Documents

Islam, M.S.[a] , Kayser Azam, S.M.[b] , Zakir Hossain, A.K.M.[c] , Ibrahimy, M.I.[a] , Motakabber, S.M.A.[a]

A low-profile flexible planar monopole antenna for biomedical applications
(2022) *Engineering Science and Technology, an International Journal*, 35, art. no. 101112, .

DOI: 10.1016/j.jestch.2022.101112

[a] Department of Electrical and Computer Engineering, International Islamic University Malaysia, Jalan Gombak 53100, Selangor, Malaysia
[b] Department of Electrical Engineering, University of Malaya, Kuala Lumpur, 50603, Malaysia
[c] Centre for Telecommunication Research & Innovation, Fakulti Teknologi Kejuruteraan Elektrik & Elektronik, Universiti Teknikal Malaysia Melaka, Jalan Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia

Abstract
This article proposes a low profile planar monopole antenna on flexible substrate. The antenna is designed with an elliptical slot inserted in a rectangular patch by utilizing the coplanar waveguide (CPW) feeding technique on a polyimide substrate. The proposed antenna operates within 7–14 GHz (S11 < − 10 dB) with a minimum return loss is observed as low as – 58 dB by simulation, whereas the entire X-band is covered by the – 20 dB bandwidth while maintaining an excellent VSWR of almost 1. Also, the antenna exhibits an average gain of 4 dBi while the average radiation efficiency is 92%. The maximum SAR of the proposed antenna for 1 g mass is below 1.0 W/Kg throughout the entire bandwidth. To observe flexibility, four different bending conditions of the antenna have been analyzed. For experimentation, the antenna has been realized as a prototype by using a low-cost fabrication process. The measurement reveals that the prototype has a −10 dB bandwidth of 5.4 GHz. During In-Vivo test, over the variation of 0 ~ 3 mm distance between the antenna-prototype and the human chest/chicken breast tissue, the best performance is obtained at 3 mm in terms of the return loss. One of the significant features of the proposed design is its measured average and peak gain of 4.4 dBi and of 6.33 dBi respectively with a measured average efficiency of 65%. The proposed antenna has a compact size of 13 × 13 mm2 (0.35λg×0.35λg), and its performance remains nominally constant even under different bending conditions which makes the antenna suitable for biomedical imaging applications. A new figure-of-merit has been introduced to evaluate the overall performance based on different antenna key parameters. The fabricated antenna would contribute to the future biomedical research by utilizing X-band frequencies. © 2022 Karabuk University

Author Keywords
Biomedical application; Figure of merit; Flexible antenna; In-Vivo test; X-band frequency

References
- Alibakhshi-Kenari, M., Naser-Moghadasi, M., Sadeghzadeh, R.A., Virdee, B.S., Limiti, E.
A new planar broadband antenna based on meandered line loops for portable wireless communication devices
(2016) *Radio Sci.*, 51 (7), pp. 1109-1117.

- Alibakhshikenari, M., Virdee, B.S., Limiti, E.
Compact Single-Layer Traveling-Wave Antenna DesignUsing Metamaterial Transmission Lines
(2017) *Radio Sci.*, 52 (12), pp. 1510-1521.

- Palanivel Rajan, S., Vivek, C.
Analysis and Design of Microstrip Patch Antenna for Radar Communication
(2019) *J. Electr. Eng. Technol.*, 14 (2), pp. 923-929.

- Alibakhshikenari, M., Virdee, B.S., Shukla, P., Parchin, N.O., Azpilicueta, L., See, C.H., Abd-Alhameed, R.A., Limiti, E.
Metamaterial-Inspired Antenna Array for Application in Microwave Breast Imaging

Systems for Tumor Detection
(2020) *IEEE Access*, 8, pp. 174667-174678.

- Mobashsher, A.T., Bialkowski, K.S., Abbosh, A.M., Crozier, S., Zhang, X.
Design and Experimental Evaluation of a Non-Invasive Microwave Head Imaging System for Intracranial Haemorrhage Detection
(2016) *PLoS ONE*, 11 (4), p. e0152351.

- Bahramiabarghouei, H., Porter, E., Santorelli, A., Gosselin, B., Popovic, M., Rusch, L.A.
Flexible 16 Antenna Array for Microwave Breast Cancer Detection
(2015) *IEEE Trans. Biomed. Eng.*, 62 (10), pp. 2516-2525.

- Nikolova, N.
Microwave Imaging for Breast Cancer
(2011) *IEEE Microwave Mag.*, 12 (7), pp. 78-94.

- Porter, E., Bahrami, H., Santorelli, A., Gosselin, B., Rusch, L.A., Popovic, M.
A Wearable Microwave Antenna Array for Time-Domain Breast Tumor Screening
(2016) *IEEE Trans. Med. Imaging*, 35 (6), pp. 1501-1509.

- Rahman, A., Islam, M.T., Singh, M.J., Kibria, S., Akhtaruzzaman, M.
Electromagnetic Performances Analysis of an Ultra-wideband and Flexible Material Antenna in Microwave Breast Imaging: To Implement A Wearable Medical Bra
(2016) *Sci. Rep.*, 6, p. 38906.

- Mahmud, M.Z., Islam, M.T., Samsuzzaman, M., Kibria, S., Misran, N.
Design and parametric investigation of directional antenna for microwave imaging application
(2017) *IET Microwaves Antennas Propag.*, 11 (6), pp. 770-778.

- Islam, M.T., Mahmud, M.Z., Misran, N., Takada, J., Cho, M.
Microwave Breast Phantom Measurement System With Compact Side Slotted Directional Antenna
(2017) *IEEE Access*, 5, pp. 5321-5330.

- Islam, M.T., Samsuzzaman, M., Islam, M.T., Kibria, S., Singh, M.J.
A Homogeneous Breast Phantom Measurement System with an Improved Modified Microwave Imaging Antenna Sensor
(2018) *Sensors.*, 18, p. 2962.

- Mahmud, M.Z., Islam, M.T., Misran, N., Kibria, S., Samsuzzaman, M.D.
Microwave Imaging for Breast Tumor Detection Using Uniplanar AMC Based CPW-Fed Microstrip Antenna
(2018) *IEEE Access*, 6, pp. 44763-44775.

- Topfer, F., Oberhammer, J.
Millimeter-Wave Tissue Diagnosis: The Most Promising Fields for Medical Applications
(2015) *IEEE Microwave Mag.*, 16 (4), pp. 97-113.

- Fitzgerald, A.J., Wallace, V.P., Jimenez-Linan, M., Bobrow, L., Pye, R.J., Purushotham, A.D., Arnone, D.D.
Terahertz Pulsed Imaging of Human Breast Tumors
(2006) *Radiology*, 239 (2), pp. 533-540.

- Bennett, D.B., Taylor, Z.D., Tewari, P., Sung, S., Maccabi, A., Singh, R.S., Culjat, M.O. (2012), W.S.G. M.d, J.-P. Hubschman, E.R. Brown, Assessment of corneal hydration sensing in the terahertz band: in vivo results at 100 GHz, JBO. 17 097008.

- Nikawa, Y., Hoshi, N., Kawai, K., Ebisu, S.
Study on dental diagnosis and treatment using millimeter waves
(2000) *IEEE Trans. Microw. Theory Tech.*, 48, pp. 1783-1788.

- Taeb, A., Gigoyan, S., Safavi-Naeini, S.
Millimetre-wave waveguide reflectometers for early detection of skin cancer
(2013) *IET Microwaves Antennas Propag.*, 7 (14), pp. 1182-1186.

- Moscato, S., Matrone, G., Pasian, M., Mazzanti, A., Bozzi, M., Perregrini, L., Svelto, F., Summers, P.
A mm-Wave 2D Ultra-Wideband Imaging Radar for Breast Cancer Detection
(2013) *Int. J. Antennas Propag.*, 2013, pp. 1-8.

- Erickson-Bhatt, S.J., Roman, M., Gonzalez, J., Nunez, A., Kiszonas, R., Lopez-Penalver, C., Godavarty, A.
Noninvasive surface imaging of breast cancer in humans using a hand-held optical imager
(2015) *Biomed. Phys. Eng. Express*, 1 (4), p. 045001.

- Yu, C., Fan, S., Sun, Y., Pickwell-MacPherson, E.
The potential of terahertz imaging for cancer diagnosis: A review of investigations to date
(2012) *Quant Imaging Med Surg.*, 2, pp. 33-45.

- Lazebnik, M., Popovic, D., McCartney, L., Watkins, C.B., Lindstrom, M.J., Harter, J., Sewall, S., Hagness, S.C.
A large-scale study of the ultrawideband microwave dielectric properties of normal, benign and malignant breast tissues obtained from cancer surgeries
(2007) *Phys. Med. Biol.*, 52 (20), pp. 6093-6115.

- Lazebnik, M., McCartney, L., Popovic, D., Watkins, C.B., Lindstrom, M.J., Harter, J., Sewall, S., Hagness, S.C.
A large-scale study of the ultrawideband microwave dielectric properties of normal breast tissue obtained from reduction surgeries
(2007) *Phys. Med. Biol.*, 52 (10), pp. 2637-2656.

- Ashworth, P.C., Pickwell-MacPherson, E., Provenzano, E., Pinder, S.E., Purushotham, A.D., Pepper, M., Wallace, V.P.
Terahertz pulsed spectroscopy of freshly excised human breast cancer
(2009) *Opt. Express, OE.*, 17, pp. 12444-12454.

- Truong, B.C.Q., Tuan, H.D., Fitzgerald, A.J., Wallace, V.P., Nguyen, H.T.
A Dielectric Model of Human Breast Tissue in Terahertz Regime
(2015) *IEEE Trans. Biomed. Eng.*, 62 (2), pp. 699-707.

- Martellosio, A., Bellomi, M., Pasian, M., Bozzi, M., Perregrini, L., Mazzanti, A., Svelto, F., Preda, L.
Dielectric Properties Characterization From 0.5 to 50 GHz of Breast Cancer Tissues
(2017) *IEEE Trans. Microw. Theory Tech.*, 65 (3), pp. 998-1011.

- Di Meo, S., Svelto, F., Summers, P.E., Renne, G., Preda, L., Bellomi, M., Espin-Lopez, P.F., Perregrini, L.
  On the Feasibility of Breast Cancer Imaging Systems at Millimeter-Waves Frequencies
  (2017) *IEEE Trans. Microw. Theory Tech.*, 65 (5), pp. 1795-1806.

- Islam, M.S., Ibrahimy, M.I., Motakabber, S.M.A., Hossain, A.K.M.Z., Azam, S.M.K.
  A wideband millimeter-wave printable antenna on flexible substrate for breast cancer imaging
  (2019),
  Putrajaya (accessed December 23, 2019).

- Tighezza, M., Rahim, S.K.A., Islam, M.T.
  Flexible wideband antenna for 5G applications
  (2018) *Microwave Opt. Technol. Lett.*, 60 (1), pp. 38-44.

- Mersani, A., Osman, L., Ribero, J.-M.
  Flexible UWB AMC Antenna for Early Stage Skin Cancer Identification
  (2019) *Prog. Electromagn. Res.*, 80, pp. 71-81.

- Islam, M.S., Ibrahimy, M.I., Motakabber, S.M.A., Hossain, A.K.M.Z.
  A Rectangular Inset-Fed Patch Antenna with Defected Ground Structure for ISM Band
  (2018) *2018 7th International Conference on Computer and Communication Engineering (ICCCE)*, pp. 104-108.

- Islam, M.S., Ibrahimy, M.I., Motakabber, S.M.A., Hossain, A.K.M.Z., Azam, S.M.K.
  Microstrip patch antenna with defected ground structure for biomedical application
  (2019) *Bull. Electr. Eng. Inf.*, 8, pp. 586-595.

- Sharma, A., Khanna, P., Shinghal, K., Kumar, A.
  Design of CPW-Fed Antenna with Defected Substrate for Wideband Applications
  (2016) *J. Electr. Comput. Eng.*, 2016, pp. 1-10.

- Zafary, S.
  A Single Term Formula for Approximating the Circumference of an Ellipse, (n.d.).

- Gabriel, S., Lau, R.W., Gabriel, C.
  The dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz
  (1996) *Phys. Med. Biol.*, 41 (11), pp. 2251-2269.

- Bah, A.O., Qin, P.-Y., Ziolkowski, R.W., Guo, Y.J., Bird, T.S.
  A Wideband Low-Profile Tightly Coupled Antenna Array With a Very High Figure of Merit
  (2019) *IEEE Trans. Antennas Propag.*, 67 (4), pp. 2332-2343.

- Nadh, B.P., Madhav, B.T.P., Kumar, M.S.
  Design and analysis of dual band implantable DGS antenna for medical applications
  (2019) *Sādhanā*, 44, p. 131.

- Padmanabharaju, M., Madhav, B.T.P., Phani Kishore, D.S., Datta Prasad, P.V.
  Conductive fabric material based compact novel wideband textile antenna for wireless medical applications
  (2019) *Mater. Res. Express*, 6 (8), p. 086327.

- Prudhvi Nadh, B., Madhav, B.T.P., Siva Kumar, M., Anilkumar, T., Venkateswara Rao, M., Kishore, P.V.V.
  Windmill-shaped antenna with artificial magnetic conductor-backed structure for wearable medical applications
  (2020) *Int. J. Numer. Model. Electron. Networks Devices Fields*, 33 (6).

Correspondence Address
Zakir Hossain A.K.M.; Centre for Telecommunication Research & Innovation, Jalan Hang Tuah Jaya, Durian Tunggal, Malaysia; email: zakir@utem.edu.my

Publisher: Elsevier B.V.

ISSN: 22150986
Language of Original Document: English
Abbreviated Source Title: Eng. Sci. Technol. Int. J.
2-s2.0-85124568051
Document Type: Article
Publication Stage: Final
Source: Scopus