

MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS 1963-A



1. Report No. FAA-RD-79-53	2. Government Accession No. AD-811117-1	3. Recipient's Catalog No.	
4. Title and Subtitle Zoom Antenna		5. Report Date 12 February 1980	6. Performing Organization Code
		8. Performing Organization Report No. ATC-90	
7. Author(s) Jean-Claude Sureau		10. Work Unit No. (TRAI5)	
9. Performing Organization Name and Address Massachusetts Institute of Technology Lincoln Laboratory P.O. Box 73 Lexington, MA 02173		11. Contract or Grant No. DOT-FATQ-WAI-679	
		13. Type of Report and Period Covered Project Report	
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, DC 20591		14. Sponsoring Agency Code	
		15. Supplementary Notes The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology under Air Force Contract F19628-80-C-0002.	
16. Abstract  In current ATC radars, high altitude targets are at a disadvantage when competing with low altitude undesired returns such as ground clutter and birds. The "zoom antenna" technique is proposed as a means of virtually eliminating this problem. An implementation based on control of multiple elevation beams during each range sweep interval is recommended as applicable to both S-band and L-band ATC radars.			
17. Key Words  primary radar antennas surveillance		18. Distribution Statement  Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 24	

CONTENTS

1.0	INTRODUCTION	1
2.0	ZOOM ANTENNA	3
	2.1 Principle	3
	2.2 Implementation	3
3.0	APPLICATION TO S-BAND ASR	7
4.0	APPLICATION TO L-BAND RADAR/BEACON ANTENNA	18
5.0	DISCUSSION	18



DTIC

COPY

INSPECTED

2

A

## 1.0 INTRODUCTION

Present day ATC surveillance radars are two-dimensional systems which use fan beam antennas. The elevation pattern typically has a 3 dB beamwidth of several degrees and is "spoiled" for high angle coverage, typically 30 to 40 degrees (see Figure 1). The beam shaping is a compromise between providing high gain at low elevation angles for long range coverage and adequate gain at high elevation angles to maintain high altitude coverage at the shorter ranges. In older models, transmission and reception occur over the same beam while in more recent models a second receiver beam is available. This auxiliary beam ("passive horn") is nearly identical in shape to the principal beam except that it is tilted up. It is activated during the early portion of a range sweep interval and is used primarily as a means of reducing the short range ground clutter.

However, even equipped with a modern signal processor, (See below\*) a conventional fan system still has some deficiencies. The heart of the problem lies in the large variation in the two-way gain within the elevation sector, typically 30 dB for an Airport Surveillance Radar (ASR) and 20 dB for an Air Route Surveillance Radar (ARSR). This implies a large variation in the system performance as a function of elevation angle/altitude. Sources of undesired returns such as birds, rain clutter and ground clutter are enhanced with respect to high altitude desired targets. The use of Sensitivity Time Control (STC) to maintain a nearly constant minimum detectable signal (to eliminate birds for example) at lower altitudes will result in loss of coverage at high altitude. If allowed to be detected, these spurious targets are particularly troublesome in an automated system which must attempt to cope with a contaminated data base.

The most straightforward approach to the solution of the problem is to transmit and receive over a wide "flat top" sector, which retains sharp cut-off at the horizon to minimize ground clutter and multipath, together with an "R<sup>4</sup>" STC. This system would provide constant sensitivity throughout the entire scan volume. Unfortunately, the resulting low antenna gain makes the system extremely wasteful of RF energy and consequently requires an intolerable high transmitter power.

\* L. Cartledge and R. M. O'Donnell, "Description and Performance Evaluation of the Moving Target Detector," Project Report ATC-69, Lincoln Laboratory, M.I.T. (8 March 1977).

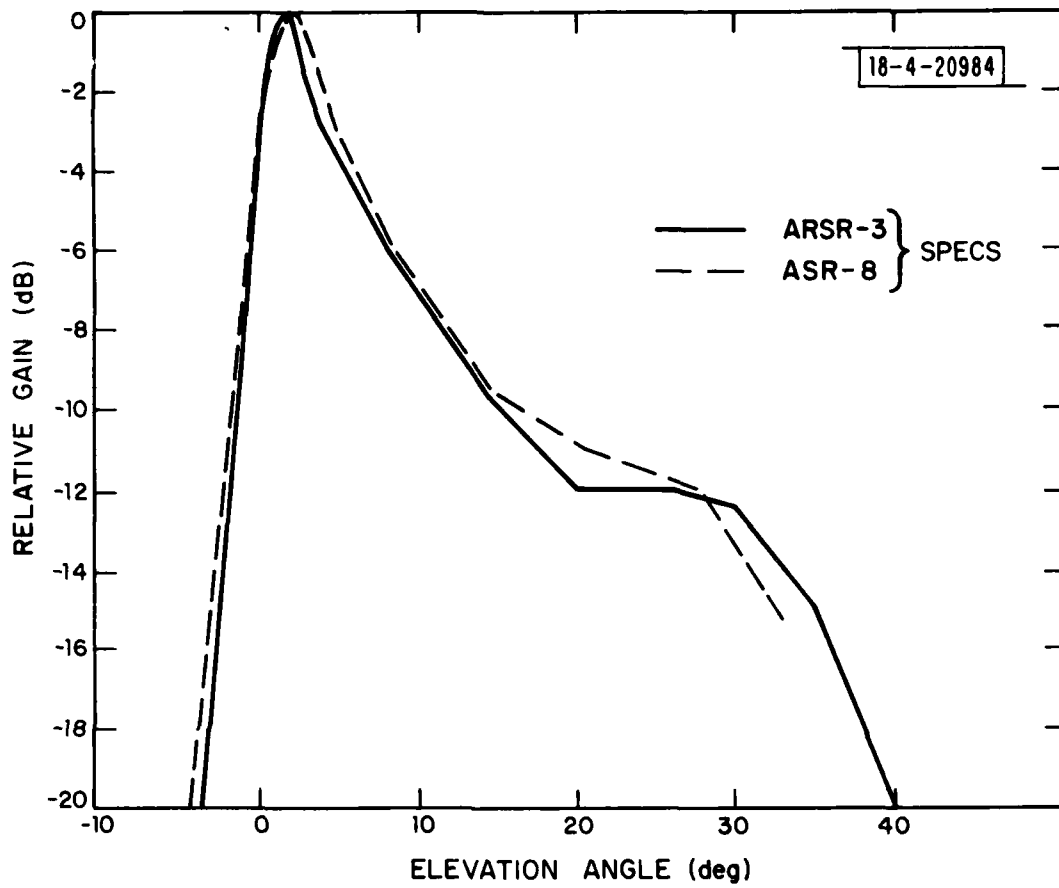


Fig. 1. Typical ATC radars.

The solution which is proposed in this document, termed a "zoom antenna," represents a compromise in that it retains the energy efficiency of the current configuration but introduces additional complexity in the antenna. The "zoom" principle is described in Section 2 and two specific examples of implementation are described in Sections 3 and 4.

## 2.0 "ZOOM ANTENNA"

### 2.1 Principle

The "Zoom Antenna" is based on two observations. Firstly, the radar system operation is determined by the product of the transmit and receive patterns and that these two patterns need not be identical. Secondly, while the transmit is fixed during a range sweep interval since it is used only during the short period of time corresponding to the pulse length, the receive pattern need not be fixed. This latter point has already been exploited in systems using a "passive horn" and is based on the fact that there is a unique association between time and range within a sweep interval (PRI).

At any instant of time, the optimum two-way pattern (product of transmit and receive patterns) which leads to an altitude independent performance is depicted in Figure 2. Already this simplistic picture illustrates the principle of zoom which is simply a variation of the effective two-way beamwidth, or field-of-view during a range sweep interval. To retain high system energy efficiency, it is proposed that the desired two-way pattern be generated as depicted in Figure 3. The transmit pattern (Figure 3a) retains its shape as a basically narrow beam which has been spoiled so as to reach a plateau up to the maximum desired coverage angle. The bulk of the "zoom" operation is confined to the receive pattern (Figure 3b) which is varied (in principle continuously, in practice in discrete steps) within the range sweep. Note that not only is the beamwidth varied but also that the shape is perturbed to compensate for the transmit pattern shaping. The net result (Figure 3c) has the desired property.

### 2.2 Implementation

While the "zoom" action can be implemented in several ways, the antenna configuration shown in Figure 4 is the recommended one. The multiple beam

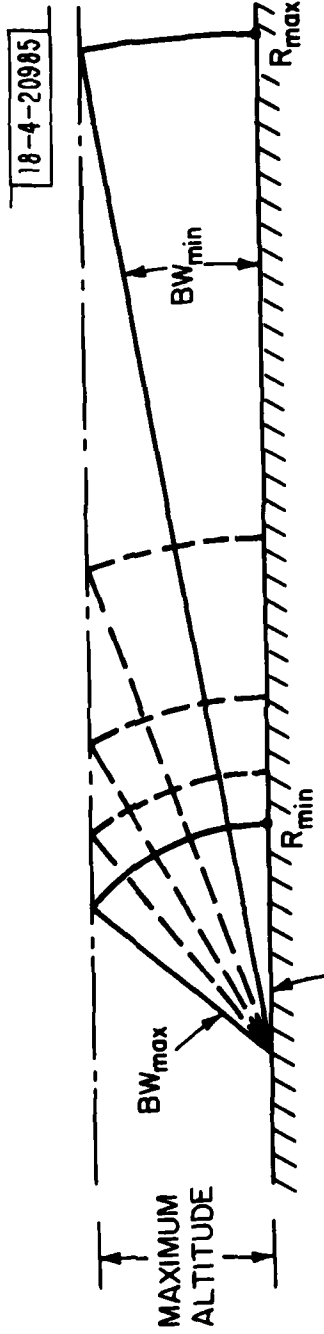
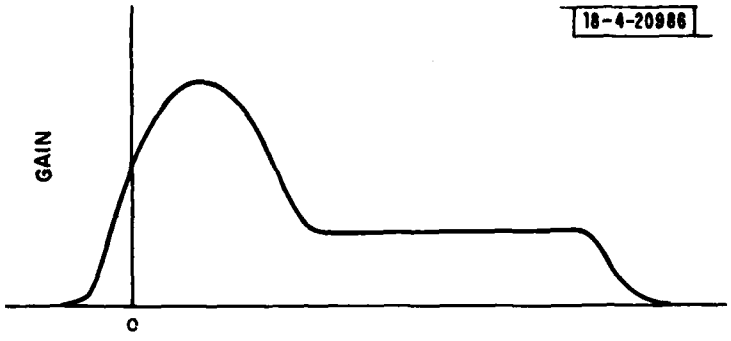
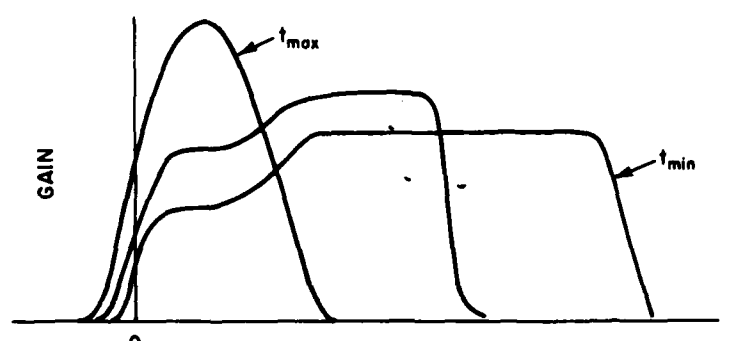


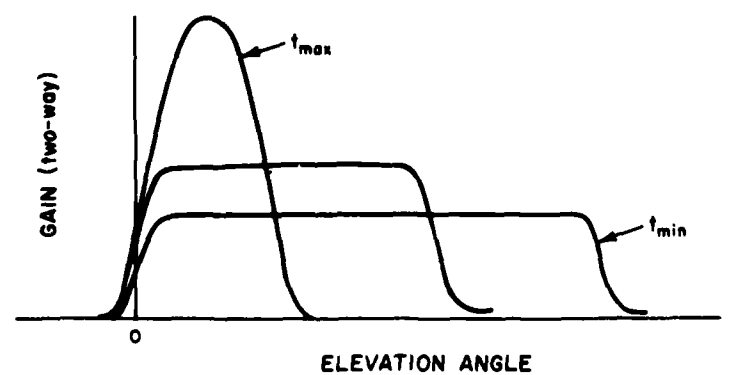
Fig. 2. Optimized coverage (zoom).



(a)



(b)



(c)

Fig. 3(a-c). Synthesis of zoomed patterns.

18-4-20987

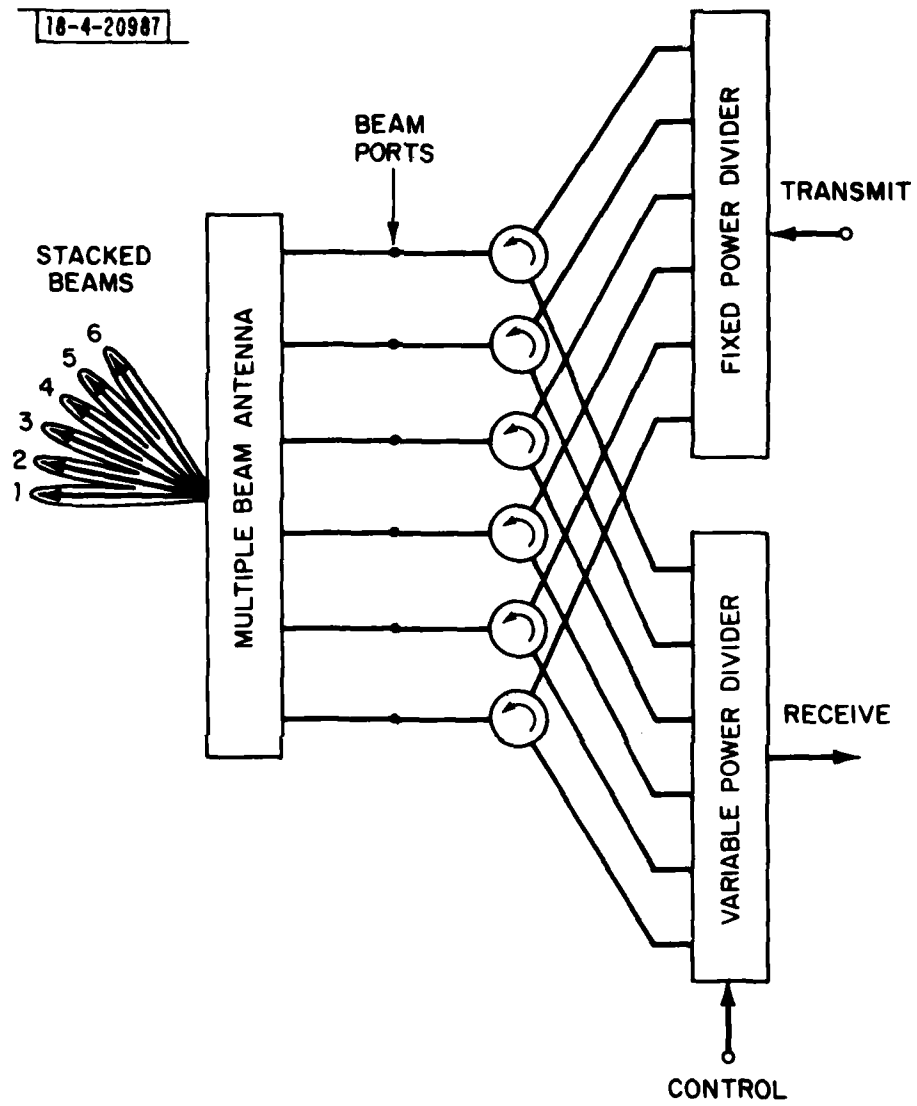


Fig. 4. Multiple beam zoom antenna.

system guarantees a high rate of underside role-off while minimizing the number of ports to be controlled, commensurate with the gain and coverage requirements. Separate duplexed-transmit and receive-combining networks permit the optimization of each pattern while sharing the same beam-forming structure. The transmit-combining network must be capable of handling high power; since it is fixed, hence devoid of control elements, this does not generally represent a problem. The receive combining network is a variable power divider and hence contains control elements. Fortunately it is called upon to handle only low power signals; this facilitates the implementation problem which is characterized by two basic requirements, i.e., fast switching and low insertion loss. Several techniques are available for the implementation of a variable power divider. The most straightforward uses the two-port variable combiner shown in Figure 5 as the basic building block. Note that depending on the number of discrete steps used to approximate continuously variable beamwidth, some significant simplifications to the variable power divider can result. For example, in a good many cases a two-step (three states) approximation is sufficient; in this case the control elements might be most simply implemented as switches rather than multi-state phase shifters. This design optimization should be performed for each design and as such its detailed treatment is beyond the scope of this report.

### 3.0 APPLICATION TO S-BAND ASR

The intent of this discussion below is to provide some perspective on the implementation of the zoom feature. The design is illustrative only, but could be used as the foundation of a more formal design specification.

Current ASR's operate at S-band (2.7 to 2.9 GHz) and use spoiled paraboloidal reflectors which are nominally 17 ft. wide by 9 ft. high. An unspoiled reflector 17 ft. wide by 5 ft. high, fed by a vertically-stacked feed horn array, is adequate to support the zoom feature while maintaining the same basic capability as current antennas. To minimize feed blocking, an offset configuration such as the one shown on Figure 6 is recommended. Based on the results of simplified computations (scalar diffraction) it appears that

16-4-20988

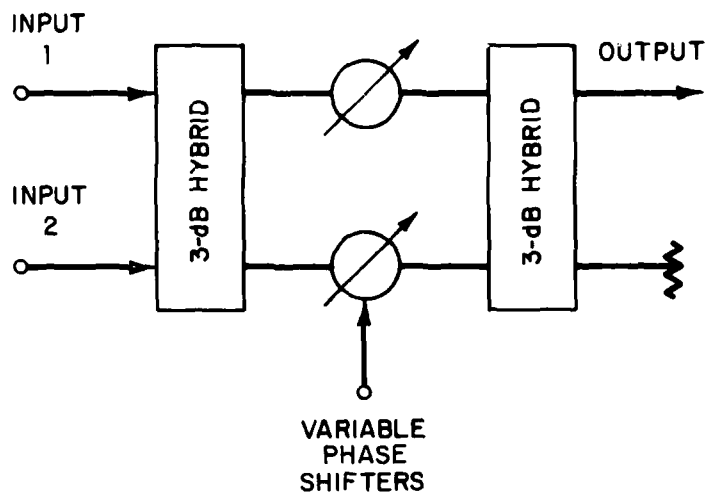


Fig. 5. Variable power combiner.

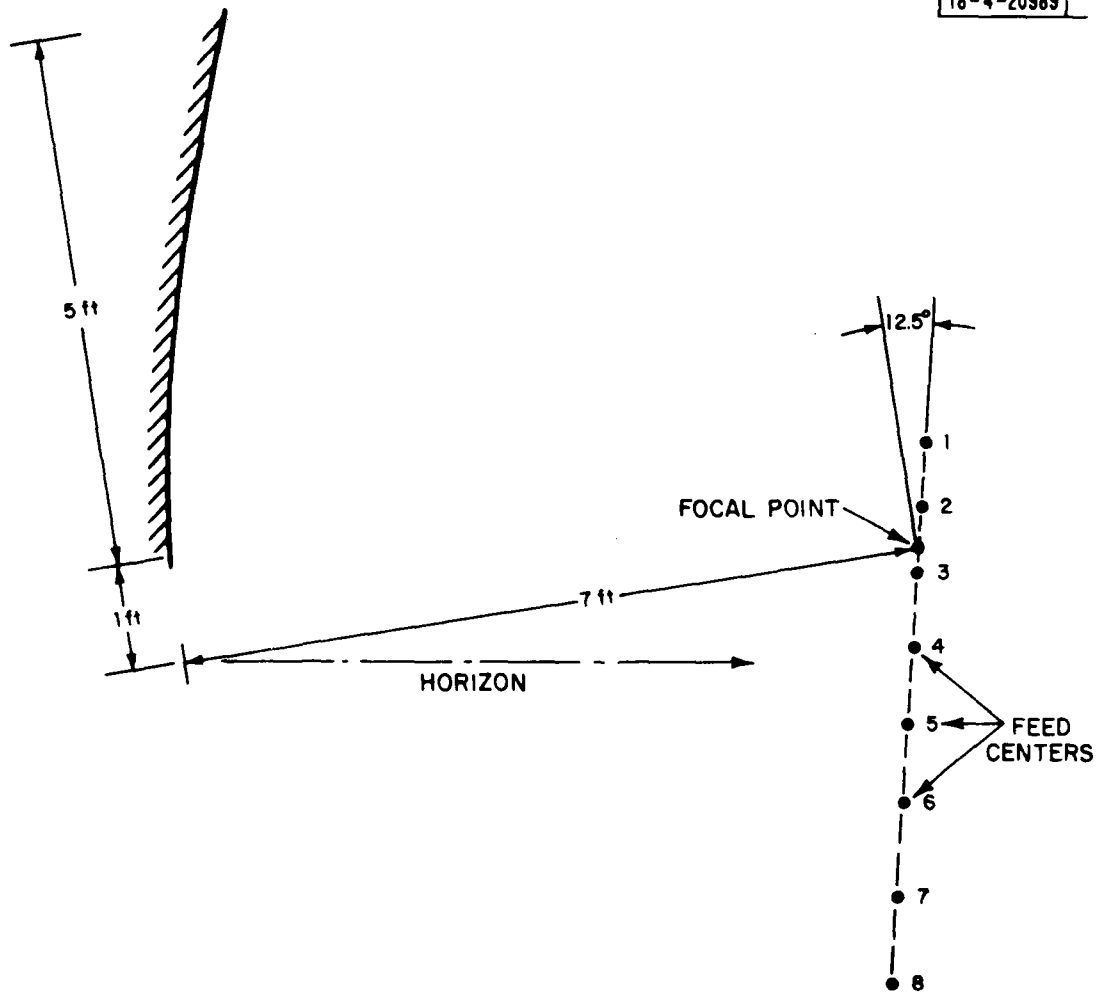


Fig. 6. Off-set feed multiple-beam reflector.

feed locations can be found for which the off-axis aberrations of the reflector are tolerable. This is demonstrated on Figures 7 and 8 which show the principal plane elevation and azimuth patterns for beams corresponding to individual feeds.

The next step in the design process is the selection of a transmit elevation beam pattern. A basic trade-off exists between the peak gain and the flatness of the pattern over the desired coverage. In the example shown on Figure 9, the pattern levels out at high angles to about -10 dB. This represents a loss of 2.5 dB over the maximum which could be extracted from the aperture and 0.5 to 1.0 dB more than a conventional "cosecant squared" design. Azimuth patterns are shown on Figure 10 for various elevation angles and appear to be acceptable.

An example of the achievable "zoomed" effect was computed for the three-state receiver power combining network shown in Figure 11. The receiver patterns are synthesized as follows: For long ranges only component beam #1 is used, for medium ranges beams 1, 2 and 3 are used and at short ranges all beams are used. The relative excitation of each receiver component beam was chosen to be the inverse of its transmit coefficient as a first-order approximation to flat top two-way patterns.

The three resulting two-way patterns are shown on Figure 12. Even though these represent only a two-step approximation to the total continuous zoom feature, they are typically adequate in the sense that it is possible to define three range segments over which each beam has an adequate absolute gain while providing constant gain vs. altitude. This is explicitly demonstrated by the range/altitude coverage diagrams shown on Figure 13. It has been assumed that the system sensitivity was such as to provide a 50-mile range with the long-range beam. Note that in this example, the short-range beam could be used inside of 20 miles where STC could be used to maintain nearly constant sensitivity and not suffer any loss of altitude coverage.

One of the key components for successful zoom operation is a phase shifter (or switch) which can change state at a time which is a fraction of a range gate. This is required to minimize the amount of data contaminated by

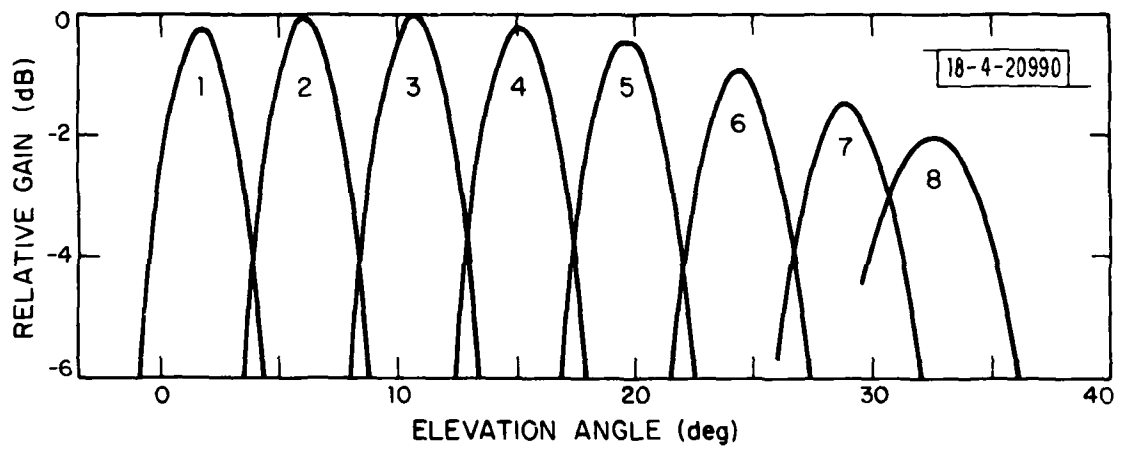


Fig. 7. Component beams elevation patterns.

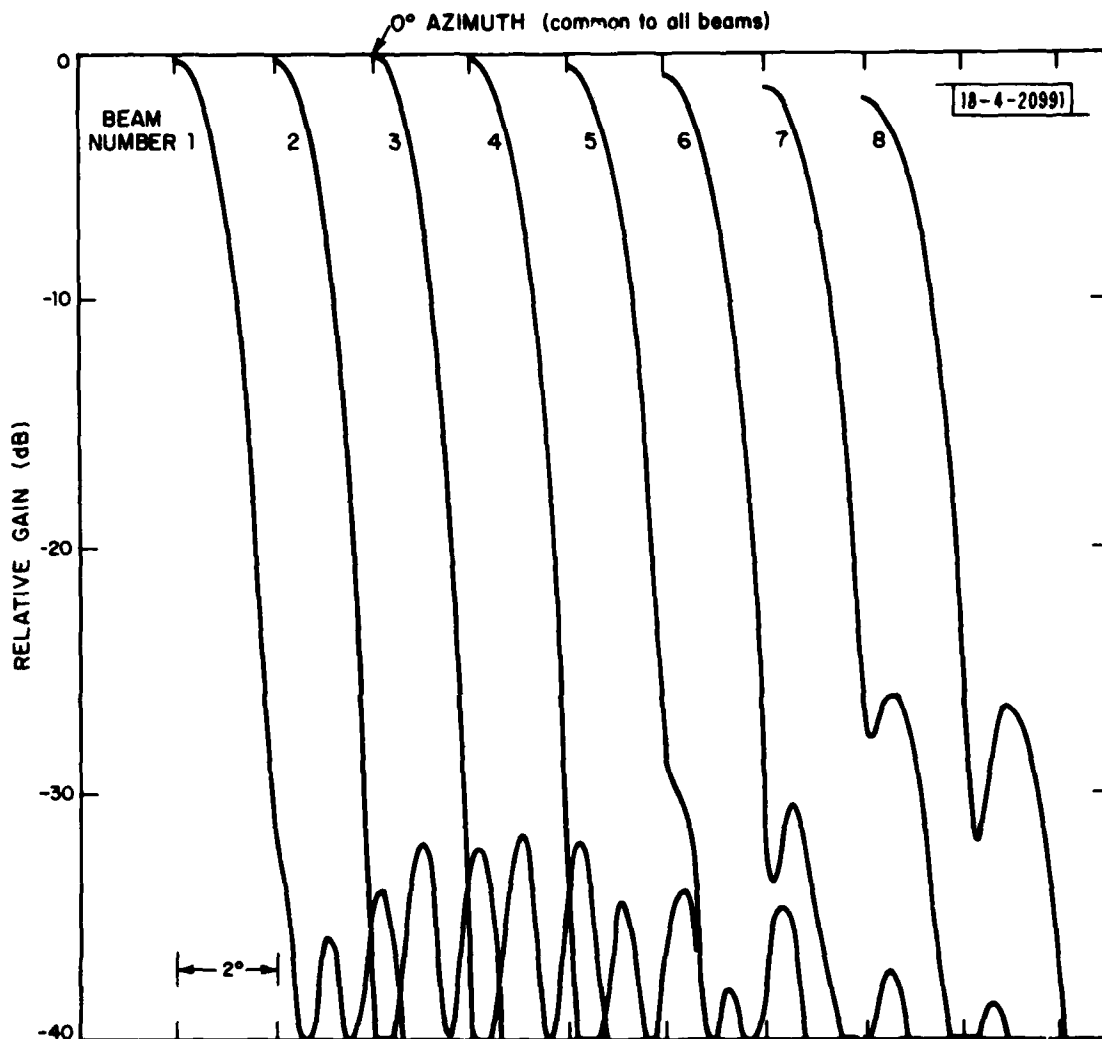


Fig. 8. Component beams azimuth patterns.

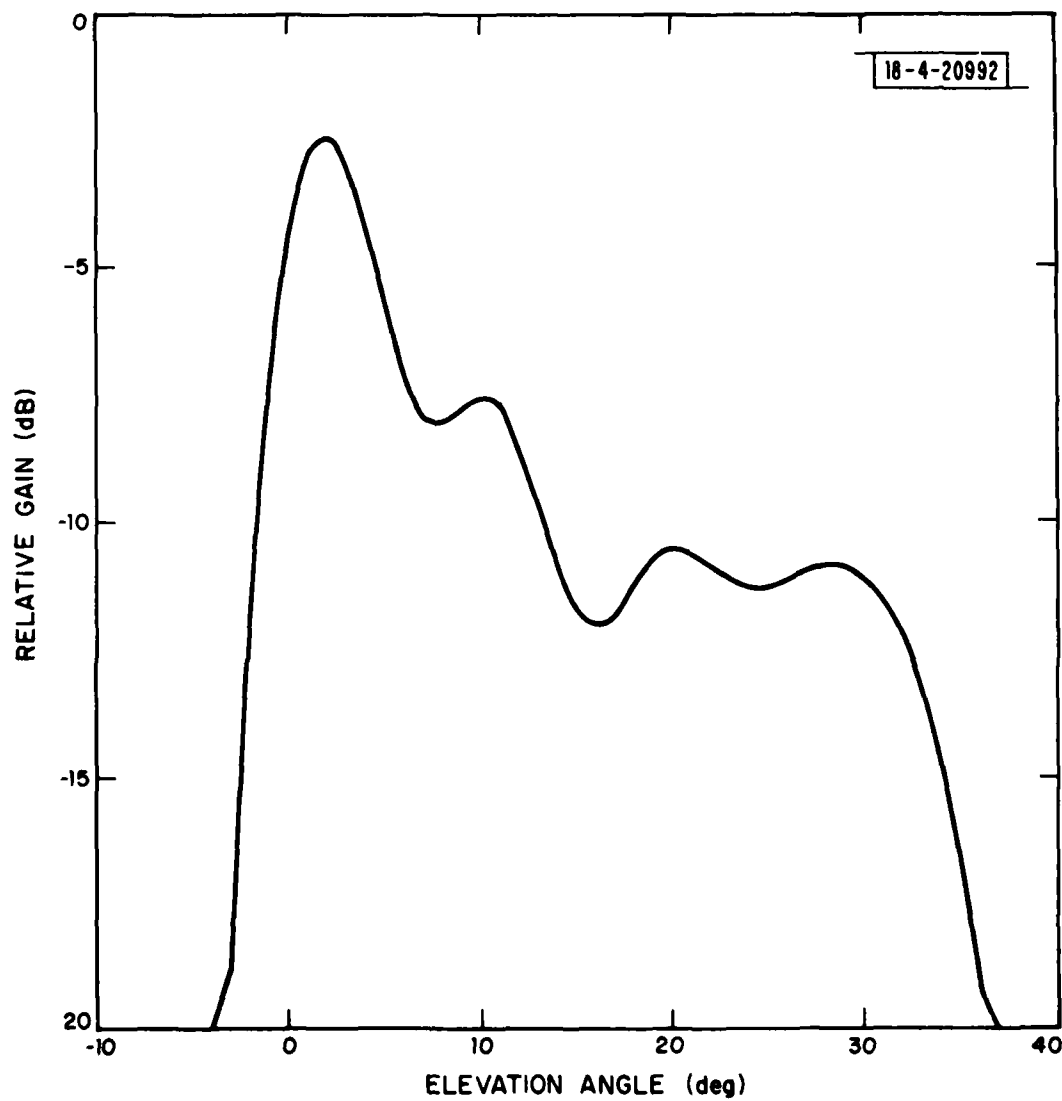


Fig. 9. Transmit beam elevation pattern.

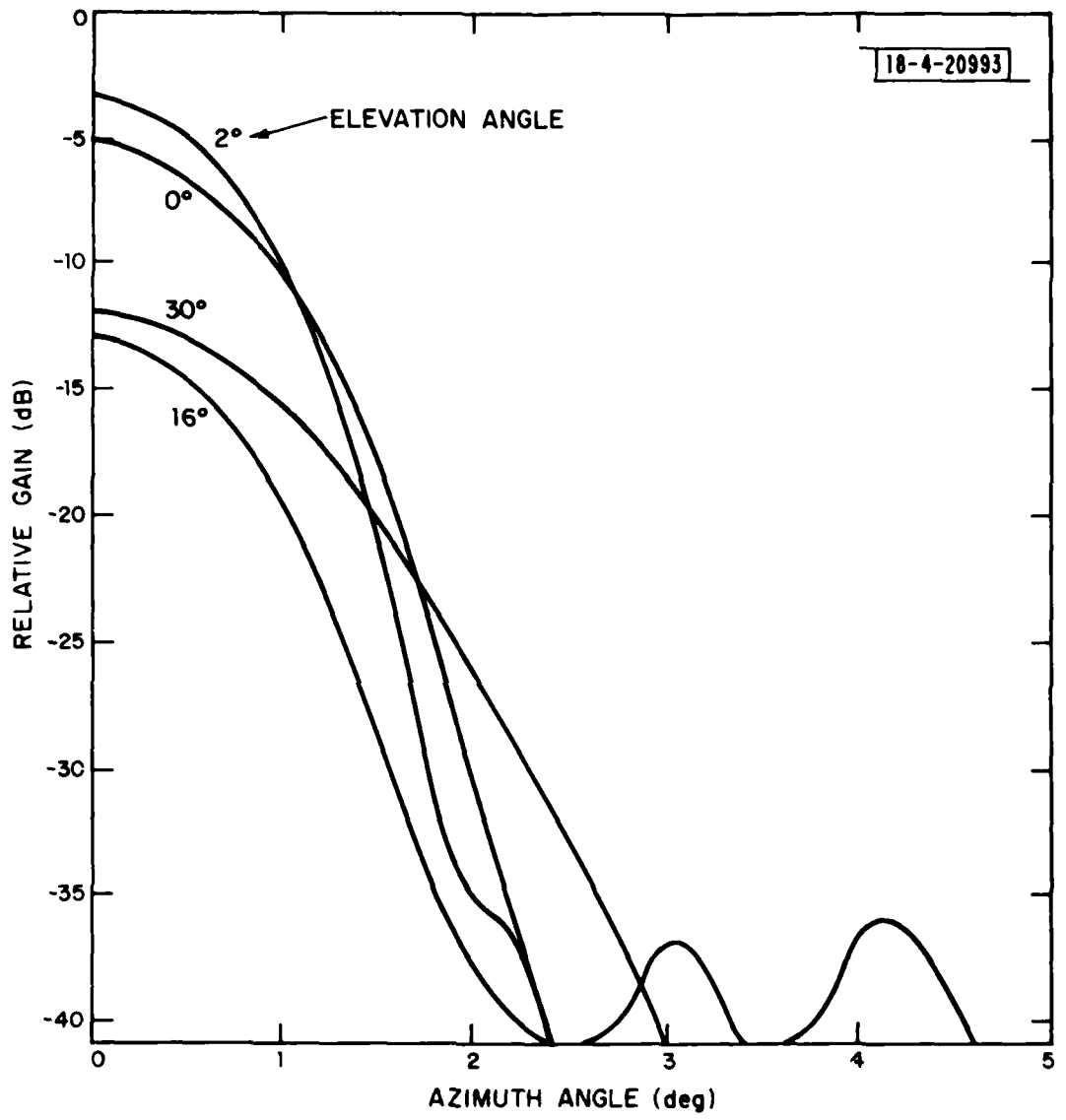


Fig. 10. Transmit beam azimuth pattern.

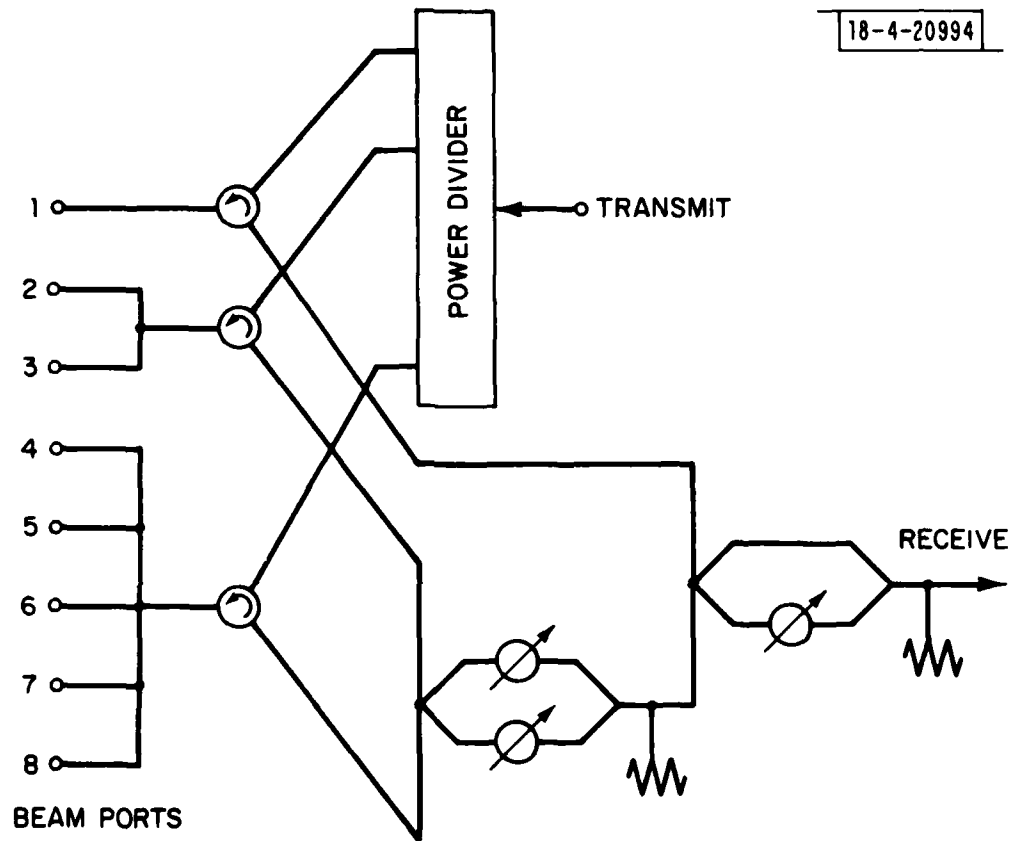


Fig. 11. Three state feed network.

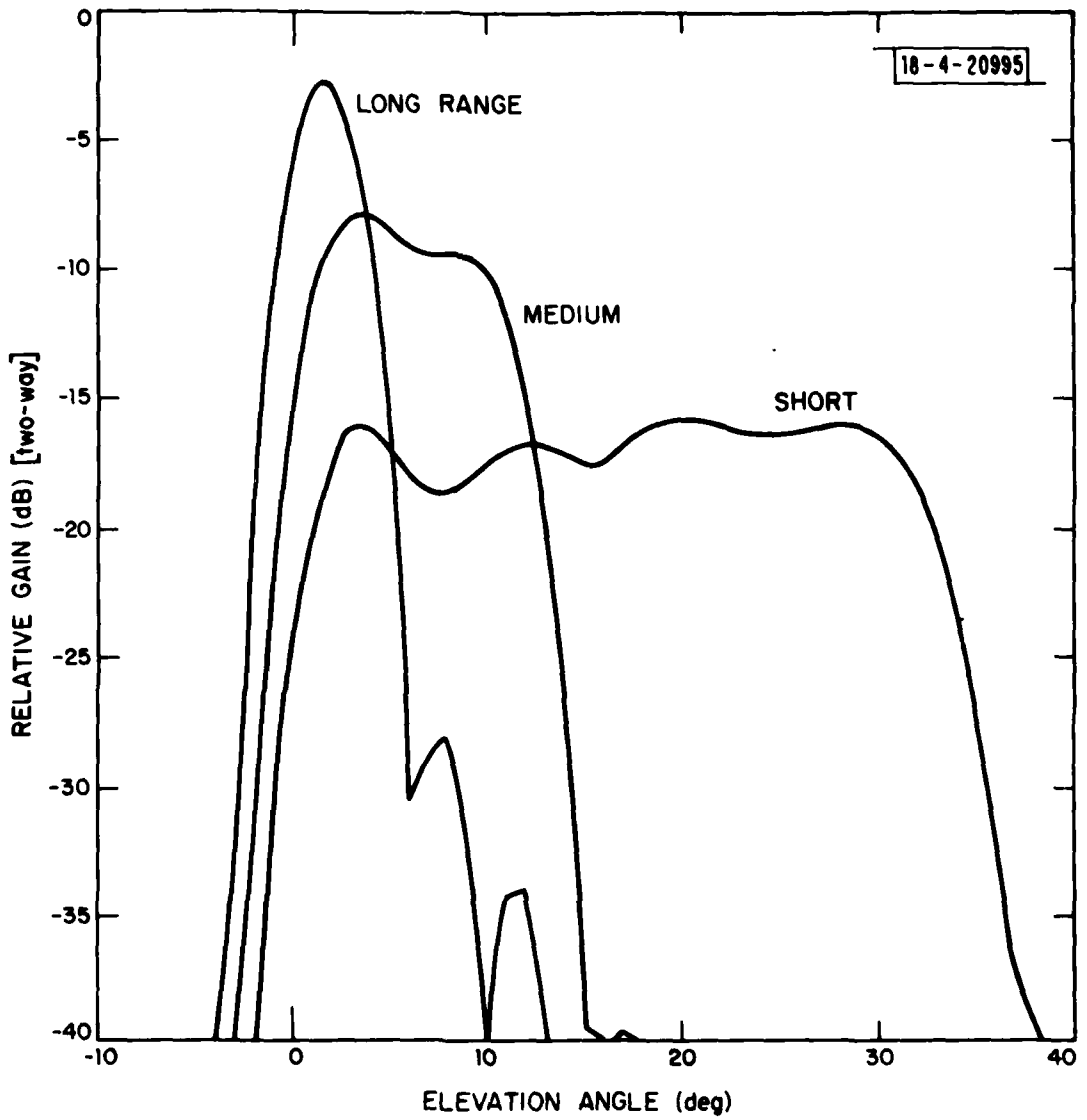


Fig. 12. Two-way elevation patterns.

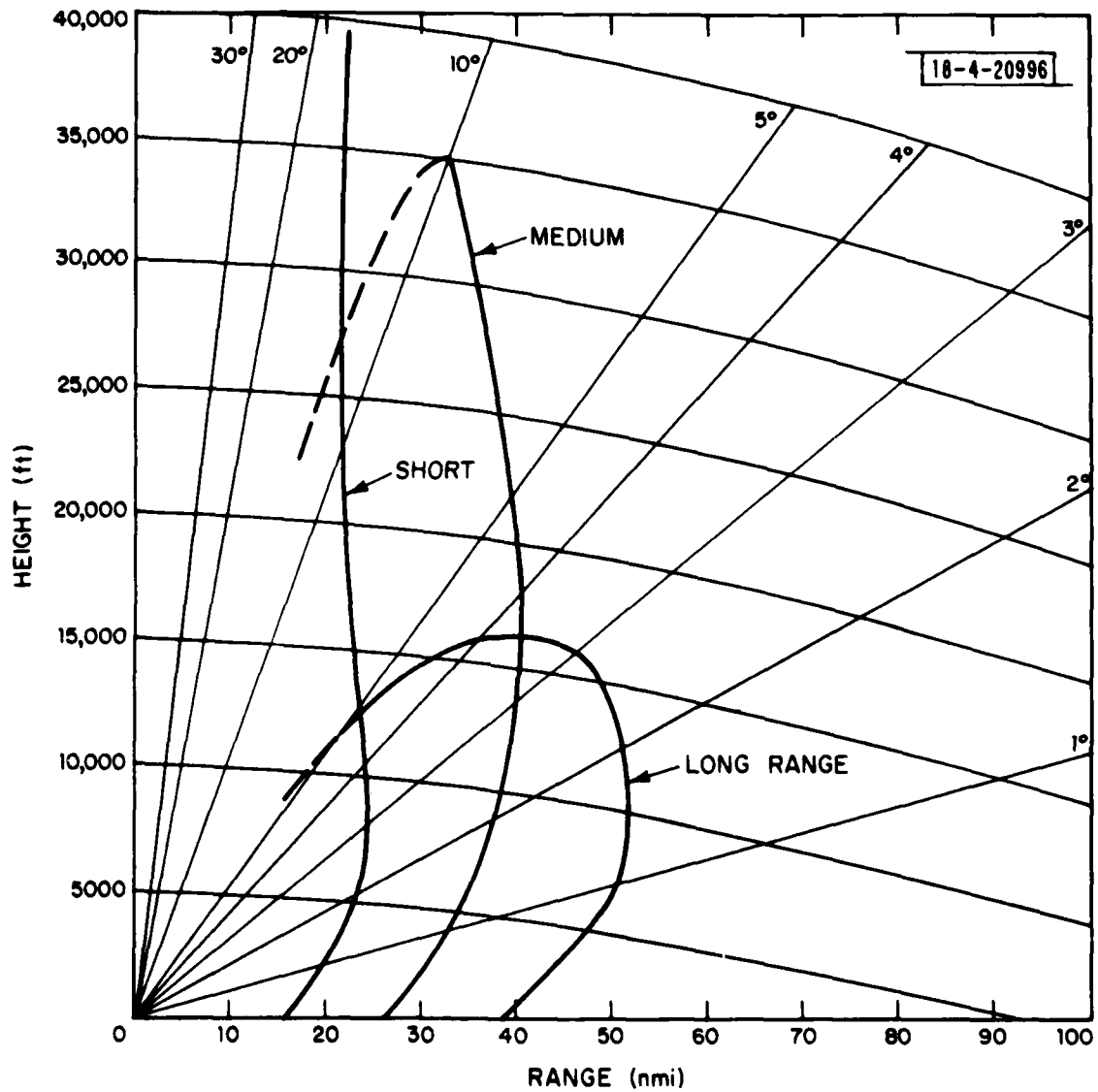


Fig. 13. Range/altitude coverage diagrams.

transient effects (see Section 5 for further discussion). A demonstration phase shifter was implemented by Microwave Associates. The essential characteristics of the device are given in Table 1. An optimized design for the receiver combining network, should strive to minimize the loss in the long-range conditions. Also note that it is desirable for the phase shifters to survive the leakage transmit pulse energy, thereby avoiding the need for additional T/R switches; the demonstration unit seemed adequate.

#### 4.0 APPLICATION TO L-BAND RADAR/BEACON ANTENNA

There has been, from time to time, some interest in a combined radar/beacon antenna where the radar is itself at L-band as is the case for the Air Route Surveillance Radars. The current ARSR-3 is an example of such a configuration in which a spoiled paraboloidal reflector is shared by radar and beacon feeds.

The inclusion of the zoom feature for such a system again implies the use of an unspoiled reflector, about half the height of the current one, a stacked feed array to generate the multitude component beams, and separate transmit and variable receive power dividers for radar. The design process and issues are the same as that for the S-band radar previously discussed.

With radar operating in horizontal polarization it would when be possible to implement the vertically-polarized beacon feed as an interleaved stacked array. This would result in a beacon elevation pattern with a high underside cutoff, as determined by the reflector's full height, and an upper coverage shaped independently of the radar's by tailoring the beacon feed array's own vertical power combiner.

#### 5.0 DISCUSSION

The inclusion of the zoom features in any radar system has some clearly identifiable consequences on the implementation. A number of antenna design optimization issues have been briefly examined in this report and would need to be examined in detail as part of a development process. On the other hand, some issues of a system nature need to be examined in more depth before

TABLE 1

FAST-SWITCHING PHASE SHIFTER CHARACTERISTICS

(From Microwave Associates)

Number of Bits:	4
Insertion Loss:	$1.15 \pm 0.4$ dB
Switching Time:	20 nanosec max
Reverse Bias Power Handling:	1 kw (at -30v)

commitment to implementation is made. For one, there is the issue of the impact of the step discontinuities in the elevation pattern. This is relevant when the detection threshold in one range cell is determined by levels in neighboring cells (CFAR processors). Clearly this process is somewhat corrupted in the vicinity of beam switch-over points. This problem is alleviated by increasing the number of steps in the zoom action. However, as the number of steps increases so does the number of transient time increments. It is not clear that the information collected during the phase shifter transition from one state to another is usable. This is especially crucial for processors in which groups of pulses are coherently integrated. Is it, in fact, necessary to blank each range gate during which a transition has occurred? The experience with systems equipped with a "passive" horn should provide a partial answer to that question. The impact of transition on the integrity of the receive signal is particularly significant when pulse compression is used since there is the potential for contamination of several range gates at a time.

The aim of the above remarks has been to alert the reader that while the "zoom" technique appears effective, practical and possibly cost-effective from a purely antenna viewpoint, a number of systems related issues, for which there is little existing experience, need to be examined.

DATE  
FILME  
— 8