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APERTURE COUPLED PATCH ANTENNAS AND ARRAYS

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ABSTRACT

Phased arrays of microstrip patch antennas are being studied extensively for millimeter wave applications, in which the feeds for several elements including the T/R modules might be integrated onto a single *GaAs* substrate. It is hoped that this integrated method of fabrication will improve performance and reduce the cost per element in large arrays. Many investigators are finding, however, that patch arrays on *GaAs* do not perform as well as they would on a lower permittivity substrate. Also, the area available in the unit cell (generally $\lambda_o/2$ by $\lambda_o/2$) is not sufficient to place the radiators and all of the circuit components on a single surface. The aperture coupled patch antenna permits the use of a low ϵ_r substrate for the antenna, and *GaAs* for the active circuits. An intervening ground plane isolates the feed network from the radiating face of the array, and undesirable via connections are not required. This paper describes an eight-element linear array of aperture coupled patches that is designed for E-plane scanning. Element and array performance are discussed. An aperture coupled patch with a perpendicular feed also is described. This arrangement allows the feed circuit to occupy as much depth behind the array as needed. The impedance and radiation patterns of the element are typical of other patch antennas.

1.0 INTRODUCTION

Microstrip antennas have been popular elements for planar and conformal arrays. A traditional means of fabricating these arrays that takes maximum advantage of the economies of printed circuit fabrication involves the layout of radiating elements and a feed network on a single surface of a grounded substrate. This minimizes the size and weight of the total array and requires the installation of only one coaxial connector to feed the array, thus reducing the cost. However, the microstrip feed network radiates small amounts of power that can degrade the sidelobe and polarization characteristics of the array. Also, the radiators and feed lines occupy much of the available area, leaving little space for the phase shifters that are required for beam steering. Furthermore, for monolithic phase shifters, the substrate must be *GaAs*, which is not a desirable substrate for the radiators.[1]

Most of these problems can be alleviated by using a two-layer structure that has the radiating elements and their substrate on one side of a ground plane and the feed network and its substrate on the other. In the past, arrays fabricated in this fashion have utilized a via connection probe at each element in order to transfer power from the feed network to the radiators. However, these via connections are increasingly difficult to fabricate as the frequency increases. Also, the use of *GaAs* as a feed substrate complicates the fabrication.

A useful alternative to the via connection probe is aperture coupling.[2,3] In this configuration, power is coupled from the microstripline feed to the radiating patch through an electrically small aperture in the ground plane (see Fig. 1). No electrical connection is required and the performance is relatively insensitive to small errors in the alignment of the two circuits. Single elements have performed well at frequencies as high as K_u band.[4]

The objectives of this paper are (i) to present the performance of an 8–element linear array of aperture coupled patches that was designed to demonstrate the use of this type of element in a phased array that utilizes a (simulated) monolithic feed network, and (ii) to present an alternative aperture coupled geometry that offers some potential benefits compared to the original design. The next section describes the 8–element array, presents the performance of various elements in the array and mutual impedance data, and finally shows the overall array perofmance. The third section describes a perpendicular feed geometry and presents some ideas for its use in phased arrays.

2.0 EIGHT–ELEMENT ARRAY OF APERTURE–COUPLED PATCHES

The primary objective of this array is to demonstrate that an array of aperture coupled patches with $PTFE$ substrate for the antennas and high permittivity substrate ($\epsilon_r = 10.2$ to simulate approximately $GaAs$) for the feed network can be used as an integrated, phase–steered array at EHF. Rather than to operate at EHF where measurements and phase shifting are difficult, a scaled model was built at 5 GHz. Tolerance studies have shown that misalignment of the feed network on the order of 10 % of the patch length has minimal effect on the performance of the antenna elements, so that the scale model should be representative of the results that can be achieved at 20 or 25 GHz. The use of 25–mil Duroid 6010.2 for the feed substrate simulates approximately 5–mil $GaAs$ at 25 GHz, and the 60–mil

Duroid 5880 antenna substrate is 0.025 λ_o thick at the operating frequency. The dimensions of the array are given in Figure 2. In a monolithic feed version, phase shifters would be fabricated on *GaAs*, but the antenna tested here has microstriplines (approximately λ_o long) that connect to the feed network through coax–to–microstripline transitions.

2.1 *ELEMENT CHARACTERISTICS*

The input impedance, referenced to the center of the coupling slot, of an isolated element is shown in Figure 3. The element is well matched at 5 GHz. The input impedance of a typical element in the array (measured with the other elements terminated in 50 ohms) is shown in Figure 4. The return of loss plots of some of the elements (referenced to the coaxial input connector) are shown in Figure 5, where the worst case return loss at 5 GHz is about 12 dB. Mutual coupling is approximately –20 dB between adjacent elements of the array and drops to –30 dB for center–to–end element coupling (see Table 1).

E–plane radiation patterns of several elements are shown in Figures 6 and 7. The unused elements are terminated in 50 ohms. The expected mirror symmetries are evident, otherwise the patterns exhibit the broad beamwidth and endfire levels of approximately –10 dB that are typical of patch radiators. Some pattern irregularities and scattering behind the ground plane, which was approximately $4\lambda_o \times 2\lambda_o$, are seen, but the patterns are generally good and should result in useful array patterns over a fairly wide range of scan angles.

2.2 *ARRAY CHARACTERISTICS*

Radiation patterns of the array were obtained by feeding the elements with equal–amplitude, in–phase signals. This was accomplished by using a commercially available 8–way power divider connected to the array by equal lengths of semi–rigid coaxial cable. The return loss of the array measured at the input to power divider is shown in Figure 8. The VSWR is less than 2:1 over the frequency range 4.9–5.2 GHz. E–plane radiation patterns at four frequencies are shown in Figure 9. The 20–dB front–to–back ratio implies that the slot apertures in the ground plane do not radiate significantly on the feed side. The sidelobes are a little higher than one would expect for a uniform distribution and they exhibit some asymmetries, but the patterns are generally good. It appears that the performance of the aperture coupled patch in small arrays will be about the same as that of the probe–fed patch, but the fabrication may be simpler.

A scan blindness can occur in aperture coupled arrays due to the surface wave on either the antenna substrate or the feed substrate. However, the blindness caused by the low permittivity antenna substrate is very near to endfire. Also, the blindness caused by the $GaAs$ feed substrate occurs at scan angles greater than 80^o for thicknesses up to 0.02 λ_o and element spacings of

0.5 λ_o. Therefore, scan blindness induced by the *GaAs* substrate should not limit the scan range of practical antennas at frequencies below 50–60 GHz.

3.0 *ARRAY GEOMETRY WITH A PERPENDICULAR FEED SUBSTRATE*

Another design that uses separate substrates for the radiating elements and active circuitry is shown in Figure 10. In this case a vertical substrate holding the radiating elements is fed by a number of parallel feed substrates. Coupling is again through apertures in the ground plane of the antenna substrate. This design also allows the use of a low dielectric constant substrate for the radiating elements and a separate semiconductor substrate for the active circuitry, similar to the two–sided geometry, and so has the same advantages in relation to scan blindness/bandwidth performance and shielding of spurious radiation or coupling. In addition, this architecture has a number of other advantages.

First is the fact that the feed substrate can be of virtually unlimited size, since there is not immediate restriction on the "depth" dimension away from the vertical antenna substrate. Waveguide phased arrays usually use this depth dimension to a similar advantage. The geometry also permits a modular construction, where feed modules could conceivably be plugged in to recepticles on the antenna substrate.

This design also allows efficient heat transfer from the ground plane of the feed substrate. At millimeter wave frequencies low device efficiency requires efficient heat transfer from active circuitry. The unobstructed ground plane of the feed substrates allows such heat removal to take place, while the embedded ground plane of the two-sided design makes heat removal more difficult.

Finally, such a geometry would lend itself well to space-fed phased array lens designs, which may be of interst for some applications. This could be implemented by having antenna substrates at both ends of the feed substrates. It does not appear, however, that this geometry would be useful if dual polarization were required.

The array with perpendicular feed substrates depends on the feasibility of feeding a single patch through an aperture with a microstrip line on a perpendicularly oriented substrate. Such a geometry is shown in Figure 11, and has been verified experimentally, but no theory has been developed beyond simple arguments.[5]

Figure 12 shows a Smith chart plot of the measured input impedance of a model at 2.2 GHz. This case used antenna and feed substrates both with $\epsilon_r = 2.55$, but a higher dielectric constant substrate could be used for the feed, as well. Figure 13 shows measured E- and H-plane radiaton patterns for this antenna. Most of the back lobe radiation is due to the use of a small ground plane, and scattering from the connecting cable.

The geometry in Figure 11 shows a direct connection from the feedline to the top of the aperture; the two ground planes are also in electrical contact. Another version of the perpendicularly fed antenna excites the aperture by proximity coupling, eliminating the need for a direct connection of the feedline.

4.0 SUMMARY

Aperture coupled microstrip antennas offer some potential advantages in phased arrays compared to probe–fed and microstripline–fed patches. A linear eight–element, E–plane array of patches using the two–sided approach has been fabricated to demonstrate the use of this technique in small arrays. The array performed well. An alternative configuration that provides more space for feed circuits utilizes a perpendicular feed substrate. Single elements of this type have been fabricated and tested, and arrays could be built.

References

1. Pozar, D.M. and D.H. Schaubert, "Comparison of Architectures for Monolithic Phased Array Antennas," Microwave Journal 29 (No. 3): 93—104.
2. Pozar, D.M., "Microstrip Antenna Aperture Coupled to a Microstripline, " Electronics Letters, 21:49—50.
3. Sullivan, P.L. and D.H. Schaubert, "Analysis of an Aperture Coupled Microstrip Antenna," IEEE Trans. Antennas and Propagation, to appear August 1986.

4. Schaubert, D.H., R.W. Jackson and D.M. Pozar, "Antenna Elements for Integrated Phased Arrays," Proc. 1985 Antenna Applications Symposium, Univ . of Illinois.
5. Buck, A.C. and D.M. Pozar, "An Aperture Coupled Microstrip Antenna with a Perpendicular Feed," Electronics Letters 22:125—126.

Table 1. Mutual Coupling in Array

5 GHz

$P_L = 1.78$ cm $P_W = 2.54$ cm $s = 3.0$ cm

$\epsilon_r^{ant} = 2.22$ $d^{ant} = 0.159$ cm

$\epsilon_r^{feed} = 10.2$ $d^{feed} = 0.064$ cm

	$\lvert S_{ij}\rvert (dB)$	$\angle S_{ij}(deg)$
S_{41}	–30.7	–79
S_{42}	–24.8	102
S_{43}	–21.6	–46
S_{45}	–22.1	–52
S_{46}	–27.0	103
S_{47}	–30.3	–110
S_{48}	–31.8	70

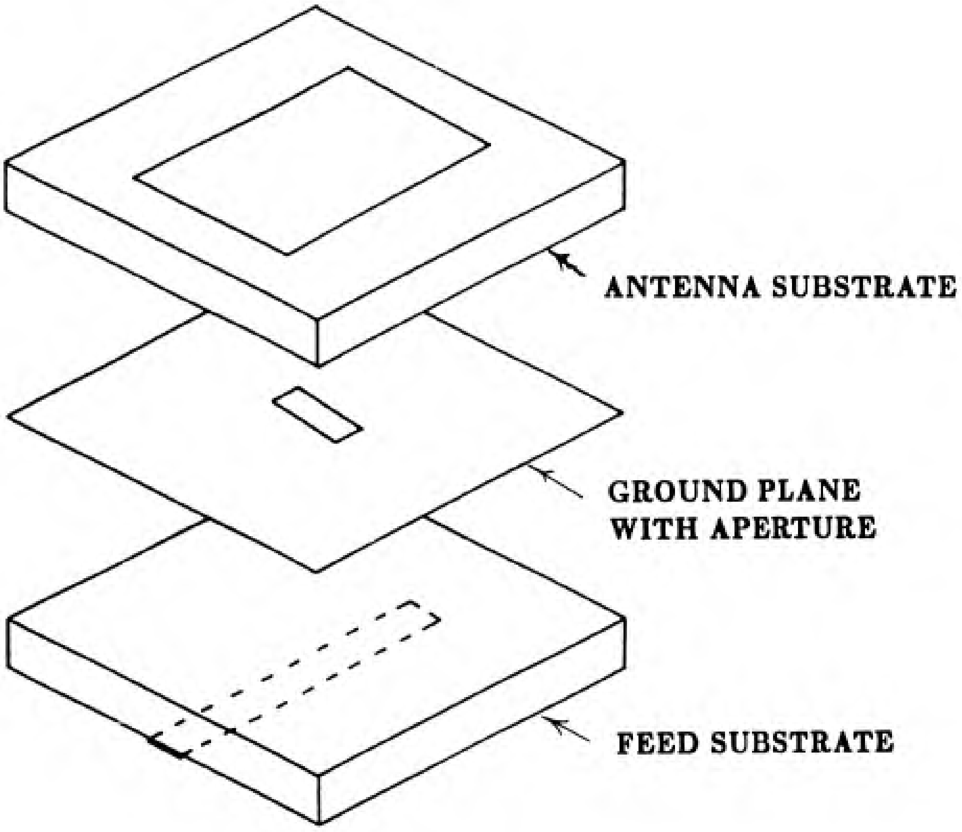
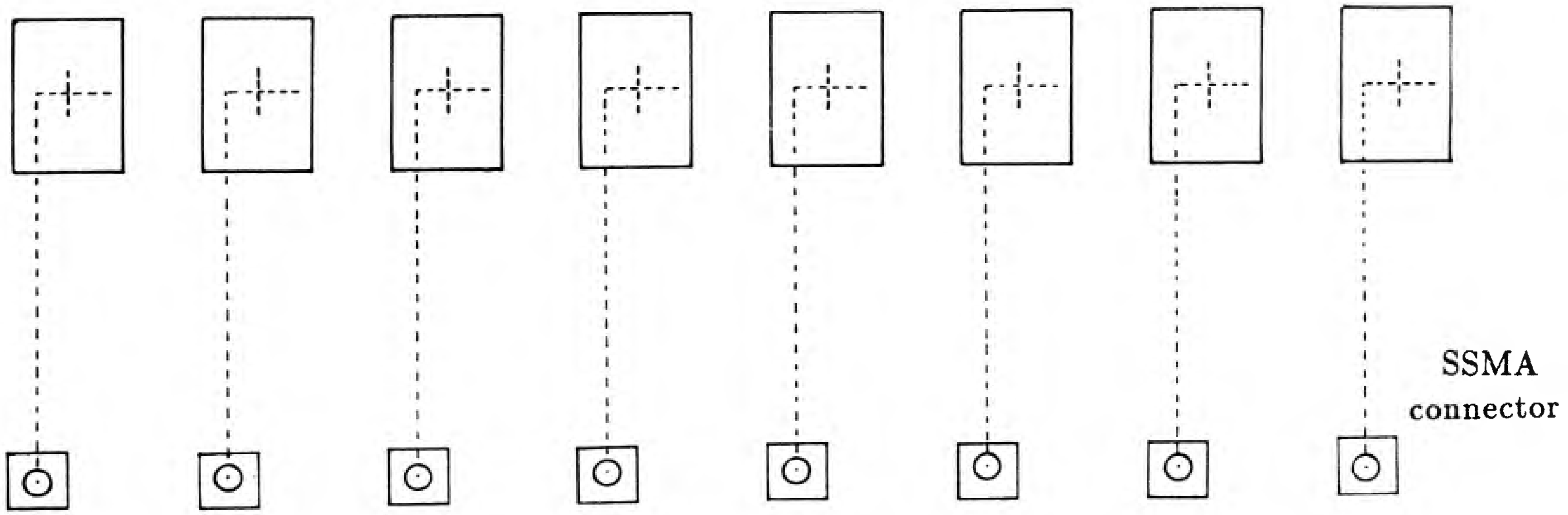


Figure 1. Aperture coupled microstrip patch antenna element.



Patch Length = 1.78 cm
Patch Width = 2.54 cm
Slot Length = 0.83 cm
$\epsilon_r^{ant} = 2.22$
$d^{ant} = 0.159$ cm

Element Spacing = 3.0 cm
Stub Length = 0.42 cm
Slot Width = 0.056 cm
$\epsilon_r^{feed} = 10.2$
$d^{feed} = 0.064$ cm

Figure 2. Eight–element, E–plane array.

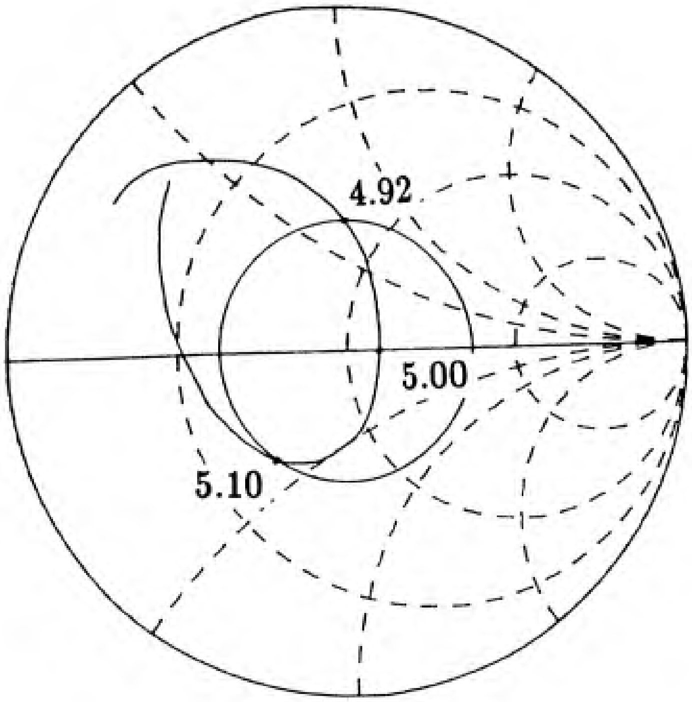


Figure 3. Input impedance of isolated element, 4.5–5.5 GHz. Circle indicates $VSWR = 2$.

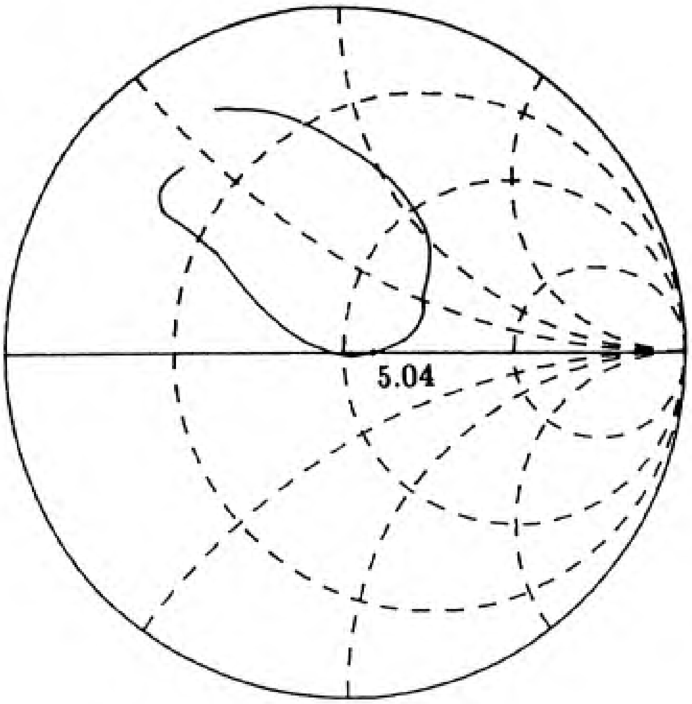
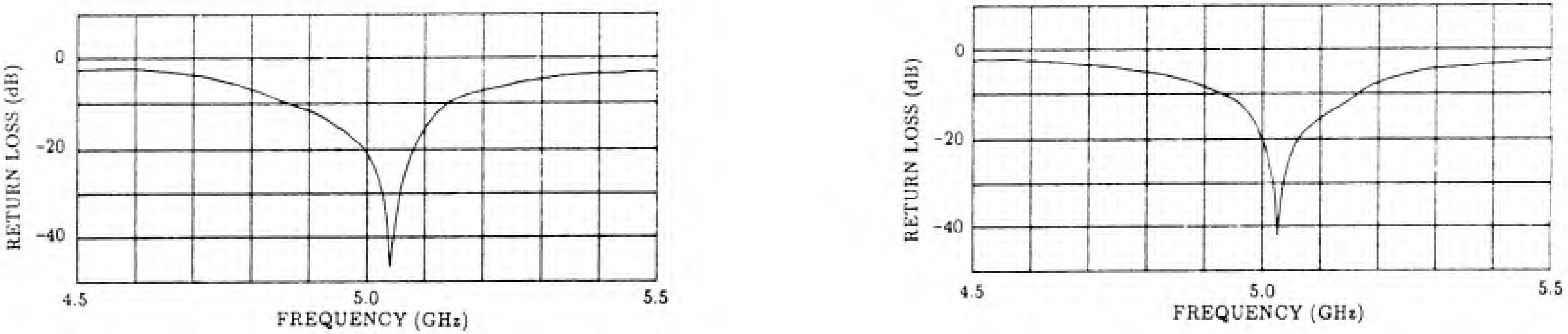
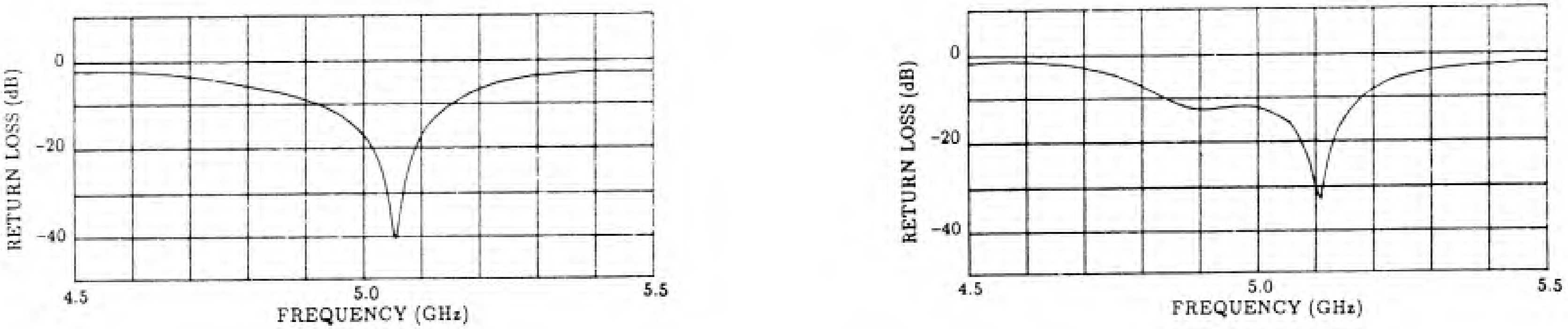


Figure 4. Input impedance of element 6 in the array. Other elements terminated in 50 ohms.

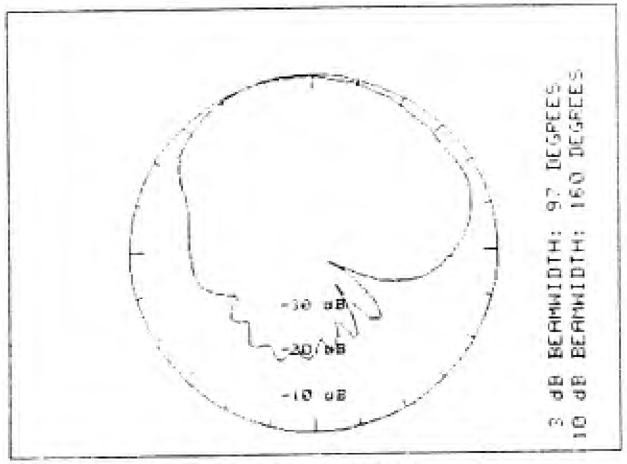


ELEMENT 1 **ELEMENT 2**

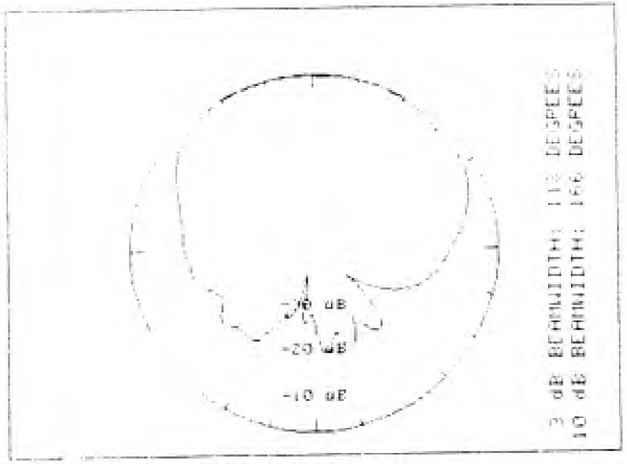


ELEMENT 3 **ELEMENT 4**

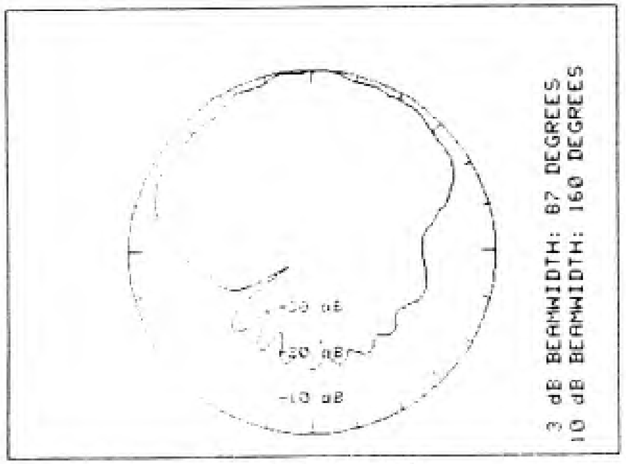
Figure 5. Return loss of elements 1, 2, 3 and 4 measured at the coaxial connectors.



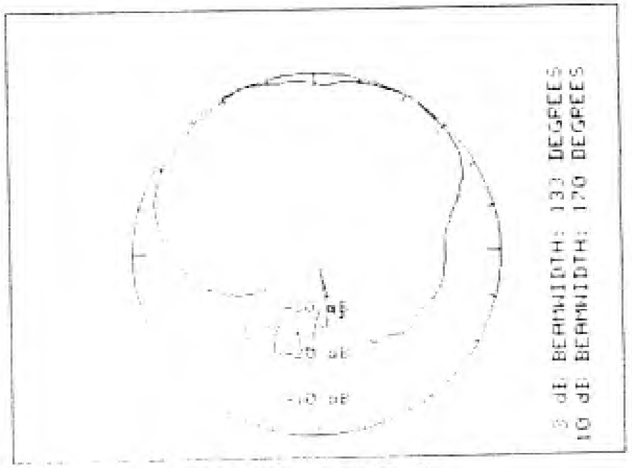
ELEMENT 1



ELEMENT 2

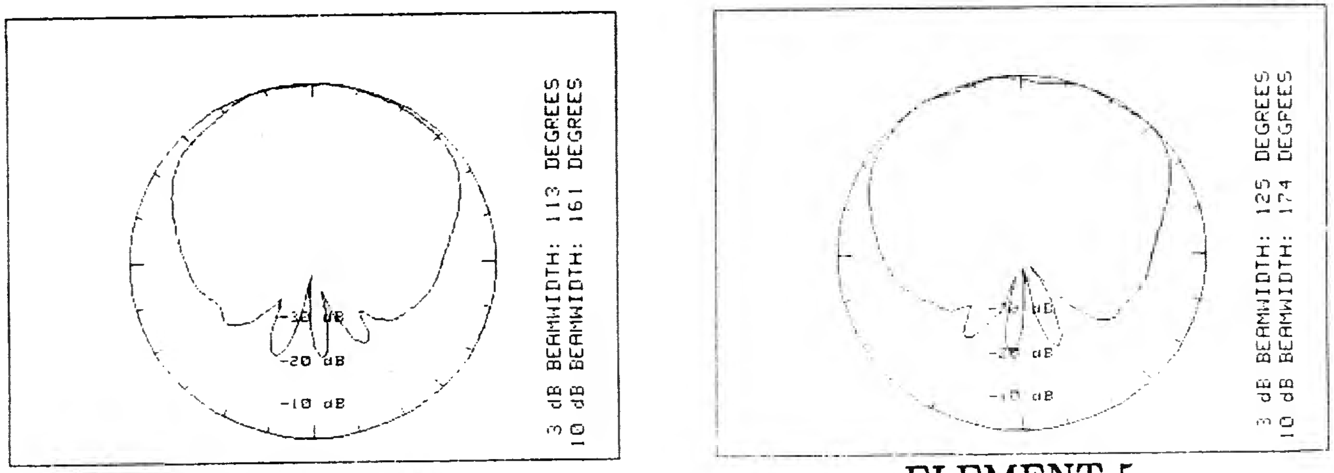


ELEMENT 8



ELEMENT 7

Figure 6. E–plane patterns of end elements in array at 5.0 GHz. Unused elements terminated in 50 ohms.



ELEMENT 4

ELEMENT 5

Figure 7. E–plane patterns of central elements in array at 5.0 GHz. Unused elements terminated in 50 ohms.

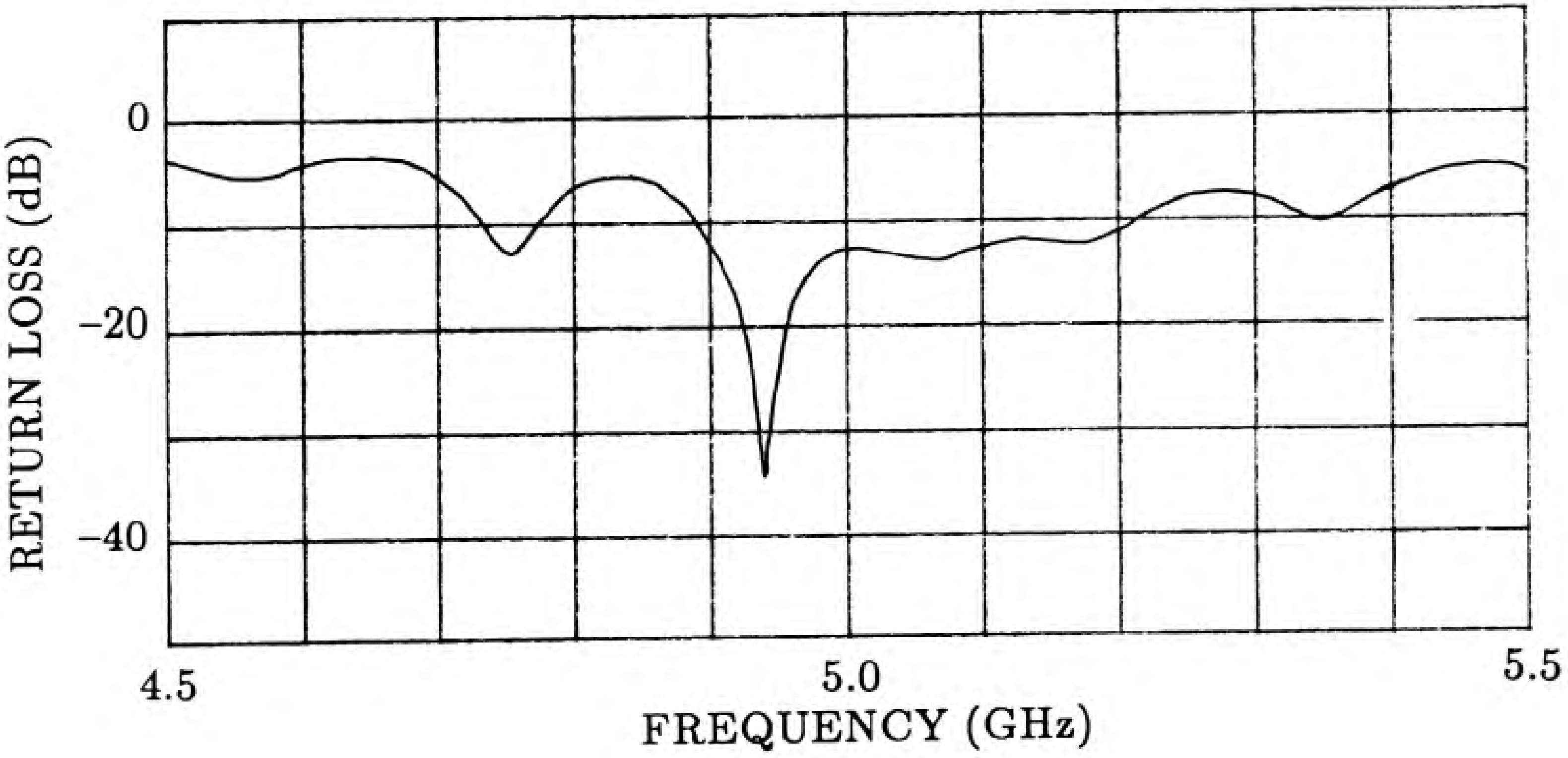
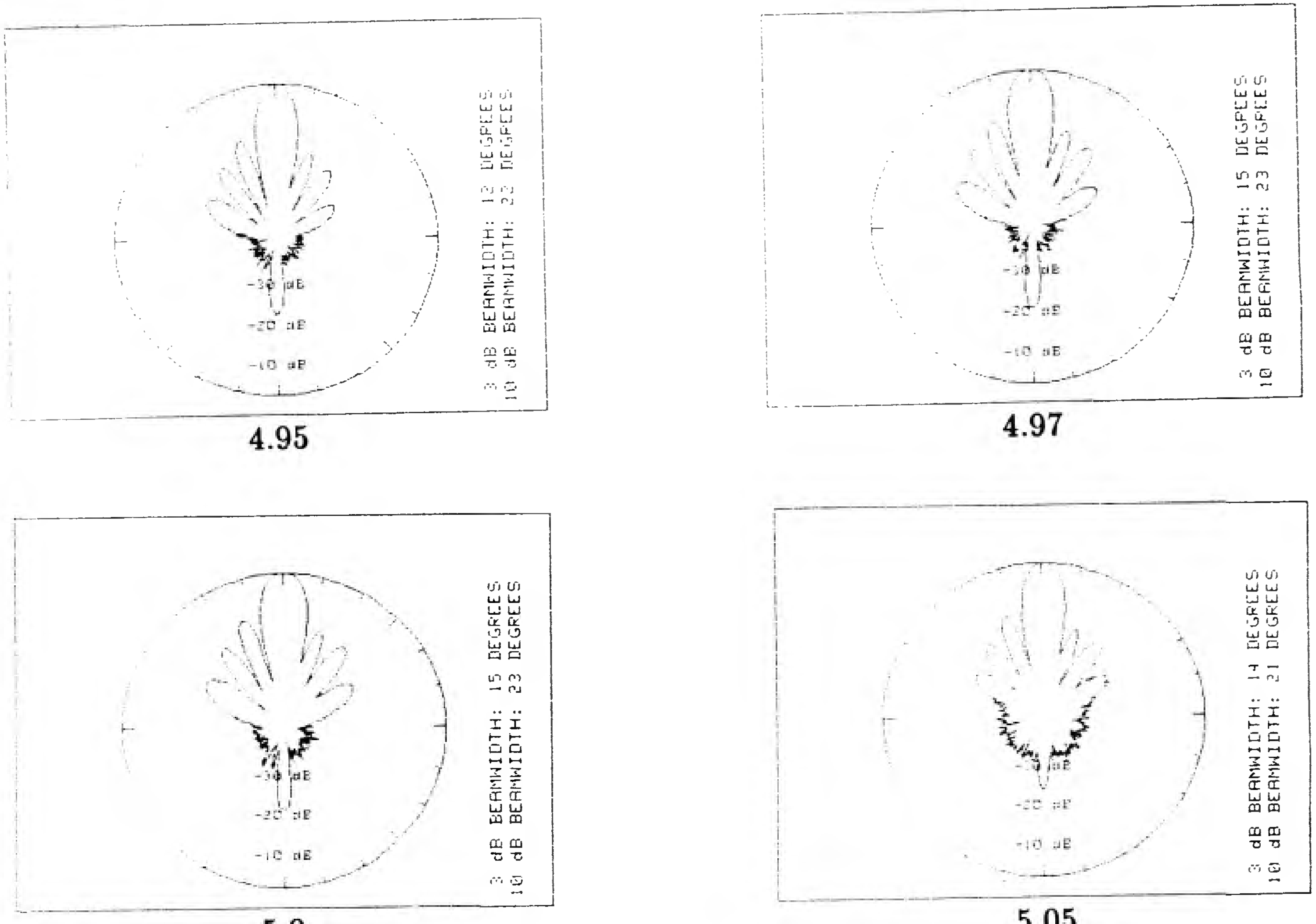


Figure 8. Return loss of 8–element array at input to coaxial power divider .



4.95 **4.97**

5.0 **5.05**

Figure 9. E–plane radiation patterns of 8–element array.

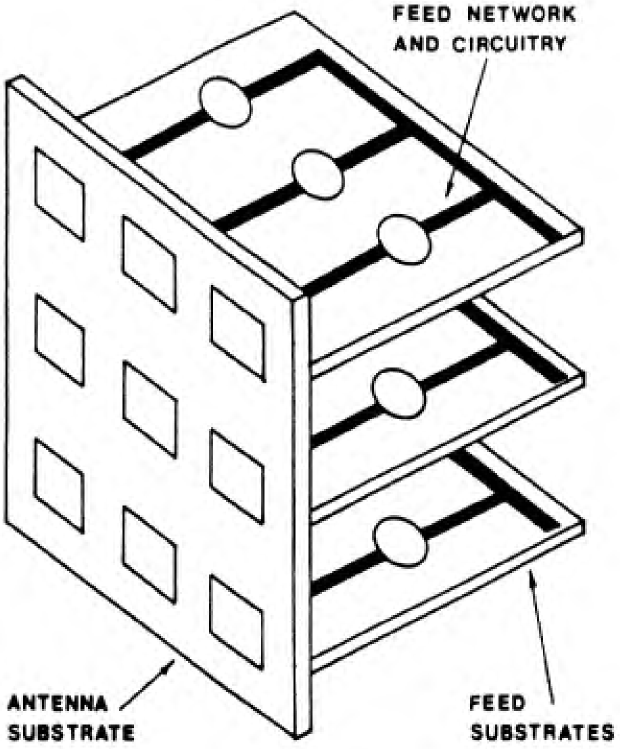


Figure 10. Integrated phased array configuration using feed substrate perpendicular to radiating element substrate.

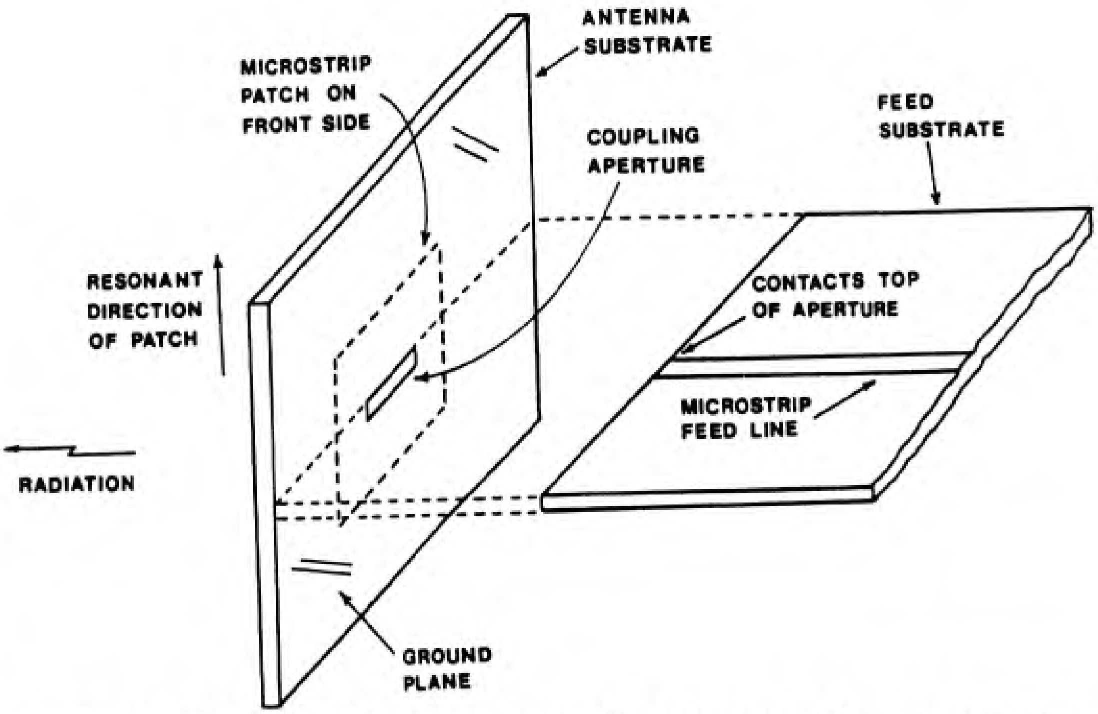


Figure 11. Geometry of isolated microstrip antenna fed through aperture with microstrip line on perpendicularly oriented feed substrate.

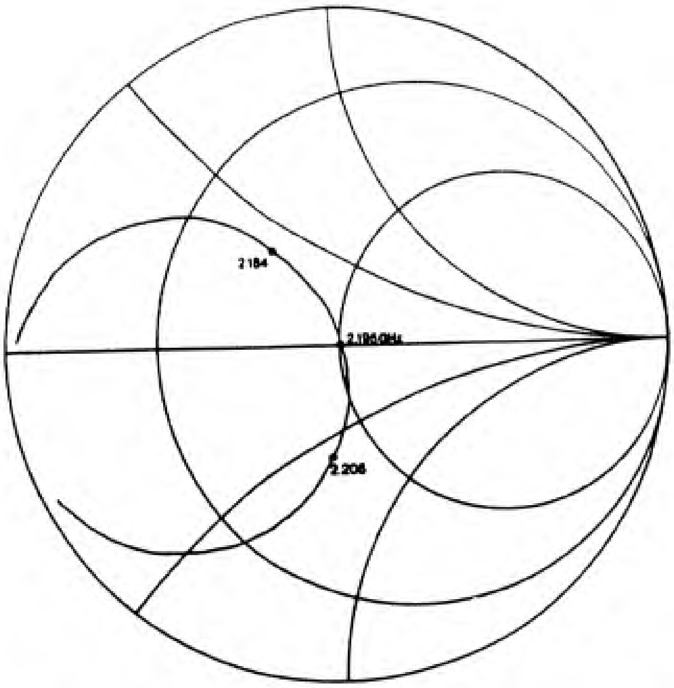


Figure 12. Smith chart plot of measured input impedances of perpendicularly fed microstrip antenna with aperture coupling.

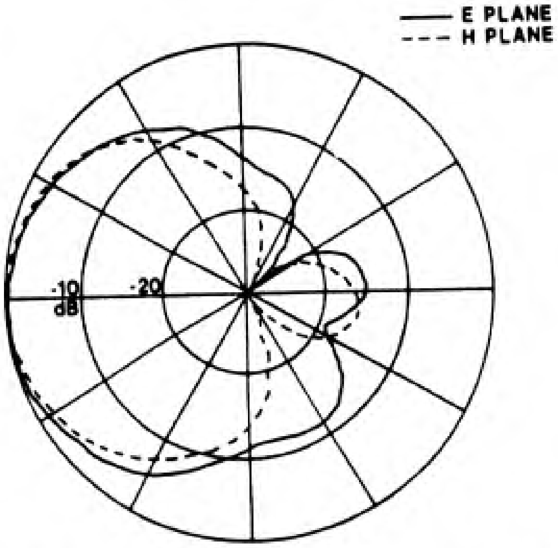


Figure 13. Measured radiation patterns of perpendicularly fed microstrip antenna with aperture coupling.