Dual-Band Dual-Polarized Perforated Microstrip Antennas for SAR Applications

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***Abstract*—For dual-band dual-polarized synthetic aperture radar (SAR) applications a compact low-profile design is investigated. The operating frequencies are at the L and C-bands, centered about 1.275 and 5.3 GHz, respectively. Since the C-band frequency is larger by a factor of four, its array elements and interelement separations are smaller by the same ratio. Thus, to allow similar scan ranges for both bands, the L-band elements are selected as perforated patches to enable the placement of C-band elements within them. Stacked-patch configurations were used to meet the bandwidth requirements, especially in the L-band. The C-band element was designed numerically, but the perforated L-band one required final experimental optimization. Also, in the latter case of L-band, balanced transmission line feed was used to minimize cross polarization. For the C-band elements, slot coupling was used and, to simplify the feed, symmetric parasitic slots were incorporated to minimize cross polarization. No vertical connections were utilized, and electromagnetic couplings resulted in a compact low-profile design, with an electrically and thermally symmetric geometry.**

***Index Terms*—Dual-polarization, microstrip antennas, synthetic aperture radar.**

I. Introduction

DUAL-POLARIZED multiband synthetic aperture radar (SAR) antennas offer several advantages for spaceborne remote sensing satellite applications [1]. Dual-polarization enhances the information content by providing two copolar and two cross polar scattering data. In addition, the cross- polarization SAR imagery is important at high-incidence angles. The multiband operation, on the other hand, can provide a finer resolution scanning and better penetration and reflection data from various scatterers. Sharing the same antenna aperture by arrays of all operating bands will also reduce the size and weight of the spacecraft. However, moving to higher frequencies while improving the imaging resolution can put stringent surface tolerance requirements on the array flatness. This will be required to control the aperture phase errors and scan resolution while maintaining stable array gains.

Historically, SAR antennas have used slotted waveguide arrays [2]–[6]. The technology is well established and slotted arrays can be designed with excellent polarization and sidelobe controls. Dual polarization is also feasible and can be implemented using two separate waveguide arrays [7], [8]. Waveguides are, however, bulky and difficult to manufacture, especially with lightweight for space applications. Sharing the same aperture for two separate arrays, operating at two widely separate frequencies is also not feasible without limiting the array scan capability. Microstrip antennas appear to be more suitable for such applications, but the substrate technology and design or fabrication tolerances are not advanced to the level of waveguide arrays.

A dual linearly polarized microstrip SAR prototype antenna reported in [9] composed of an 8×8 element array. Two separate "series" and "parallel" feeds were used for generation of the horizontal and vertical polarizations. For larger arrays, a combination must be used to reduce the bandwidth limitations and the beam squint. Also, the exposed feed lines, especially bends and discontinuities, will radiate increasingly with frequency and contribute to cross polarization. They must be placed below the ground plane to reduce the cross polarization. In [10], this was used along with seven-element linear subarrays to reduce both cross polarization and sidelobe levels in a *C*-band SAR antenna. The elements were probe-fed individually. A "pairwise" anti-phase feed technique improved the array cross polarization significantly in the symmetric plane. In [11], different configurations of the feed and subarray arrangements were studied to reduce also the sidelobe levels, in addition to the cross polarization.

Microstrip patch antennas can be made dual polarized with low cross polarization. In array forms, they can be fed using probes or coupling apertures from feed lines below the ground plane. The former is simpler to design and more suitable for thick substrates, providing wider bandwidths. However, it is more difficult to implement in large arrays. The latter is more complex to design, but eliminates vertical connection, and soldering, resulting in easier implementations in large arrays. The lack of vertical connections also make the structure more symmetric, minimizing the mechanical or thermal stress. The performance of microstrip arrays, regardless of the feeding technique, is dependent on the substrate parameters, which, in general, are not uniform. Also, while the design tools are improving steadily, they still suffer from limitations in accuracy and computation speed when complex patch or array configurations are studied. Experimental verifications are necessary to verify the designs and used in the present investigations.

In this study, candidates for dual-band dual-polarized operation in the *L* and *C*-bands are investigated. The frequencies at the band centers are 1.275 and 5.3 GHz with 100-MHz bandwidths in each band. The scan range in both bands was required

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TABLE I
DESIGN PARAMETERS FOR DUAL-BAND DUAL-POLARIZED *L* AND *C*-BAND ANTENNA

Parameters	C-band	L-band
Frequency	5.3GHz	1.275GHz
Bandwidth	100MHz	100MHz
Polarization	dual-linear	dual-linear
Scan range		
1st-axis	+/- 25°	+/- 25°
2nd-axis	+/- 5°	+/- 5°
Cross-polarization	< -25dB with +/- 25° of broadside	< -25dB with +/- 25° of broadside

to be $\pm 25^\circ$ and the cross polarization in this scan range had to be less than -25 dB. These specifications are indicated in Table I. In the following sections, the design concepts are presented and discussed. The geometrical detail and array performances are provided for only one configuration. Others were discussed in previous publications.

II. DESIGN CONCEPTS

The specifications of the antenna to be designed are shown in Table I. It is dual-band dual-polarized with targeted bandwidths of around 100 MHz in both *L* and *C*-bands. The fractional bandwidth is, therefore, largest in the *L*-band at about 8%. This is not a large bandwidth for microstrip antennas, but must be met in the presence of the *C*-band array, as well as the other array specifications. The scan range of 25° requires an array element spacing of about 0.7λ, to avoid the grating lobes. In the *L* and *C*-bands, this requirement sets the element spacings to $d_L = 16.5$ cm and $d_c = 3.96$ cm, respectively. To make the array configuration manageable, these spacings were modified to $d_L = 16$ cm and $d_c = 4$ cm. This means that if the same aperture area is shared by both antennas, then each *L*-band element will be surrounded by 16 *C*-band elements. However, since the *L*-band element is about four times larger to maintain the spacing of 0.7λ, at the *C*-band, its elements must be placed within the *L*-band elements. That is, conventional square-patch antennas for dual polarization will not be acceptable for this design. After a preliminary investigation, three different designs of microstrip ring, mesh, and perforated patch were selected for further investigation. For the *C*-band array, square patches were selected. For this array two issues became a source of difficulty, the feed-line radiation and interaction with the *L*-band elements. The former could be eliminated by placing the feed lines below the ground plane and feeding the *C*-band elements using slot coupling. However, to minimize the cross polarization, while maintaining simple and coplanar feed networks for both polarizations, a new dual-slot feed configuration had to be designed. The latter problem, i.e., interaction of the *C*-band elements with the *L*-band elements, could not be eliminated for each *C*-band element, but was done so for their subarray. An array unit cell was defined as a single *L*-band element and 16 *C*-band elements. It was found that maintaining a symmetry for the *C*-band elements within this unit cell about the *L*-band element, minimizes their interaction and keeps the cross polarization to acceptable levels.

For the *L*-band arrays, the feed lines were placed on thin TMM3 substrates over the ground plane. This was sufficient to reduce their radiation to acceptable levels. A balanced feeding with 180° phase shifts was selected in all *L*-band cases to maintain symmetry and minimize cross polarization. For the *L*-band element three candidates were investigated and optimized: 1) a microstrip ring antenna; 2) a microstrip mesh antenna; and 3) two stacked perforated square-patch antennas.

The first two configurations used probe-fed single-layer antennas, where the bandwidth was obtained by the substrate thickness. They were, consequently, thicker antennas. Their configuration and performance were discussed previously in [12] and [13]. The third configuration used stacked geometry and electromagnetically coupled resonators. It therefore resulted in a low-profile design. Vertical connections were also eliminated, simplifying the fabrication process and reducing mechanical stress. Its configuration for a unit cell consisting of a single perforated *L*-band element, and 16 interlaced and surrounding *C*-band patches is shown in Fig. 1.

In the cross section of Fig. 1 three layers are shown. The lower two layers are TMM3 substrates and the third upper one is honeycomb. In the larger array implementation, this honeycomb was replaced by a Rohacell substrate. The upper TMM3 substrate supports the perforated lower *L*-band element, its feed network, and the lower slot-coupled *C*-band elements. While, the lower one supports the *C*-band feed. Their common ground plane sandwiched in between is slotted for dual-polarized feeding of the *C*-band elements. Small 2×4 arrays of unit cells, i.e., a perforated *L*-band element with 16 *C*-band elements, are shown in Fig. 2(a) and (b) and the ground plane slot configuration is shown in Fig. 2(c).

Fig. 2(b) also shows the balanced feeding network of the *L*-band element. For the horizontal polarization the interconnection of the balanced feed was placed on the lower substrate. The performance of this design in various stages of development was discussed earlier [14]–[17] and provided below in detail.

III. *L*-BAND ANTENNA ELEMENT

As indicated above in Fig. 1, for enhanced bandwidth and low profile, a stacked configuration is used. The lower *L*-band antenna is etched on its 15 m TMM3 feed substrate, is thus a transmission-line-fed square patch. The upper patch is on a honeycomb substrate of about 8-mm thickness and is electromagnetically coupled to the lower patch. Both these patches are perforated, symmetrically so that the induced currents are symmetric and cross polarization is kept to a minimum. Because the lower patch is on a high-dielectric constant substrate, it is smaller in size and care must be taken in its perforation. Excessive perforation reduces the bandwidth or increases the upper patch height. Also, to minimize the loss and radiation from the feed lines, an attempt was made to optimize the configuration for 50-Ω match at each patch edge. This would allow direct connection to the feed line without the necessity for tuning stubs or impedance transformers.

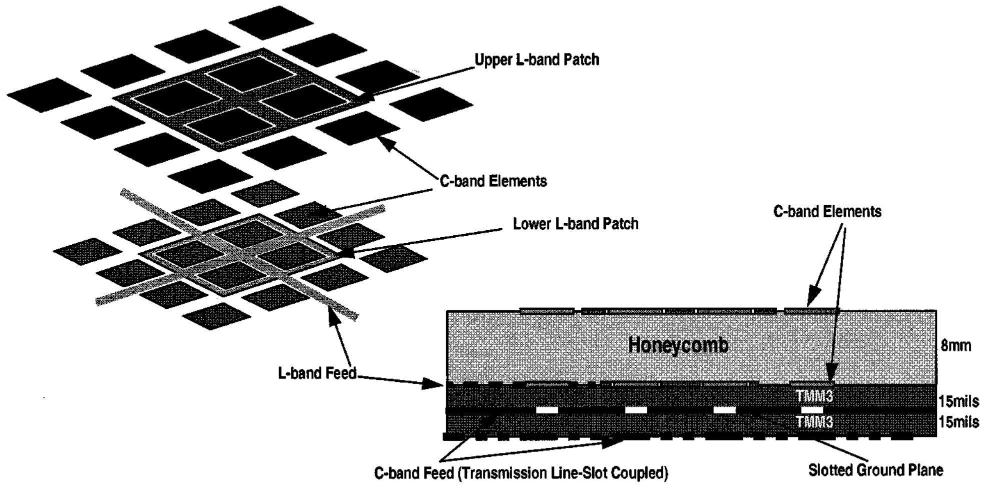


Fig. 1. Geometry of the stacked perforated *L*-band patches with 16 stacked *C*-band patches forming a unit cell.

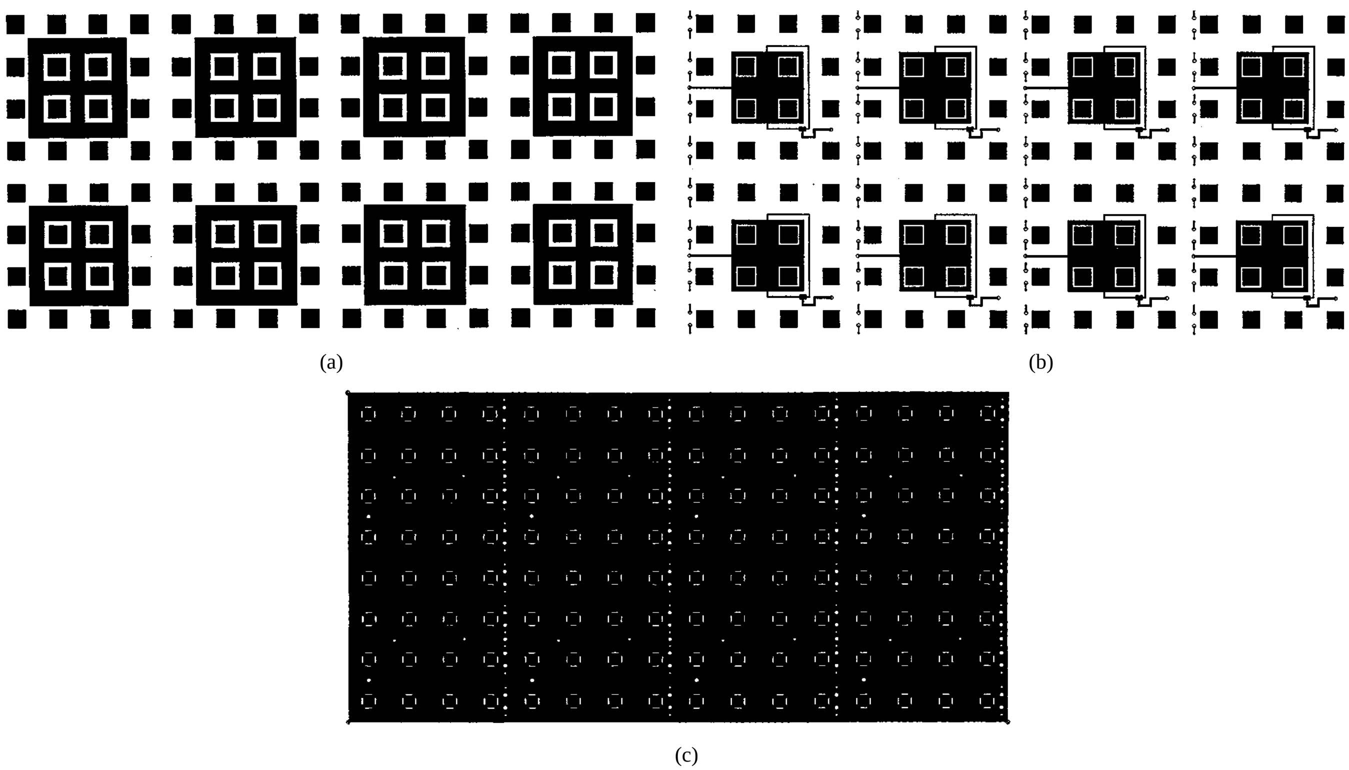


Fig. 2. Geometry of a 2 × 4 unit-cell subarray. (a) Upper layer metallization showing passive patches. (b) Lower layer metallization showing *L*-band feed. (c) Ground plane metallization showing feed slots.

Optimization of this antenna was a challenging task. Perforations cause rapid variations of the surface currents, in particular, near the perforation corners. Thus, in using integral-equation-type solutions such as moment methods, one requires very fine rooftop basis functions to model these current variations accurately. However, excessive meshing causes matrix ill conditioning, again causing further difficulty with solution accuracy. For these reasons, the final optimization of the perforated patches of Fig. 1 was accomplished experimentally. A sample of its measured return loss is shown in Fig. 3, providing the required impedance bandwidth. Note that in this configuration, attempt was made to minimize also the overall antenna height, keeping the honeycomb thickness to around 8 mm. Aside from a thicker antenna a thicker honeycomb substrate meant a lower coupling for the *C*-band patches.

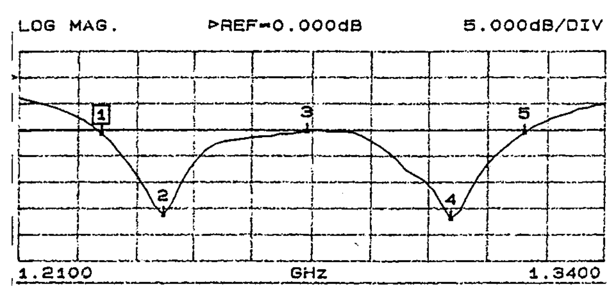


Fig. 3. Measured return loss of the stacked *L*-band perforated antenna.

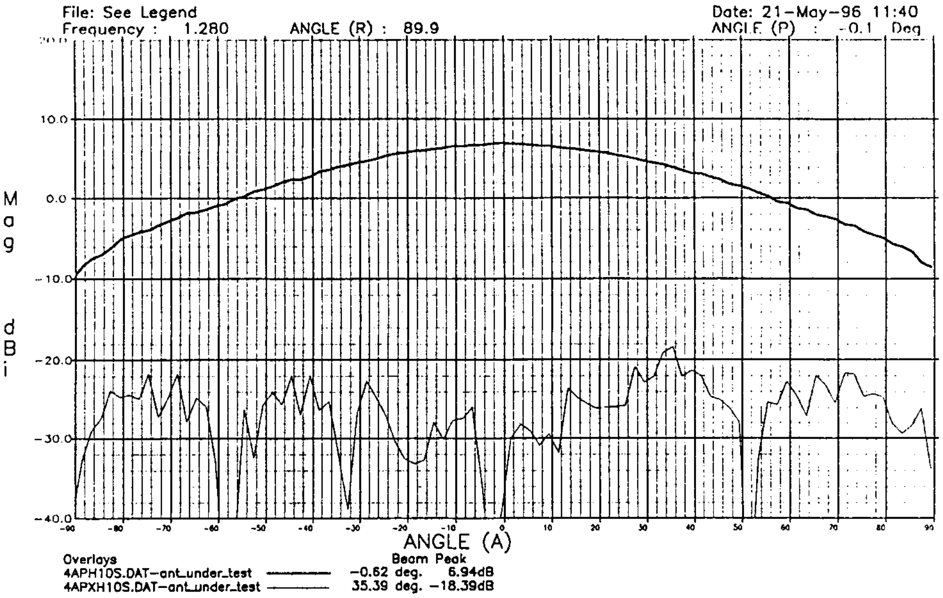


Fig. 4. Measured copolar and cross-polar patterns of the stacked perforated *L*-band antenna.

The perforations generate higher order mode currents and make the pattern symmetry very difficult to achieve. Both simulations and experimental studies showed that for this configuration the feed and geometrical symmetry must be maintained at all times. Therefore, a balanced feeding with 180° phase relationship is essential for cross-polar minimization. The perforation of the lower and upper patches also had to be made symmetric about the patch axes and with respect to each other. These symmetry requirements pushed some of the difficulties to the design of the *C*-band patches, which also required total symmetry to meet the low cross-polarization level.

The copolar and cross-polar radiation patterns were also measured and are shown in Fig. 4. The cross polarization is well within the specifications and is mostly caused by the mounting structure. For these measurements, a unit cell of the array, i.e., one *L*-band and 16 *C*-band elements as shown in Fig. 1, was fabricated and mounted on a 12-in ground plane. The size of the ground plane and the mounting structure in the antenna chamber were found to influence the shape of the radiation patterns and cross-polarization level. But, they are still acceptable.

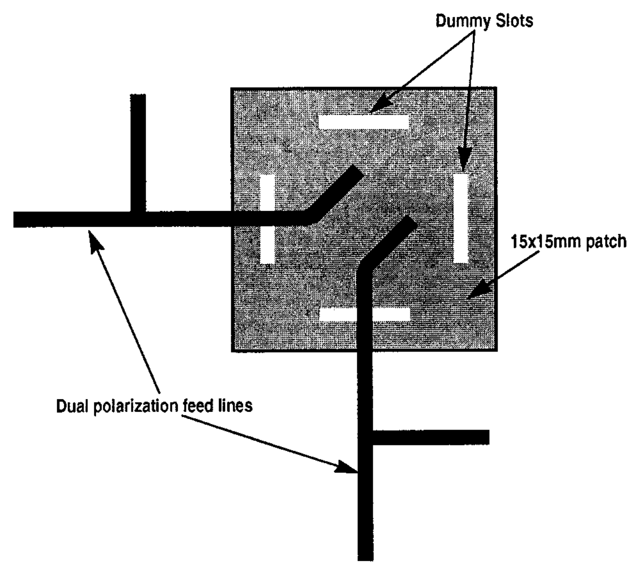


Fig. 5. Geometry of a low cross-polarization dual-polarized slot coupled C-band patch antenna.

IV. *C*-BAND ANTENNA

The required fractional bandwidth of the *C*-band array is about 2% and can easily be met by slot-coupled patches on their substrates. However, in designing the *L*-band patch, it was found that its bandwidth reduces by increasing the perforation size. Also, to minimize the coupling between the *C*- and *L*-band patches, a spacing of about twice the substrate thickness must be maintained. This placed a tight tolerance on the perforation size and the *C*-band patch became under resonance. Stacking the *C*-band patch, allowed a reduction of the lower *C*-band patch size and eased the design problem.

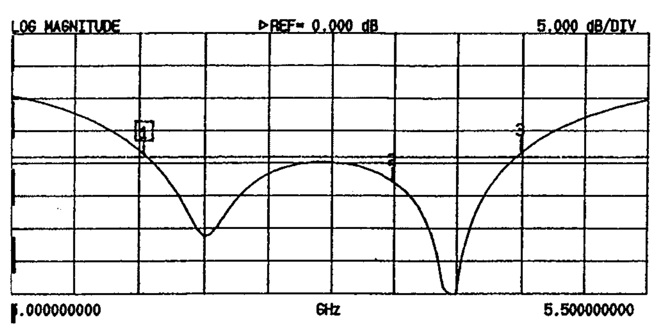


Fig. 6. Measured return loss of the slot-coupled *C*-band patch antenna.

The next problem was the complexity of the dual-polarized feed network. To enable their placement on a single substrate, the balance feeding approach was abandoned, which meant high cross polarization with a single-slot feeding, even with two centrally located orthogonal slots. The symmetric configuration of

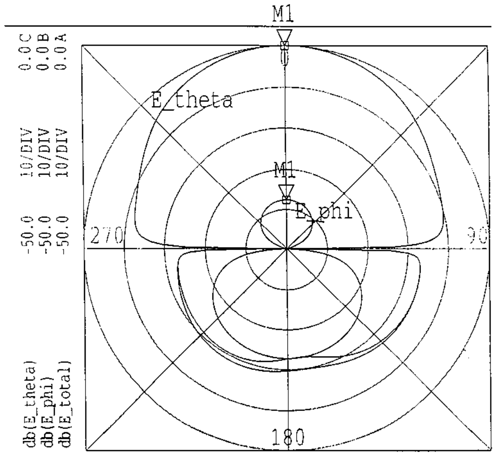


Fig. 7. Computed radiation patterns of the *C*-band element 10 dB/Div.

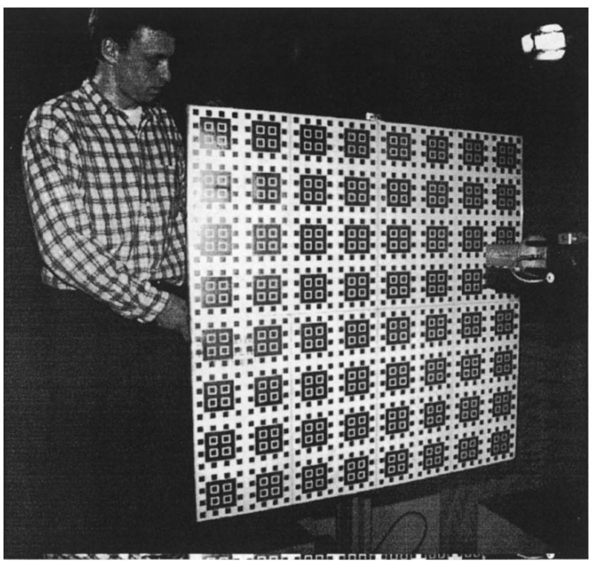
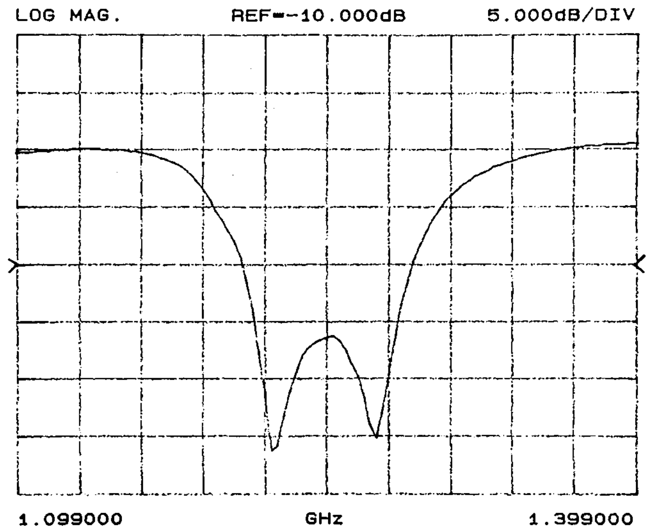
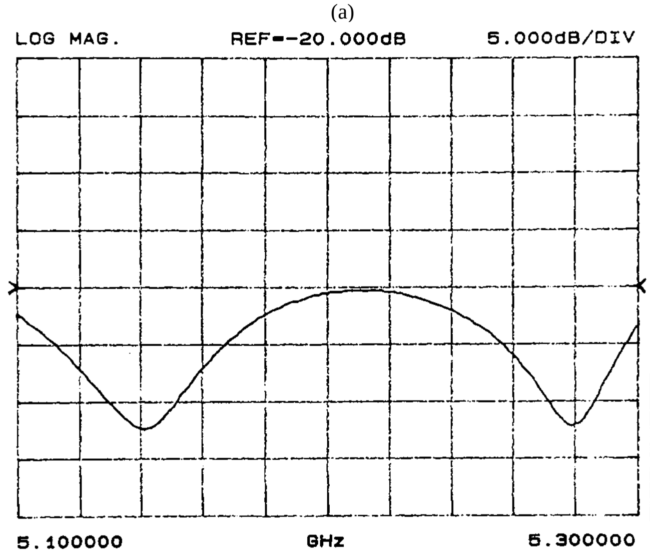


Fig. 8. Implemented 8 × 8 unit-cell array.



(a)



(b)

Fig. 9. Measured return loss of the *L*-band and *C*-band elements of the array. (a) *L*-band. (b) *C*-band.

Fig. 5 was adopted, where only one slot of each polarization was fed by the feed line. This allowed adequate control space for the stub section of the feed line to be etched on the available space under the *C*-band patch. The second slot was passive, but helped in reducing the cross polarization to below −30-dB range. The slot offset and dimensions, along with the feed-line stubs, were then optimized to meet the bandwidth requirement at the *C*-band. A sample of the measured −14-dB S_{11} bandwidth in excess of 300 MHz is shown in Fig. 6.

The *C*-band element, aside from its dual-slot feed, is a conventional stacked patch antenna. Its simulated radiation patterns, using HP-Momentum software, are shown in Fig. 7, which indicates good pattern symmetry and low cross polarization. The measured pattern results, however, are not shown as different *C*-band elements of the unit cell in Fig. 1 and are located at different asymmetric locations with respect to the perforated *L*-band element. Their radiation pattern shape and cross polarization are, therefore, different. These measured results are provided for a subarray and discussed below.

V. Array Antenna

The unit-cell configuration of Fig. 1 was used to implement its 8 × 8 array. It is shown in Fig. 8, where the honeycomb spacer was replaced by a Rohacell Foam substrate of 0.375 inch thickness. For this array typical return-loss performances of both *L*- and *C*-bands are shown in Figs. 9(a) and (b). They are still satisfactory. Next, the radiation characteristics were investigated. Since the *L*-band array is small, beam shaping was not attempted. A small 1 × 4 subarray was excited uniformly. Its measured relative radiation patterns for copolar (solid) and cross-polar (dashed) radiations are shown in Fig. 10. The peak cross polarization is below −32 dB, which is better than the required −25-dB level.

For the *C*-band case, a larger array of 32 elements in elevation (shaped beam) by four elements in azimuth (uniform) was selected. The feed network for the latter four elements is shown in

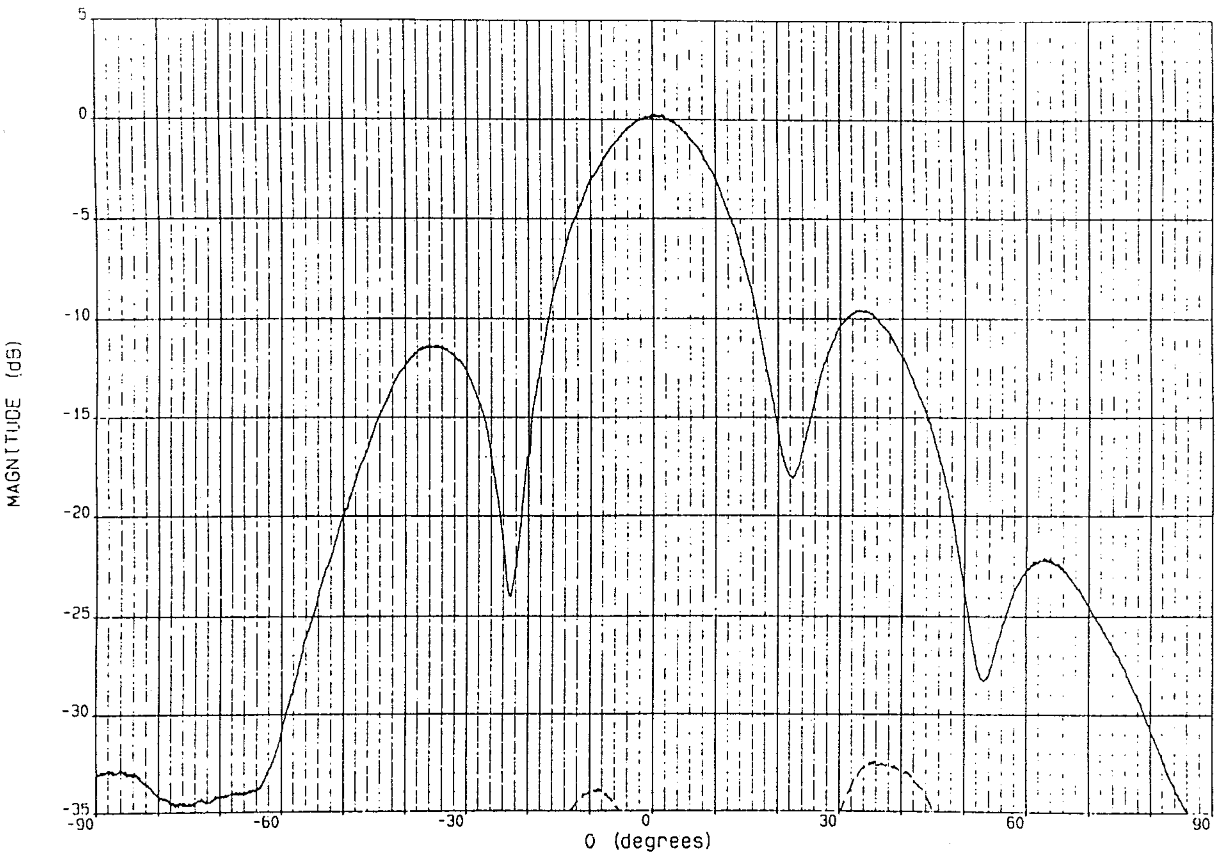


Fig. 10. Measured copolar and cross-polar patterns of the four-element *L*-band subarray.

Fig. 11(a). In the elevation, the elements were excited nonuniformly using appropriate power dividers and phase shifters, to generate typical SAR patterns. The configuration of the 32-way power divider is shown in Fig. 11(b). The measured copolar and cross-polar radiation patterns of a typical SAR beam are shown in Figs. 12(a) and (b), respectively. The peak cross polarization is about -30 dB below the copolar peak—again, better than the requirement of -25 dB.

VI. Conclusion

In this paper, the results of our investigations on implementing a dual-band dual- polarized *L*- and *C*-band arrays on a single shared aperture were presented. The operating frequencies at the band centers were 1.275 and 5.3 GHz, respectively, resulting in a four to one frequency ratio. To obtain a similar scan performance from both arrays, four of the *C*-band patches had to be placed within the *L*-band ones. This resulted in a perforated *L*-band element surrounded by 16 *C*-band patches, forming a unit cell. To meet the bandwidth requirements with a low-profile lightweight design, a stacked configuration was utilized. The lower elements were placed on a thin 15-mil TMM3 substrate, which also contained the feed network of the *L*-band array directly coupled to its elements. The upper elements were placed on a honeycomb or foam substrate. The *C*-band elements were slot-coupled fed from a lower 15 mil TMM3 substrate. Thus, the entire array in both bands used electromagnetic coupling eliminating vertical connections.

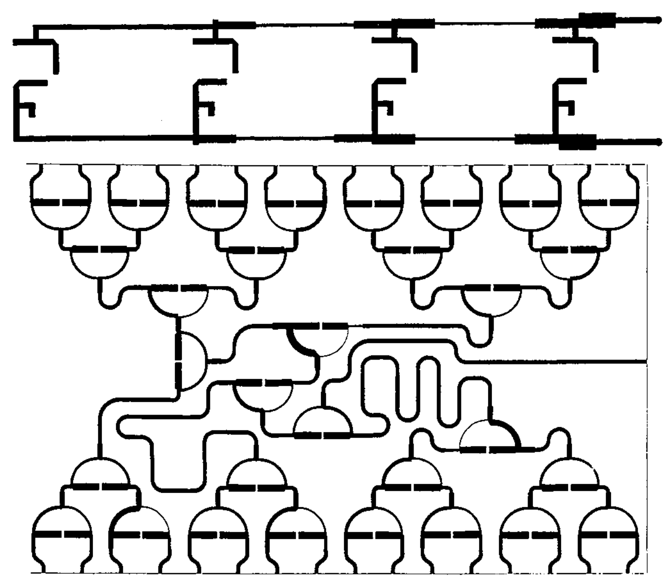
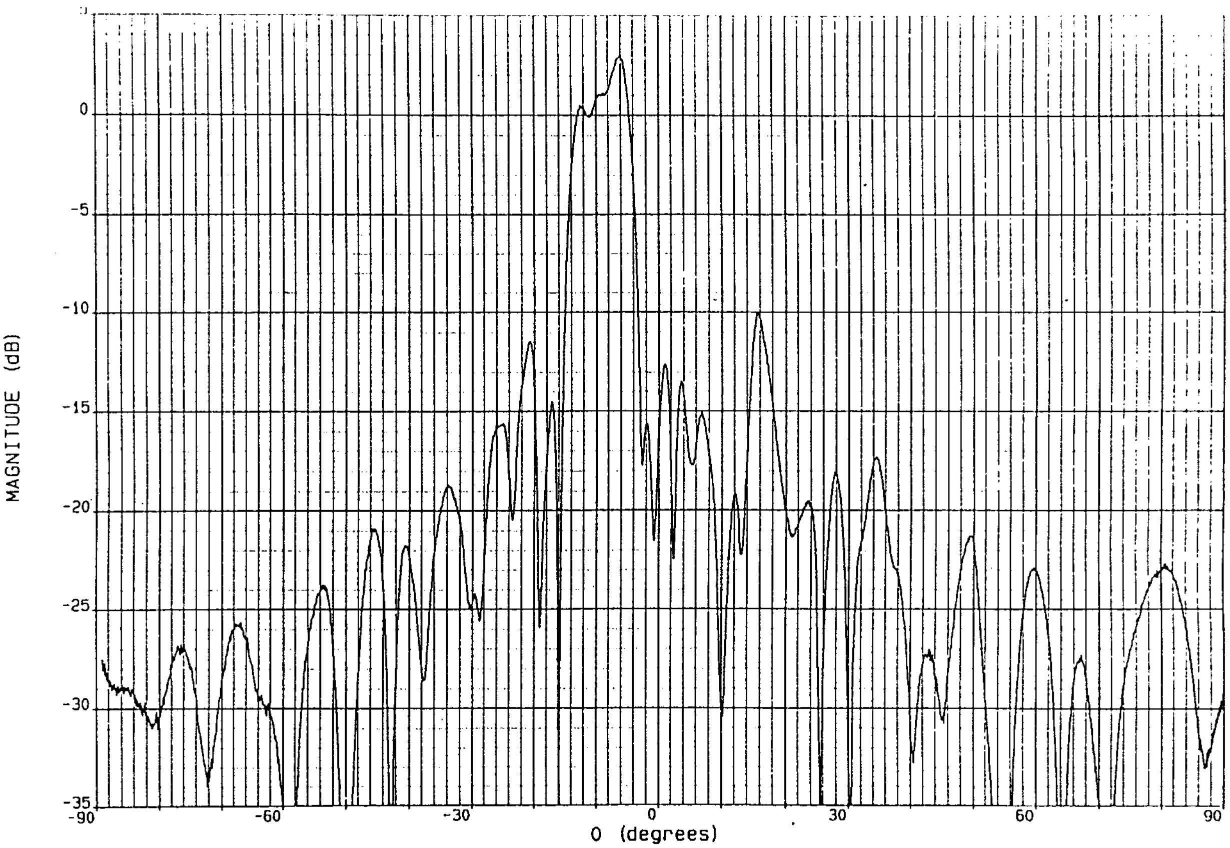
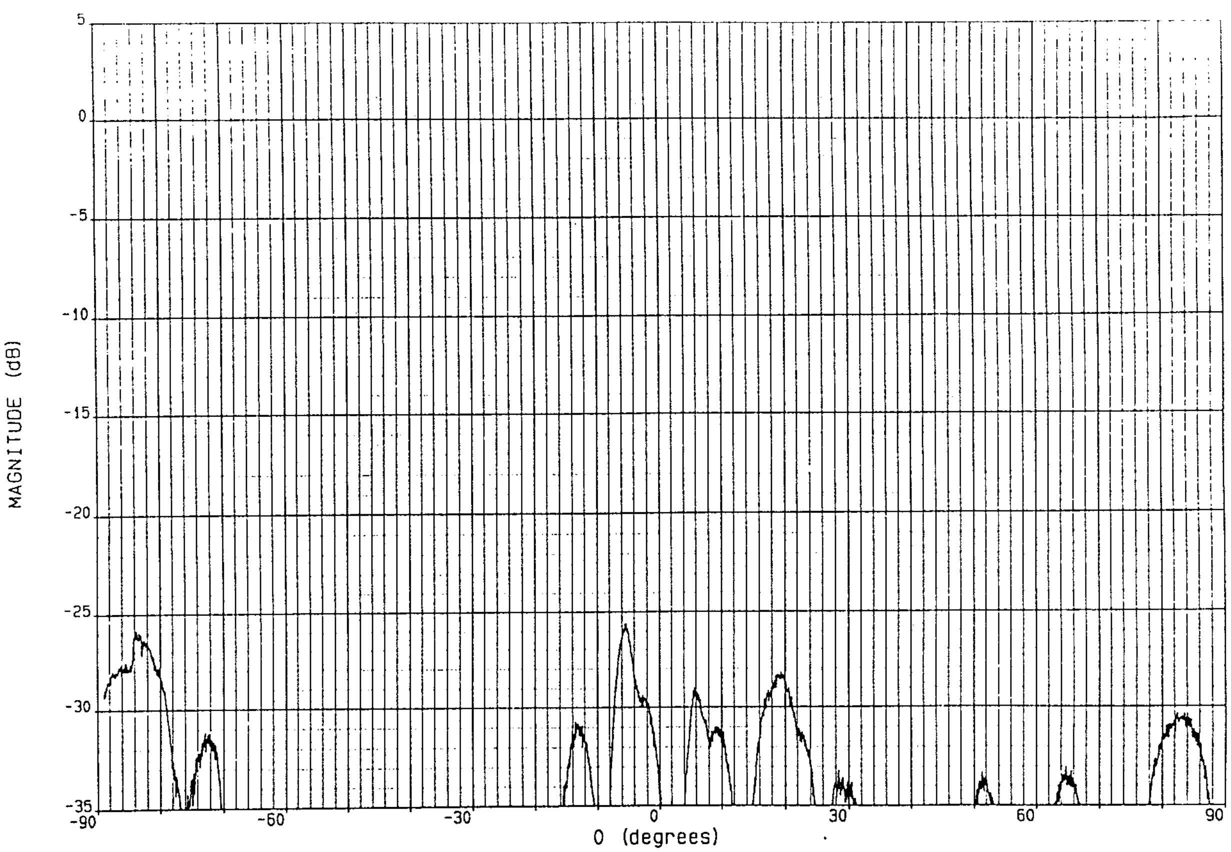


Fig. 11. Feed networks for the 4 × 32 element *C*-band subarray. (a) Four-element uniform excitation network. (b) 32-element unequal excitation network.

An 8 × 8 array of the unit cell was developed for evaluation. For the *L*-band a four-element linear subarray was investigated that achieved the bandwidth and low cross polarization. For the *C*-band a subarray of 4 × 32 elements was investigated. Four azimuth elements were excited uniformly, to allow a comparative study with the *L*-band. The elevation elements



(a)



(b)

Fig. 12. Measured radiation patterns of the *C*-band subarray. (a) Copolar pattern for beam #1. (b) Cross-polar pattern for beam #1.

were excited using a 32-way nonuniform power divider. Appropriate phase shifters were used to generate selected SAR patterns. They showed excellent pattern shape and very low cross polarization.

In array implementation, the honeycomb spacer was replaced by Rohacell foam and both *L*- and *C*-band subarrays used etched feed networks. In spite of the changes in the construction and feed networks, the array measurements confirmed the design goals. In fact, the measured cross polarizations of the array were substantially lower than those of the elements. This is attributed to the coupling effects in the cross-polarization measurements of the elements, which, because of its small size, is influenced more readily by its setup than the large array. The configuration, therefore, has an excellent polarization characteristics.

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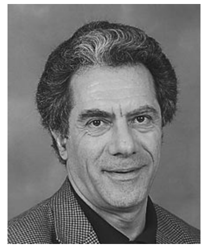

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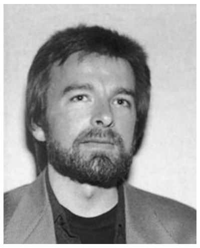
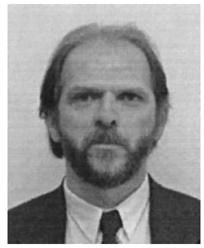
He has over 30 years of experience in industry, academia, and government. He has been an Adjunct Professor at the University of Manitoba since 1983. Currently, he is the CEO of InfoMagnetics Technologies Corporation (IMT) and Spectraworks, both of Winnipeg.

Dr. Barakat is the Director of the Canadian Advanced Technology Association (CATA), Norsat International, Economic Development Authority of WhiteShell and Vice-Chair Manitoba Innovation Network. In 1998 he was the recipient of the Merit Award from the Association of Professional Engineers of Manitoba. At the National Research Council (NRC) he was the Chair of the Canadian Technology Network Advisory Board (1996–1997), and is currently the Chair of the Advisory Board for Industrial Research Assistance Program (IRAP). At NSERC he was a member of the Strategic Project Panel (1995–1996) and the Chair in 1997. At Manitoba Electronic and Information Association he was the Director (1990–1993), Vice-President in 1994, and President in 1995.



Peter C. Strickland was born in Midland, ON, Canada, in 1958. He received the B.Sc. degree from the University of Waterloo, Canada, in 1982, the M.Sc. degree from the University of Massachusetts, Amherst, in 1984, and the Ph.D. degree from Carleton University, Ottowa, Canada, in 1990.

He is currently the Leader of the Antenna and Low Noise Amplifier Design Group, SatCom Division, EMS Technologies, Ottowa, Canada. He has been with EMS (formerly CAL Corporation and Canadian Astronautics Limited) since 1983 in various microwave design and microwave system analysis rolls. Prior to joining EMS he was with Raytheon in the Navaids Group, where he was involved in the development of VHF omni range (VOR) and secondary surveillance radar (SSR) systems. He has been a Sessional Lecturer and Adjunct Professor with Carleton University, Ottowa, Canada, since 1990 and has taught graduate courses in antenna theory and radar systems. His research interests include microwave applications for medical applications, dichroic surfaces, series-fed printed arrays, and novel radiating elements. He has patented the *u-slot patch*, the *mini-cap radiator*, the *disc-loaded helix*, and a variety of other antenna structures used in EMS products.



Guy Séguin was born in St-Jérôme, P.Q., Canada, on August 15, 1952. He received the B.S. and M.S. degrees in physics from the University of Moncton N.B., Canada, and the Ph.D. degree in electrical engineering from McGill University, Canada, in 1977, 1979 and 1998, respectively.

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