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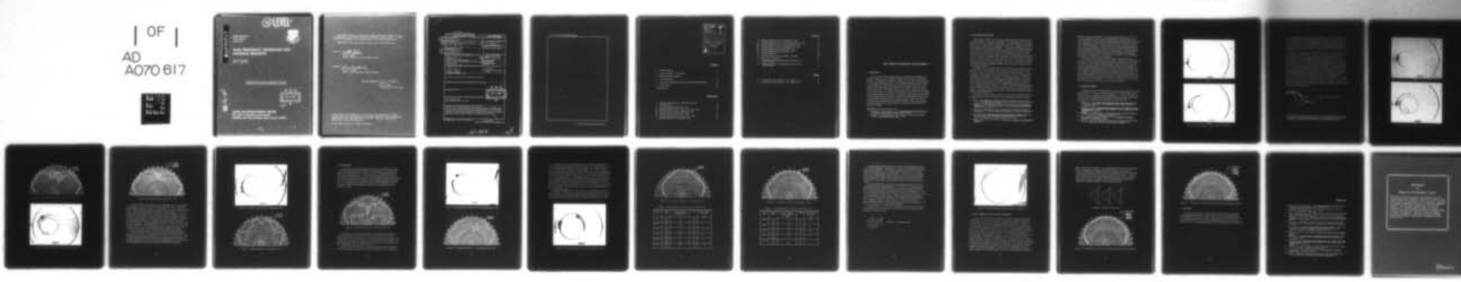

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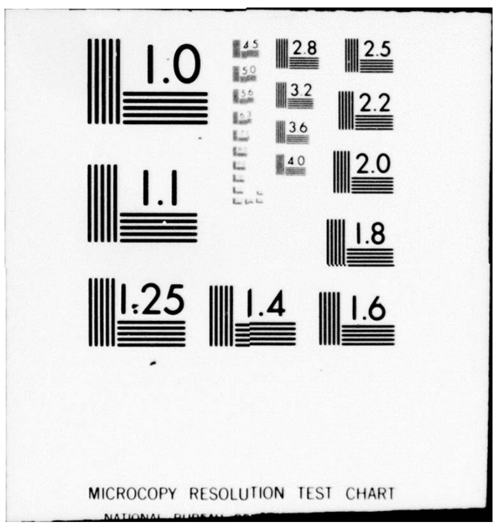
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RADC-TR-79-74
In-House Report
March 1979

DUAL FREQUENCY MICROSTRIP DISC ANTENNA ELEMENTS

Nicholas Kernweis
John F. McIlvenna

ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Two radial conducting strips, placed on the edge of a microstrip disc antenna, can be used to produce a dual frequency element. The strip length and circumferential location determine the frequency spread. This report describes a series of experiments that catalog the various effects produced by single and double strips in a variety of circumferential locations.

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Dual Frequency Microstrip Disc Antenna Elements

1. INTRODUCTION

In earlier papers,[1,2] the authors discussed a technique for modifying microstrip disc antenna elements to produce characteristics not inherent in the basic element. The modification consisted of placing one or two radial conducting strips in various circumferential locations. This modification produces drastic changes in the impedance and radiation characteristics of the basic disc element. These changes can be controlled by proper selection of the length, width, and angular location of the strips. The addition of the strips to the disc element alters neither its low profile nor the ease with which such elements can be fabricated. Among the many changes produced by the strips, it was noted that both single and double strips produced multiple loops on the network analyzer trace indicating resonance at two, sometimes three different frequencies. Such behavior promised simultaneous multiple frequency operation from a single disc element. This report describes some experiments and the results obtained in modifying disc elements for dual frequency operation.

(Received for publication 29 March 1979)

1. Kernweis, N., and McIlvenna, J. (1979) Microstrip Antenna Element for Use in Hemispherically Scanned Arrays, RADC-TR-79-43.
2. McIlvenna, J., and Kernweis, N. (1979) Modified microstrip disc antenna elements, IEE Electron. Lett. 15(No. 7):207.

2. DUAL FREQUENCY OPERATION

Dual frequency operation with microstrip antenna elements has been discussed by several authors. Long[3] used a combination of two separate disc elements, each resonant at one of the two desired frequencies. Derneryd[4] designed a two frequency feed to match a single element (rectangular or disc) at two frequencies 12 percent above and below the disc resonant frequency. Sanford[5] used two separate rectangular elements, one inside the other. At the high frequency, the smaller solid inner element serves as the radiator, while at the lower frequency, the outer annular element is connected to the inner element by suitably chosen lengths of transmission line, and the whole combination of inner and outer rectangles becomes the radiating element. Yu[6] also used two concentric elements, that is, a disc inside an annular ring, but like Long, each element resonates at one of the two frequencies. Howell[7] claimed that exciting a rectangular element on both long and short sides produced a dual frequency element.

Designs that use two separate elements are versatile and can operate at almost any spread in the two frequencies. Since each element is tailored to its specific frequency, there are no problems with impedance and pattern deviations. On the other hand, a dual frequency array of such elements is physically complicated by the abundance of elements. The designer must consider packaging for minimum space and this entails the inevitable interelement coupling problems. Operating a single element at two frequencies is therefore appealing from an array point of view. Microstrip elements have a narrow impedance bandwidth but the pattern is not as sensitive a function of frequency. In order to keep mismatch problems under control, the frequency spread is more restricted than in the two separate element design. The discussion in this report centers on the design of single disc elements for dual frequency operation.

Almost any microstrip antenna element can be operated at multiple frequencies. Like any resonant cavity, microstrip element modes offer the option of changing

---

3. Long, S., and Walton, M. (1978) A dual frequency stacked circular disc antenna, Proc. URSI-IEEE Conference, 1978, University of Maryland, pp 260-263.
4. Derneryd, A. (1978) Multiple frequency microstrip disc antenna, Microwave Journal, 21:77-80, also: (1978) Design of Microstrip Patch Antenna Elements, RADC-TR-78-46, AD A053728.
5. Sanford, G., and Munson, R. (1975) Conformal VHF antenna for the Apollo-Soyuz test project, IEE Conference on Antennas for Aircraft and Spacecraft pp 130-135.
6. Yu, I-Ping, (1976) Low Cost Dual-Frequency Microwave Antenna, NASA Tech. Brief MSC-1600, 1976, Technology Utilization Office, P.O. Box 8757, Baltimore/Washington International Airport, MD, 21240.
7. Howell, J. (1975) Microstrip antennas, IEEE Trans. Antennas and Propagation, AP-23:90-93.

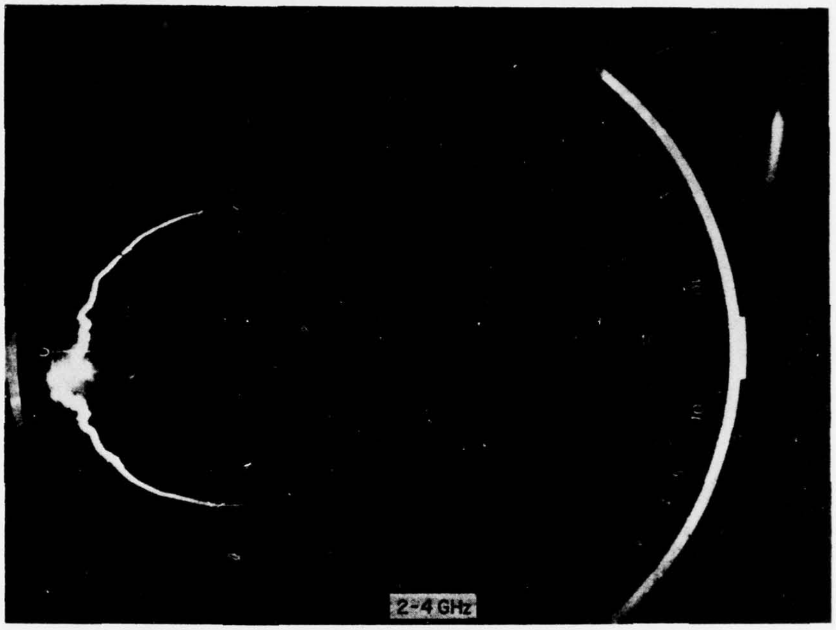
frequency, driving point impedance, and radiation pattern structure.[1,8,9] It is not usually possible, however, to excite different disc modes efficiently from a single feed position[10] and the differences between dominant and first order resonance radiation patterns, for example, are so pronounced[8] as to make their use suited only to special applications. A better approach is to seek techniques that perturb the dominant mode sufficiently to obtain two similar radiation patterns while providing an acceptable impedance match at the two frequencies. Derneryd[4] adopted this approach and left the element unchanged while incorporating the frequency dependence in the feed network. In this report, the emphasis is on modifying the element itself to produce the two frequencies.

Kerr[11] has recently reported on a dual frequency rectangular element. He found that adding a narrow strip to the element edge changes the resonant frequency and further, produces a second resonant frequency when the strip end is shorted to ground. The strip length controls the frequency spread. Thus, a single rectangular element designed for L-band, can be made to operate at either one of two other frequencies separated by about 0.5 to 0.75 GHz. By making the strip longer, Kerr detected two resonances under the short condition and two more under the open circuited condition. He was able to select two of these frequencies with good VSWR and similar patterns obtaining simultaneous operation with about 1.2 to 2.2 GHz spread in the two frequencies. This approach is quite similar to that investigated by the authors for the disc element and reported on below.

3. MODIFIED DISC ELEMENT

A plain disc element is characterized by a simple circular trace on the network analyzer (Figure 1). The axis crossing (resonance) for an element with 1.84 cm radius on 1/16 in. thick board of teflon-fiberglass, $\epsilon_R = 2.55$, is 2.88 GHz which compares with 2.85 GHz obtained by calculation[12] for the dominant mode. First and second order resonances were observed at 4.84 and 6.80 GHz.

8. Derneryd, A. (1977) Analysis of the Microstrip Disc Antenna Element, RADC-TR-77-383, ADA051187. To be published in IEEE Trans. Antennas and Propagation, 1979.
9. Derneryd, A. (1977) A Theoretical Investigation of the Rectangular Microstrip Antenna Element, RADC-TR-77-206, ADA045775, also: IEEE Trans. AP, AP-26:532-535, July 1978.
10. Kernweis, N., and McIlvenna, J. (1977) Liquid crystal diagnostic techniques: an antenna design aid, Microwave Journal, 20:47-51.
11. Kerr, J. (1978) Terminated microstrip antenna, Symposium on Antenna Applications, University of Illinois.
12. Shen, L.C., et al (1977) Resonant frequency of a circular disc printed circuit antenna, IEEE Trans. Antennas and Propagation, AP-25:595-596.



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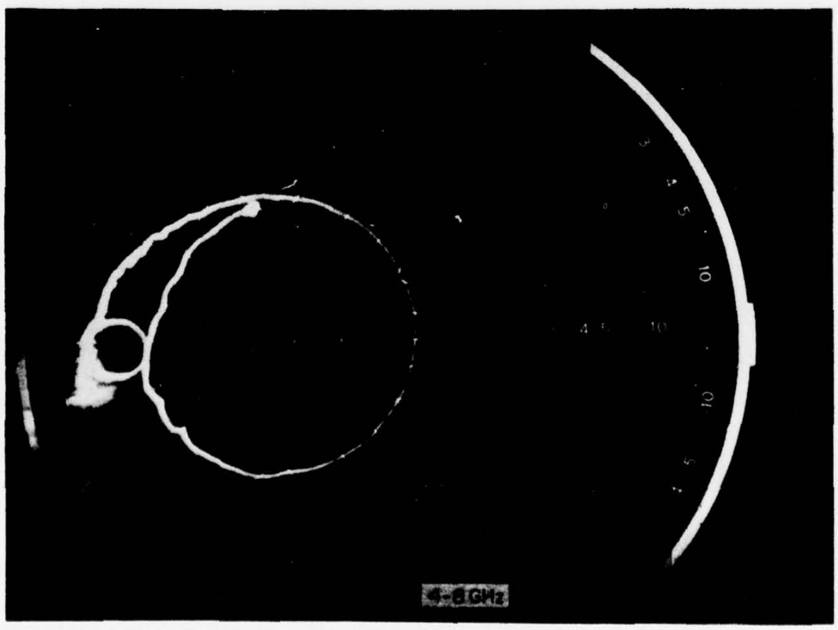


(b)

Figure 1. Network Analyzer Trace of a Plain Disc Element

A small circular tab, placed as shown in Figure 2, lowers the dominant mode resonant frequency by 6 percent and as indicated in Figure 3, produces a good VSWR at 5.90 and 6.76 GHz. The corresponding radiation patterns are not very similar however, displaying the dips and nulls typical of the higher order mode patterns of the plain disc (Figure 4).* Relocation of the tab to other positions around the disc circumference produced a slight pattern tilt but no significant change in the results noted above.

The tab can be lengthened and widened to form a strip. Like the small tab, short strips, that is, those about $\lambda_\epsilon/8$ long, where λ_ϵ is the wavelength in dielectric of the dominant mode of the plain disc, produce multiple loops on the network analyzer trace. The axis crossings are however, at frequencies well above the plain disc dominant mode. Figure 5a shows a typical trace produced by a strip $\lambda_\epsilon/8$ long and $\lambda_\epsilon/4$ wide. Figure 5b shows the corresponding patterns. Except for the 70°-90° sector, the three patterns are quite dissimilar. (In an earlier paper[2] the authors presented complete data for a disc with strips whose width varied from $\lambda_\epsilon/16$ to $\lambda_\epsilon/2$ while lengths ranged from $\lambda_\epsilon/8$ to $\lambda_\epsilon/2$). Although all of the strips caused significant changes in the element behavior, and some of the strips caused multiple resonance behavior with some frequency pairs perfectly matched at VSWR = 1.0, none of the strips produced good dual frequency patterns. (The small tabs and strips can be useful in shifting the dominant mode frequency up or down by amounts that range from +43 percent to -12 percent, respectively, with little change in that radiation pattern. They represent, therefore, an easy means to trim or tune the disc to a desired frequency.)

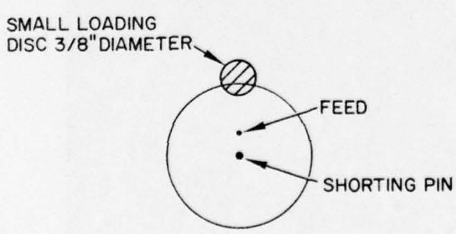
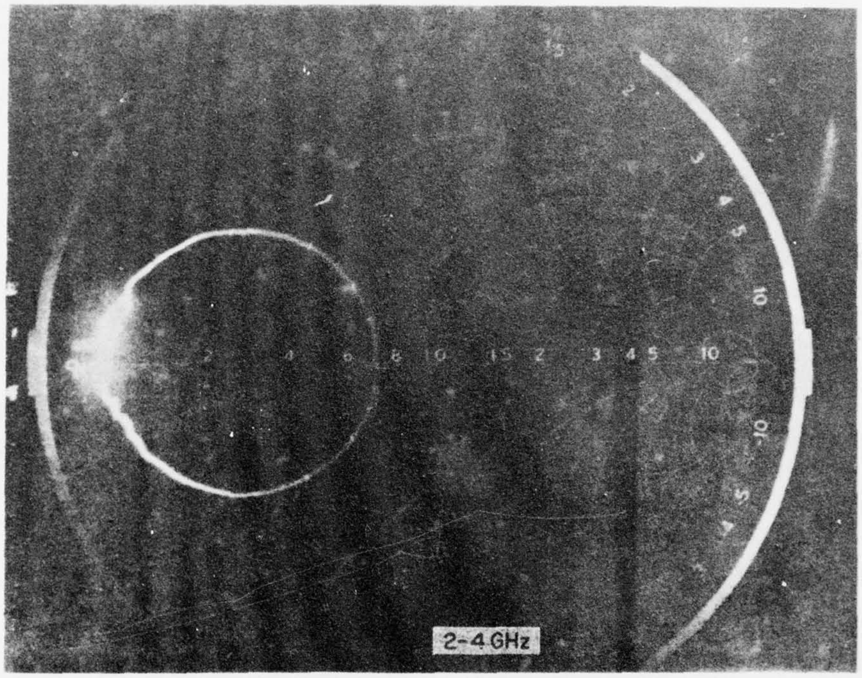


Figure 2. Tab Modified Disc

*All radiation patterns mentioned in this report are E_θ patterns with the element mounted on a large (6λ) circular ground plane. E_ϕ patterns have a deep endfire null and were not significantly affected by any of the strip modifications.



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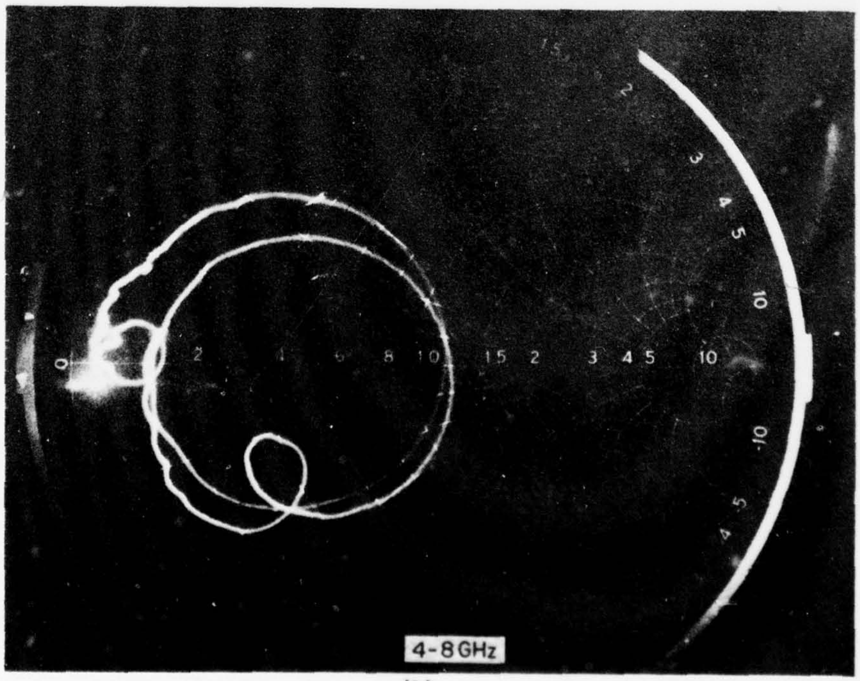

(b)

Figure 3. Network Analyzer Trace of Tab - Disc

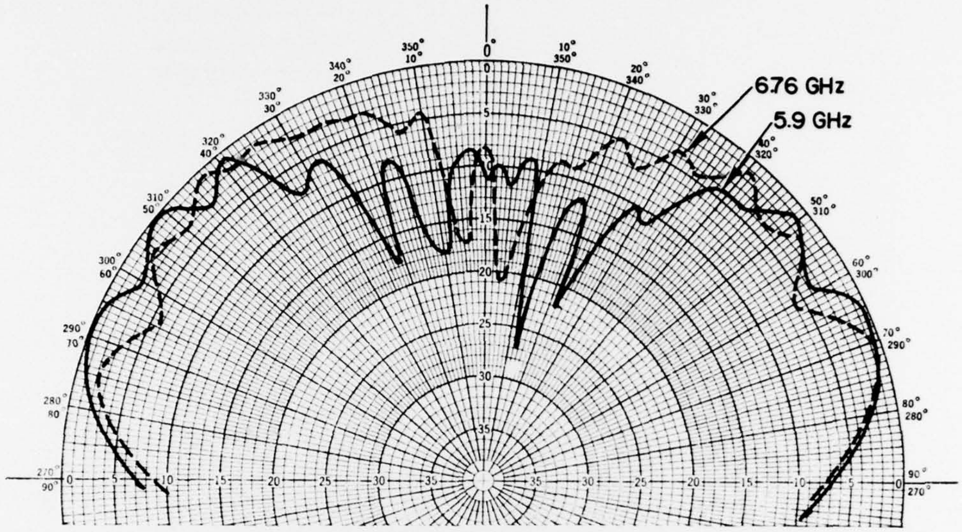

Figure 4. Radiation Patterns of Tab - Disc at 5.9 and 6.76 GHz

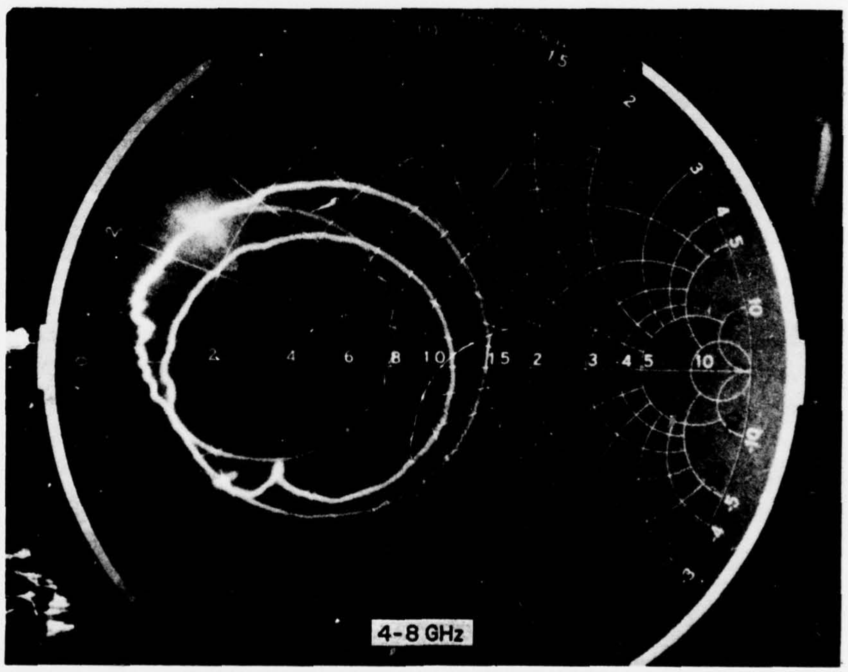

Figure 5a. Network Analyzer Trace of Short Strip - Disc

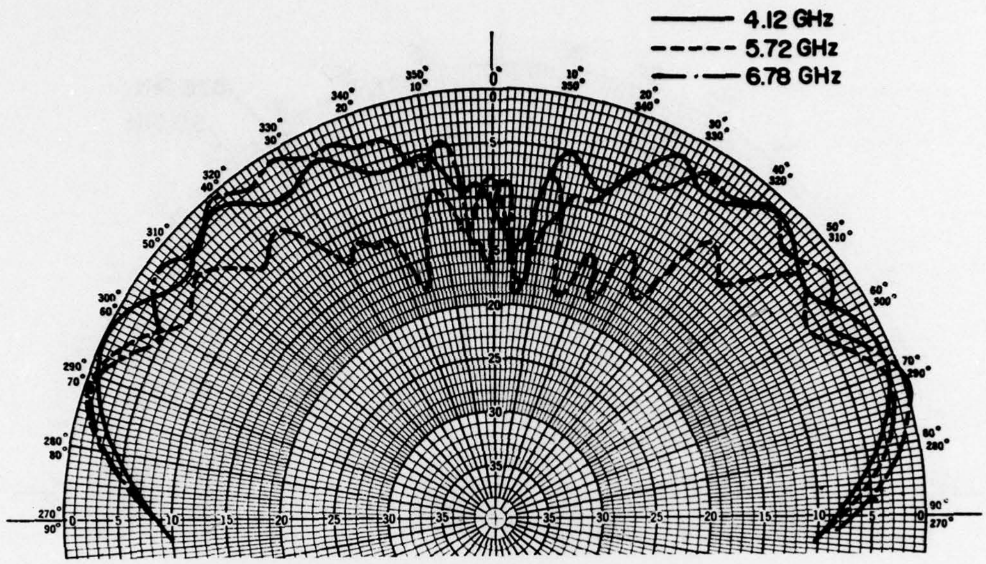

Figure 5b. Radiation Patterns of Short Strip - Disc

At the other extreme, long strips, that is, longer than $\lambda_\epsilon/2$, caused multiple axis crossings at frequencies closer to the dominant mode. Figure 6 shows the network analyzer trace for a strip 0.6 λ_ϵ long and 0.15 λ_ϵ wide, over the 2 to 4 GHz range. The corresponding patterns (at frequencies 4 percent below and 29 percent above the plain disc dominant mode frequency) are shown in Figure 7. The long strips, like the short strips, also cause multiple resonances at higher frequencies, but patterns at each of these resonant frequencies are quite dissimilar. Increasing the strip length in steps to 0.9 λ_ϵ changes the resonant frequencies but not the nature of the patterns. Strip width changes can be used to improve the VSWR match at the two frequencies. Decreasing the width from 0.15 λ_ϵ to 0.04 λ_ϵ for example, produces a VSWR of 1.0 at both frequencies, causes a slight perturbation, that is, 1-2 percent, in frequency values and leaves the pattern behavior unchanged.

In summary, single strips on a disc element can induce multi-frequency behavior. The short strips (or tabs) produce good VSWR at frequencies well above the original dominant mode with patterns that are however not very similar. Longer strips induce dual frequency behavior closer to the dominant mode frequency but the patterns differ by as much as 15 dB in some angular sectors. None of the single strips investigated produced good match and good patterns simultaneously.

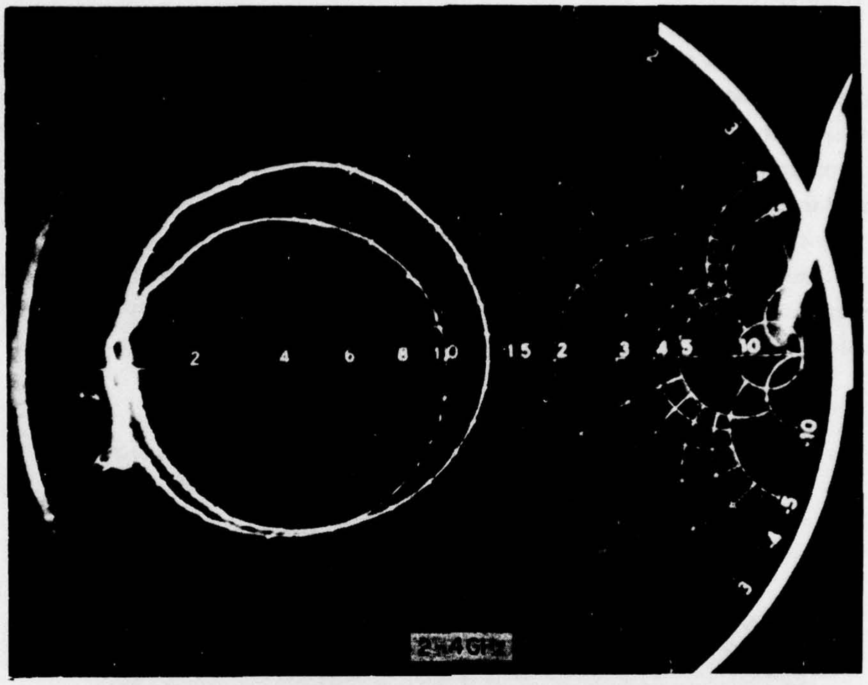

Figure 6. Network Analyzer Trace of a Long Strip - Disc

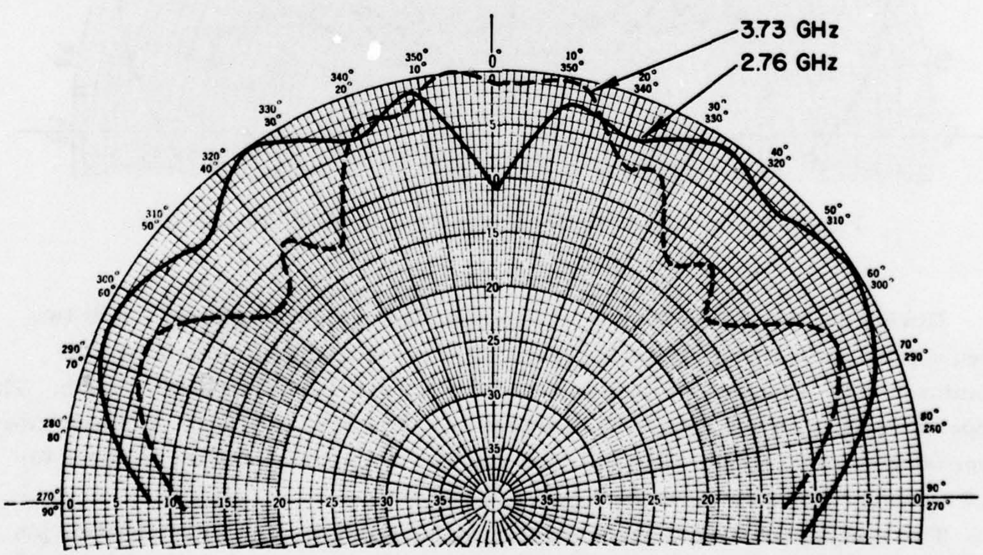

Figure 7. Radiation Patterns of a Long Strip - Disc

4. TWO STRIP DISCS

Placing a second strip on the opposite side of the disc, provided two resonant frequencies separated by about 1.2 GHz. The strips were 0.15 λ_ϵ wide and the lengths were varied between 0.6 λ_ϵ and 0.2 λ_ϵ; as the strip length changed, the two resonant frequencies varied. The lowest frequency obtained was 28 percent below the dominant mode of the plain disc, while the highest obtained was 37 percent above. The two patterns were not similar; the low frequency pattern being characterized by a broadside null and the high frequency pattern displaying a variety of shapes that changed with strip length. Figure 8 shows a typical result for two strips 0.6 λ_ϵ long.

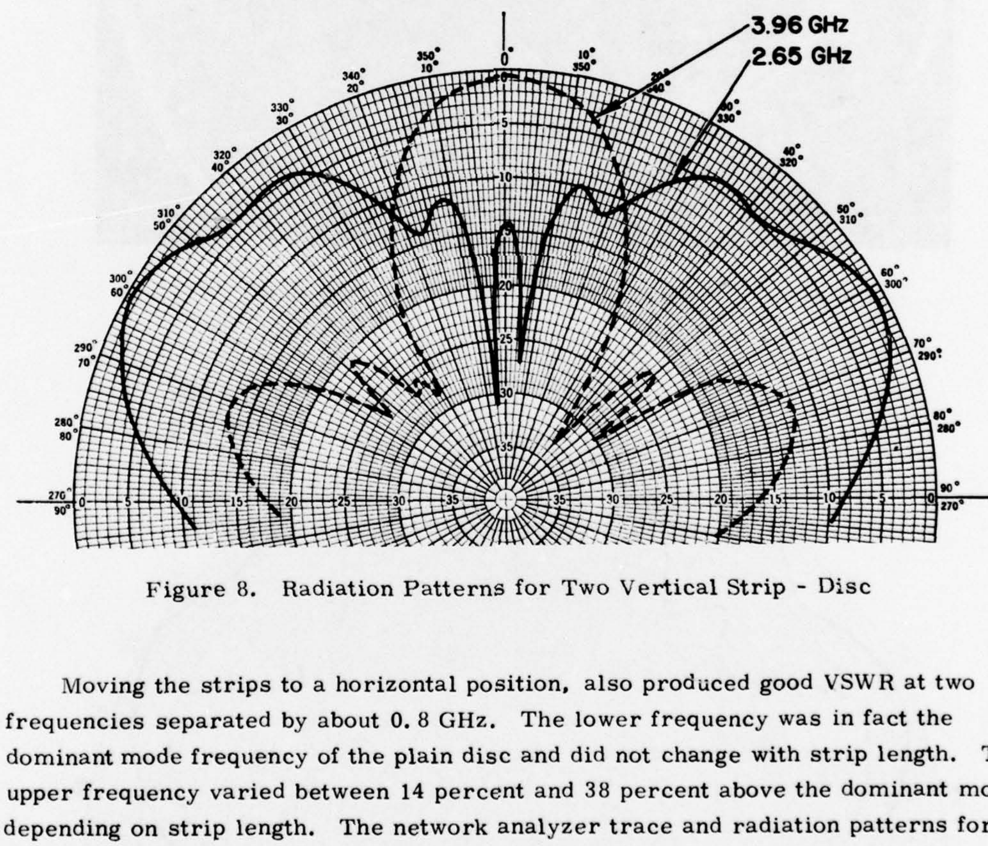

Figure 8. Radiation Patterns for Two Vertical Strip - Disc

Moving the strips to a horizontal position, also produced good VSWR at two frequencies separated by about 0.8 GHz. The lower frequency was in fact the dominant mode frequency of the plain disc and did not change with strip length. The upper frequency varied between 14 percent and 38 percent above the dominant mode depending on strip length. The network analyzer trace and radiation patterns for 0.6 λ_ϵ long strips are shown in Figures 9a and 9b.

Two strips placed ± 30° from the vertical line joining center and shorting pin provided dual frequency behavior with poor VSWR match and dissimilar patterns.

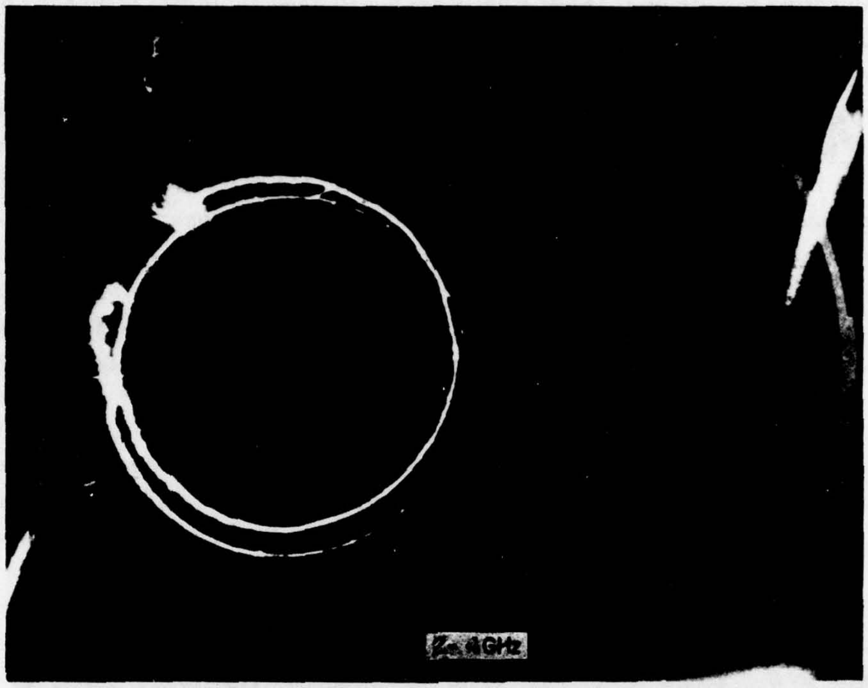

Figure 9a. Network Analyzer Trace for a Two Horizontal Strip - Disc

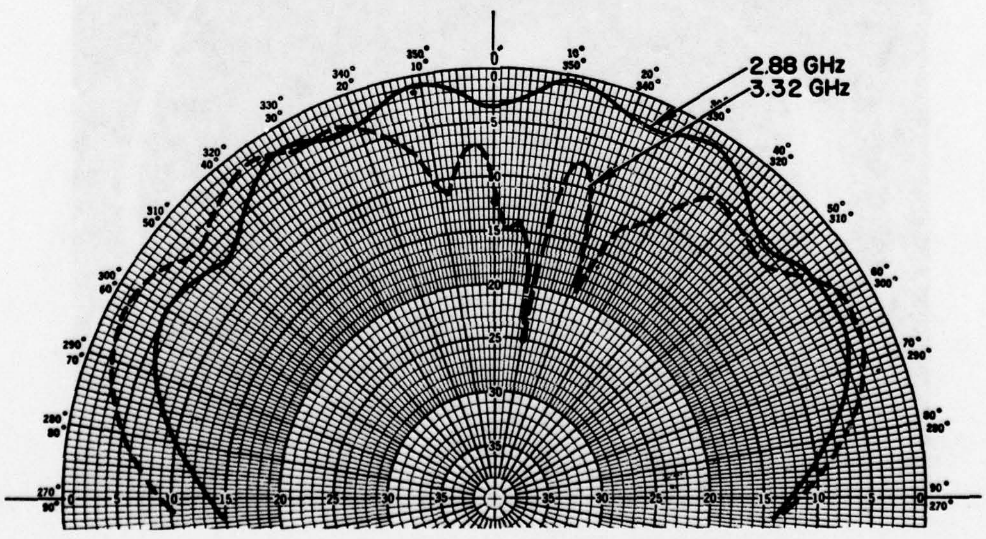

Figure 9b. Radiation Patterns for a Two Horizontal Strip - Disc

Relocating the strips to ± 60° finally produced acceptable two frequency behavior. Figures 10a and 10b show results for strips 0.4 λ_ϵ long and 0.15 λ_ϵ wide and are typical of those obtained for various lengths. The two patterns differ at most by about 5 dB and both have the dominant mode shape. Table 1 summarizes the results obtained for two strips at ± 60°. The data shows that strips longer than about 0.5 λ_ϵ tend to produce one frequency close to the plain disc dominant mode and a second higher frequency. The shorter strips produce one frequency close to the dominant mode and a second lower frequency. Strip lengths shorter than those shown in Table 1 produced two frequencies, one about 65 percent lower than the plain disc dominant mode, the second anywhere from 20 to 35 percent above depending on strip length. The VSWR was poor, that is, 2.5 at the higher frequency and 5.0 at the lower frequency.

Moving the two strips to ± 75° of the center line also produced good dual frequency patterns. The spread in frequencies was somewhat less than that obtained with ± 60° strips but the difference between patterns was also smaller. Figure 11 shows typical pattern results and Table 2 summarizes the data for ± 75° strips.

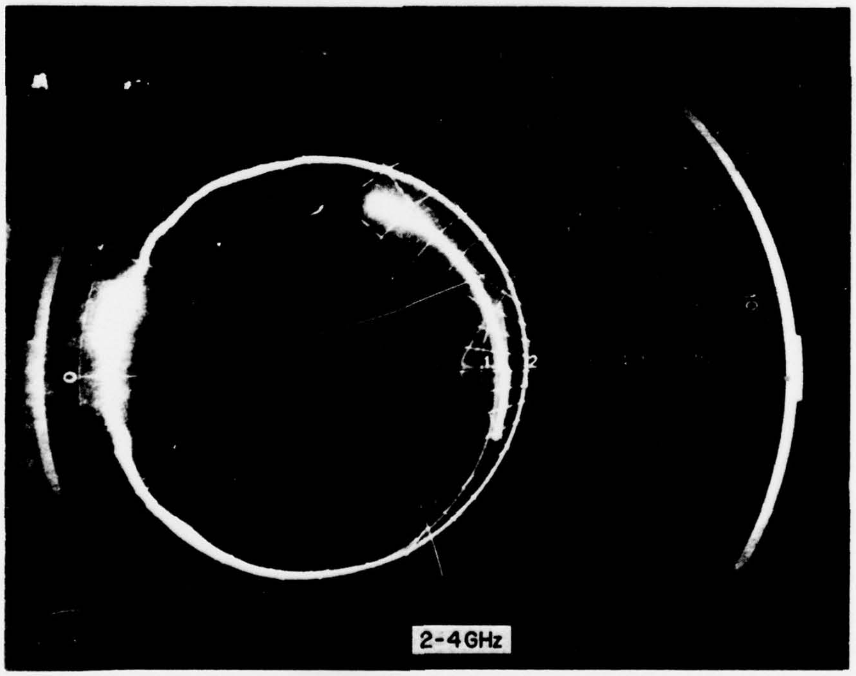

Figure 10a. Network Analyzer Trace for Two Strip Disc (± 60°)

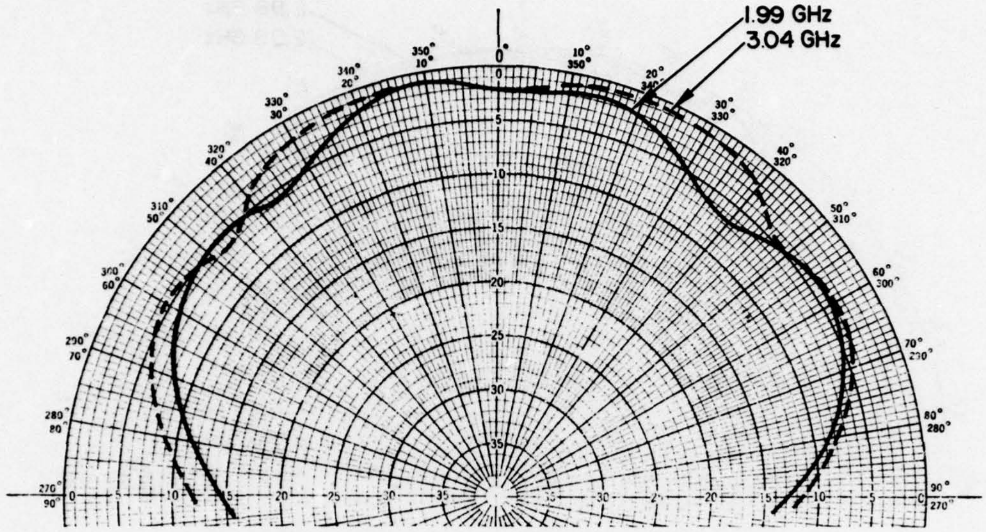

Figure 10b. Radiation Patterns for Two Strip Disc (± 60°)

Table 1. Two Strip Disc Data (Location: ± 60°, Width: 0.15)

Length (λ_ϵ)	Freqs. (GHz)	Freq. Change from Dominant Mode of Plain Disc (%)	VSWR	Max. Pattern Difference (dB)
0.66	2.83	- 1.7	2.5	4
	3.60	+ 25	2.2	
0.62	2.90	+ 0.7	2.0	5
	3.73	+ 29	2.2	
0.55	2.85	- 1	1.0	5
	3.84	+ 33	2.1	
0.46	1.86	- 35	2.8	5
	3.04	+ 6	1.0	
0.38	1.99	- 31	1.5	4
	3.04	+ 6	2.0	
0.31	2.06	- 28	1.5	4.5
	3.11	+ 8	1.6	

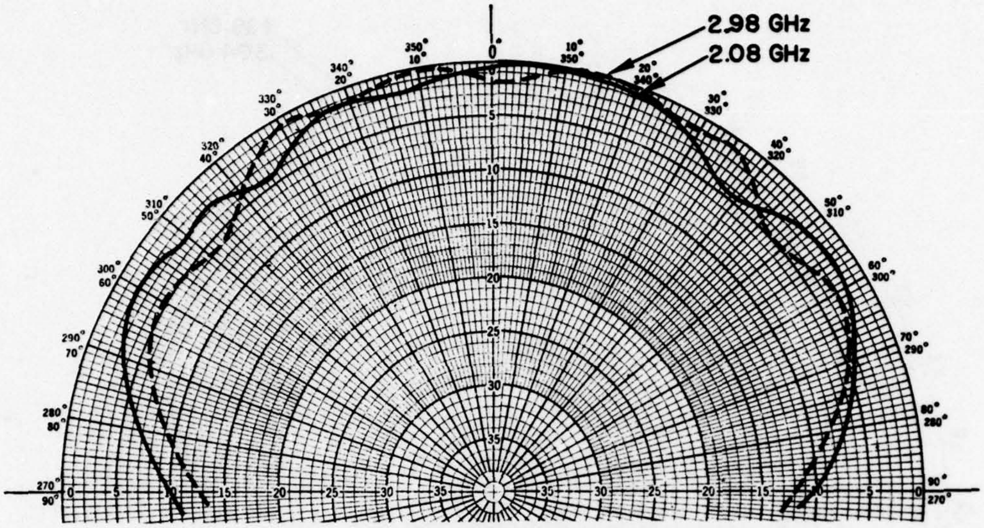

Figure 11. Radiation Patterns for Two Strip Disc (± 75°)

Table 2. Two Strip Disc Data; Location ± 75°, Width: 0. 15

Length (λ_ϵ)	Freqs. (GHz)	Freq. Change from Dominant Mode of Plain Disc (%)	VSWR	Max. Pattern Difference (dB)
0. 62	2. 87	- 0. 3	1. 1	2. 5
	3. 43	+ 19	2. 1	
0. 55	2. 92	+ 1. 3	1. 1	4
	3. 74	+ 30	1. 7	
0. 38	2. 08	- 28	2. 6	3. 5
	2. 98	+ 3. 5	1. 5	
0. 31	2. 26	- 21	1. 4	4
	3. 02	+ 5	1. 6	
0. 23	2. 75	- 4	2. 5	5
	3. 45	+ 20	2. 6	

It should be pointed out that each of the strips does not independently control one of the two frequencies. Both strips are required to produce the dual frequency behavior described above. If two unequal length strips are used, the element usually loses its dual frequency characteristics. The second loop in the network analyzer trace degenerates to a "kink" and there is only one resonance indicated. Some adjustment of the VSWR shown in Tables 1 and 2 is possible by judicious trimming of the strip length. Width adjustments are much less effective in this regard.

The logical extension to the two strip, dual frequency element is the N-strip, M-frequency element. Measurements on 4-, 6-, and 12-strip elements showed however that even dual frequency behavior was not always obtained, and when it was, the element was often very inefficient at one of the two frequencies. A variation of the multistrip element is the "rising sun" element shown in Figure 12, formed by removing sections of the basic disc. Figure 13 shows the network analyzer trace over the 2-4 GHz range. Only two of the multiple resonances indicated provided acceptable patterns. These occurred at 2.195 and 2.29 GHz (a narrow spread in frequency) and were basically dominant mode type patterns. The element was inefficient at the remaining frequencies.

In summary then, the ± 60° and ± 75° locations were the only ones to provide both acceptable VSWR and patterns for a two strip disc. There seemed to be no advantage in using more strips.

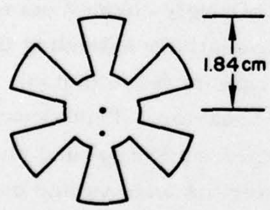

Figure 12. The Multi-Strip Disc

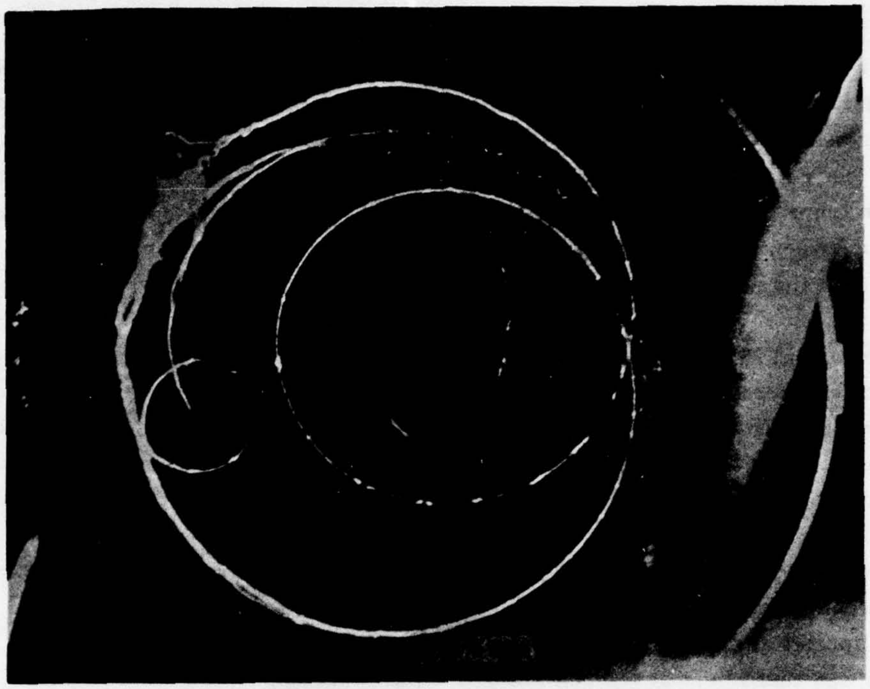

Figure 13. Network Analyzer Trace of the Multi - Strip Disc

5. THE DUAL FREQUENCY DISC IN AN ARRAY ENVIRONMENT

Liquid crystal detectors[10] showed that the two strips strongly coupled energy from the disc. In an array environment, with the strips essentially extending the element fringing fields, one could question whether the strips increase mutual coupling effects to the point of altering the dual frequency behavior. This situation was studied with a three-element strip disc array on a large, square ground plane. The outer two elements were moved so that center-to-center distance varied between 0.25 λ_{01} and 0.55 λ_{01} for the lower of the two frequencies; this is equivalent to 0.38 λ_{02} to 0.85 λ_{02} at the higher frequency. At the close spacings, the discs were almost touching. The elements, oriented as shown in Figure 14, were those of Figure 10, that is, strips 0.4 λ_ϵ long and 0.15 λ_ϵ wide, placed at ± 60°. Measurements on the center element of the three element array showed that the two resonant frequencies were unchanged as the array spacing varied. The center element radiation patterns are compared in Figures 15 and 16 for the isolated element, and the closest, and the furthest spacings at each frequency. Note that there are some pattern changes at the closest spacing, however, they are restricted to the angular sector well away from broadside. It is interesting to note that this type of change, that is, a decrease in the pattern fall-off close to endfire, is exactly what is desired when designing an element for use in hemispherically scanning arrays such as those proposed for aircraft-to-satellite communication systems.[1] Thus, the strips provide not only dual frequency operation but an improved element pattern when closely arrayed. In summary, mutual coupling effects on the strip disc element pose no serious problems to dual frequency operation.

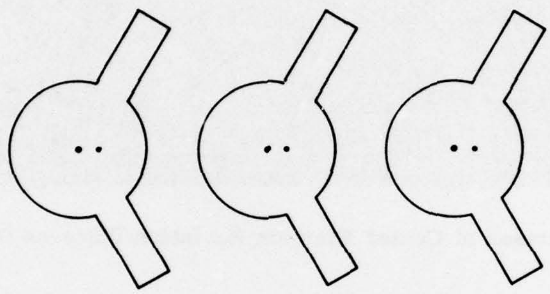

Figure 14. Three Strip - Disc Array

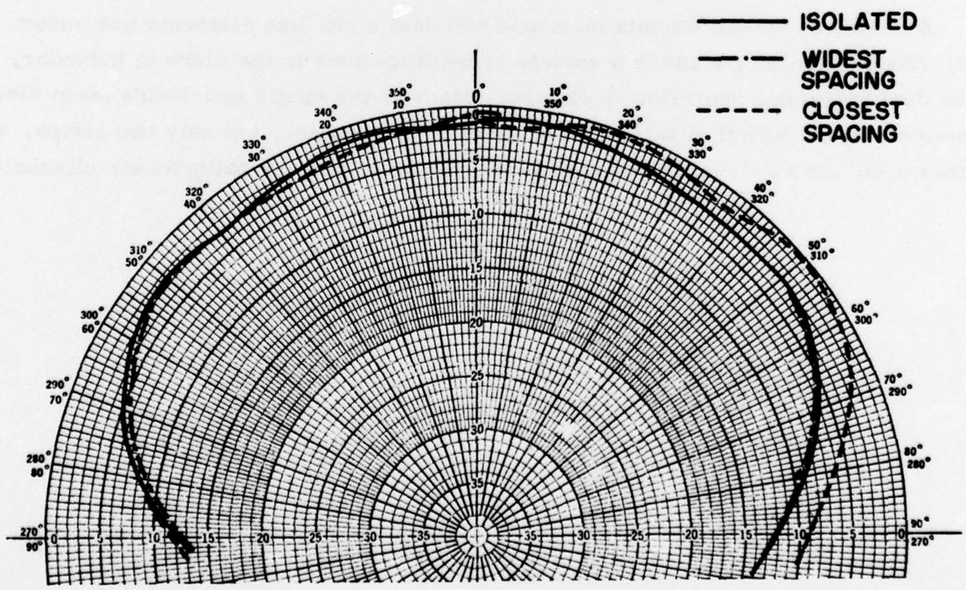

Figure 15. Comparison of Center Element Radiation Patterns for Low Frequency

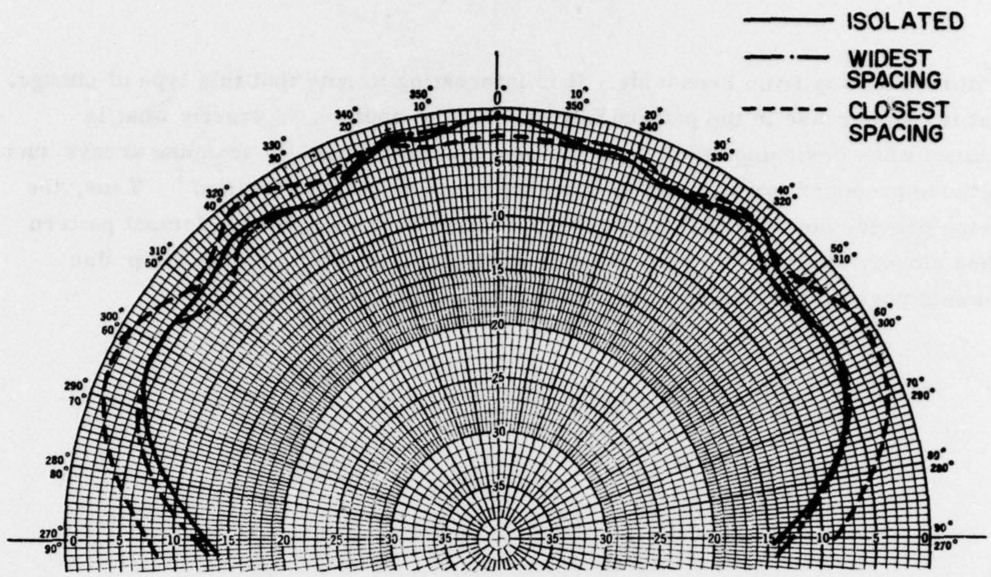

Figure 16. Comparison of Center Element Radiation Patterns for High Frequency

6. CONCLUSION

A series of measurements on single and dual strip disc elements has shown that although the strips cause a variety of modifications to the element behavior, true dual frequency operation is elusive. Many of the single and double strip discs provided a good VSWR at two or more distinct frequencies, but only two strips, at either ± 60° or ± 75°, provided both good match and similar patterns simultaneously.

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