Integrated Multi-Operational Antenna System Design for CR Applications

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Abstract. A four-port multi-operational antenna system is designed for Cognitive Radio application. It consists of a sensing ultra-wideband antenna and three communicating narrowband antennas. The CPW fed monopole is a sensing antenna. It covers 2-11 GHz of the UWB band. The three narrow band antennas are operating at 5.834 GHz, 6.42 GHz, 7.355 GHz, and 8.786 GHz respectively. The mutual coupling is below -15 dB. This integrated UWB/NB antenna system can also be a good candidate for C-band, Maritime radio navigation, and X-band applications.

Keywords - Cognitive Radio (CR), Ultra-Wideband (UWB), Narrowband (NB)

1. Introduction

In the last few years, most of the allocated radio spectrum is underutilized for the exponential growth of wireless communication users. For efficient spectrum utilization, Cognitive Radio (CR) emerged as an efficient solution [1, 2]. The antenna is a vital part for CR system [3-12]. This system needs a UWB antenna for continuous spectrum sensing [13]. However, if any channels are available or vacant, the communication is established through a narrowband (NB) antenna. Several communication bands are classified within UWB. To use these bands, more number of NB antennas is needed. However, UWB and the number of NB antennas are responsible for large physical dimensions and coupling issues in a CR antenna system [14-19].

Ebrahim et al. proposed a two-port antenna system of dimension 68 x 54 x 0.79 mm³ which can operate in quad-band mode and covers 3.1-11 GHz band for sensing operation [20]; In another work [21], the system of dimension 80 x 65 x 1.58 mm³ operates in single-band mode and used 2-5.5 GHz band for sensing purpose. A various integrated antenna system for cognitive radio is reported in [22, 23]. However, such an antenna system suffers from lower sensing bands, poor gain, and isolation, also larger antenna size. Now a day, researchers are using extra circuitry to improve isolation [24]. Without adding any extra circuitry and components to achieve high isolation is an open challenge. Further, reconfigurable antennas are gaining more popular [25-26]. The reconfiguration can be done by using switching components (i.e p-i-n diodes, varactor diodes, etc.). In [27], the authors highlight the drawbacks of such kind of switching techniques. Again, the number of NB states is limited to the underutilization of available system areas [28].

A compact four-port antenna system is proposed in this article. This CR system is maximally meets the above challenges.
2. Antenna design

The Integrated UWB/NB antenna system is shown in Fig. 1. It consists of one sensing and three communicating antennas integrated in a proper manner.

![Figure 1](image1.png)

**Figure 1.** Integrated four-port antennas structure (a) Top view, (b) Back view, and (c) Side view

A. Ultra-wideband Sensing Antenna

We choose a CPW fed monopole antenna for spectrum sensing (Fig. 2). It helps to easy integration of narrowband communicating antennas within the available area. The geometrical parameters of the CPW-fed monopole antenna are well documented in [13]. The lower cut-edge frequency (UWB antenna) is determined by using Equation -1.

\[
f_L = \frac{c}{\lambda} = \frac{7.2}{(l+r+g)\times k} \text{ GHz}
\]

where the equivalent cylindrical height, radius, and the gap of the monopole antenna are represented with l, r, and g. Empirically, we fixed the value of k to obtained \( f_L \).

![Figure 2](image2.png)

**Figure 2.** UWB sensing antenna (Antenna-1) \([W_1=3 \text{ mm}, W_2=18.20 \text{ mm}, W_3=14.80 \text{ mm}, L_1=5.83 \text{ mm}, L_2=14.80 \text{ mm}, L_G=16 \text{ mm}, R_1=12 \text{ mm}, g=0.5 \text{ mm}]\)

B. Narrow-band Communicating Antenna

Three NB antennas are chosen for communication purposes are shown in Fig. 3. These are well-known slot antennas reported in [3, 19]. The side edge of the hexagonal patch antenna is 6 mm (Fig. 3 (c)).
Figure 3. NB communicating antennas (a) G-shaped (Antenna-2), (b) U-slot (Antenna-3), and (c) Semi-triangular slot (Antenna-4) \[W_4=9.50 \text{ mm}, W_5=7.50 \text{ mm}, W_6=3 \text{ mm}, W_7=3.50 \text{ mm}, W_8=0.25 \text{ mm}, W_9=6.50 \text{ mm}, W_{10}=0.25 \text{ mm}, L_4=9 \text{ mm}, L_5=2 \text{ mm}, L_6=6 \text{ mm}, L_7=3 \text{ mm}, L_8=5 \text{ mm}, L_9=7.50 \text{ mm}, L_{10}=7 \text{ mm}, L_{11}=5 \text{ mm}, L_{12}=4.50 \text{ mm}, L_{13}=6 \text{ mm}].

3. Results and discussion

CST 2019 is used for simulating and analyzing the system performances. The system is simulated by using a low-cost FR-4 substrate ($\varepsilon_r = 4.4$ and loss tangent=0.02) of size 45 x 40 x 1.6 mm$^3$.

Figure 4. Simulated surface current densities (Monopole antenna) at (a) 2.35 GHz, (b) 4.52 GHz, (c) 8.1 GHz, and (d) 10.12 GHz.

Figure 4 shows the surface current distribution of the UWB monopole antenna at different frequencies. It helps in identifying the areas where the current amplitude is minimal. So we, incorporate the NB communicating antennas in that location (Both center of ground plane and the radiator) where the magnitude of the current is less. Also, they indicate the formation of higher order modes as frequency increases. It helps to increase the NB states by efficiently utilizing the system area. Figure 5 shows the reflection coefficient vs. frequency plot of the proposed antenna system. It observed that the UWB antenna operates from 2 GHz to 11 GHz, and the NB antennas operating at 5.834 GHz, 6.42 GHz, 7.355 GHz, and 8.786 GHz. The simulated gains of the UWB antenna are 2.07 dBi, 3.36 dBi, 5.51 dBi at 2.35 GHz, 4.52 GHz, and 10.12 GHz.
Figure 5. Reflection coefficient of the integrated UWB/NB antennas system

Figure 6 illustrates the isolation plot of the proposed antenna system. The isolation is less than -15 dB throughout the Ultra-wideband range. Figure 7, 8, and 9 shows the simulated radiation patterns for the individual antennas. Table I indicates the performance and applications of NB antennas.

Figure 6. Simulated isolation plot

Figure 7. Radiation patterns of Antenna-1 at (a) 2.35 GHz, (b) 4.52 GHz, and 10.12 GHz
Figure 8. Radiation patterns of Antenna-2 at (a) 5.834GHz, and (b) 8.786 GHz.

Figure 9. Radiation pattern (a) 7.355 GHz (Antenna-3), and (b) 6.42 GHz (Antenna-4)

Table 1. Performance and applications of communicating antennas

| Parameters          | Port-3 (G-shaped) | Port-2 (U-slot) | Port-4 (Semi-triangular slot) |
|---------------------|-------------------|-----------------|-------------------------------|
| Operating Freq. (GHz) | 5.834, 8.786      | 7.355           | 6.42                          |
| Bandwidth (GHz)     | 5.70-6, 8.44-9.02 | 7.1-7.7         | 6.22-6.55                     |
| Gain (dBi)          | 2.76, 2.69        | 4.47            | 3.857                         |
| Applications        | Maritime Radio Navigation | X-band       | C-band                        |

Table II shows comparison between proposed works with previously reported work. It is found that our system has provided maximum number of NBs and compact in size.
Table II. Comparison of the proposed antenna with previously reported antennas

| Ref. | UWB Range (GHz) | Number of Narrowbands | Number of Ports | Antenna Size (mm²) |
|------|-----------------|-----------------------|-----------------|-------------------|
| [20] | 3-11            | 4                     | 2               | 68 x 54           |
| [21] | 2-5.5           | 1                     | 2               | 80 x 65           |
| [22] | 3.3-12          | 2                     | 2               | 58.35 x 75.7      |
| Proposed antenna | 2-11            | 4                     | 4               | 45 x 40           |

4. Conclusion

A small four-port antenna system of dimension 45 x 40 x 1.6 mm³ is proposed. The major contribution is that the number of NB states increases by proper utilization of the available system area. The coupling between the antennas below -15 dB is obtained.

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References

[1] FCC, “FCC report and order on ultra wideband technology,” Federal Commun. Commission, Washington, DC, USA, 2002.
[2] MS. Haykin, “Cognitive radio: brain-empowered wireless communications,” IEEE Journal on Selected Areas in Communications, vol. 23, no. 2, pp. 201–220, Feb. 2005.
[3] S. Shrestha, S.-K. Noh, and D.-Y. Choi, “Comparative Study of Antenna Designs for RF Energy Harvesting,” International Journal of Antennas and Propagation, vol. 2013, pp. 1–10, 2013.
[4] Immadii G., Venkata Narayana M., Anuradha S.Y., Rani M.A., Lokesh K., Meghana B., “Dynamic frequency selection in wireless access systems including the band reallocation and allocation by using cognitive radios,” Journal of Advanced Research in Dynamical and Control Systems, 10 (2), pp. 516-522, 2018.
[5] B B Shankar, D Anantha Sai Kumar, G Venkata Kowndinya, Arjuna Muduli, Deepak Kumar Nayak, “An Ultra-Wide Band Octagonal Antenna with Reconfigurable Narrowband Antenna for Cognitive Radio Applications,” International Journal of Scientific & Technology Research, ISSN 2277-8616, Vol. 9, pp: 1573-1576, Issue 1 January 2020.
[6] Lakshmi M.V., Pardhasaradhi P., Madhav B.T.P., “Circular monopole reconfigurable antenna with notch band filter characteristics,” Journal of Engineering Science and Technology Review, 11 (5), pp. 139-143, 2018.
[7] Teja Babu K., Syam Sundar P., Madhav B.T.P., Prudhvi Nadh B., Kotamraju S.K. “Dual notch UWB monopole antenna with u-shaped slots,” ARPN Journal of Engineering and Applied Sciences, 14(11), pp. 2125-2130, 2019.
[8] Rama Krishna T.V., Madhav B.T.P., Geetanjali S., Parnika B., Bhargavi M.L., Tanmai A.S., Anilkumar T. “Design and study of a CPW fed truncated circular patch switchable band-notched UWB antenna,” International Journal of Recent Technology and Engineering, 8(1), pp. 3037-3043, 2019.
[9] Prabakaran N., Kalyan S., Murthy K., Sai Baba D., Naveen C., Sai R. (2019), “A coplanar waveguide (CPW) fed circular microstrip antenna for UWB applications,” International Journal of Innovative Technology and Exploring Engineering, 8(6), pp. 531-534.

[10] Mishra, S. R., & Lalitha, S. K. “Filtennas for wireless application: A review,” International Journal of RF and Microwave Computer-Aided Engineering, 29 (10), 2019.

[11] Murthy K.S.R., Umakantham K., Murthy K.S.N., Madhav B.T.P. (2019), “Design and analysis of a reconfigurable antenna for dual band ISM medical and Wi-Fi applications,” International Journal of Innovative Technology and Exploring Engineering, 8(10), pp. 3630-3634.

[12] Gundu R.P., Saradhi P.P., Madhav B.T.P., Nadh B.P. (2019), “Frequency reconfigurable lungs-shaped microstrip antenna using pin diodes and annular ring,” International Journal of Innovative Technology and Exploring Engineering, 8(8), pp. 181-184.

[13] R. K. Parida, R. K. Mishra, N. K. Sahoo, A. Muduli, D. C. Panda, and R. K. Mishra, “A Hybrid Multi-Port Antenna System for Cognitive Radio,” Progress In Electromagnetics Research, vol. 106, pp. 1–16, 2020.

[14] R. K. Parida, A. K. Sahu, D. K. Naik, N. K. Sahoo, D. C. Panda, and A. Muduli, “A UWB and Multiband Reconfigurable Antenna for Application in Cognitive Radio,” in 2019 IEEE Indian Conference on Antennas and Propogation (InCAP), pp. 1–3, Dec. 2019.

[15] A. Muduli and R. K. Mishra, “Modified UWB microstrip monopole antenna for cognitive radio application,” in 2015 IEEE Applied Electromagnetics Conference (AEMC), pp. 1–2, Dec. 2015.

[16] A. Nella and A. S. Gandhi, “A Five-Port Integrated UWB and Narrowband Antennas System Design for CR Applications,” IEEE Trans. Antennas Propagat., vol. 66, no. 4, pp. 1669–1676, Apr. 2018.

[17] S. Atapattu, C. Tellambura, and H. Jiang, Energy Detection for Spectrum Sensing in Cognitive Radio. New York: Springer-Verlag, 2014.

[18] Y. Tawk, J. Costantine, and C. Christodoulou, Antenna Design for Cognitive Radio, Artech House, 289, 2016.

[19] A. Zaidi, W. A. Awan, N. Hussain, and A. Baghdad, “A Wide and Tri-band Flexible Antennas with Independently Controllable Notch Bands for Sub-6-GHz Communication System,” Radioengineering, vol. 29, no. 1, pp. 44–51, Apr. 2020.

[20] E. Ebrahimi, J. R. Kelly, and P. S. Hall, “Integrated Wide-Narrowband Antenna for Multi-Standard Radio,” IEEE Transactions on Antennas and Propagation, vol. 59, no. 7, pp. 2628–2635, Jul. 2011.

[21] H. Nachouane, A. Najid, A. Tribak, and F. Riouch, “Dual Port Antenna Combining Sensing and Communication Tasks for Cognitive Radio,” International Journal of Electronics and Telecommunications, vol. 62, no. 2, pp. 121–127, Jun. 2016.

[22] S. Pahadsingh and S. Sahu, “A two port UWB-dual narrowband antenna for cognitive radios,” Microwave and Optical Technology Letters, vol. 58, no. 8, pp. 1973–1978, 2016.

[23] A. Nella and A. S. Gandhi, “A Survey on Planar Antenna Designs for Cognitive Radio Applications,” Wireless Pers Commun, vol. 98, no. 1, pp. 541–569, Jan. 2018.

[24] N. Anveshkumar and A. S. Gandhi, “Lumped Equivalent Models of Narrowband Antennas and Isolation Enhancement in a Three Antennas System,” Radioengineering, vol. 27, no. 3, pp. 646–653, Sep. 2018.

[25] R. Kumar and R. Vijay, “Frequency agile quadrilateral patch and slot based optimal antenna design for cognitive radio system,” International Journal of RF and Microwave Computer-Aided Engineering, vol. 28, no. 2, p. e21176, 2018.

[26] Allam V.K., Madhav B.T.P., Anilkumar T., Maloji S., ‘A novel reconfigurable bandpass filtering antenna for IoT communication applications’, Progress In Electromagnetics Research C, 96, pp.13-26, 2019.
[27] N. A. Kumar and A. S. Gandhi, “A Compact Novel Three-Port Integrated Wide and Narrow Band Antennas System for Cognitive Radio Applications,” International Journal of Antennas and Propagation, vol. 2016.

[28] S. Sharma and C. C. Tripathi, “An Integrated Frequency Reconfigurable Antenna for Cognitive Radio Application,” Radioengineering, vol. 26, pp. 746–754, Sep. 2017.