Performance analysis of a microwave dielectric ceramic (MDC) substrate based Ku-band antenna

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In this paper, a microwave dielectric ceramic (MDC) substrate based probe-fed patch antenna for Ku-band microwave applications is introduced and experimentally inspected. The substrate material is fabricated from Manganese-zinc ferrite. The material is synthesized using the sol-gel method and the structure formation is verified using X-ray diffraction method. The focusing point of this research is using MDC material for microwave antenna design and performance analysis. The proposed antenna shows impedance bandwidth of 118MHz (15.506 GHz to 15.624 GHz) and realized gain of 4.25 dB with a compact size of 20×20× 0.5 mm^3.

(Received January 16, 2018; accepted October 10, 2018)

Keywords: Antenna, Composite, Ku-band, MDC, Mn–Zn ferrite, Sol-gel method

1. Introduction

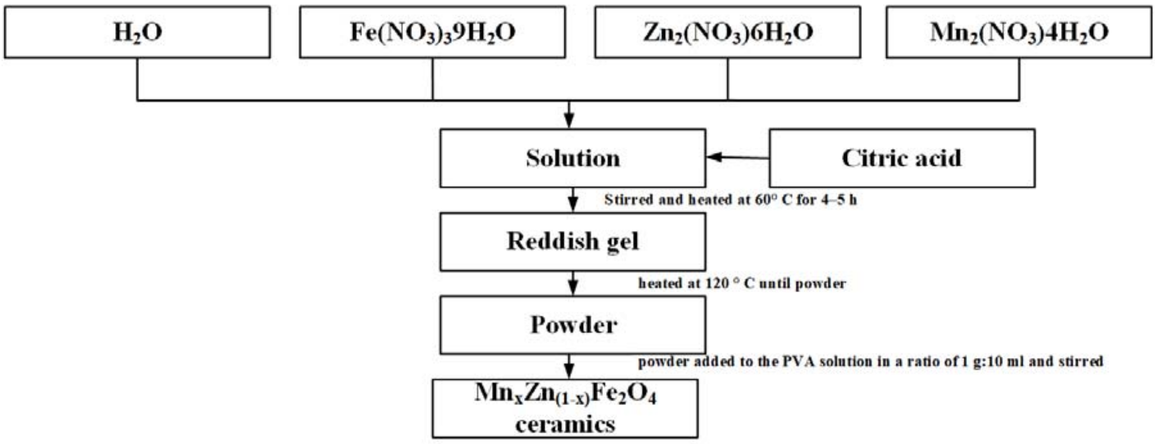
The modern wireless communication system has imbued the development of compact patch antennas. Printed patch antennas are widely utilized due to their some special features such as lightweight, compactness, ease of assembly and integration, cost-effectiveness and low profile. However, narrow operating bandwidth is the main limitation of the microstrip antenna. Several methods are implemented to analyze the performance of the patch antenna like radiator shapes, feeding technique, and using different types of dielectric substrate materials [1-4]. Ceramic dielectric material plays important role in antenna design. High dielectric materials are used to reduce antenna size. In recent years, many new dielectric substrates have been used for microwave applications. Ranjkesh et al. developed high-efficiency antenna using silicon-on-glass (SOG) substrate material [1]. In [3] CaTiO3-modified Mg1.8Ti1.1O4 ceramics was used to make a dielectric resonator antenna. In [4], Rahman et al. used Phenyl-Thiophene-2-Carbaldehyde Compound based flexible substrate material to design wideband antenna. Moreover, LDPE/TIO_2 based composite substrate material has been used for designing x-band microstrip patch antenna and found improvement on reflection coefficient with impedance bandwidth for using graded composite as substrate material [5]. Borah et al. also designed an X-band antenna using Cobalt ferrite LDPE magnetodielectric composite (CFLDPE-MDC) substrate material, where the fractional bandwidth of 0.8% was achieved [6]. The author explained the reason behind narrow bandwidth and that is high-quality factor Q of the antenna.

To date, various techniques have been proposed for Ku-band antenna design, such as slotted patch [7], dual port technique [8], stacked substrate integrated waveguide [9], and metamaterial attachment [10] etc. Though these techniques have been utilized to achieve Ku-band with high performance, but the challenge is the design complexity.

In this paper, synthesized MDC substrate material-based antenna is presented for Ku-band microwave application. The antenna prototype has been designed and fabricated on presented MDC substrate. The antenna performances are experimentally validated with simulated results to ensure the compatibility of the presented MDC substrate for microwave antenna design.

2. Methodology

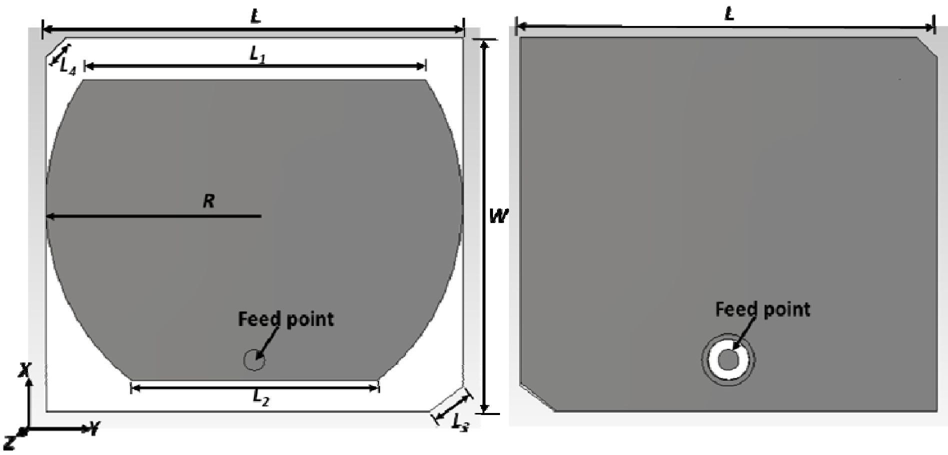
The substrate material of the proposed antenna is a form of $Mn_xZn_{(1-x)}Fe_2O_4$ ceramics, which were synthesized by the sol-gel method. The $Mn_xZn_{(1-x)}Fe_2O_4$ ceramics were prepared from $Fe(NO_3)_39H_2O$, $Zn_2(NO_3)6H_2O$, $Mn_2(NO_3)4H_2O$([99 %). The nitrate powder was dissolved in distilled water and citric acid was used as a chelating agent [11]. To get final MDC substrate, the synthesized powder was added to the PVA solution in a ratio of 1g : 10 ml and stirred until the formation of the substrate. Copper coating has been used to make radiating element of the antenna on both sides of the substrate. The flow chart of the substrate processing are illustrated Fig. 1(a). The dielectric constant and loss tangent of the fabricated substrate has been measured using LCR meter (HP 4284A). The graphical abstract of the works are illustrated in Fig. 1. Moreover, the SEM and AFM image of the developed MDC substrate has been analyzed [11].



(a)

(b)

Fig. 1. (a) Material Processing flow chart by sol-gel Technique and (b) graphical abstract of the presented work



Top View *Bottom View*

Fig. 2 Geometric layout of the developed antenna

Table. 1. Antenna design parameters

Parameters	Value (mm)	Parameters	Value (mm)
L	20	L_3	2.08
W	20	L_4	1.41
L_1	16.41	R	10
L_2	11.74		

The design and simulation of the proposed antenna have been performed by using the commercially available Computer Simulation Technology (CST) microwave studio software package. Fig. 2 depicts the top and bottom views of the proposed antenna. The proposed antenna consisting of a drum-shaped patch, which is excited by 50 Ω impedance coaxial probe fed. The parameters of the proposed antenna are listed in Table 1.

3. Result and discussion

In this section, the performance of the proposed MDC substrate based antenna is verified through measurement and some discussions are provided. The prototype of the proposed antenna has been fabricated, presented in Fig. 3. The reflection coefficient of the fabricated antenna was measured using performance network analyzer (PNA) (N5227A). The measured -10 dB reflection coefficient bandwidth ranges from 15.506 GHz to 15.624 GHz. The measured and simulated reflection coefficient is plotted in Fig. 3. The surface current distributions at 15.56 GHz is demonstrated in Fig. 4, where it can be observed that the surface current splits into several current panels. These current panels can make variation on the azimuthal current density.

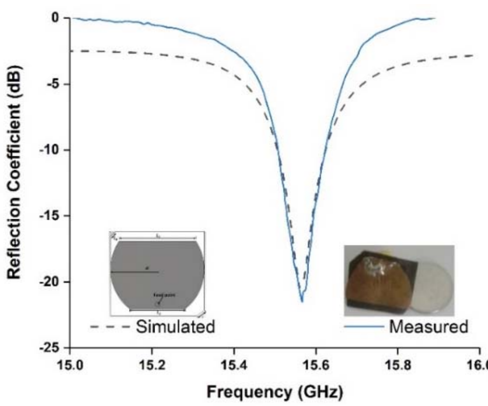


Fig. 3. Reflection coefficient of the presented antenna

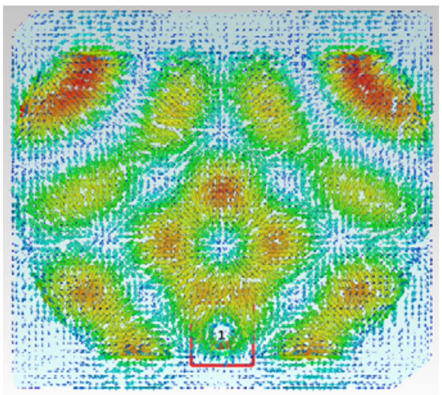


Fig. 4. Surface current distribution of the developed antenna at 15.56 GHz

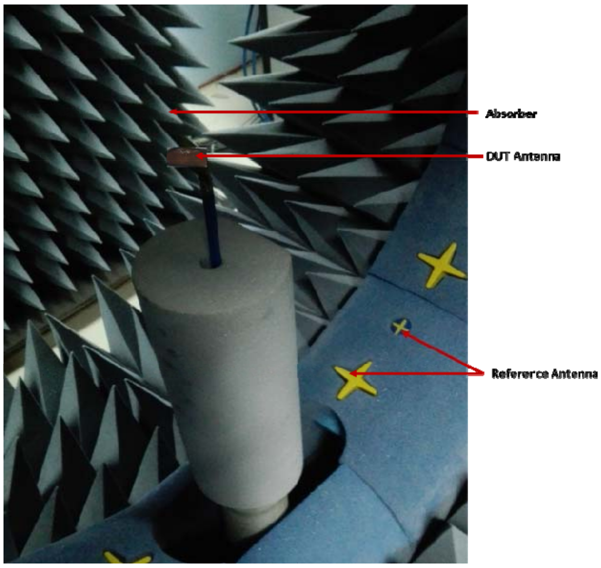


Fig. 5. Farfield characteristics measurement setup (Satimo nearfield measurement system)

The radiation characteristics of the proposed MDC antenna has been analyzed using Satimo nearfield measurement system, demonstrated in Fig.5. The polar radiation patterns of the proposed antenna at frequency 15.56 GHz are plotted in Fig. 6. From Fig. 6 it is observed that antenna operation frequency exhibits non-uniform radiation pattern due to variation in azimuthul current density, which can be observed from Fig. 4. The cross polarization level is always remain below -25dB for E-plane and -15dB for H-plane. Moreover, measured and simulated 3D radiation pattern of the proposed antenna has also been investigated, illustrated in Fig. 7. A good agreement is observed in the Fig. 6 and Fig. 7. The realized gain of the proposed antenna is plotted in Fig. 8, which exhibits realized gain of approximately 3.5–4.20 dB in the operating band with maximum gain of 4.2 dB at 15.56 GHz. Moreover, the measured radiation efficiency of the proposed antenna is achieved up to 83%, shown in Fig. 8.

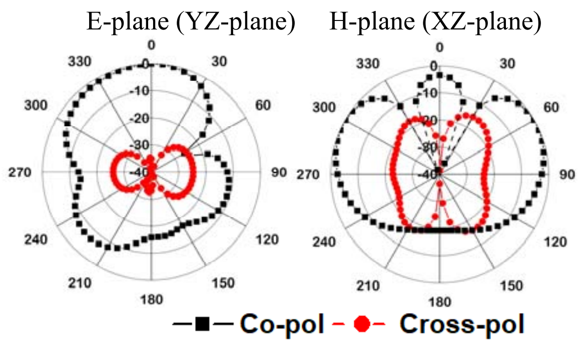
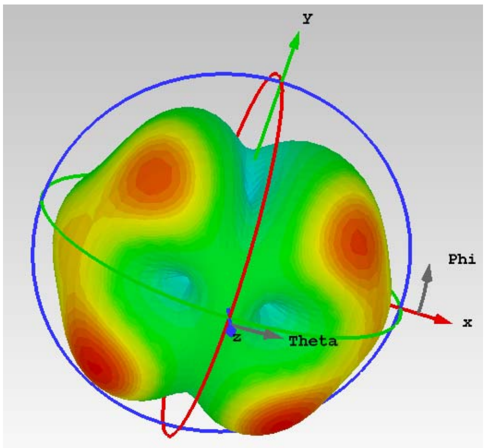
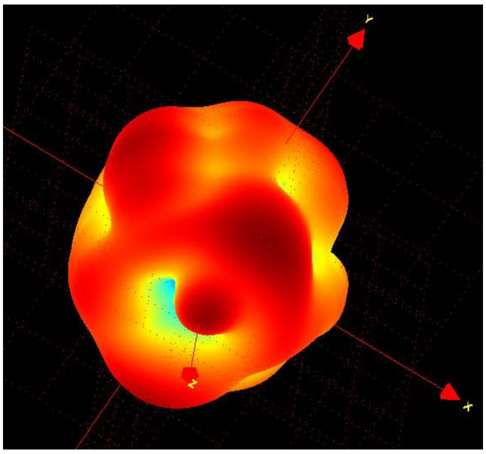


Fig. 6. Polar radiation pattern of the presented antenna at 15.56 GHz



Simulated



Measured

Fig. 7. 3D Radiation pattern of the presented antenna

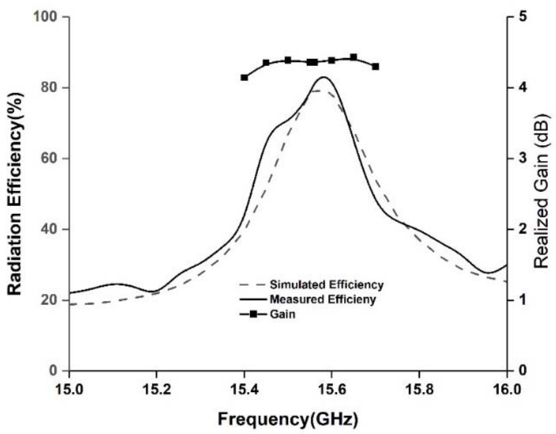


Fig. 8. Radiation efficiency and realized gain of the presented antenna

4. Conclusion

In this paper, higher MDC substrate is used to design and performance analysis of a Ku-band antenna. The antenna is successfully designed, fabricated and measured. The measured results exhibit that the proposed antenna offers -10 dB impedance bandwidth of 118MHz, which ranges from 15.506 to 15.624 GHz. Moreover, the antenna achieved a satisfactory gain and nearly omnidirectional radiation patterns in the entire operating band.

Acknowledgements

This work was supported by the research university Grant of the Universiti Kebangsaan Malaysia (UKM).

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