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SENSITIVITY ANALYSIS OF A 15.0 GHz MONOPULSE RADAR RECEIVER USING A LOGARITHMIC AMPLIFIER DETECTOR SCHEME

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SUMMARY

Sensitivity analysis of a 15.0 GHz monopulse radar receiver using logarithmic amplifiers as the detection scheme is presented. The effects of receiver gain, noise figure, bandwidth, and phase and amplitude balance on system tracking performance are discussed. Special emphasis is given to the influence of noise on tracking sensitivity. A brief overivew of the system as well as actual test results are included.

INTRODUCTION

A 15.0 GHz monopulse radar receiver which utilizes a logarithmic amplifier detector scheme is shown in Figure 1. This type of monopulse processor is often used to obtain a Log Σ search channel and a normalized difference channel for tracking(1). It offers several advantages over closed-loop monopulse systems, and if properly designed can rival them in sensitivity and dynamic range performance. Instantaneous dynamic range, automatic error channel normalization, and simplicity of design are a few of the features of this approach. Also, no AGC delay is experienced as with closed-loop systmes. However, if maximum sensitivity is to be realized with this technique, system parameters such as noise, gain, noise figure, and bandwidth should be examined to allow the best possible search and track performance.

System gain and noise figure are of critical importance to the system detection sensitivity, which is the ability to detect targets at or near the input noise level. This is true because the signal-to-noise ratio of a logarithmic amplifier decreases with signal strength(2). Therefore, one must carefully consider the system noise level to ensure it does not exceed the logartihmic amplifiers low end dynamic range threshold or loss of target detection and tracking sensitivty will result. IF bandwidth also has a significant effect

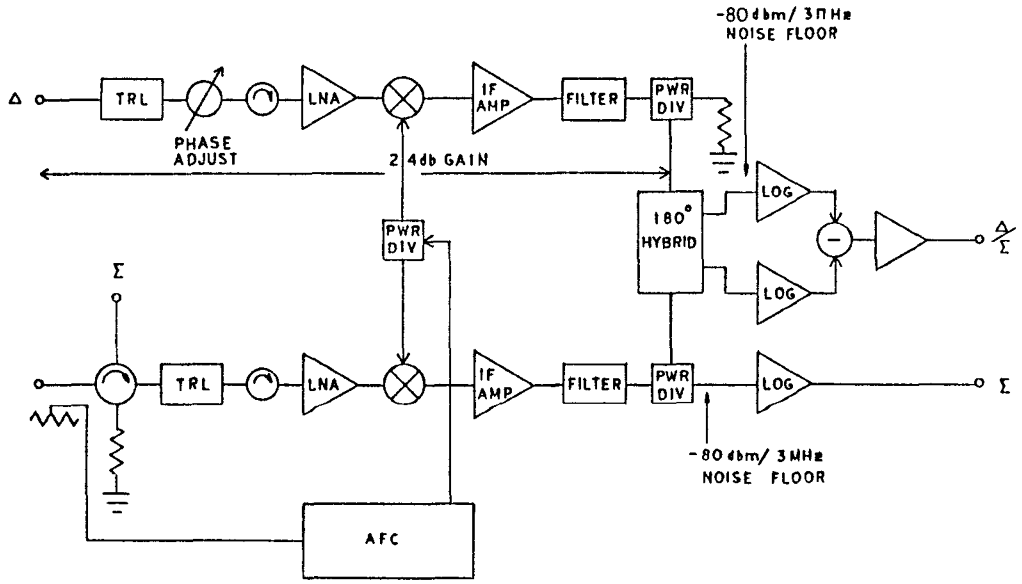

FIGURE 1. SYSTEM CONFIGUARTION -- MONOPULSE RADAR RECEIVER

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on sensitivity and should be made as narrow as possible without sacrificing pulse fidelity. 3 MHz was selected as the optimum bandwidth for this receiver.

The design relies on the non-coherent detection process of the logarithmic amplifiers. Hence, little improvement in sensitivity can be obtained by post-detection filtering or signal averaging techniques, which underscores the importance of optimizing the RF parameters.

SYSTEM DESCRIPTION

The receiver described in this paper is a pulsed 15 GHz, frequency agile monopulse system with a 60 MHz IF frequency. Both Σ and Δ channels are phase and amplitude balanced to $\pm$ 10° and $\pm$ .5 dB respectively, and the system gain is 24 dB. The logarithmic amplifier slope is 22.5 mv/dB, and it's dynamic range extends from 0 dBm to -80 dBm. Thus, the RF front end dynamic range extends from -24 dBm to -104 dBm, which is the input KTB noise floor at 3 MHz bandwidth with a 5.5 dB noise figure. Δ / Σ video gain is 11.4 dB and determines the limits for maximum Δ / Σ video voltage (i.e. $\Sigma = \Delta$) which is $\pm$ 2 volts. With the indicated gain, noise figure, and bandwidth, the noise floor at the input to the Log Σ channel logarithmic amplifier is -80 dbm. The noise floor at the same point in the error channel is also -80 dbm due to the non-coherent addition of noise in the hybrid.

The monopulse detector video output is not a true Δ / Σ response, but is a first order approximation. An expression for the detector function is given by(3)

$$F(x)=\mathrm{Log}[V_{\Sigma}+V_{\Delta}]-\mathrm{Log}[V_{\Sigma}-V_{\Delta}]=\mathrm{Log}\left(\frac{1+X}{1-X}\right) \quad (1)$$

where $x = V_{\Delta}/V_{\Sigma}$. Expanding F (x) into a Taylor series and retaining only the first two terms yields

$$F(x) \sim [2/\ln 10]X = K\left(V_{\Sigma}/V_{\Delta}\right) \quad (2)$$

This expression is only valid for $V_{\Delta} << V_{\Sigma}$, but can be used to generate a useful bipolar error response over the entire tracking window, Δ / Σ =-1 to +1.

Accuracy of the bipolar Δ / Σ video curve is a function of the logarithmic amplifiers' linearity tracking, and the null resolution in the 180° hybrid. Symmetry of this curve is dependent on the system phase and gain balance. Differences in Σ and Δ gain will cause boresight errors for small Δ / Σ ratios and thus degrade tracking sensitivity. An actual bipolar Δ / Σ video curve is shown in Figure 2. for a sum channel input of -84 dbm.

Sensitivity Analysis

One of the most important aspects in analyzing sensitivity limitations in this type of monopulse processor is understanding the response of the 0, 180° "magic-tee" hybrid as a function of input and output power(4). The response is given by

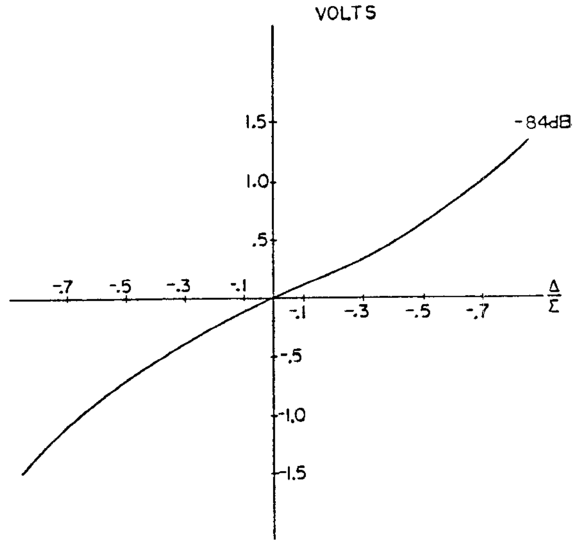
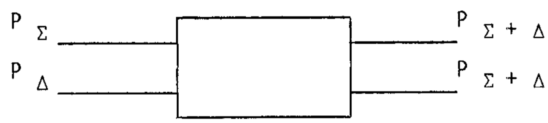


FIGURE 2. MEASURED MONOPULSE Δ / Σ CURVE

$$P_{\Sigma+\Delta} = \left(P_{\Sigma}\right)/2\left[1 + \frac{1}{n} + 2\sqrt{\frac{1}{n}}\right] \quad (3)$$

$$P_{\Sigma-\Delta} = \left(P_{\Delta}\right)/2\left[1 + \frac{1}{n} + 2\sqrt{\frac{1}{n}}\right] \quad (4)$$

where $n = P_{\Sigma}/P_{\Delta}$, and is summarized in Table 1 for values of n between 1 and 1000.



n	Δ / Σ	dB	$P_{\Sigma+\Delta}$ (dB)	$P_{\Sigma-\Delta}$ (dB)
1	1	0	+3	- ∞
2	.707	-3	+1.64	-13.9
3	.577	-4.77	+0.93	-10.4
4	.5	-6	+0.51	- 9
10	.316	-10	-0.624	- 6.3
100	.1	-20	-2.18	- 3.92
1000	.0316	-30	-2.74	- 3.29

TABLE 1. --180° HYBRID CALCULATIONS

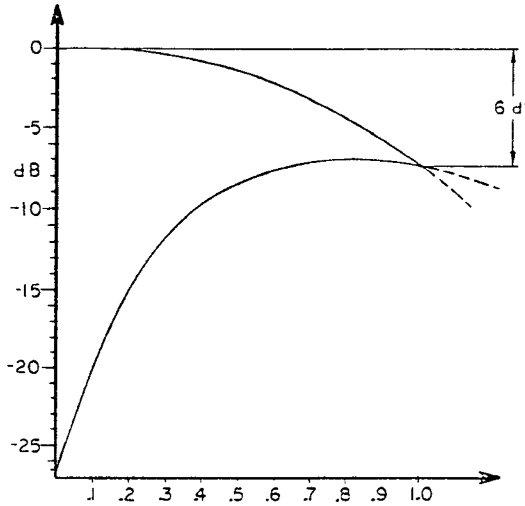


FIGURE 3. ANTENNA SUM AND DIFFERENCE PATTERNS

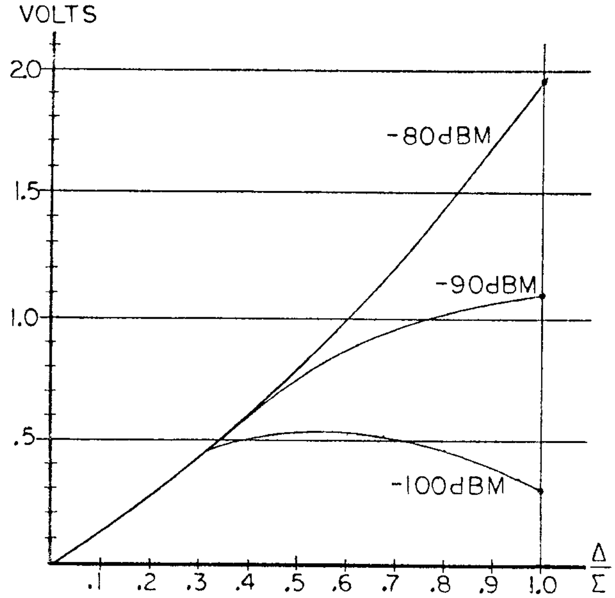


FIGURE 4. CALCULATED BIPOLAR OUTPUT VOLTAGE VS Δ / Σ

CONSTANT RANGE	Δ / Σ (dB)	INPUTS (DBm) Σ	INPUTS (DBm) Δ	HYBRID INPUT (dBm)	HYBRID OUTPUT (dBm) Σ + Δ	HYBRID OUTPUT (dBm) Σ = Δ	(Σ + Δ)- (Σ - Δ) (dB)	DIFFERENCE AMP OUTPUT (mv)	Δ / Σ (mv)
1)	0	-80	- 80	-56	-53	-83	23.7	533.9mv	1.97v
	- 6	-75	- 81	-51	-50.3	-60	9.5	213.8	.79
	-10	-74	- 74	-50	-50.6	-56.3	5.7	128.3	.47
	-30	-74	-104	-50	-52.7	-53.3	.55	12.4	.046
2)	0	-90	- 90	-66	-63	-93	13	293 mv	1.08v
	- 6	-85	- 91	-61	-60.5	-70	9.5	213.8	.79
	-10	-84	- 94	-60.6	-60.6	-66.3	5.7	128.3	.47
	-30	-84	-114	-60	-62.7	-63.3	.55	12.4	.046
3)	0	-100	-100	-76	-74	-103*	3.73	83.4	.31
	- 6	-95	-101	-71	-70.5	-80	6.23	140.2	.52
	-10	-94	-104	-70	-70.6	-76.3	5.7	128.3	.47
	-30	-94	-124	-70	-72.7	-73.3	.55	12.4	.046
4)	0	-106.5	-106.5	-82.5	-79.5	-109.5*	*	--	--
	- 6	-101.5	-107.5	-77.5	-77	-107*	*	--	--
	-10	-100.5	-110.5	-76.5	-75.9	-82.8*	.83	18.7	.07
	-30	-100.5	-130.5	-76.5	-73.8	-75.2	.55	12.4	.046

*INDICATED SIGNAL IS BELOW NOISE LEVEL OF -80 dBm AT LOG AMP INPUT

TABLE 2

For large Δ / Σ, $P_{\Sigma - \Delta}$ approaches $-\infty$; however, the isolation of a practical hybrid is about 30 db, which limits the effective null of $P_{\Sigma - \Delta}$. As the sum channel power level decreases, the $P_{\Sigma - \Delta}$ term drops below the -80 dbm input noise threshold for small Δ / Σ ratios. Under these conditions the bipolar video output gain drops and the slope "flattens out" for increasing Δ / Σ. Additionally, when one considers the effects of an actual antenna sum pattern as shown in Figure 3, we find that the sum channel loses 6 db of power as the scan angle varies from boresight to $\Sigma = \Delta$. The resulting bipolar video curve becomes non-monotonic and exhibits a gain drop for large Δ / Σ. An ambiguous tracking curve occurs at this point which is not suitable for proper monopulse performance. This effect is illustrated in Figure 4 as a function of decreasing sum channel input power. Table 2 shows the signal levels at various points in the receiver for input levels between -80 dbm and -106 dbm. The antenna pattern effects are also included in the table.

CONCLUSION

Monopulse receivers of the type discussed in this paper can provide excellent, low cost search and track performance if the appropriate parameters are optimized as outlined in the paper. The single most critical factor in obtaining maximum sensitivity is insuring that the system noise level does not exceed the logarithmic amplifiers' low end dynamic range threshold.

While this scheme may offer good tracking accuracy over more than 60 db of dynamic range, the non-coherent detection process of the logarithmic amplifiers limit the ultimate tracking sensitivity. For very low level input signals the resulting bipolar video curve becomes non-monotonic and results in an ambiguous tracking curve.

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ACKNOWLEDGEMENTS

The authors wish to express their gratitude to Steve Prokop, Laura McCabe, Jerry Hobbs and Onnig Shahan of the Microwave Division for their contributions and continued support.