

SYSTEM CONSIDERATIONS OF A WIDE-OPEN, CRYSTAL-VIDEO, TWO-CHANNEL DIRECTION FINDER

A. J. Jesswein, Jr.

RADIO DIVISION

8 June 1956



NAVAL RESEARCH LABORATORY
Washington, D.C.

APPROVED FOR PUBLIC RELEASE
DISTRIBUTION UNLIMITED

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE 08 JUN 1956		2. REPORT TYPE		3. DATES COVERED 00-00-1956 to 00-00-1956	
4. TITLE AND SUBTITLE System Considerations of a Wide-Open, Crystal-Video, Two-Channel Direction Finder				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory, 4555 Overlook Ave SW, Washington, DC, 20375				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES 27	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

SYSTEM CONSIDERATIONS OF A WIDE-OPEN,
CRYSTAL-VIDEO, TWO-CHANNEL DIRECTION FINDER

A. J. Jesswein, Jr.

8 June 1956

Countermeasures Branch
Radio Division
Naval Research Laboratory
Washington 25, D. C.

DISTRIBUTION

BUSHIPS, Code 840	-5
BUAER, Code EL-8	-5
OPNAV	
Code Op-371C	-1
Code Op-347	-1
Code Op-30GT	-1
Code Op-555C	-1
ONI	
Code Op-922F-2	-1
ONR, Code 427	-1
CINCNELM	-4
Head, Sec, Group ELM	
Navy 100, FPO, New York	
COMNAVFE	-2
Co- VQ-1, Attn: ECM Officer	
Eglin AFB, Fla.	-1
SCEL, Attn: Dir, CM Div	-1
CG, Wright Air Development Center	-1
Attn: WCLRC	

CONTENTS

	Page
ABSTRACT	ii
PROBLEM STATUS	ii
AUTHORIZATION	ii
INTRODUCTION	1
SYSTEM OPERATION	2
REQUIREMENTS OF ANTENNA PATTERNS	2
SIGNAL MIXING TECHNIQUES	6
PRACTICAL CONSIDERATIONS OF THE MIXERS	6
INSTRUMENTAL ERRORS	8
TWO AND FOUR-CHANNEL SYSTEM COMPARISON	9
A BILATERAL VIDEO AMPLIFIER	10
CONCLUSIONS	10
REFERENCES	11
APPENDIX I	12

ABSTRACT

A wide-open, crystal-video, four-channel direction finder, the NL/ALD-A, was previously developed at the Naval Research Laboratory for the detection of amplitude modulated signals. This development suggested the possibility of a two-channel direction finder system; therefore, an investigation was undertaken to determine the fundamental requirements of a two-channel type direction finder, from theoretical and practical viewpoints.

The basic theoretical antenna pattern function, for a zero-bearing-error, two-channel d-f system, was determined and found to be of a practical configuration. Effects of channel gain mismatch are analyzed and the two-channel d-f system was found to result in greater mismatch errors compared to the four-channel d-f system when each incorporates square-root-law amplifiers. Tighter tolerances on mismatch in the two-channel system would, therefore, be necessary for comparable operation.

Less than 20 percent reduction in power drain, and 10 percent in weight and volume is anticipated by the use of a two-channel d-f system.

Except for small reduction in power drain, weight and volume, the two-channel direction finder has no definite advantages. In general, the four-channel direction finder has better over-all accuracy and dependability of d-f bearings.

PROBLEM STATUS

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

AUTHORIZATION

NRL 54R06-20
BuAer EL-45008
R&D NL 460 076

INTRODUCTION

In the development of any electronic equipment emphasis is placed upon obtaining the required electrical characteristics with the greatest simplicity in design and maintenance.

Airborne equipment has the added specifications of miniaturization which may be accomplished in some cases by altering the design or fundamental concept of a system to reduce the number of circuit components. Analysis of the new systems' general characteristics is then required in order that its performance may be compared with the original.

In the latter stages of developing a wide-open four-channel crystal-video direction finder, the NL/ALD-A (reference (a)) a method of modifying the basic system into a two-channel direction finder was proposed and its characteristics as compared with the original four-channel system were considered worthy of investigation. This report was, therefore, prepared to analyze the wide-open, two-channel d-f system as to (1) the requirements placed on the antenna radiation patterns for zero error, (2) the methods of video mixing required to provide a working system, (3) instrumental error effects and (4) the two-channel d-f versus four-channel d-f system comparison. A developed two-channel amplifier design is presented along with measured operational data. By analyzing and comparing the two systems, a better understanding of the capabilities of each can be obtained, permitting a better choice of equipments for future developmental or operational problems.

SYSTEM OPERATION

In general, the basic operation of the two-channel d-f system (Figure 1) and four-channel d-f system (Figure 2) is the same, i.e., the visual angular indication of azimuth bearing depends upon that portion of the signal power received and detected in each of four antennas equally spaced in the azimuth plane (references (b) and (c)). However, the four-channel direction finder effectively performs both subtraction and division directly at the plates of the oscilloscope, whereas the two-channel type direction finder requires that the former (subtraction) occur immediately following r-f detection at the crystals as video mixing. In the two-channel system directional information from the four antenna elements is retained after detection by video mixing signals from opposite antenna elements.

The polarity of the mixed video signal output (positive or negative) is an indication of which of the two opposed antennas is receiving the most r-f energy.

Two bilateral video amplifiers, which amplify both positive and negative pulse signals, are required to transfer the information from the four antennas to the CRT visual indicator for bearing display. The deflected direction of the CRT trace depends upon the polarity and magnitude of the two video signals which are applied to the horizontal and vertical plates.

Four unilateral video amplifiers are necessary in the four-channel direction finder to accomplish the same results.

REQUIREMENTS OF ANTENNA PATTERNS

In a two- or four-channel, crystal-video direction finder the antenna radiation patterns play a very important role in the accuracy of the system, for it is here that the first effect of d-f bearing error is encountered. The antenna requirements of a four-channel d-f system are discussed in reference (b), but these do not apply to the two-channel direction finder, except for specialized cases. Thus, it is necessary to analyze the antenna radiation pattern requirements needed to provide zero bearing error in a two-channel direction finder. To eliminate repetition of the derivations in reference (b), the two d-f systems are compared as to their respective mathematical expression of indicated bearing (ϕ_{df}) as a function of the true bearing (ϕ). In this way similarities are noted easily.

The general mathematical expression of indicated bearing for the four-channel d-f, using the coordinate system of Figure 3, is

$$(1) \quad \tan \phi_{d-f} = \frac{[E_2(\phi, \theta_i)]^{2p} - [E_4(\phi, \theta_i)]^{2p}}{[E_1(\phi, \theta_i)]^{2p} - [E_3(\phi, \theta_i)]^{2p}}$$

and for the two-channel d-f

$$(2) \tan \phi_{d-f} = \left\{ \frac{[E_2(\phi, \theta_i)]^2 - [E_4(\phi, \theta_i)]^2}{[E_1(\phi, \theta_i)]^2 - [E_3(\phi, \theta_i)]^2} \right\}^p$$

p indicates the exponential law of the amplifier.
 $E_n(\phi, \theta_i)$ antenna voltage radiation function for a constant θ_i .
 Square law detectors are assumed.

For convenience of terminology in this report, it is noted that there are three combinations of system characteristics which are of interest when considering the antenna radiation response and transfer law of the amplifiers. These combinations are listed below with a type number; hereafter, reference will be made to type only.

Type I Antenna response pattern greater than 180°
 Receiver amplifier law linear ($p=1$)

Type II Antenna response pattern less than 180° (hemispherical response)
 All exponential receiver laws ($-\infty \leq p \leq \infty$)
 (Principal interest in $p=\frac{1}{2}$)

Type III Antenna response pattern greater than 180°
 All exponential receiver laws except linear ($p \neq 1$)
 (Principal interest in $p=\frac{1}{2}$) ($-\infty \leq p \leq \infty$)

It is noted that for the conditions of system Types I and II, equations (1) and (2) are identical and, therefore, the two-channel d-f is covered by the antenna requirements of the four-channel d-f. The power patterns for the two conditions are contained in the general expression (for θ_i a constant):

$$(3) E_1^2(\phi) = \left[a_0 + \frac{1}{2}H(Lp\phi) \cos \phi + \sum_{n=1}^{\infty} a_{2n} \cos(2n\phi) \right]^{1/p}$$

$$(4) E_2^2(\phi) = E_1^2(\phi-90)$$

$$(5) E_3^2(\phi) = E_1^2(\phi-180)$$

$$(6) E_4^2(\phi) = E_1^2(\phi-270)$$

An analysis of the two-channel system antenna pattern requirements for the Type III characteristics is somewhat more complex and not covered in reference (b). The solution for the special case of interest (for $p=\frac{1}{2}$) is given later in this report.

In general, amplifier laws in which the exponent is less than unity ($p \leq 1$) are of principal interest, because of the increased effective dynamic range that results. The four-channel direction finder, employing a square-rooting amplifier, also resulted in a minimization of instrumental error by its reduction in gain mismatch variations (reference (c) and (d)). Amplifier laws in which the exponent is less than unity do require increased gain relative to linear-law amplifier. Hence, the square-root law ($p = \frac{1}{2}$) is the limiting type discussed.

In the two-channel system, assuming no gain mismatch between channels, for zero error to exist the difference function, from equation (2), has to be expressible as:

$$(7) \quad [E_1(\phi)]^2 - [E_3(\phi)]^2 = [H(\phi)\cos(\phi)]^{1/p} = G(\phi)[\cos(\phi)]^{1/p}$$

$$(8) \quad [E_2(\phi)]^2 - [E_4(\phi)]^2 = [H(\phi)\sin(\phi)]^{1/p} = G(\phi)[\sin(\phi)]^{1/p}$$

Because of the natural bilateral function of $\cos \phi$ and $\sin \phi$, precautions have to be taken in the use of the mathematical properties of the exponential function. The difference function, however, can be handled as in reference (b). In order that the functional orientation of the four patterns in the azimuth plane be retained, $G(\phi)$ has to be a function of $(\ln \phi)$. Thus, taking into account the characteristics of the two-channel system, the general power function required of the antenna response is

$$(9) \quad E_1^2(\phi) = a_0 + G(\ln \phi) [\cos \phi]^{1/p} + \sum_{n=1}^{\infty} a_{2n} \cos 2n \phi$$

$$(10) \quad E_2^2(\phi) = E_1^2(\phi - 90)$$

$$(11) \quad E_3^2(\phi) = E_1^2(\phi - 180)$$

$$(12) \quad E_4^2(\phi) = E_1^2(\phi - 270)$$

Note that the difference between equation (3) and (9) is in the placement of the exponent (p). The necessary zero-error antenna power response can now be determined for use with the square-rooting amplifier characteristic.

It may be shown that the Fourier expansion of $(\cos \phi)^{1/p}$, for $p = \frac{1}{2}$, is

$$(13) \quad [\cos \phi]^2 = \sum_{n=0}^{\infty} (-1)^{(n+1)} \left(\frac{8}{(2n-1) 2n+1 (2n+3)} \right) \cos (2n+1) \phi$$

By substitution into equations (9) thru (12) the zero-error antenna function for the Type III two-channel d-f is

$$(14) \quad E_1^2(\phi) = a_0 + G(\ln \phi) \sum_{n=0}^{\infty} \left[(-1)^{n+1} \left(\frac{8}{(2n-1)(2n+1)(2n+3)} \right) \cos(2n+1)\phi \right] \\ + \sum_{n=1}^{\infty} a_{2n} \cos 2n\phi$$

$$(15) \quad E_2^2(\phi) = E_1^2(\phi-90)$$

$$(16) \quad E_3^2(\phi) = E_1^2(\phi-180)$$

$$(17) \quad E_4^2(\phi) = E_1^2(\phi-270)$$

An infinite number of zero-error power patterns may be obtained from this function. Three possible power patterns, giving zero-system error, are expressible as

$$(18) \quad E_1^2(\phi) = 1 + \sum_{n=0}^{\infty} \left[(-1)^{n+1} \left(\frac{8}{(2n-1)(2n+1)(2n+3)} \right) \cos(2n+1)\phi \right]$$

$$(19) \quad E_1^2(\phi) = 1 + 3/2 \sum_{n=0}^{\infty} \left[(-1)^{n+1} \left(\frac{8}{(2n-1)(2n+1)(2n+3)} \right) \cos(2n+1)\phi \right] + \frac{1}{2} \cos 2\phi$$

$$(20) \quad E_1^2(\phi) = 2 + 3/2 \sum_{n=0}^{\infty} \left[(-1)^{n+1} \left(\frac{8}{(2n-1)(2n+1)(2n+3)} \right) \cos(2n+1)\phi \right] + \frac{1}{2} \cos 2\phi$$

The normalized voltage plots are shown in Figure 4 and approach the shape of known response patterns. For example, the pattern of equation (18) resembles the cardioid type as obtained in the four-channel antenna development while equation (20) produces a pattern similar to that obtained from a slot on a cylinder whose diameter is small compared to a wavelength ($D < .15 \lambda$) (reference (e)). However, a reduction in sensitivity, as well as difficulty in maintaining good patterns over a sufficiently broad band, will result from the latter pattern because of pickup at $\phi = 180^\circ$. No effort has been extended toward the design of antennas with these response characteristics. In a later section, the antennas of the four-channel system are investigated as to their use with the two-channel d-f system.

A logarithmic amplifier is at times considered as a means of increasing the dynamic range of a system (reference (d)). In the two-channel type d-f its use results in the displayed bearing being a function of the channel gain and signal envelope even though gain matched channels are assumed (Appendix I). Therefore, logarithmic amplification is not considered for use in the two-channel system.

SIGNAL MIXING TECHNIQUES

Proper operation of the two-channel direction finder of Figure 1 depends upon having pulse polarity discrimination between diametrically opposite antenna elements, i.e., the composite pulse polarity (positive or negative) provides the intelligence needed for indicating the bearing. Thus, the method of mixing signals from two opposite antenna elements, to obtain a combined signal, is important in the over-all compliance of the system with the required characteristics. To provide as nearly a true two-channel direction finder as possible, the signal mixing has to be accomplished at an early stage in the system. Combining of r-f signals is entirely too complex principally because of the necessarily precise phasing and matching problems which would be involved for broad-band operation. Video mixing offers the fewest problems and may take place directly after detection in the crystal diodes.

Either of two types of mixing (Figure 5) may be employed depending upon the polarity of the video signals obtained from the detectors. If the video signals, from an opposite antenna element pair, are of the same polarity, then a subtractive type mixer must be used, but with signals of opposite polarity, direct mixing is applicable.

PRACTICAL CONSIDERATIONS OF THE MIXERS

A subtractive mixer allows all r-f components (including the crystal detector and mount) to be identical, with signal polarity discrimination determined in the mixer circuit itself. This is a desirable characteristic when r-f gain matching is considered. One simple type of subtractive mixer is a balanced to unbalanced pulse transformer. The principal problem involved in this subtractive type mixer is one of providing good balance with minimum insertion loss. Presence of any electrical unbalance will appear as an effective change in video gain prior to mixing and thus introduce a new element of instrumental error. The insertion loss, of course, affects the system sensitivity.

References (f) and (g) indicate that wide-band video transformer designs are practical with insertion losses of approximately 3 db or less, and their windings balanced to better than 1 percent. Limited experimental design has shown that transformers having less than 3 percent unbalance are practical without using special balancing techniques. This is acceptable for system Types I and II; however, for Type III a 17.5 percent unbalance (or gain mismatch) at the deflection plates would be observed using this transformer. This is due to the effects of the square-rooting network. To obtain an acceptable gain mismatch of 3 percent for Type III, the transformer would require a balance better than 0.1 percent. The error effects of gain mismatch for the two-channel direction finder will be shown later. Other subtractive mixers employing vacuum tubes are possible and will have the same limiting electrical requirements as the transformer.

The direct mixing technique may be accomplished in two ways, by using (1) standard crystals (as the 1N23B) and their counterparts, reversed crystals (as the 1N23BR) or (2) altered crystal mounts which would invert two of the four necessary crystals physically in their mounts. In each case dual polarity signals are obtainable.

The system requires that, for minimum mismatch error, the transfer characteristics of each antenna plus crystal mount and crystal be matched within a stated tolerance. With careful fabrication, the antenna discontinuities should contribute only a minor part to this error. Ability to match crystals and their mounts over a broad band of frequencies is, therefore, the ultimate criterion, and the merit of either method of component placement depends upon this result.

Investigation into matching a limited number of 1N23B and 1N23BR crystals (14 each) to less than ± 0.25 db power sensitivity and over a frequency range of 2,500 Mc to 10,000 Mc (covered in 2 bands) has shown the possible yield of matched crystals which might be expected from a finite supply. Over the 2,500 Mc to 5,000 Mc band, 50 percent of the crystals were matchable in sets of four (containing 2-1N23B and 2-1N23BR), but only 15 percent in the 5,000 Mc to 10,000 Mc band. The small yield of the latter was caused principally by impedance mismatch conditions above 9,000 Mc.

The problem of gain matching crystals becomes more difficult when the second method, involving standard and altered crystal mounts, is used with 1N23B crystal diodes. An NRL developed wave guide mount was altered so that a cartridge type crystal diode could be reversed physically in the wave guide mount. The performance of the crystal in the reversed and normal positions was then compared. Experimental data involving the fourteen 1N23B crystals indicates that about 20 percent yield of gain matched crystals plus mounts was obtained in the 2,500 Mc to 5,000 Mc band, but negligible yield above 5,000 Mc. Although the original and altered mounts which were employed provided adequate over-all sensitivity response, the mismatch difficulty was apparently caused by dissimilar mount impedance characteristics as a function of frequency. A more careful design of the crystal mounts should increase the probable yield, but the problem will definitely be more exacting at the higher frequencies. These percentages given are true for only a finite number of samples. Larger batches would, of course, yield greater percentages of matchable crystals, in the limit being 100 percent for an infinite number if only matching and not sensitivity limits is considered.

In summary, gain mismatch effects are encountered in both types of mixers. In subtractive mixing, the crystals and mounts offer no added problem, but the unbalance effect of the mixing network is always present. Direct mixing offers no matching problem, but rather here it is the crystals and mounts which add to the mismatch. From the information presently available, it would appear that the technique of

using standard and reverse crystals is the best solution considering gain matching and maximum sensitivity. At the higher frequencies dependence is placed upon how well the manufacturer can produce standard and reversed crystals to meet the same specifications.

INSTRUMENTAL ERRORS

Instrumental bearing errors result from two sources, the effective antenna pattern response and gain mismatch between channels. Theoretical zero error antenna patterns have been discussed previously and show the trend toward which we must work for minimum error. Perfect zero error patterns would be very difficult to realize practically at any one frequency and nearly impossible over a wide frequency band. Thus, a tolerable error has to be established as a practical limit. Experience with the four-channel d-f system has shown that a ± 7.5 degree maximum error is acceptable. This tolerance in error should be applicable to the two-channel direction finder as well. An antenna design specifically for the two-channel system, incorporating a square rooting network was not attempted; however, patterns of the developed four-channel antenna system (the NL/ALD-A) may be employed as a practical first-order approximation. The X-band antenna patterns (5,000 Mc to 10,000 Mc) of the four-channel direction finder, Figure 6, are very similar to the S-band patterns (2,500 Mc to 5,000 Mc) and are used here to calculate the maximum pattern errors over the band, Figure 7, when used with a two-channel system. An octantal error characteristic is obtained as in the four-channel direction finder. Note that the errors of the two-channel system (square-root-law amplifiers) exceed the established ± 7.5 degrees at all points in the band. The errors are not extremely large; however, they are less than ± 17 degrees. A reduction in the error is observed at the higher frequencies where the beamwidth decreases. Thus, increasing the effective aperture of the present antenna elements may be a possible method of decreasing the over-all error and allowing the use of the basic four-channel antenna configuration.

Gain mismatch, as stated, also contributes to the over-all error and the amount by which the system is affected determines its usefulness. References (c) and (d) indicate the extent that gain mismatch affects the four-channel system when zero-error antenna patterns are assumed. These also apply to the two-channel system (Types I and II); however, Type III, which employs a square-root amplifier, is again the special case and has a correspondingly special gain mismatch characteristic. Zero pattern error functions, equations (18) and (19), were chosen to demonstrate the gain mismatch effects of this system type. Figure 8 compares the calculated maximum error of Type III as a function of gain mismatch in one channel with those of a four-channel direction finder as obtained from Figure 4 of reference (d). Here again, it is evident that the two-channel direction finder (Type III) does not meet the same standards as the four-channel direction finder (Type III) considering gain mismatch. Note that of the patterns of Figure 4, the one having

the least pick-up at ± 90 degrees off axis results in lower gain mismatch error as shown by curve 6 in Figure 8. Patterns having relatively little side pick-up would, therefore, be recommended to minimize mismatch error effects in the two-channel direction finder using a square-rooting amplifier.

TWO AND FOUR-CHANNEL SYSTEM COMPARISON

The two-channel system requires only two amplifier channels instead of four and may thus be expected to result in some reduction of weight, volume and power drain, with a possible increase in reliability. This will not be a decisive benefit, since each amplifier channel comprises only a small portion of the entire equipment. A reduction of less than 20 percent in power drain and 10 percent in volume and weight is anticipated when compared with the four-channel equipment.

Each system is theoretically capable of providing zero instrumental error since each has an infinite number of zero bearing error antenna patterns available although these perfect patterns are not readily produced over the required 2:1 band. Errors due to the azimuth response of the d-f antennas depend, for both d-f systems, upon how nearly their zero error antenna functions can be approached. Because of the nature of the required antenna response for the Type III two-channel direction finder, some difficulty may be expected in developing suitable antenna elements. It should be possible, however, to obtain patterns providing the same bearing accuracy as obtained in the four channel direction finder.

Mismatch between channel gains will, in general, provide the most difference between systems. Mismatch effects of the two and four-channel direction finders (Types I and II) will be identical; however, Type III two-channel direction finder theoretically results in much greater mismatch error effects (Figure 8). In the two-channel system the requirement placed upon the r-f and video input circuitry, that of pulse polarity discrimination, demands that a tighter tolerance be placed upon the matching of r-f components. A Type III two-channel system would require even closer tolerance for operational use.

As previously stated, an antenna system has been developed at NRL for use with the four-channel, wide-open d-f, the NL/ALD-A, and provides antenna patterns which are somewhat similar to those required in the two-channel d-f. A comparison of the theoretical maximum pattern errors of both systems, using the X-band antenna elements, is seen in Figure 7. Note that the pattern shape errors of the two systems, each with linear amplifier laws, are very good except at the higher frequencies where the narrower patterns of vertical polarization have detrimental effects. The dynamic range of the system would, of course, be just one-half that using a square-rooting amplifier.

A BILATERAL VIDEO AMPLIFIER

A bilateral video amplifier was developed to determine its feasibility and compliance with the required characteristics. A wide dynamic range and equality in gain in the amplification of both positive and negative video pulses is desired. As much of the four-channel design circuitry as possible was incorporated in the bilateral amplifier, varying the design only where necessary. The final circuit, Figure 9, does not include a square-rooting network, but a modification of the network used in the NL/ALD-A should be a possible solution (back to back square-rooting diodes employed). The amplifier has push-pull outputs to the CRT plates to provide the required full deflection potentials. Its measured video bandwidth is 9 kc to 1.4 Mc at 3 db points with a mid-band gain of approximately 120 db. A comparison of the dynamic range and gain for positive and negative pulsed inputs, Figure 10, indicates the close similarity for the two amplifier conditions. A further check of the gain match conditions of the bilateral amplifier was made by observing the error in angular bearing presentation on the CRT when known input pulse potentials were applied (Figure 11). Included in this is the measurement error which might exceed ± 1 degree in this case and occurs as a random variation.

CONCLUSIONS

(1) Theoretical antenna patterns, providing zero-errors, are possible for the two-channel system and are of a practical configuration.

(2) The two-and four-channel systems have identical characteristics if the antenna response is greater than 180 degrees and the receiver amplifier law is linear or if the antenna response is less than 180 degrees with any exponential receiver law.

(3) For the case where antenna patterns having pick-up beyond ± 90 degrees and square-root-law amplifiers are employed, the two-channel system has more detrimental effects due to gain mismatch than the four-channel system. The mismatch varies directly with the amount of antenna side pick-up at the ± 90 degree angles.

(4) Standard and reverse crystal detectors are matchable in sets of four (2 each) in the 2,500 Mc to 10,000 Mc band, and are usable in the two-channel system. The yield of matched crystals in X-band is less than at S-band for a given batch of crystals. Direct mixing offers the most promise for the two-channel system.

(5) The two-channel d-f system offers no advantages by its use, compared to the four-channel d-f system, except for a small reduction in volume, weight and power-drain.

REFERENCES

- (a) Gruber, J. R., Jesswein, A. J., and Rose, V. S., "An Airborne Instantaneous Microwave Direction Finder, The NL/ALD-A," NRL Report 4526 (Confidential), May 3, 1955
- (b) Youmans, A. B., "Antenna Considerations for a Four-Channel Crystal-Video Direction Finding System," NRL Memorandum Report 215, October 1, 1953
- (c) Jesswein, A. J., "Instrumental Errors of a Four-Channel Crystal-Video Direction Finder," NRL Memorandum Report 160, April 23, 1953
- (d) Gruber, J. R., "The Effect of Channel Mismatch Upon the Bearing Accuracy of a Four-Channel Direction Finder," NRL Memorandum Report 303, June 15, 1954
- (e) Sinclair, G., "The Patterns of Slotted-Cylinder Antennas," Proc. IRE, Vol. 36, pp. 1487 - 1492; December, 1948
- (f) Maurice, D. and Minns, R. H., "Very-Wide Band Radio-Frequency Transformers," Wireless Engineers, pp. 168 - 177; June, 1947, pp. 209 - 216; July, 1947
- (g) Struszynski, W. and Marshall, J. H., "An Investigation of Symmetrical Screened Transformers for H. F. Radio Direction-Finders," The Journal of the Institution of Electrical Engineers, pp. 857 - 867, Vol. 94; 1947

APPENDIX I

With logarithmic amplifiers employed in the two-channel system, the indicated bearing (ϕ_{d-f}) will be expressed as:

$$\phi_{d-f} = \tan^{-1} \left[\frac{\log_a(e_2 - e_4)}{\log_a(e_1 - e_3)} \right]$$

where a = base of logarithm
 e_n = instantaneous potentials at the logarithmic network input

The instantaneous potentials (e_n) are functions of the envelope of the signal, antenna patterns and system gain.

$$e_n = G_n (P(t) P_n^{\frac{1}{2}}(\phi))^r$$

n = respective channel designation

G_n = gain of the n -th channel before the logarithmic network

$P(t)$ = the envelope of the signal at the antenna

$P_n(\phi)$ = absolute radiation power pattern of the antennas

r = response law of the detector (assumed to be square law, $r=2$)

Assuming all channels to be gain matched

$$\phi_{d-f} = \tan^{-1} \left[\frac{\log_a GP^2(t) + \log_a(P_2(\phi) - P_4(\phi))}{\log_a GP^2(t) + \log_a(P_1(\phi) - P_3(\phi))} \right]$$

Thus, even though the gain (G) and signal envelope ($P(t)$) in each channel are identical, the d-f bearing will depend upon and vary with both G and $P(t)$ as well as the antenna power pattern.

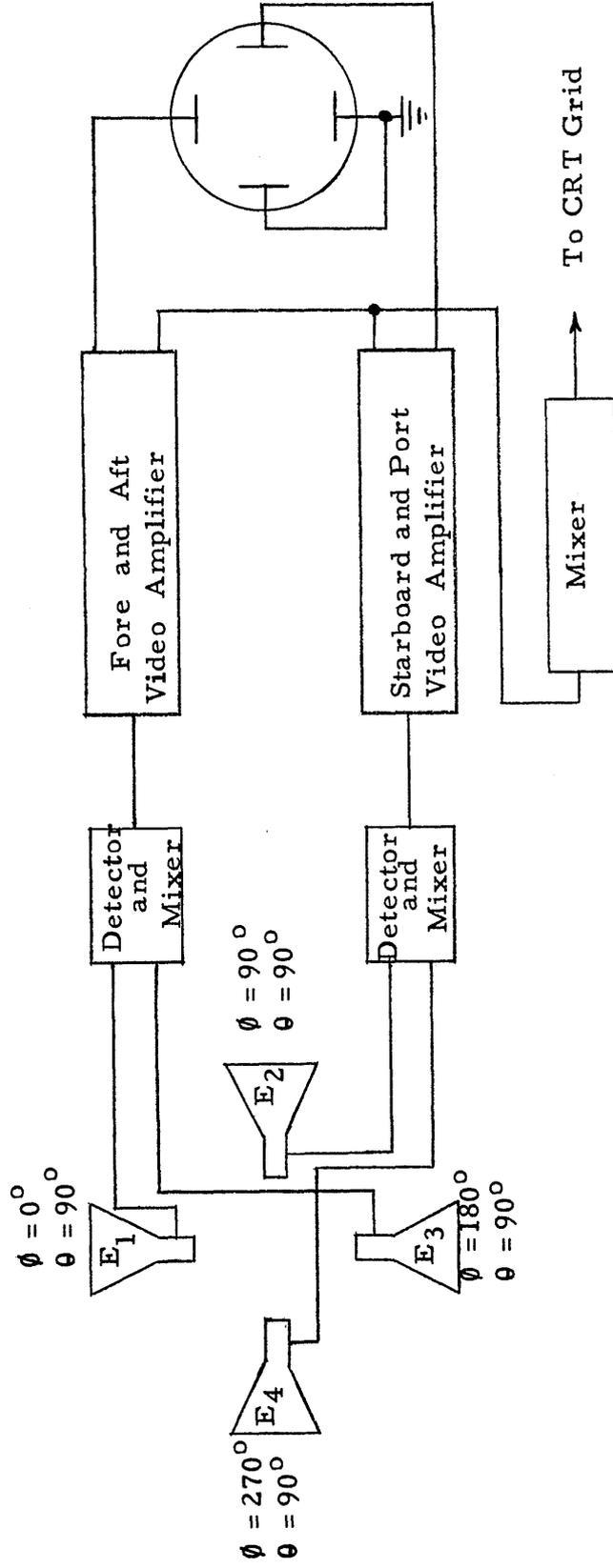


Figure 1 - Block Diagram of Two-Channel Direction Finder System

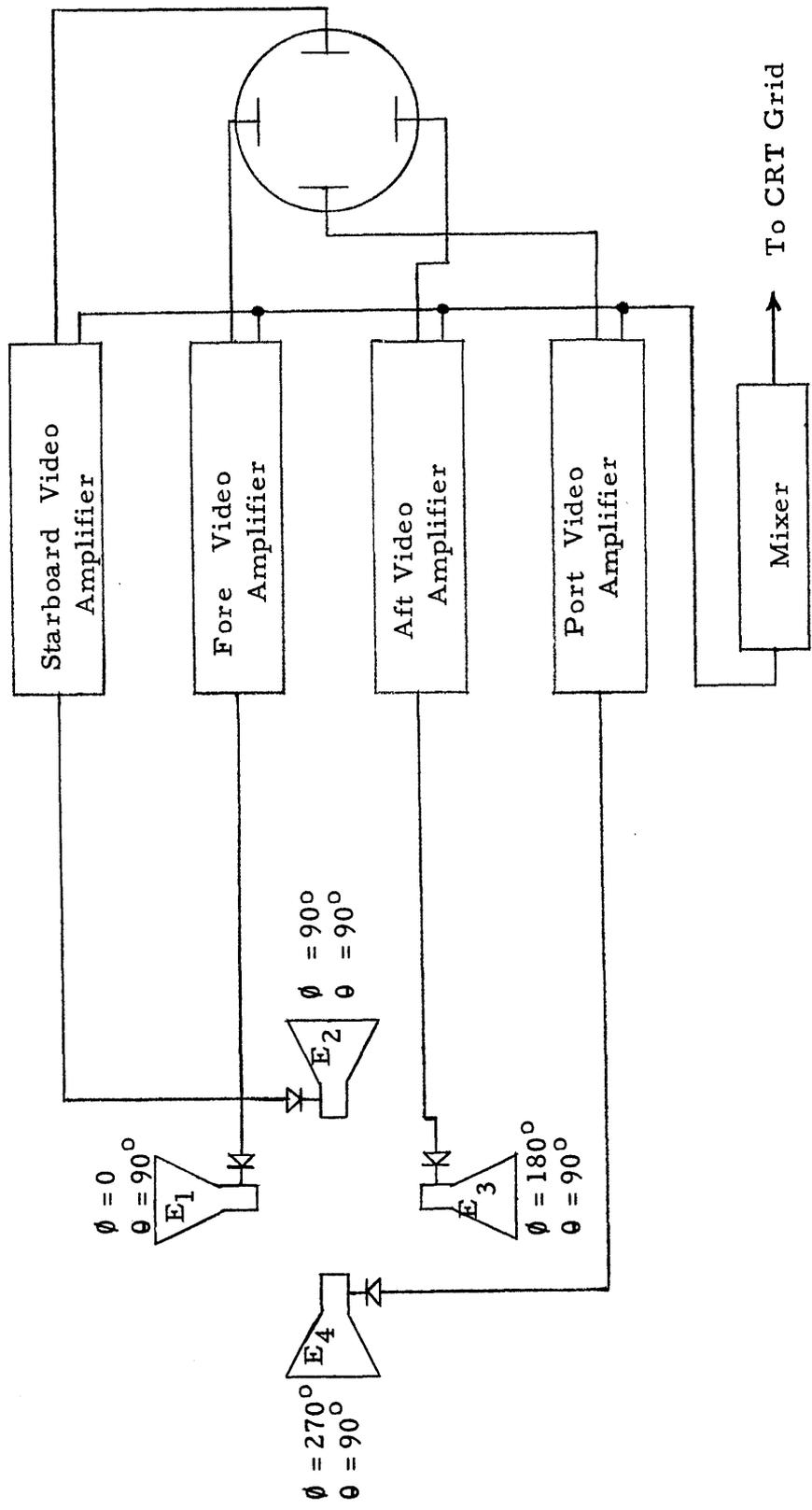


Figure 2 - Block Diagram of Four-Channel Direction Finder System

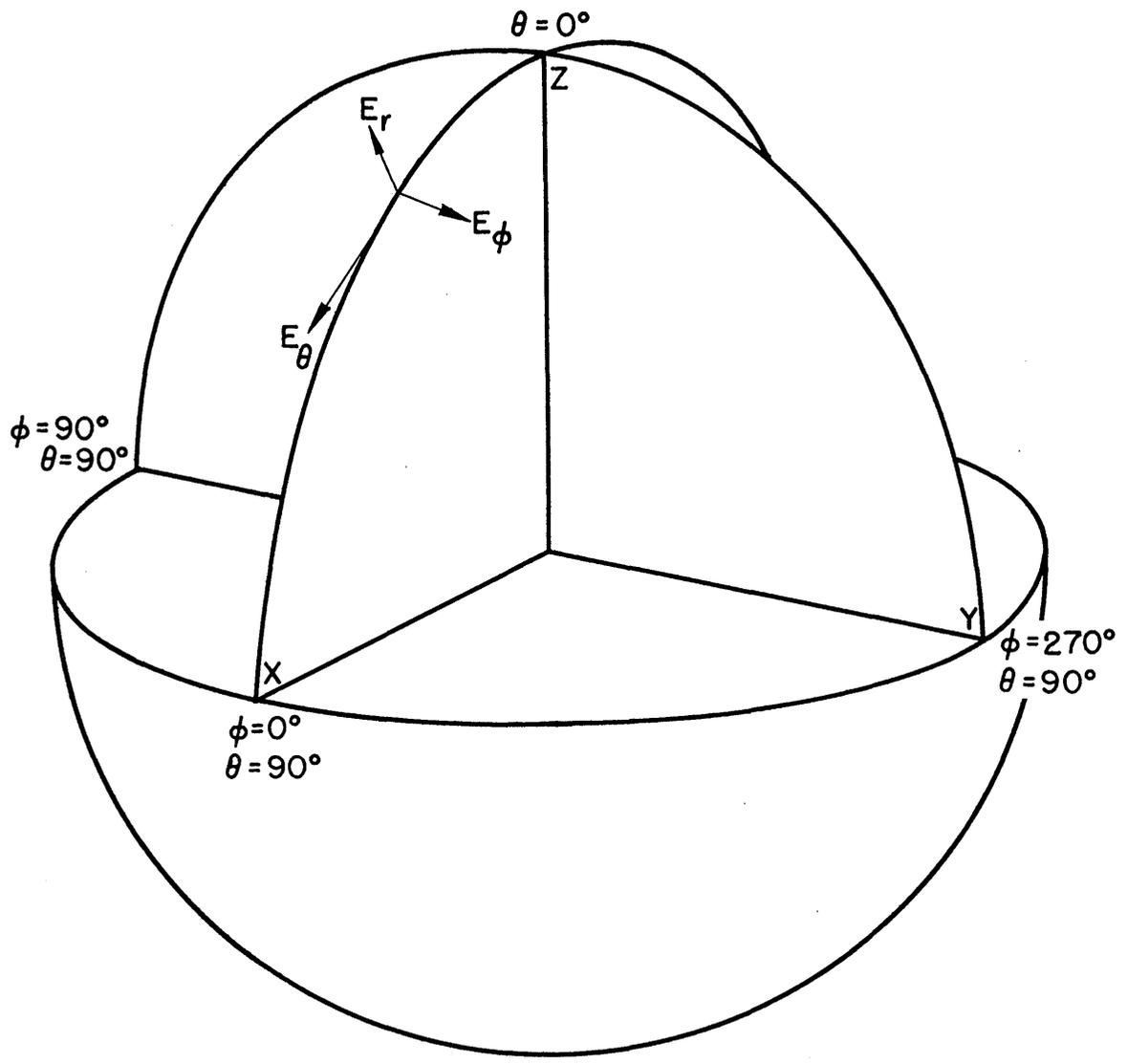


Figure 3 - Coordinate System

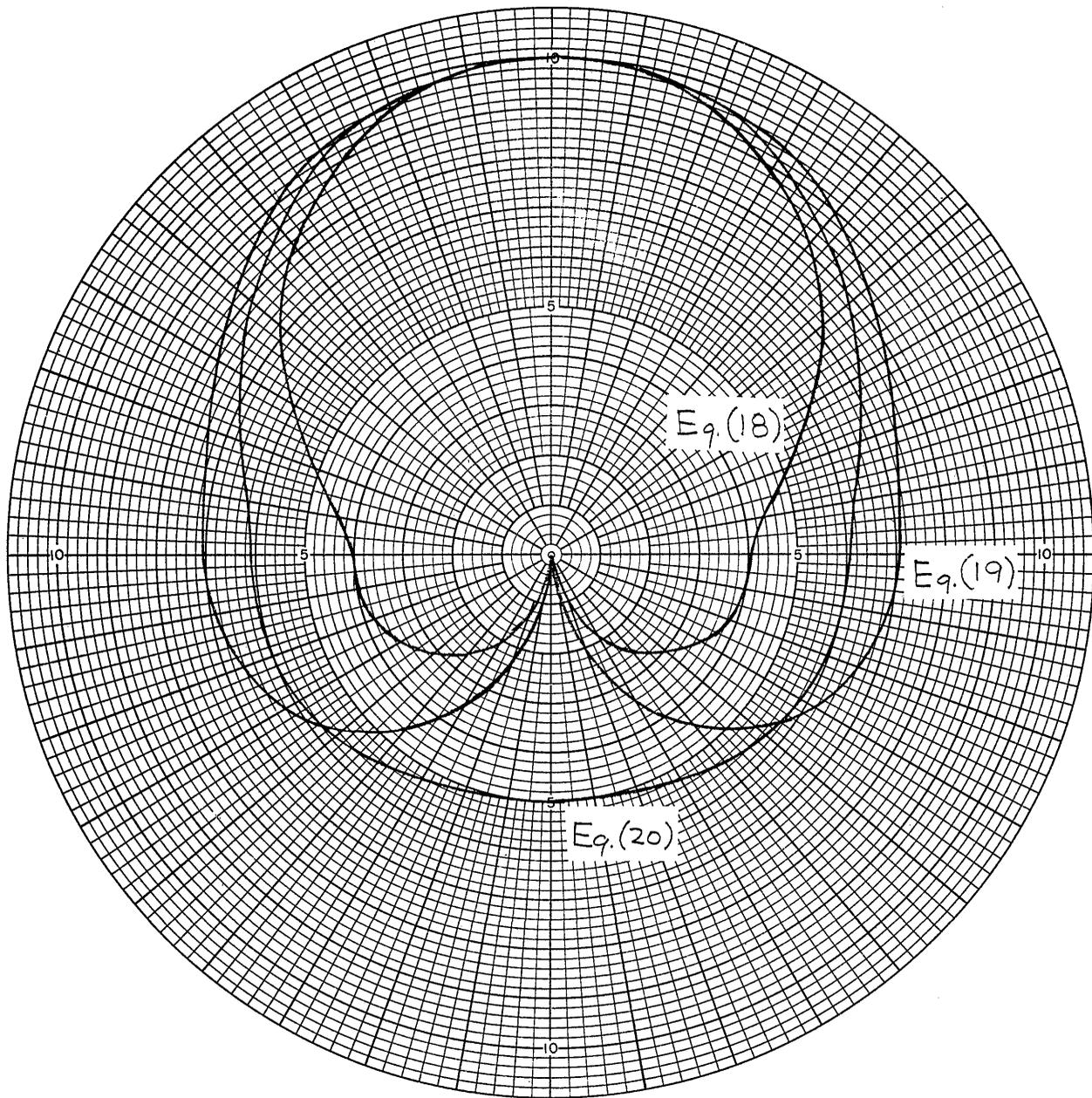
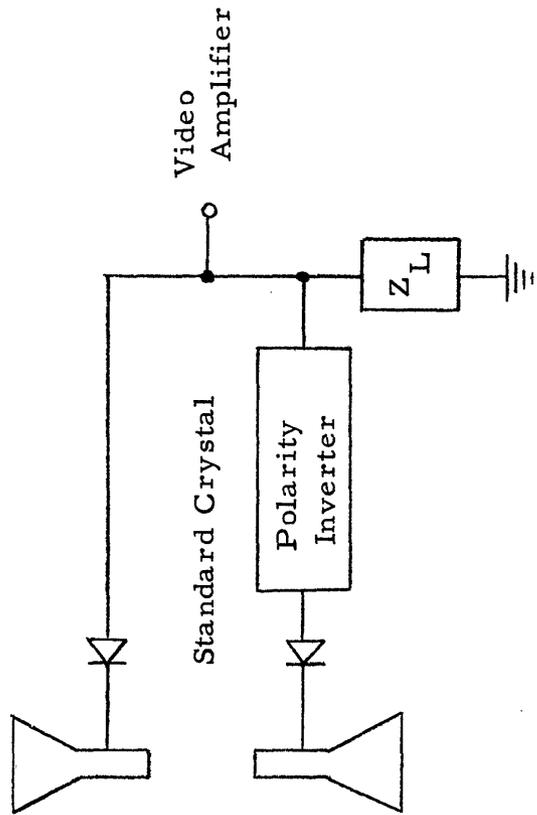
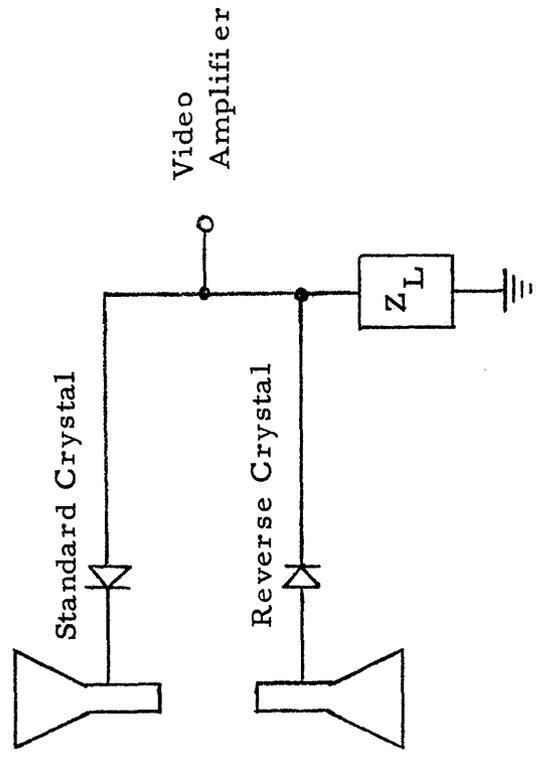


Figure 4 - Theoretical Zero Error Antenna Voltage Patterns for Two-Channel System

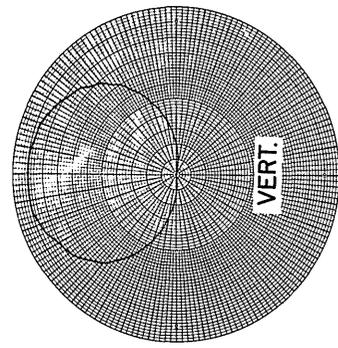


(a) Subtractive Mixing

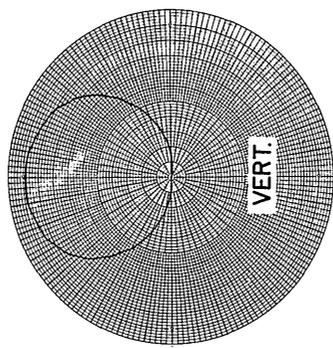


(b) Direct Mixing

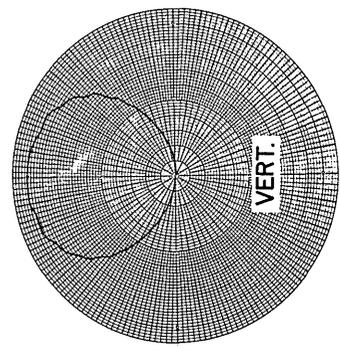
Figure 5 Mixing Circuits



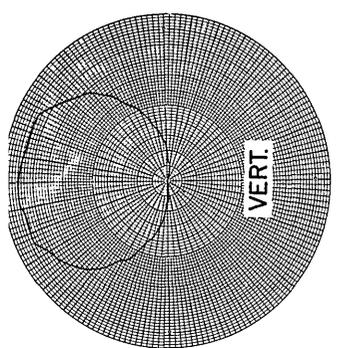
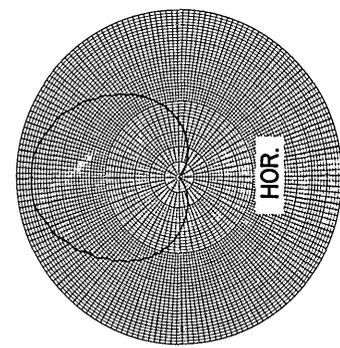
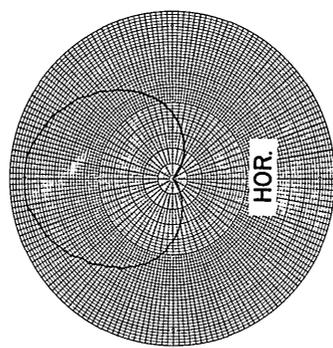
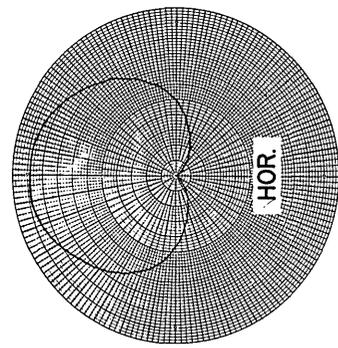
8000mc



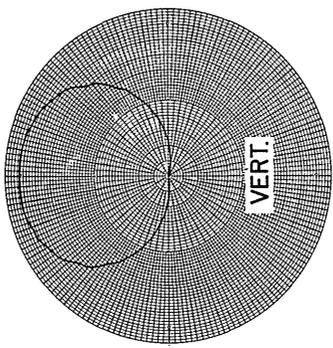
9000mc



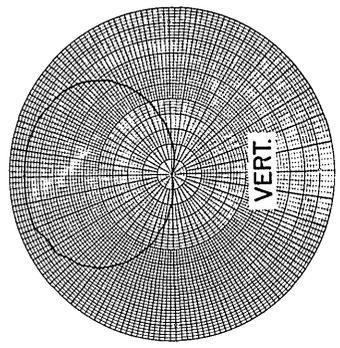
10000mc



5000mc



6000mc



7000mc

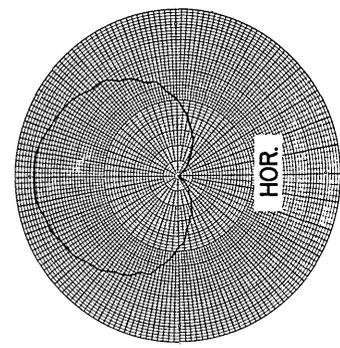
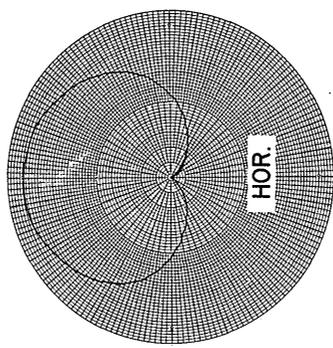
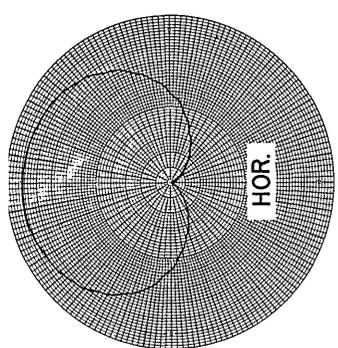
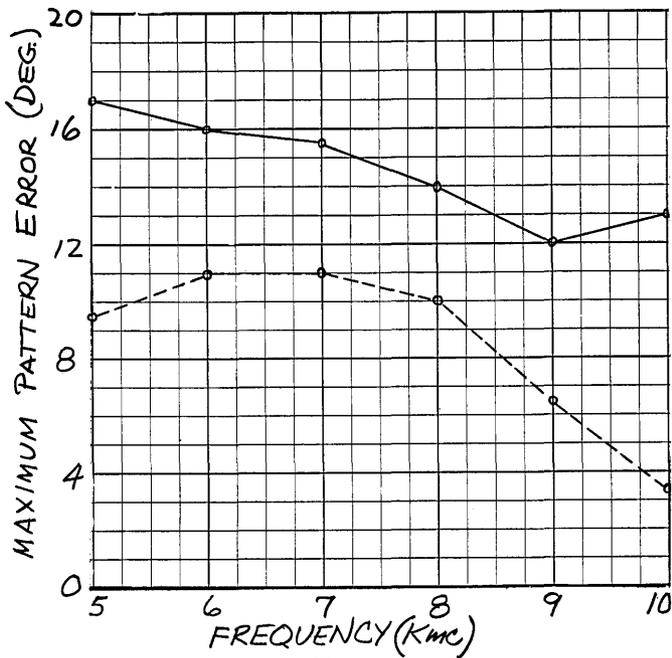
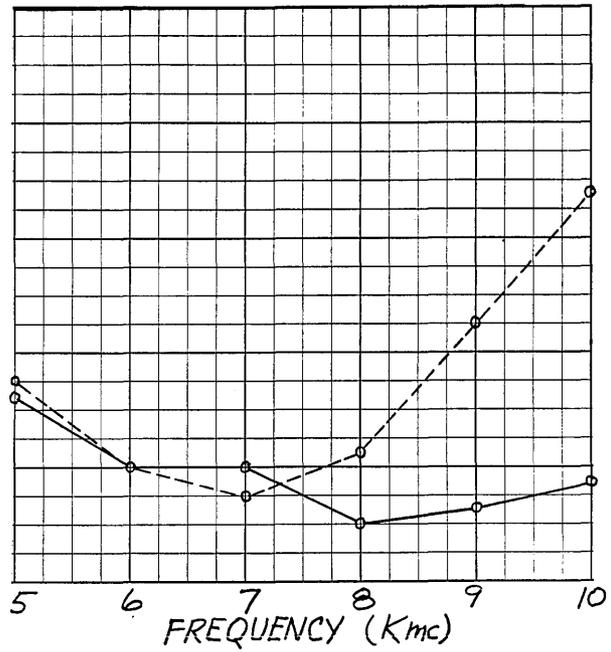


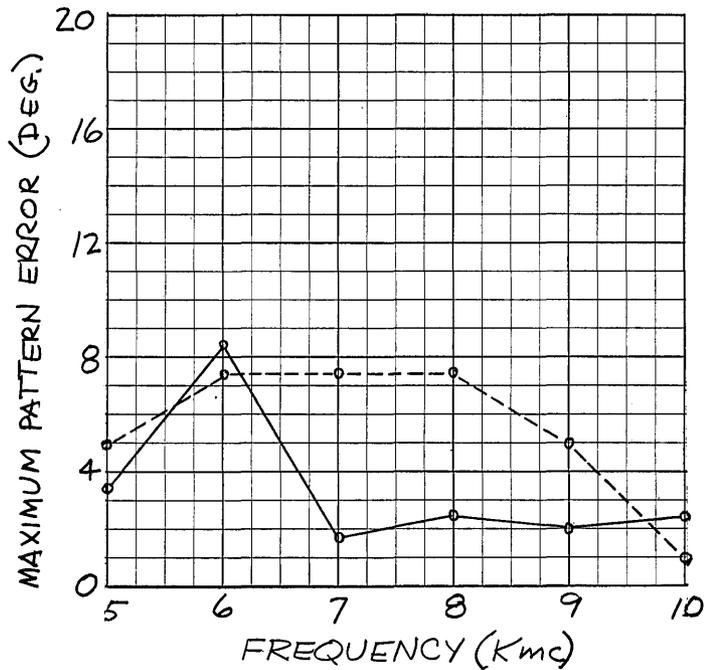
Figure 6 - Radiation Patterns of Four-Channel D-F Antenna Elements (X-Band)



Two Channel System,
Square-root-law Amplifiers



Two and Four Channel Systems,
Linear Law Amplifiers



Four Channel System
Square-root Law Amplifiers

— HORIZONTAL POLARIZATION
 - - - VERTICAL POLARIZATION

Figure 7 - Calculated Pattern Error using NL/ALD-A, X-Band Antenna Patterns

System	Law of Amplifier	$f(\theta)^*$	Curve
2 or 4 channel	linear	Cardioid or $(\text{Cosine})^{1/2}$	1
2 or 4 channel	linear	$(\text{Cardioid})^{1/2}$	2
4 channel	square-root	$\text{Cosine or } (\text{Cardioid})^2$	3
4 channel	square-root	Cardioid	4
2 channel	square-root	Pattern of figure 3 (eq. (19))	5
2 channel	square-root	Pattern of figure 3 (eq. (18))	6

Relative match at crystal output
for channel 1 = $(1+k)A$
Relative match at crystal output
for channels 2, 3 and 4 = A
* $f(\theta)$ is the zero error antenna pattern
function for calculation of curve

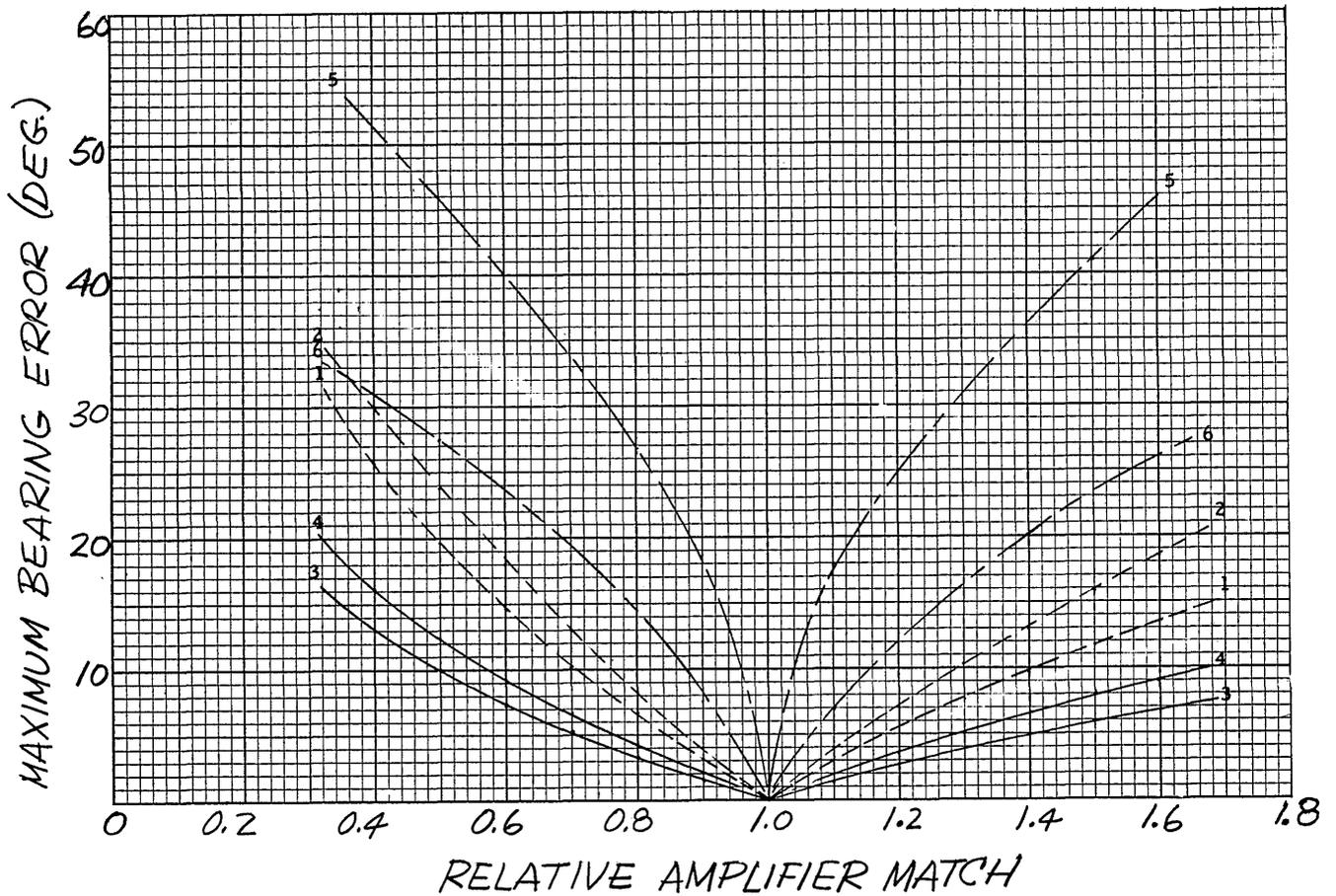


Figure 8 - Theoretical Maximum Gain Mismatch Error

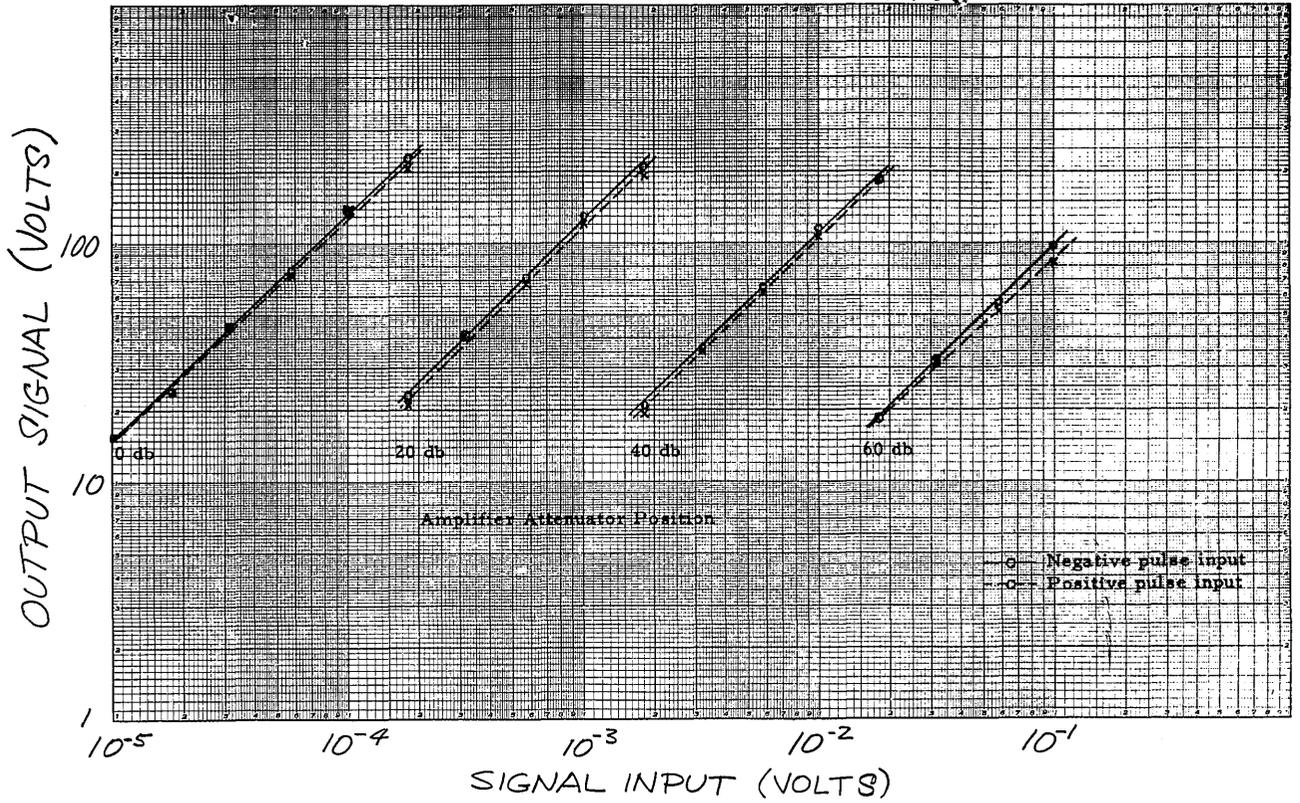


Figure 10 - Dynamic Characteristics for Bilateral Video Amplifier

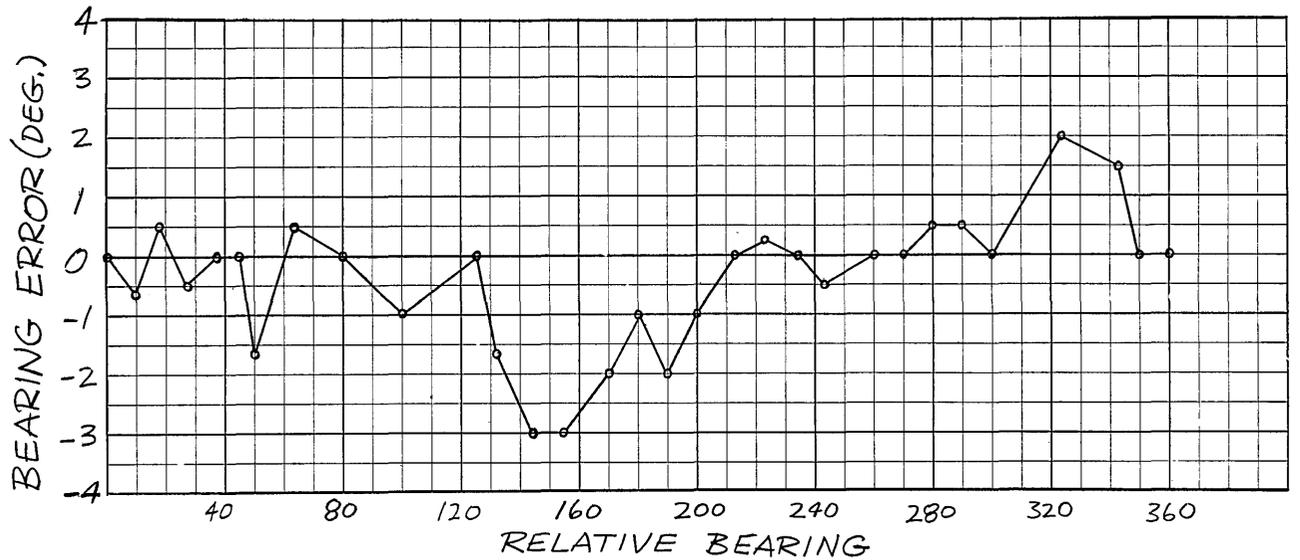


Figure 11 - Bilateral Video Amplifier Instrumental Gain Mismatch Error