A Self-Matching Wideband Feed Network for Microstrip Arrays

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***Abstract*—A novel technique for feeding microstrip antenna arrays is proposed. It consists of a microstrip feed network designed to operate in dual standing and traveling-wave modes and provide uniform excitation to its elements with either mode. It, therefore, produces a uniform aperture distribution, regardless of the array element input impedances. The traveling wave propagates when radiating elements are matched, but resonant standing wave prevails if loads become mismatched. Since the feed network resonance does not alter the array excitation, it can be used in combination with the radiating patch resonance to broaden the impedance bandwidth. The physical reasons for such behaviors are explained and experimental verification are provided. The generalization of the concept to large arrays is also discussed.**

***Index Terms*—Microstrip arrays.**

I. Introduction

MICROSTRIP antenna arrays are promising candidates for microwave and millimeter wave applications, especially in mobile communications where low profile and light weight are important considerations. Recent developments in solid-state devices and integrated circuits have also made it possible to combine active devices with printed radiators to form active arrays. In either case, the power must be distributed to the array elements by means of a feed network. In this respect, microstrip arrays can be categorized as series-fed or corporate-fed arrays. The series-fed arrays, formed by interconnecting the radiating elements using high-impedance microstrip line sections, have the advantage of simple and compact feed networks, but are subject to beam squint with frequency. In the corporate feed configuration, the elements are fed by a power divider with identical path lengths from the feed point to each element which insures phase coherence and a broadside array beam. Its design is based upon the duplication of a four-element building block [an H-type feed as shown in Fig. 1(a)], to form 8, 16, 32, $\cdots$ element arrays [1]. The implementation of an active device at any low subarray level, makes this subarray a better candidate for active arrays. However, it experiences efficiency limitations [2], [3] especially in large arrays, where the feed network is long and complicated.

The new feed concept presented in this paper combines the above two properties of electromagnetic coupling and bandwidth enhancement by an additional resonator. The H-shaped feed network used in corporate arrays to feed a quad-element block is modified to support a resonant standing wave [Fig. 1(b)]. It consists of two rows and a central column. Each row feeds two patches at two opposite sides of the central arm with half wavelength arms, and the central arm is also half wavelength in length. Thus, the electrical distance between any two patches in different rows is three half wavelengths, and its phase reversal corrects the phase of the feed that couples to the respective patches. The selected location of the feed in the new H resonator also allows operation in the conventional traveling wave mode and can deliver equal signals to its four radiating patches provided a satisfactory impedance match is achieved.

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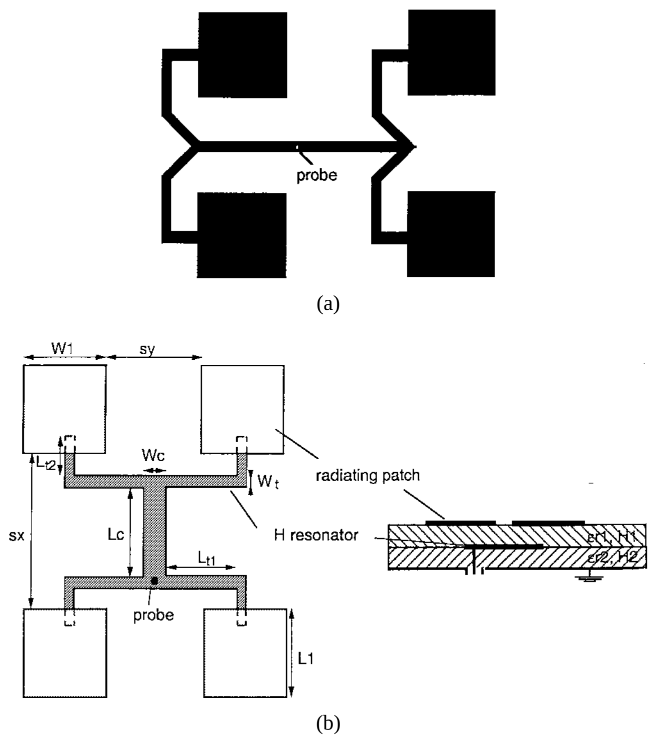


Fig. 1. A four-element subarray with (a) a corporate feed and (b) an H feed.

In Section I, the properties of the H resonator are investigated, and its capability to handle both standing and traveling wave-type modes is demonstrated. This is an attractive feature since microstrip radiators exhibit complex input impedance characteristics with frequency, and the new feed enables the array operation regardless of its load size or type. In Section II, experimental results for an H-resonator fed quad array is presented, and its superior performance is compared with

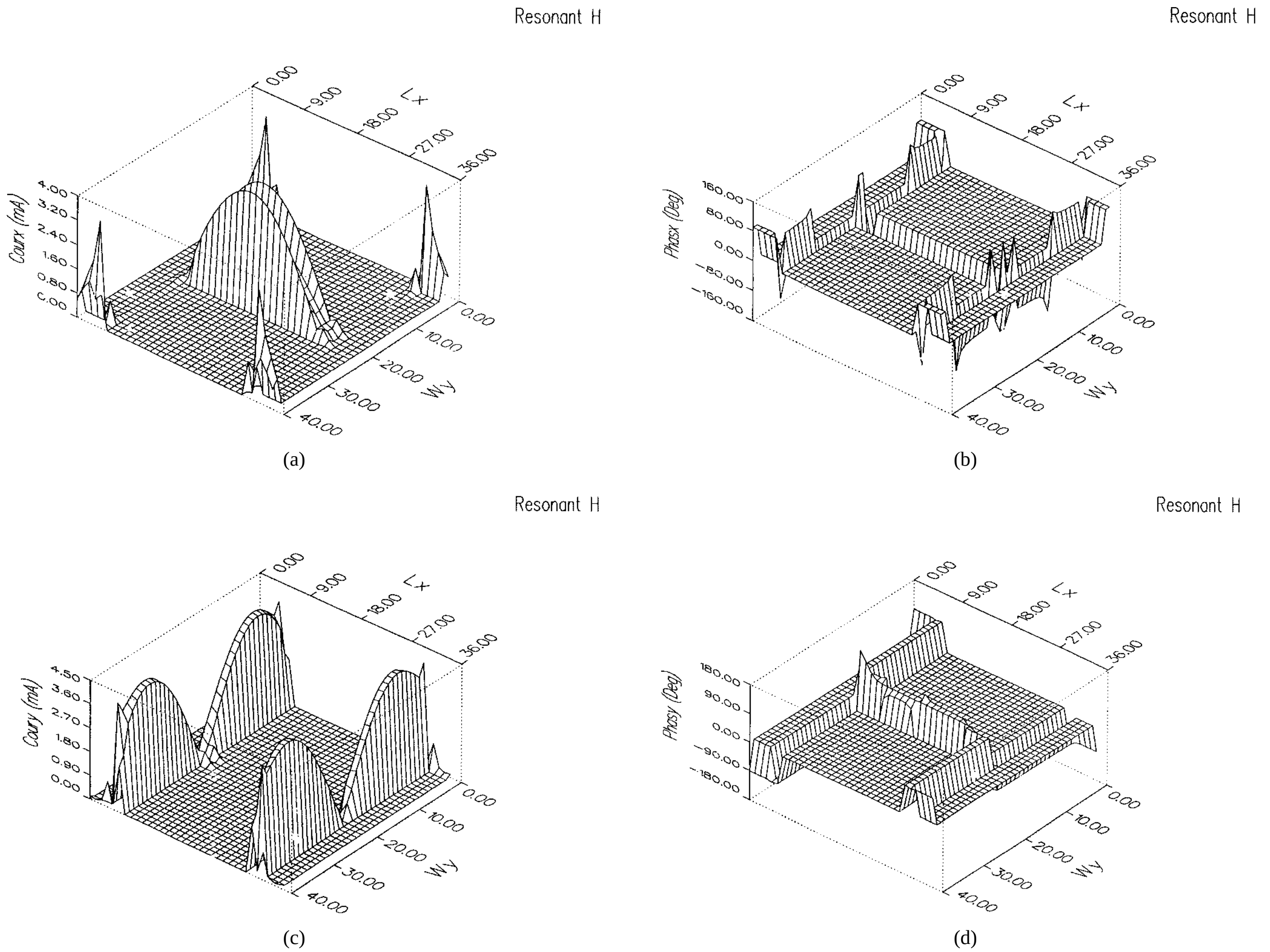


Fig. 2. Magnitude and phase of the current distribution on the H resonator. Operation in a standing wave mode, Lx and Wy are not true scale. (a) and (b) Horizontal current. (c) and (d) Vertical current $\varepsilon_{r2} = 2.55$, $H_2 = 1.58$ mm, $L_{t1} = 16$ mm, $L_{t2} = 4$ mm, $L_c = 21$ mm, $W_c = 3$ mm, and $W_t = 1.5$ mm.

conventional corporate fed arrays. In Section III, the concept of resonant feed networks is extended to large arrays.

II. The H Resonator

The H resonator shown in Fig. 1(b) consists of four horizontal line sections used to distribute the input power to four corners of a rectangular aperture and a central vertical section that connects the horizontal sections together. The four horizontal sections are bent near the end to generate vertical polarization and define the four outputs. When no load or infinite loads are connected to these points, i.e., an open circuit condition, a third-order resonance establishes between the two opposite ports in the E plane, i.e., between the upper and lower terminals. To verify this property a particular configuration is analyzed numerically, using an antenna software based on the integral equations. The H resonator was etched on a Duroid substrate ($\varepsilon_{r2} = 2.55$, $H_2 = 1.58$ mm). It was made up of four arms divided into two orthogonal sections $L_{t1} = 16$ mm, $L_{t2} = 4$ mm, and connected to a straight central section $L_c = 21$ mm. The width of the central line $W_c = 3$ mm is twice that of the horizontal lines, $W_t = 1.5$ mm. The H resonator is probe fed at the junction of two arms and the central line. At the resonant frequency and open circuit condition, the magnitude and phase of its current distribution are shown in Fig. 2(a)–(d). They indicate a sinusoidal current magnitude associated with a constant phase in all five line sections. That is, the H resonator supports a standing wave and, at its output terminals, the signal has equal magnitude and phase. Also, this condition was found not to be too sensitive to the feed-probe location. While the resonance is better excited by placing the probe at an electric-field maximum (namely the edges of each section) a satisfactory resonance was still observed when the probe was slightly moved away from the maxima.

An interesting feature of the H resonator is that it also delivers equal signals at each output, when it propagates a traveling wave. This happens when matched loads are connected, or seen at its four output ports. In the present study, this condition was simulated by electromagnetically coupled dipoles and, again, the H-resonator current distribution was computed numerically and shown in Fig. 3(a)–(d). In the central line, a nearly zero standing-wave ratio is observed, where the current magnitude is nearly constant. The same is true over the horizontal line sections. This confirms that on the feed network the wave is primarily due to an incident wave and the reflected wave is negligible. In particular, the phase

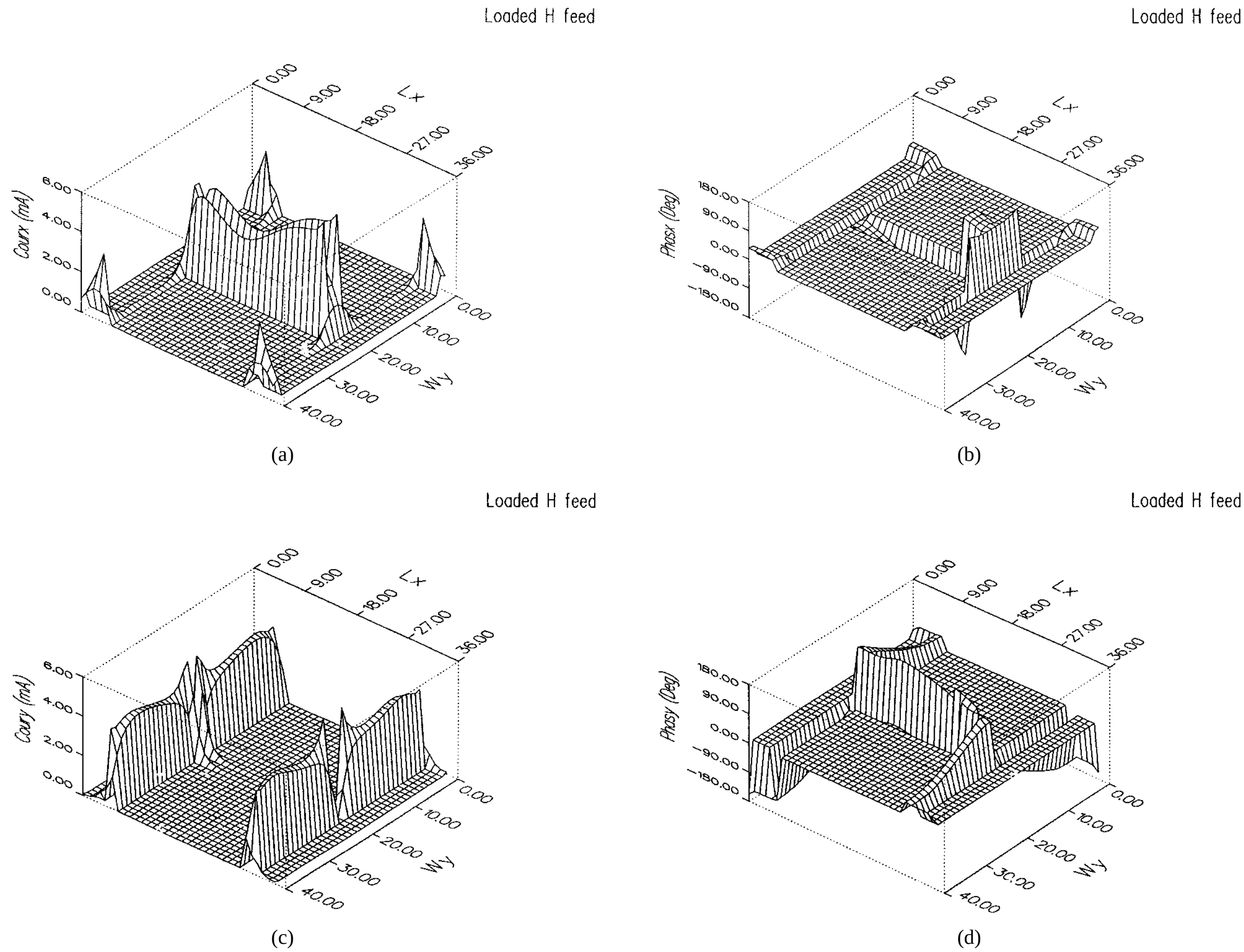


Fig. 3. Magnitude and phase of the current distribution on the H resonator connected to matched loads at its outputs. Operation in a traveling-wave mode. (a) and (b) Horizontal current. (c) and (d) Vertical current.

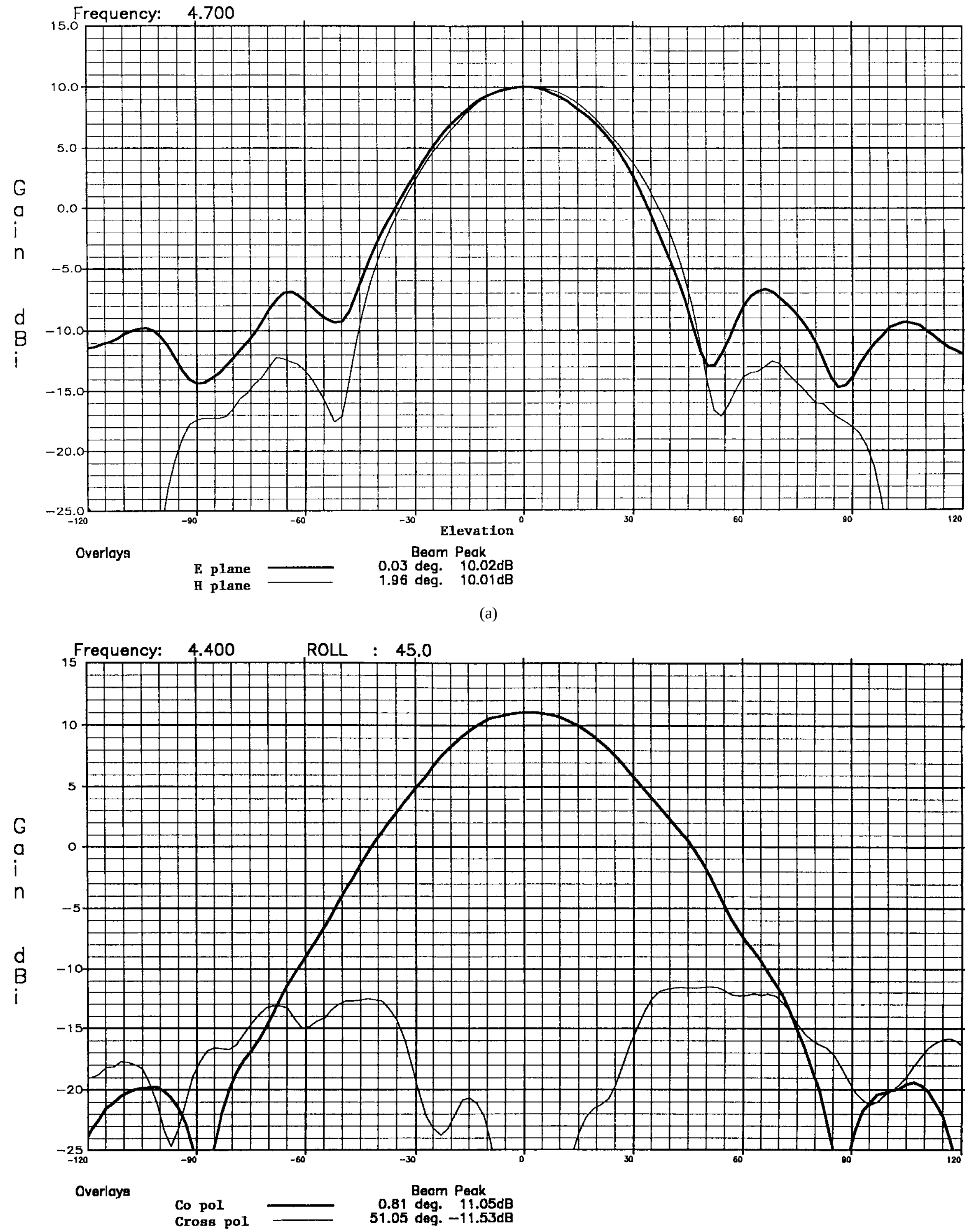
of the wave varies linearly in each line section in accordance with the propagation of a traveling wave. A quick look at the outputs show that once again, the signals are identical. However, with the feed location at one end of the central section, the upper terminals are located one half wavelength further from the probe. This generates a phase inversion clearly shown in Fig. 3(d) to compensate for the geometrical inversion of the currents. The location of the probe is, therefore, critical for this condition.

Since the H feed delivers equal signals at its outputs regardless of the standing wave or propagating wave, it should also do so for a linear combination of the two, i.e., for its partially matched ends. Consequently, it should provide uniform power division among its ports regardless of their loads as long as the loads are identical. This is particularly suitable for microstrip patches, the input impedance of which varies rapidly with frequency. For the electromagnetically fed configuration of Fig. 1(b), this was confirmed by a numerical analysis. The results are however omitted here for brevity.

There are two important implications of the above properties of the H resonator for array design. Similar to parasitically coupled patches, the additional resonance of the H resonator can be used to broaden its impedance bandwidth. This can be achieved by offsetting slightly the resonant frequency of the feed from that of the radiating patches, acting as its loads. Its other advantage is in the fact that the feed may be designed independent of the array elements. In this manner, it can be optimized to reduce its radiation or dissipative losses without altering the power distribution on array elements. In practice, however, with electromagnetic compatibility (EMC) rectangular array patches must be used to prevent the excitation of cross-polarized radiation which can be excited by coupling the standing wave on the arm sections.

III. Experimental Results on a Subarray of Four Patches Fed by an H Feed

Using the above feed concept and a software based on the integral equations and moment method, a sample antenna was numerically optimized. By adjusting the location of the patches with respect to the outputs of the H resonator, it was possible to theoretically obtain a wide-input impedance bandwidth. The antenna was then fabricated and experimentally tested. Its two dielectric layers were of identical substrates and had the same relative permittivity $\varepsilon_r = 2.55$ and thickness 1.58 mm. The upper four patches were rectangular in shape ($L_1 = 20$ mm, $W_1 = 12$ mm) and separated with horizontal and vertical



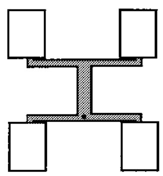
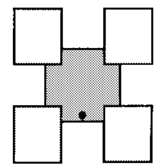
(b)

Fig. 4. (a) Radiation patterns at the upper edge of the frequency band, $f = 4.7$ GHz. E plane, H plane, H resonator same as Fig. 2. $\varepsilon_r = 2.55$, $H_1 = H_2 = 1.58$ mm, $L_1 = 20$ mm, $W_1 = 12$ mm, $s_x = 21$ mm, $x_y = 30$ mm. (b) Copolarized and cross-polarized patterns in the diagonal plane, band center $f = 4.4$ GHz.

spacings $s_x = 21$ mm and $s_y = 30$ mm, respectively. They were coupled to an H resonator, analyzed in the previous section with $L_{t1} = 16$ mm, $L_{t2} = 4$ mm, $L_c = 21$ mm, $W_c = 3$ mm, $W_t = 1.5$ mm. The H resonator was probe fed at the junction between two arms and the central line. The entrance of the probe was selected as the reference plane.

TABLE I
COMPARISON OF AN H-FED SUBARRAY WITH A QUAD EMC PATCH

Comparison

Subarray with H feed		Quad EMC Patch
		
61 * 54 mm2	*Antenna Aperture*	56 * 48 mm2
4.20 - 4.70 GHz	*Couping loop*	3.80 - 4.50 GHz
12. dB	*Maximal Gain*	11.5 dB
4.20 - 4.70 GHz	*Gain > 11 dB*	4.20 - 4.50 GHz
75 deg (E plane) 72 deg (H plane)	*10 dB Beamwidth*	71 deg (E plane) 91 deg (H plane)
-17 dB (E plane) -20 dB (H plane)	*Maximum sidelobes*	-17 dB (E plane) -20 dB (H plane)
-20 dB (4.20 GHz) -27 dB (Mid Band) -20 dB (4.70 GHz)	*Crosspol in diagonal plane*	-25 dB (3.80 GHz) -22 dB (Mid Band) -17 dB (4.50 GHz)
		Constructional simplicity
		Possible operation in dual band with orthogonal polarization

Within the band of 4.2–4.7 GHz, stable and directive patterns were measured. Two samples for frequencies at the band edge and band center are shown in Fig. 4(a) and (b). At the lower band edge, i.e., 4.2 GHz, the measured patterns were similar to those at 4.7 GHz and, therefore, omitted for brevity. The antenna directivity was computed to be around 12 dBi, and the loss of 1.0 dB at the band center in Fig. 4(b) is attributed to the losses due to the mismatch loss (0.2 dB), small ground plane size (0.5 dB), and calibration errors. Within the band, the sidelobes were maintained below −15 dB of the main beam in the E plane, and below −20 dB in the H plane. They are lower in Fig. 4(a) and are −17 and −22 dB, respectively. The beamwidths are nearly equal in both E and H planes, in spite of the fact that the aperture, defined by the extreme corners of four patches, is slightly rectangular (61 mm × 54 mm). This is due to the fact that the patch-surface currents in the E plane are sinusoidal, as opposed to a uniform distribution in the H plane.

The measured cross and copolar patterns in Fig. 4(b) are in the 45° plane. The beamwidth of the copolar pattern is the same as the E and H plane ones in Fig. 4(a), but its sidelobes are much lower at −32 dB, a property of uniformly excited diagonal apertures. The cross polarization is generated mainly by the standing wave on the horizontal sections of the H feed. In both E and H planes it was negligible due to the symmetry of the current and feed geometry, and is not shown. In the diagonal 45° plane it peaks at $\theta = \pm 60°$ and is around −22 dB, below the main beam peak at the band center, i.e., 4.4 GHz. At the band edges its peak increased slightly to −20 dB. Since at the band center the radiating patches were better matched to the feed lines, i.e., lower standing waves, the radiation of traveling wave from the feed lines is, therefore, lower.

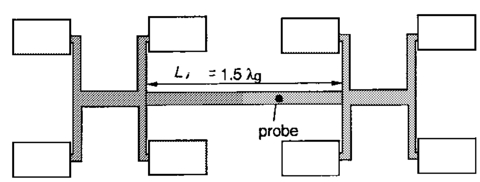


Fig. 5. An eight-element array fed with a resonant network.

The subarray of four patches fed by an H feed may be compared to one fed by a driven patch [8]. The results are reported in Table I. The aperture of the new subarray with an H feed is larger, and results in a slightly higher gain. Also, its beamwidths in the E and H planes are identical,

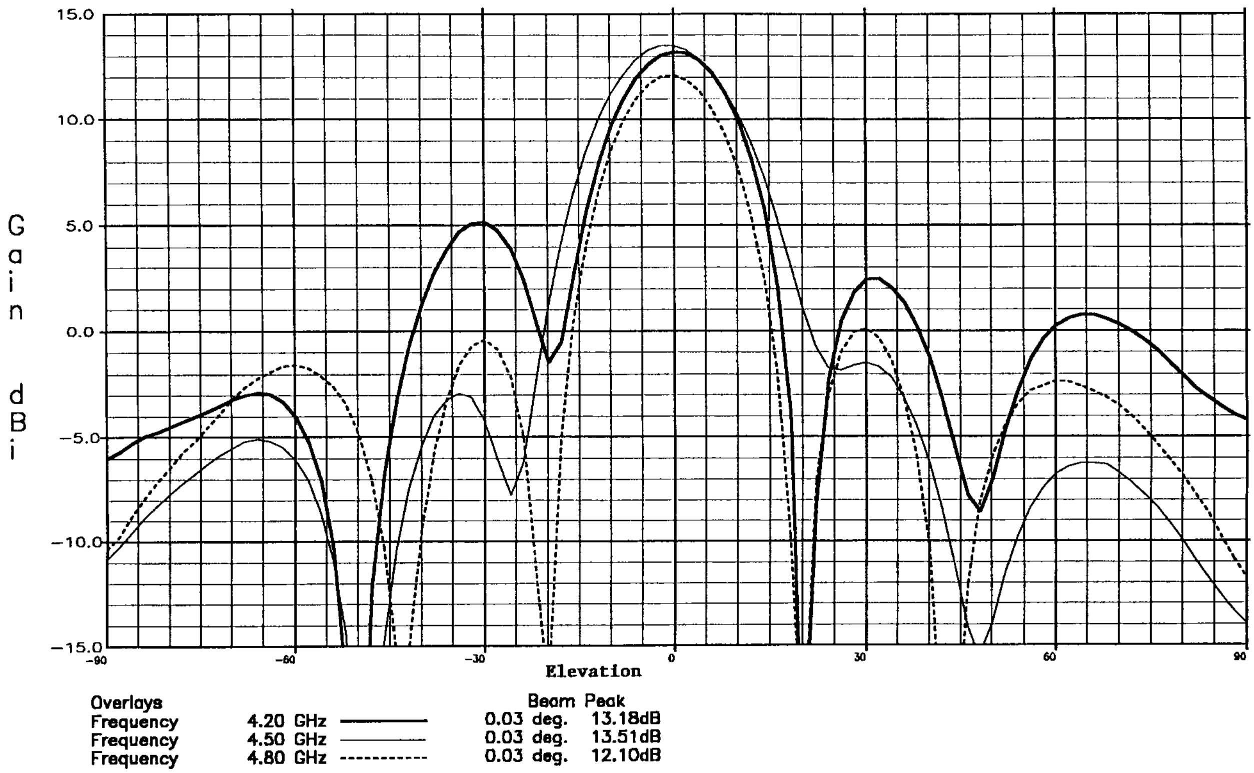


Fig. 6. Radiation patterns in the E plane of the eight-element array. $L_i = 66$ mm, $W_i = 2.5$ mm.

and the cross polarization is lower. However, the H feed is more elaborate and cannot handle dual-band operation with orthogonal polarizations which can easily be accomplished by the patch-fed array.

IV. Generalization of the Concept to Large Arrays

The above subarray of four patches with its H feed may be considered as the building block for large arrays. An aperture or electromagnetically coupled corporate feed etched on a separate layer can provide satisfactory power distribution to each H feed and, thus, subarrays. However, as indicated earlier, this can be lossy. Here, we examine a simpler coupling method and investigate its performance.

A first-stage generalization may be accomplished by interconnecting two subarrays of four elements using a section of microstrip line. Then, an array of eight patches is obtained, as shown in Fig. 5, where the length of the interconnecting line is about one and a half wavelength, i.e., $L_i = 66$ mm. The choice to etch the interconnecting line on the same layer as the H resonators was made to facilitate the calculation and fabrication of the antenna. Also, to have a uniform separation of all eight patches, the interelement separation of subarray elements presented in the previous section were slightly changed. The other parameters remained unchanged.

An experimental configuration was fabricated and tested. First it was designed with a small central line width of $W_i = 2.5$ mm to minimize its radiation. The line characteristic impedance was calculated to be 72 Ω, while the input impedance of the new subarrays, between 4.2 and 4.5 GHz were measured to be stable around $25 - j16\,\Omega$. Thus, there is an impedance mismatch at the intersection of the central line and H resonators and the central line supports a standing wave. This standing wave can be reduced, i.e., converted to a traveling wave, by increasing the width of the central line. Since for the selected central line length of one and a half wavelength and the feed-probe location, the power division between the two subarrays is equal, the percentage of the standing wave in the central line can be selected by other array parameters. For instance, by adjusting the central line width the input impedance of the array can be matched to the feed probe over a wider frequency band or its radiative losses can be minimized. In practice, one may achieve both by printing the central line on a separate substrate and electromagnetically coupling its power to each H resonator.

For the above direct coupled eight-patch array, the radiation patterns were also measured. Three samples in the E plane are shown in Fig. 6, for 4.2, 4.5, and 4.8 GHz. In the H plane, the patterns are identical to the subarray patterns. The first pattern at 4.2 GHz has high sidelobes around −8 dB, and the pattern shape and sidelobes improve at 4.5 GHz but begin to deteriorate again at 4.8 GHz. This is attributed to poor excitation phase between the two subarrays. At the band center, around 4.5 GHz, the phase distribution is uniform but deteriorates toward the band edges due to unequal sections of the central line. The gain variation is due to the input impedance mismatch at the probe. This was

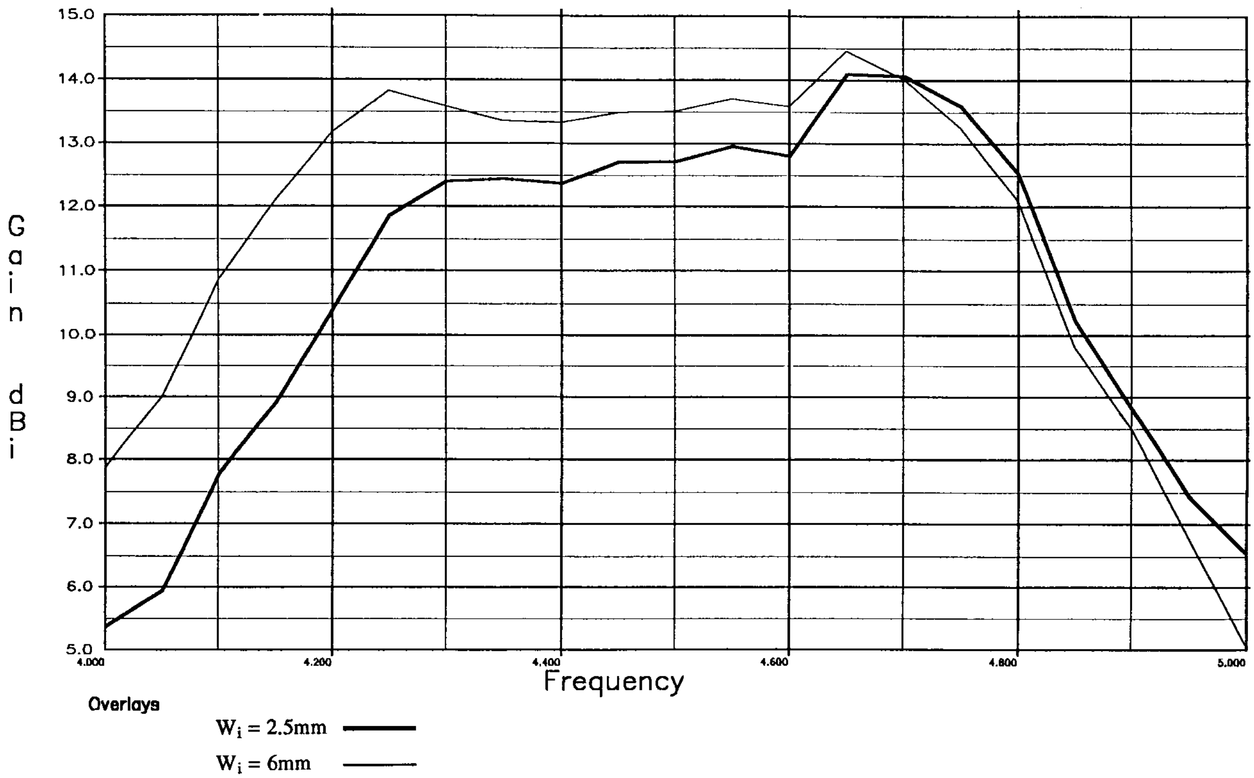


Fig. 7. Gain versus frequency of the eight-element array. $L_i = 66$ mm.

verified by increasing the width of the central line section, between the two subarrays, to 6 mm, and comparing the gain of the new array with the previous case. This is shown in Fig. 7. This simple modification did not affect the radiation pattern shapes, but increased the array gain by improving its input impedance match. However, after correction for the mismatch losses the gain of the new array, with the wider central line section, was smaller by about 0.4 dB from that of the previous case. This gain reduction was confirmed by calculating the radiative losses of the central line sections of two respective arrays. This demonstrates the advantage of using a resonating interconnecting line, since its width can be chosen to minimize the radiation losses, provided the array impedance is externally matched at its feed point. Of course, the losses can further be reduced by etching the interconnecting line closer to the ground plane, i.e., over a separate and thinner substrate, and coupling it electromagnetically to H resonators.

The poor sidelobe characteristics of the pattern at 4.2 GHz was corrected by increasing the length of interconnecting line to $L_i = 70$ mm. This was done experimentally on the sample by bending the line, so that it did not affect the layout of the H resonators and their patches. This final adjustment indicates that the concept of resonating feed line sections cannot be extended indefinitely. The line sections become longer and cause large phase errors, affecting the phase distribution on the array, with its detrimental effects on the patterns. Thus, for the range of bandwidth considered in this paper, an array of 16 patches which can be made by an arrangement of two arrays of the above eight patches may be the largest array that can be excited by this feed concept.

V. Conclusion

A new feed network concept, operating in resonant or propagating modes, was presented. An H-type feed was carefully analyzed, which near its resonance frequency distributed equal excitations to its four loads, regardless of their values. Practically this means that in array implementation impedance matching at array-element level is not necessary and that the array gain is not affected by the mismatch losses within the feed network. This is particularly suitable for microstrip arrays where radiating patches exhibit complex load impedances with frequency. The impedance matching should, however, be made at the input of the feed network. Using this concept, an array of four patches coupled by an H-type feed was fabricated and tested. It exhibited a large bandwidth and very stable radiation patterns.

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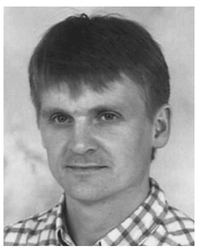
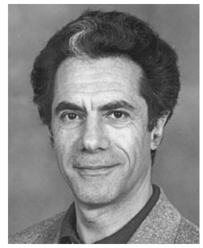


Herve Legay was born in Montauban, France, in 1965. He received the electrical engineering degree and the Ph.D. degree from the National Institute of Applied Sciences, Rennes, France, in 1988 and 1991, respectively.

From 1992 to 1993, he was a Visiting Researcher at the University of Manitoba, Winnipeg, Canada, where he worked on planar antennas. In 1994, he joined Alcatel Espace, Toulouse, France. He is currently involved in the development of active antennas for space telecommunication applications.



L. Shafai (S'67–M'69–SM'75–F'88) completed the B.S. degree at the University of Tehran, Iran, in 1963, and the M.S. and Ph.D. degrees from the Faculty of Applied Sciences and Engineering, University of Toronto, Canada, in 1966 and 1969, all in electrical engineering.

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Dr. Shafai has been a participant in nearly all antennas and propagation symposia and participates in the review committees. He is a member of URSI Commission B and was its chairman during 1985–1988. He has been the recipient of numerous awards. In 1978, his contribution to the design of a small ground station for the Hermus satellite was selected as the third Meritorious Industrial Design. In 1984, he received the Professional Engineers Merit Award, and in 1985, The Thinker Award from Canadian Patents and Development Corporation. From the University of Manitoba, he received the Research Awards" in 1983, 1987, and 1989, the Outreach Award in 1987, and the Sigma Xi, Senior Scientist Award in 1989. In 1990, he received the Maxwell Premium Award from IEE, London, and in 1993 and 1994, the Distinguished Achievement Awards from the Corporate Higher Education Forum.

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