFIED

DECLASSIFIED

METHOD OF FREQUENCY DETERMINATION

The present NL/ALD-A equipment has no provision whereby the frequency of an intercepted signal can be determined. It can only be assumed that an intercepted signal lies within the frequency band of the antenna being used at a particular time.

A possible method of frequency determination for a d-f system of the multichannel type has been proposed by F. Harris and M. J. Sheets of this Laboratory and the actual embodiment of this method into a vhf equipment, the AN/ARD-6, has been successfully accomplished (7). The actual method of determining frequency with a four-channel d-f system of the NL/ALD-A type is described in Appendix A.

A project was established at the U. S. Naval Postgraduate School in January 1953 to undertake the development of the r-f components necessary to provide frequency indication when used with the NL/ALD-A. This project has recently been terminated and a final report describing the work (8) has been issued. The r-f components developed by the Postgraduate School are not useable in an actual frequency indication device, but the work has resulted in a better understanding of the design requirements for these components.

The incorporation of a frequency-indicating component into the NL/ALD-A equipment is considered to be of sufficient importance that additional work on the development of a practical device should be planned for the future.

CONCLUSIONS

It is concluded that:

1. The NL/ALD-A direction finder provides instantaneous visual bearings on radar signals of any polarization, arriving at any azimuth angle, and at any radio frequency within a band of 2200 to 10,000 mc.

2. The NL/ALD-A, because of its exceptionally high probability of intercept, is ideal for securing bearings on the briefest of signals and for giving warning of the presence of potentially dangerous signals, such as airborne intercept or ground-controlled intercept.

3. The direction finder, when installed in an aircraft, will provide an intercept range equal to or greater than line-of-sight against high-power shipborne or ground-based radars.

4. The direction finder has good homing capabilities against brief and intermittent signals.

5. The instrumental bearing error does not exceed ±8 degrees and at most frequencies is less than ±6 degrees.

6. The direction finder is simple to operate and is small and light enough to install on carrier-type aircraft.

DECLASSIFIED

RECOMMENDATIONS

It is recommended that:

1. An investigation of crystal detector limitations be continued especially to obtain quantitative data concerning the effects upon crystals of vibration, impact, and high-level r-f power. Work of this nature is in progress.

2. Some form of protective device be incorporated in the antennas of the four-channel direction finder to protect the crystals against damage by nearby radars, particularly during take-off and landing.

3. The antennas be provided with a bandpass type frequency response so that they will not respond to signals outside the r-f band in which they give good bearing accuracy.

4. An investigation of the method of frequency indication described herein be carried out at some future time to determine the feasibility of using such a method with the NL/ALD-A.

ACKNOWLEDGMENTS

It is desired to acknowledge the valuable assistance provided by Mr. R. D. Mayo of the Naval Research Laboratory during the many flight tests of the NL/ALD-A. Mr. A. B. Youmans of this Laboratory made a major contribution toward the development of the direction finder antennas.

* * *

[redacted]

[redacted]

REFERENCES

1. Jesswein, A. J., "Instrumental Errors of a Four-Channel Crystal-Video Direction Finder," NRL Memo Report No. 160 (Confidential), April 23, 1953

2. Youmans, A. B., "Antenna Considerations for a Four-Channel Crystal Video Direction Finding System," NRL Memo Report No. 215 (Confidential), October 1, 1953

3. Gruber, J. R., "The Effect of Channel Mismatch Upon the Bearing Accuracy of a Four-Channel Direction Finder," NRL Memo Report No. 302 (Confidential), June 15, 1954

4. Mayo, R. D., "A High Fidelity Crystal-Video Receiver," NRL Memo Report No. 89, p. 4 and Fig. 9 (Confidential), November 1952

5. "Evaluation of Wide Open Airborne Direction Finder, NL/ALD-A(XB-1)," Naval Air Test Center, Patuxent River, Md.; EL 45017, Report No. 1 (Confidential), January 25, 1954

6. "Evaluation of Wide Open Airborne Direction Finder, NL/ALD-A(XB-1)," Naval Air Test Center, Patuxent River, Md.; EL 45017, Report No. 2, Final Report (Confidential), March 8, 1954

7. "Instruction Book for AN/ARD-6(XB-1), Airborne Direction Finding System," Prepared by Countermeasures Branch, Naval Research Laboratory (Confidential), October 1951

8. Final Report on BuAer Project Order 40701-53; U. S. Naval Postgraduate School, Monterey, Calif., Ser. NC4(10136), A11(937.3), of December 27, 1954

* * *

[redacted]

APPENDIX A
Method of Frequency Determination

The method of determining signal frequency described below is completely instantaneous if the system components are arranged as shown in Fig. A1. The r-f signal is picked up on an antenna and applied to a group of filters, each of which is followed by a detector and video amplifier. The outputs of the amplifiers, which are matched in gain and frequency response, are applied to the four deflection plates of a CRT indicator. The signal will produce a radial trace on the CRT whose angular position is a function of the frequency. If filters 1, 2, 3, and 4 are fixed-tuned to discrete frequencies such that filter 1 is tuned to the lowest and filter 4 to the highest frequency, the angular position of the trace will move counterclockwise as the signal frequency increases from one end of the band to the other.

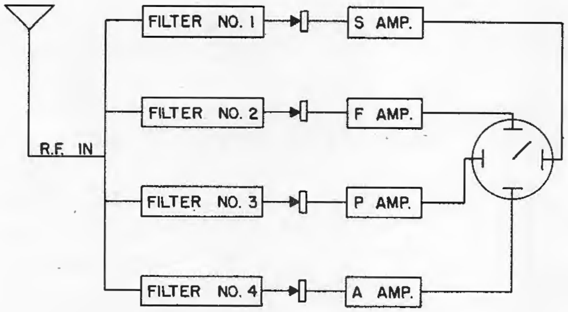
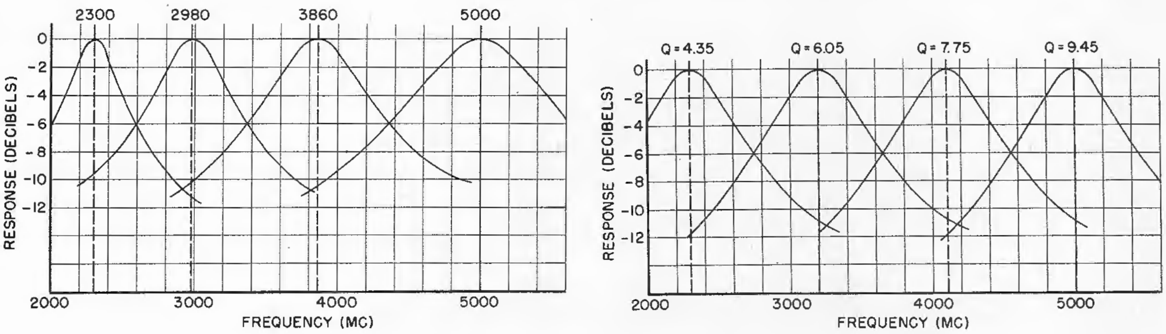


Fig. A1 - Method of frequency determination

Two possible types of filter response characteristics are shown in Fig. A2(a) and A2(b) for the S-band frequency range. It is evident from these characteristics that the filter Q's must be low if a broad frequency coverage is desired with a single set of four filters. The shape of the filter curves and the spacing of the resonant frequencies throughout the band to be covered will determine the actual calibration of the frequency scale associated with the CRT indicator. In the design of the NL/ALD-A alidade, provision has been made for incorporation of a separate frequency scale which can be read directly through the viewing window below the face of the CRT. If it is assumed that the angular accuracy of the frequency indication is within ±9 degrees, which is believed to be a reasonable assumption, the accuracy with which a frequency can be determined is about ±4 percent for the S-band range of Fig. A2. Other frequency bands can be covered by additional sets of simple low-Q filters, suitably tuned in frequency and arranged as described above.



(a) Tuned filter response, equal Q (Q = 6.52); geometrical ratio = 1.295

(b) Tune filter response with equal bandwidth filters

Fig. A2 - Possible filter characteristics for S-band

[redacted]

In using the frequency indication method of Fig. A1 with the four-channel direction finder, such as the NL/ALD-A, the most economical arrangement would be to employ the same CRT and video amplifiers for both direction finding and frequency indication. This could be accomplished by a suitable video switching arrangement. The antenna of Fig. A1 could be either a separate omnidirectional antenna or could be one of the d-f antenna elements selected by the operator after a bearing has been obtained indicating the direction of arrival of the signal. The use of an omnidirectional antenna is simpler because it eliminates the necessity for complicated r-f switching which would be required for selecting any one of the separate d-f antenna elements.

* * *

[redacted]

NAVY-DPPO PRNC. WASH., D.C.