A Concentric Multiband Patch Antenna for Wireless Coordination in Coherent Distributed Arrays

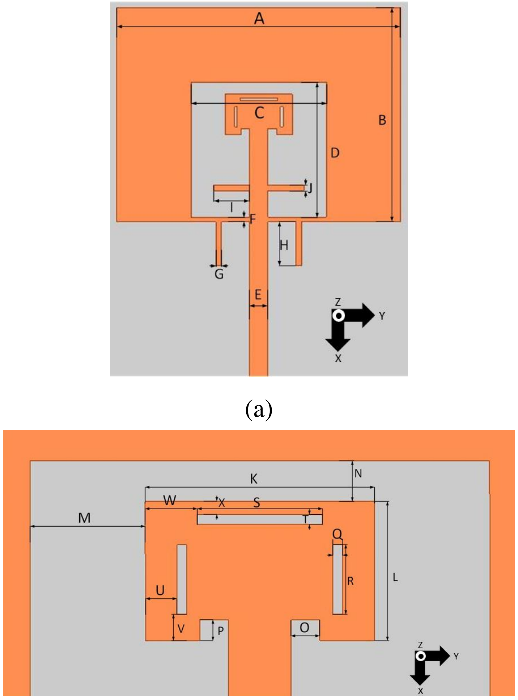
John J. Doroshewitz and Jeffrey A. Nanzer
Electrical and Computer Engineering, Michigan State University

***Abstract*—A multiband patch antenna designed for joint inter-node coordination and distributed array operation is presented. The antenna has three resonances, one in the L-band (1.880 GHz) enabling distributed array operation, and two in the X-band (9.539 GHz and 10.580 GHz) enabling inter-node coordination. These two frequency bands are addressed by two collocated patch antennas; a slotted patch antenna for the high frequencies surrounded by a larger patch that is used for the lower frequencies. Measured results of the antenna design demonstrate good radiation performance at each resonance.**

I. INTRODUCTION

Wireless communication has sparked an increase in demand for distributed antenna arrays consisting of smaller nodes that can be coordinated but independently moved in space. Distributed arrays can be cheaper, easily reconfigurable, and scalable [1]–[3]; however such arrays require high-accuracy range estimation between nodes. Previously, we demonstrated a method of achieving sub-mm range accuracy using a spectrally sparse two-tone microwave ranging waveform [4] which was then used to demonstrate the first open-loop coherent distributed transmission [5]. The relative distance needs to be measured between the antennas transmitting the coherent distributed action. One approach is to create a multiband antenna that supports the coherent distributed action and the inter-node ranging simultaneously. Collocation of these two antenna functions (coherent action and inter-node ranging) enables an accurate measure of the distance between the antennas performing the distributed wireless operation.

The microstrip patch antenna is of particular interest in this application due to its small size, low cost, ease of fabrication, and low profile. Traditionally, patch antennas have been designed to operate efficiently at one frequency, however significant effort has been focused on wideband and multiband operation. Recent work has been done in the area of multiband microstrip antennas concerning the various wireless systems and protocols that are used in smartphones, such as bluetooth, WLAN, or GPS applications [6], [7]. In this work we present a novel collocated multiband patch antenna with simultaneous operation in L-band and X-band. The L-band antenna is uniquely surrounding the smaller X-band antenna, which is designed to have dual resonances to support a two-tone ranging waveform. Operation in the L-band frequency range is achieved through a large patch antenna area with a single resonance. Dual resonances in the X-band frequency range are enabled by a slot-loaded patch design.



(a)

(b)

Fig. 1. Geometry of the multiband patch antenna. Dimensions (all in mm): A=51.5, B=38.83, C=24.5, D=24.5, E=3.34, F=0.83, G=1, H=8, I=6.5, J=1, K=12.2, L=7.4, M=6.15, N=2.155, O=1.53, P=1.1, Q=0.5, R=3.7, S=6.7, T=0.5, U=1.7, V=1.4, W=2.75, X=0.7.

II. ANTENNA DESIGN

The antenna consists of an X-band slotted patch antenna and a surrounding L-band partial patch antenna. The two X-band resonant frequencies are selected to have at least 1 GHz of separation between them with noise rejection above 10 dB in between these two tones. A slotted patch antenna was chosen for this application due to its dual-frequency operation as well as its ability to independently tune each frequency in question using only the surface area of a single traditional patch antenna. This slotted patch was initially simulated with Ansys HFSS independently to tune the two high frequencies. It was fabricated and measured to ensure proper radiation. Its geometry and dimensions can be seen in Fig. 1(b).

During the simulation of the slotted patch antenna, it was observed that the dimensions of the slots were extremely sensitive to perturbations. In order to minimize loading effects

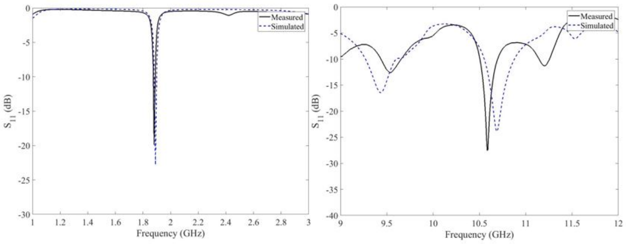


Fig. 2. Measured vs simulated return loss in the (left) L-band and (right) X-band.

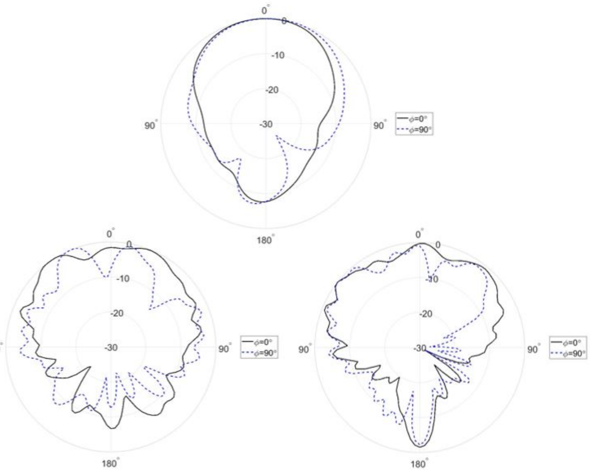


Fig. 3. Measured radiation patterns at 1.880 GHz (top), 9.539 GHz (left), and 10.580 GHz (right).

and preserve the phase centers at each frequency, as previously discussed, a ring was added around the X-band antenna to act as a low frequency, partial patch antenna. It is simply a rectangular patch antenna with the center extracted for the placement of the slotted patch. The ring geometry can be seen in Fig. 1(a).

The antenna is fed with a simple 50 Ω microstrip line. At the first juncture, the line splits off into two 100 Ω lines (in order to match the lines as best as possible) as well as a 50 Ω line to feed the slotted patch. In order to improve the functionality of the antenna, a filtering system is required. Microstrip stub filters are used rather than off the shelf passive components in order to preserve the planarity of the overall design. On the 50 Ω line feeding the slotted patch, two open stubs are connected to the line to act as a high pass filter. Although previous iterations of this design showed successful filtering using only one open stub, the asymmetrical geometry caused issues in the radiation patterns at these frequencies. On the 100 Ω line feeding the low frequency patch, shorted stub low pass filters were added.

III. Fabrication and Measurement

The antenna was fabricated on Rogers RO4350B, an RF board with a thickness of 1.524 mm and a relative dielectric constant of $\epsilon_r = 3.66$. The entire antenna dimensions were 100 mm x 100 mm x 1.524 mm. An SMA connector was added for testing purposes. The shorting holes were drilled through the end of the short stubs and a small wire was soldered on both sides of the board. This was done in order to short this stub to the ground plane on the back side of the antenna. The measured compared to the simulated return loss at the low and high bands can be seen in Fig. 2. All simulations were done using Ansys HFSS. The three primary measured resonances occurred at 1.880 GHz, 9.539 GHz, and 10.580 GHz. The initial simulations showed poor correlation with the measured results. This was found to be due to dimensional discrepancies of the inner patch. Over-etching of the copper during the fabrication process caused the slots to be slightly larger than simulated, producing resonance shifts. The measured, normalized radiation patterns can be seen in Fig. 3. The maximum gains at the low, middle, and high bands can be seen in Table I.

TABLE I
Maximum gain at each band

	1.880 GHz	9.539 GHz	10.580 GHz
$\phi = 0°$	3.8606 dB	1.9967 dB	5.6670 dB
$\phi = 90°$	3.8771 dB	8.0193 dB	6.3765 dB

IV. Conclusions

Successful three band operation was demonstrated with good antenna gain and radiation patterns at each band. For future use in distributed radar applications, it will be beneficial for the antenna to have a dipole-like toroidal pattern to improve the ability to coordinate with multiple platforms. There is also a need to address the uneven resonance in the X-band, which can impact the ranging performance of the two-tone waveform if not corrected for in signal processing.

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