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Multi-function Antennas - A Comprehensive Overview

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Abstract

This manuscript provides a comprehensive overview of the different types of multi-function antenna developments. These antennas are designed and experimentally validated using realized prototypes at SAMEER Kolkata Centre. Some of the pertinent measurement results are also presented.

1. Introduction

The demand for the sophisticated communication systems in onboard military platforms and satellites has tremendously grown over the last two decades, while the space and weight of the equipment have become more constraints. These contradictory requirements have motivated the researchers in reducing the number of antennas by combining the functions of several antennas into a single antenna. Since the same space is shared for multiple purposes, the technology results in a substantial reduction of volume, cost, weight, and radar cross section (RCS). But, the integration of multiple functionalities invites several technical challenges. These may need rigorous system analysis and performance trade-offs. However, for many practical applications, graceful degradation of some of the measured parameters in a shared aperture design is acceptable. The concept is suitable for air-borne or ship-borne application, radar and communication systems.

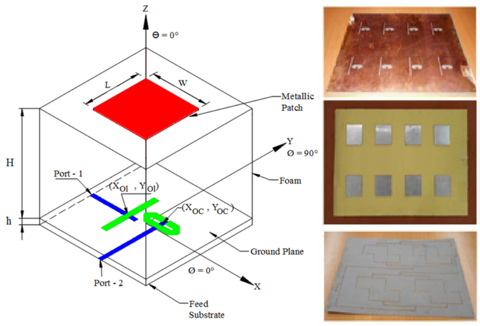
In recent years, major attention was devoted to the development of following types of multi-function antennas:

- Multi-polarized antenna with reasonable cross polarization [1]–[4]
- Multi-band antenna with same polarization [5]–[9]
- Multi-band multi-polarized antenna [10]–[16]

In this manuscript, we report the development of some multi-function antennas which have been physically realized and validated.

2. Multi-polarized Antenna

The focus of these developments is to realize antennas with dual orthogonal polarization using low profile microstrip substrate or aperture elements. These find potential applications in polarization diversity and to enhance communication capacity. One such development is a dual linearly polarized (LP) aperture coupled microstrip antenna illustrated in Figure 1 [17]. The bottom



(a) (b)

Figure 1. Aperture coupled dual LP antenna, (a) configuration, and (b) prototype of a 4*x*2 array. Square patch on grooved dielectric foam, coupling slots and feed lines on the dielectric substrate are represented by red, green and blue colors respectively.

layer of the lower substrate contains two orthogonal feed lines for producing vertical polarization (VP) and horizontal polarization (HP) exclusively. RF energies from the feed lines get coupled to a radiating patch through two orthogonal coupling apertures at the top surface of the lower substrate. The patch is placed on a foam (spacer) at a pre-optimized position. The measured *S*-parameters are shown in Figure 2. About 23.23% impedance bandwidth ($S_{11} \leq -10$dB) at port-1 and 20% at

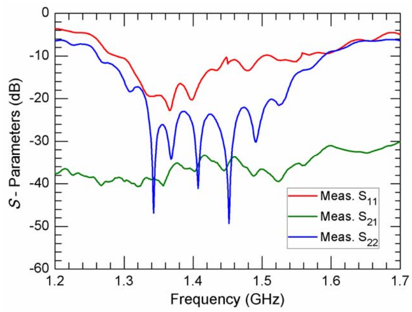
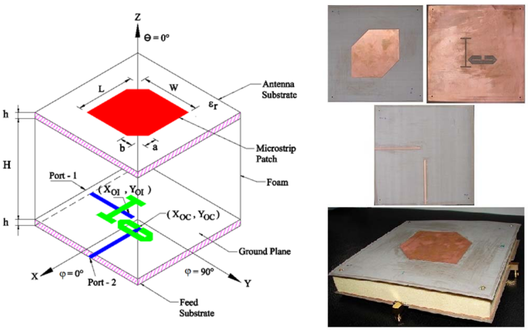


Figure 2. Measured *S*-parameters of the dual LP antenna.

port-2 are achieved with inter-port isolation better than 33dB is reported.

Figure 3 describes a dual circularly polarized (CP) aperture coupled microstrip antenna [18], similar to Figure 1. The radiating patch is truncated to generate CP and realized on a microstrip substrate. Port-1 and -2 of the antenna generate left-hand circular polarization (LHCP) and right-hand circular polarization (LHCP) respectively.



(a) (b)

Figure 3. Aperture coupled dual CP antenna, (a) configuration, and (b) fabricated prototype. The patch, coupling slots, and feed lines are symbolized by red, green and blue colors respectively.

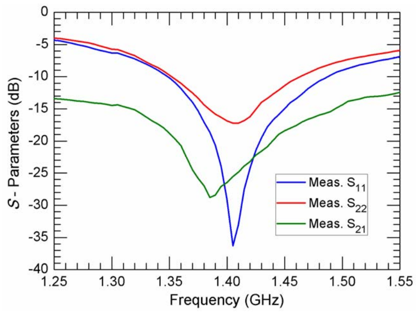
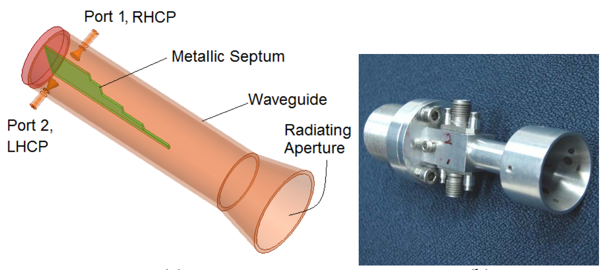


Figure 4. Measured *S*-parameters of the dual CP antenna.

The measured *S*-parameters of the antenna are documented in Figure 4 as a function of frequency. Achieved bandwidths are about 10% at port-1(LHCP) and 7.8% at port-2 (RHCP). The minimum isolation is about 18dB over the working band, the best being 28.5dB.

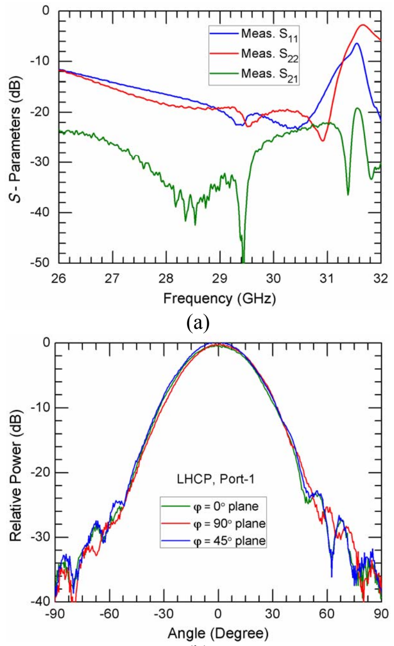
A shared aperture dual CP horn antenna conceiving a metallic stepped septum is shown in Figure 5 [19]. The



(a) (b)

Figure 5. Shared aperture dual CP conical horn, (a) configuration, and (b) the realized prototype.

septum divides the circular waveguide into two equal semicircular waveguides, each of which is excited in the dominant mode (TE_{11}) with the *E*-field normal to the septum. The asymmetric septum converts the LP fields into CP at the common aperture. RHCP and LHCP are excited at port-1 and -2 respectively. Measured S-parameters, in Figure 6, demonstrates impedance



(b)

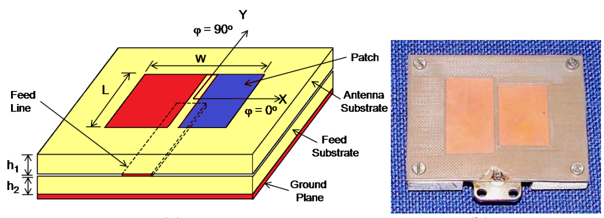
Figure 6. Measured results of the dual CP horn, (a) *S*-parameters, and (b) radiation patterns at port-1 (28 GHz).

bandwidths of about 18% with an inter-port isolation better than −23dB over the working band of the antenna. 3dB beamwidths of ≈ 34° are examined at φ=0° plane (XZ-plane), φ=45° plane, and φ=90° plane (YZ-plane). The patterns at the other port are similar.

3. Multi-band Antenna with identical Polarization

The thrust of these developments is to establish new low-profile antennas for multiband communication or radar application. Broad bandwidths at both the bands were demonstrated.

A new dual frequency antenna has been explored [20]. In this improvise concept, the original patch width is reduced



(a) (b)

Figure 7. The proximity coupled dual frequency antenna, (a) configuration, and (b) engineered prototype.

by 50%, and a 2nd patch is accommodated in the same space. Both the elements are proximity coupled to a single microstrip feed line. The resonance frequencies can be independently controlled as per requirement and the technique causes a marginal decrease in gain. The concept is portrayed in Figure 7. The measured reflection coefficient of the antenna, displayed in Figure 8, exhibits

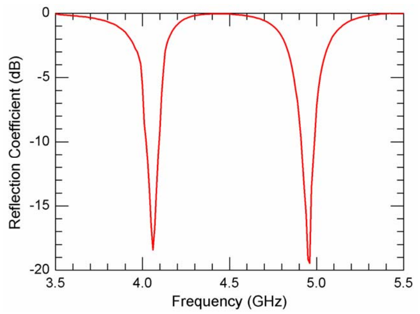
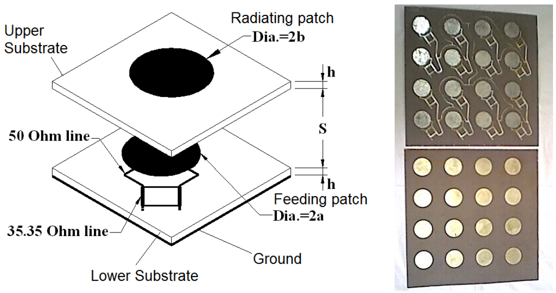


Figure 8. Measured reflection coefficients of the dual frequency antenna.

two narrowband resonances at 4.056 GHz (bandwidth ≈ 1.71%) and 4.96 GHz (bandwidth ≈ 1.41%). The gain values are 7.0 dBi (at 4.056 GHz) and 6.6 dBi (at 4.96 GHz) which are 0.3dB and 0.7 dB lower than a conventional patch. The cross-polar discriminations (XPD) are similar to the conventional patch.

Electromagnetically coupled patch (EMCP) is another convenient means of producing dual frequency with identical polarization [21]. In this configuration, two patches of slightly different sizes are stacked coaxially one-atop-another and are kept separated by a low dielectric medium, as shown in Figure 9(b). Both LP and CP can be produced by this technique. The dual frequencies are caused due to the different element sizes.



(a) (b)

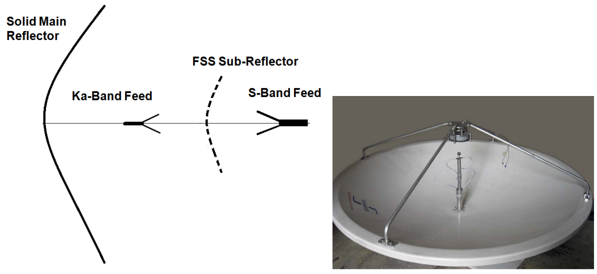
Figure 9. Electromagnetically coupled patch (EMCP) antenna, (a) element configuration, and (b) realized prototype.

By judiciously adjusting the inter-layer spacing, dual frequency or a broadband can be demonstrated.

4. Multi-band Multi-polarized Antenna

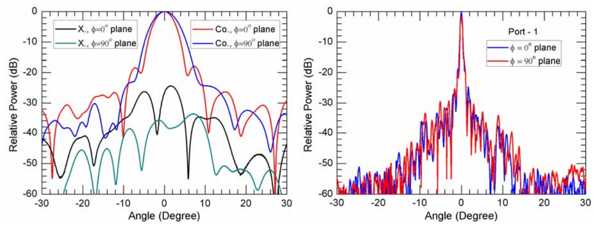
A majority of these works were for high gain or array application. The approach is the most advantageous but invites several technical challenges.

The working principle of a dual polarized reflector is described in Figure 10. By employing a frequency selective subreflector (FSSR), the antenna works in prime focus mode at S-band and in cassegrain at Ka-band [22]. The sub-reflector allows S-band signal to pass through it with low insertion loss and reflects the Ka-band signal. The patterns of the antenna are given in Figure 11. The S-



(a) (b)

Figure 10. The shared aperture reflector, (a) configuration, and (b) prototype.



(a) (b)

Figure 11. Measured patterns of the shared aperture reflector antenna, (a) S-band, and (b) Ka-band.

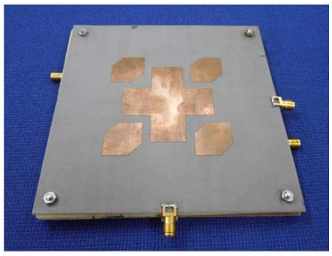


Figure 12. The dual-band dual-polarized microstrip antenna.

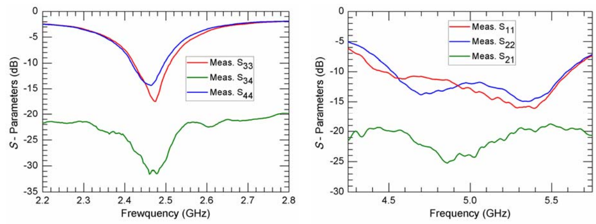


Figure 13. The dual-band dual-polarized microstrip antenna.

band patterns (2GHz, Port-1) reveals 3dB beamwidths of 4.66° *x* 5.52° with 28.5dBi gain. 3dB beamwidths of 0.42° *x* 0.50° with 50.2dBi gain is measured at Ka-band.

A dual-polarized microstrip antenna has been recently reported for S- and C-band communication [23]. Two proximity coupled orthogonal feeds are used for dual linear polarization at S-band. The C-band feeds are aperture coupled and generate LHCP and RHCP exclusively. The antenna yields ≥ 3.5% bandwidth at the S-band with an isolation ≥ 22dB. At Ka-band, ≥ 21.2%

bandwidth with isolation ≥ 18.5dB is achieved. Measured *S*-parameters are displayed in Figure 13.

5. Conclusions

Multi-function antennas are a very new subject of research interest over the last couple of decades. Combining functionalities of two or more antennas are invites several technical challenges. This needs accurate optimization of a number of antenna parameters simultaneously. The choice and design of the antenna element are very critical. The subject is still in the evolutionary state and research works are exploratory in nature.

6. References

1. A. Uz Zaman, L. Manholm, and A. Derneryd, "Dual polarised microstrip patch antenna with high port isolation," *Electron. Lett.*, vol. 43, no. 10, pp. 551-552, May 2007.
2. G. Zhao, L.-N. Chen, and Y.-C. Jiao, "Design of a broadband dual circularly polarized square slot antenna," *Microwave and Opt. Technol. Lett.*, vol. 50, No. 10, pp. 2639-2642, Oct 2008.
3. S. Gao and A. Sambell, "Dual-Polarized Broad-Band Microstrip Antennas Fed by Proximity Coupling", *IEEE Trans. Antennas Propagat.*, vol. 53, no. 1, pp. 526-530, Jan 2005.
4. G.-L. Wu, W. Mu, G. Zhao, and Y.-C. Jiao, "A novel design of dual circularly polarized antenna fed by L-strip," *Progress In Electromagn. Res.*, PIER 79, pp. 39-46, 2008.
5. K. Naishadham, R. Li, L. Yang, T. Wu, W. Hunsicker, and M. Tentzeris, "A shared-aperture dual-band planar array with self-similar printed folded dipoles," *IEEE Trans. Antennas Propagat.*, vol. 61, no. 2, pp. 606-613, Feb 2013.
6. T. Smith, U. Gothelf, O. S. Kim, and O. Breinbjerg, "An FSS-Backed 20/30 GHz Circularly Polarized Reflectarray for a Shared Aperture L- and Ka-Band Satellite Communication Antenna," *IEEE Trans. Antennas Propagat.*, vol. 62, no. 2, pp. 661-668, Feb 2014.
7. S-G. Zhou, P-K. Tan, and T-H. Chio, "Wideband, low profile P- and Ku-band shared aperture antenna with high isolation and low cross-polarisation," *IET Microw. Antennas Propag.*, vol. 7, no. 4, pp. 223–229, 2013.
8. Q.-X. Chu, MA Han-Qing, and H. Zheng, "Design of Shared Aperture Wideband Antennas Considering Band-Notch and Radiation Pattern Control," *IEEE Trans. Antennas Propagat.*, vol. 56, no. 11, pp. 3391-3395, Nov 2008.
9. S. He and J. Xie, "Analysis and Design of a Novel Dual-Band Array Antenna With a Low Profile for 2400/5800-MHz WLAN Systems", *IEEE Trans. Antennas Propagat.*, vol. 58, no. 2, pp. 391-396, June 2010.
10. L.-B. Kong, S.-S. Zhong, and Z. Sun, "Broadband microstrip element design of a DBDP shared-aperture SAR array," *Microwave and Opt. Technol. Lett.*, vol. 54, No. 1, pp. 133-136, Jan 2012.
11. G. Vetharatnam, C. B. Kuan, and C. H. Teik, "Combined Feed Network for a Shared-Aperture Dual-Band Dual-Polarized Array," *IEEE Antennas Wireless Propag. Lett.*, vol. 4, pp. 297-299, Aug 2005.
12. S-H. Hsu, Y-J. Ren, and K. Chang, "A Dual-Polarized Planar-Array Antenna for S-Band and X-Band Airborne Applications," *IEEE Trans. Antennas Propagat.*, vol. 51, no. 4, pp. 70-78, Aug 2009.
13. X. Qu, S. S. Zhong, Y. M. Zhang, and W. Wang, "Design of an S/X dual-band dual-polarised microstrip antenna array for SAR applications," *IET Microw. Antennas Propag.*, vol. 1, no. 2, pp. 513–517, Apr 2007.
14. S.-S. Zhong, Z. Sun, L.-B. Kong, C. Gao, W. Wang, and M.-P. Jin, "Tri-band dual-polarization shared-aperture microstrip array for SAR applications," *IEEE Trans. Antennas Propagat.*, vol. 60, no. 9, pp. 4157-4165, Sep 2012.
15. X. Qu, S.-S. Zhong, and Y.-M. Zhang, "Dual-band dual-polarised microstrip antenna array for SAR applications," *Electron. Lett.*, vol. 42, no. 24, pp..., Nov 2006.
16. P. Mousavi, "Multiband Multipolarization Integrated Monopole Slots Antenna for Vehicular Telematics Applications," *IEEE Trans. Antennas Propagat.*, vol. 59, no. 8, pp. 3123-3127, Aug 2011.
17. S. Chakrabarti, "Development of Shared Aperture Dual Polarized Microstrip Antenna at L-band", *IEEE Trans. Antennas Propagat.*, vol. 59, no. 1, pp. 294–297, 2011.
18. S. Chakrabarti, "Composite Feed Dual Circularly Polarized Microstrip Antenna with Improved Characteristics", *Microwave and Opt. Technol. Lett.*, vol. 58, no. 2, pp. 283–289, 2016.
19. S. Chakrabarti, "Microwave Conical Horn Antenna with Dual Circular Polarization − Close-form Design Equations", *Int. J. RF Microw. Comp. Aided Eng.*, vol. 28, no. 8, pp. 1-9, Oct 2018.
20. S. Chakrabarti, "A Compact Dual Frequency Microstrip Antenna", *Int. J. RF Microw. Comp. Aided Eng.*, vol. 28 , no. 6, pp. 1-10, Aug 2018.
21. T. Chakravarty, S. Chakrabarti, and A. L. Das, "An optimization Technique for the design of S-Band patch antenna suitable for dual frequency application," *Proc. IEEE Antennas Propagat. Symp. Dig.*, pp. 70–73, 2003.
22. S. Chakrabarti, "Development of Shared Aperture Dual Configuration Antenna for S/Ka-Band Communication", *Microwave and Opt. Technol. Lett.*, vol. 58, no. 1, pp. 139-145, 2016.
23. S. Chakrabarti, and A Chakraborty "Dual-band dual sense microstrip antenna with improved characteristics", *Electron. Lett.*, vol. 54, no. 20, pp. 1149-1150, Oct 2016.