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Investigation of Multi-Band Reconfigurable Triangular Microstrip Antenna on Magnetic YIG Substrate

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Reconfigurable antennas based on magnetised ferrite substrate and electronic components present a remarkable interest for nowadays antennas. The present research contribution deals to investigate an efficient multiband tuneable triangular microstrip antenna with acceptable characteristics, able to operate from 2.6 GHz to 5.8 GHz requiring frequency and polarization agility by dual reconfigurability using a YIG (Yttrium Iron Garnet) substrate and PIN diode. Different magnetic bias fields were applied to the proposed antenna for ON and OFF states. The obtained results and analysis demonstrate the efficiency of magnetic frequency tuning and a high stability of the radiated field, the antenna bandwidth can reach 1300 MHz for ON state, and a maximum tuning range close to 550 MHz is observed. The proposed antenna design exhibits a linear polarization and stable E and H−plane radiation pattern performance at resonance frequencies over the operating bands. These characteristics make the antenna suitable for multiband wireless communications requiring frequency agility.

Keywords: Magnetic substrate YIG; PIN Diode; Reconfigurability; Triangular Patch Antenna

I. INTRODUCTION

In modern microstrip antennas, the performance consists of good choice of the constitutive parameters and their dimensions. However, it is better to select correctly the substrate material to achieve the desired results. Nowadays, the advancements of patch antennas faces significant challenges regarding the modelling and also the design of the system, these challenges will mainly arise from the surrounding technologies which allow the multifunctional capabilities of these antennas, such as reconfigurability and tunability (Christo *et. al.,* 2012; Haider *et. al.,* 2013; Abdulraheem *et. al.,* 2017; Bernhard, 2003; Elfergani *et. al.,* 2012; Horestani *et. al.*, 2016; Mohamadzade *et al.*, 2021).

Generally, PIN diodes are used as switching elements in order to alter operating frequencies because of their simplicity of implementation (Nikolaou *et. al.,* 2006; Lai, 2009; Ramli, 2013), this will obviously bring some modifications in the impedance bandwidths, polarization, and radiation patterns of microstrip antennas according to the operating requirements. Nowadays, microstrip antennas fabricated with magneto-dielectric composites substrates, find an important study of their performance, for its certain useful patterns properties control like frequency shifting, and scattering reduction (Menezes *et al.*, 2020).

Antennas fabricated with ferrite substrates had first been explored in the early 80' s, using some typical ferrite such as nickel cobalt ferrite (Das *et al.*, 1982) and yttrium iron garnet (YIG) (Pozar, 1988). YIG is a ferrite material with excelent magneto-electric properties that consider it the best magnetic substrate for hight frequency applications (Makiyyu *et al.,* 2017). MPA (Microstrip patch antenna) fabricated on ferrite film was first demonstrated by Rainville and Harackiewicz (Rainville *et al.*, 1992). In 2016, E.Andreou (Andreou *et al.*, 2016) present a fabrication design of a reconfigurable rectangular MPA with Epoxy bonded YIG substrate. It was proved that antenna

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*Corresponding author's e-mail: l.djouablia@univ-skikda.dz polarization in all operation frequencies can be changed by applied magnetic field from 0 to 1.8 KG. In 2018, I.H.Hasan (Hasan *et al.*, 2018) explored the fabrication process of rectangular MPA with YIG thick film as substrate cover using simple screen printing technique. Recently, A.P da Costa (Costa *et al.*, 2021) investigated and fabricated a dielectric cylindrical resonator antenna with multiband controlled characteristics using YIG substrate. However, with one single feed, antennas should radiate circular polarization when they are printed on normally biased ferrites (Lee *et al.*, 1996), in this case and when the direction of the bias magnetic field is reversed, the state of polarization should be switchable between left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP) (Shah, 2014).

According to the literature, the majority of MPA fabricated with YIG or other composite substrates are of simple structures, either rectangle or simple triangle patchs, offering consequently a single bandwidth. The present work is focused on the investigation of a compact multiband triangular MPA covering the bandwidths from 2.6GHz to 5.8GHz with tuneable properties. The design is implemented on thick ferrite-based Yttrium Iron Garnet (YIG) substrate, which typically use a Y magnetostatic bias source to achieve the tunability. The patch is based on two triangular shapes separated by PIN diode to ensure the dual reconfigurability function.

II. ANTENNA DESIGN AND MATERIALS

The detailed geometry and layout patch of the proposed antenna is shown in Figure 1. The YIG substrate of surface (70 x 70 mm²) and 1.6 mm of thickness, has relative permittivity ε_f close to 15 (dielectric loss tangent tan δ ≤ 2.10⁻⁴). The Magnetic ferrite substrate properties are: substrates saturation magnetisation is M_S = 1780 Gauss, and ferromagnetic resonance line is ΔH = 30 Oe. Ferrite substrate is magnetised in a perpendicular direction to Z axis (Figure 1). The antenna is supplied by an adapted feed line of surface (3 × 22.2 mm²) with good VSWR (voltage standing wave ratio). The triangular patch, feed line and GND planes are copper made with 58 μS/m of conductivity. Patch dimensions are shown in Table 1.

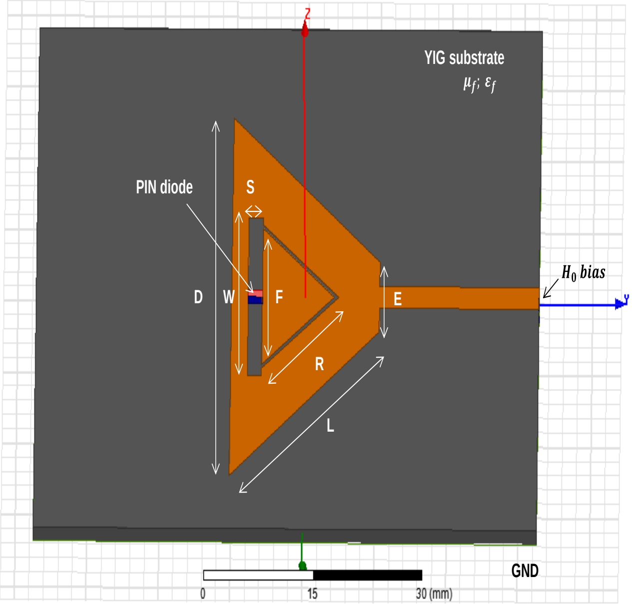


Figure 1. Upper view of the antenna

Table1. Patch dimensions

Patch Parameters	Values in mm
D	50
L	20.6
E	9.8
W	23.6
B	15.6
S	1
F	15
R	22.2

The ferrite is supposed to be saturated and the internal bias field is considered to be uniform, according to DC magnetic bias direction. Relative permeability tensor [[$\boldsymbol{\mu_{rf}}$]] is given by (Polder, 1949):

$$[\![\mu_{rf}]\!] = \begin{Vmatrix} 1 & 0 & 0 \\ 0 & \mu_f & +jK \\ 0 & -jK & \mu_f \end{Vmatrix} \tag{1}$$

where

$$\mu_f = 1 + \frac{\omega_0 \omega_M}{\omega_0^2 - \omega^2} \tag{2}$$

$$K = \frac{\omega \omega_M}{\omega_0^2 - \omega^2} \tag{3}$$

Also, we define ω_M *and* ω_0 as respectively: $\omega_M = \gamma \mu_0 M_s$ and $\omega_0 = \gamma \mu_0 H_0$. In our case, magnetic properties of the YIG substrate are: saturation magnetisation $M_s =$

$1780 Gauss$; ferromagnetic resonance line $\Delta H = 30\,O$; ferrites and gyromagnetic ratio is estimated to $\gamma = 176.109\ rad\ S^{-1}T^{-1}$. μ_0 is the vacuum permeability. In this study, we neglect the damping factor (Kasahara *et. al.*, 2022; Zermane *et al.*, 2019).

By duality principle, electric and magnetic fields patterns in TM modes with magnetic boundary conditions are the same as those for TE modes with electric conditions. For TM_{mn} modes, the electric and magnetic field distributions of an equilateral triangular resonator are given below (Bahl *et al.*, 1982):

$$E_z = A_{m,n,l}T(x,y)_{m,n,l} \tag{4}$$

$$H_x = \frac{j}{\omega\mu}\frac{\partial E_z}{\partial y} \tag{5}$$

$$H_y = \frac{-j}{\omega\mu}\frac{\partial E_z}{\partial x} \tag{6}$$

$$H_z = E_x = E_y = 0 \tag{7}$$

where

$$\begin{aligned} &T(x,y)_{m,n,l} \\ &= cos\left[\left(\frac{2\pi x}{\sqrt{3}D}\frac{2\pi}{3}\right)l\right]cos\left[\frac{2\pi(m-n)y}{3D}\right] \\ &+ cos\left[\left(\frac{2\pi x}{\sqrt{3}D}+\frac{2\pi}{3}\right)m\right]cos\left[\frac{2\pi(n-l)y}{3D}\right] \\ &+ \cos\left[\left(\frac{2\pi x}{\sqrt{3}D}+\frac{2\pi}{3}\right)n\right]\cos\left[\frac{2\pi(l-m)y}{3D}\right] \end{aligned} \tag{8}$$

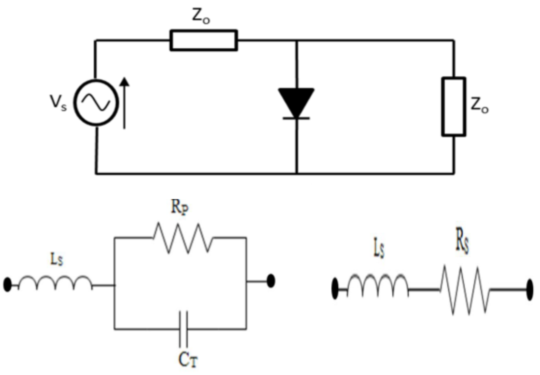
and, $A_{m,n,l}$ is an arbitrary amplitude constant, D is side-length of the triangular patch, and (n,m,l) are integers not zero and satisfying the condition n+m+l=0. However, in addition to the surface electric current, the magnetic currents are also not zero along the edges of the triangular conductor implemented on YIG substrate and may be evaluated from (Bahl & Bhartia, 1982) as:

$$M = 2\bar{E} \times \hat{n} \tag{9}$$

Concerning the fundamental mode, and for the case when the magnetic current sheet may be assumed equal to the substrate thickness, next expression may be used to define the radiation properties of the triangular patch antenna (Bahl *et al.*, 1982):

$$M = 2A_{1,0,-1}\left[2\cos\left(\frac{2\pi x}{\sqrt{3}D}+\frac{2\pi}{3}\right)cos\frac{2\pi y}{3D}+cos\frac{4\pi y}{3D}\right] \tag{10}$$

Meanwhile, the implementation of electronic reconfigurability needs the use of PIN diode, due to its good properties in ON and OFF states. Figure 2 illustrates connection of PIN diode circuits as a shunt or RF equivalent circuit for ON and OFF states. SMP1320 PIN diode was chosen for our study, according to the manufacturer's data their circuit parameters are given as: C_T = 0.3pF; LS = 0.7nH; R_S = 0.9Ω for ON mode and R_S = 20KΩ for OFF mode. Parasitic inductance L_S and value of R_P are assumed higher than the reactance C_T, thusly they are neglected from the equivalent model (Abdulraheem *et al.*, 2017). We should model PIN diode as both a simple equivalent resistance and capacitance.



(a) (b)

Figure 2. RF equivalent circuit models for PIN connected as a shunt switch; (a) OFF state, and (b) ON state

Finally, the triangular patch antenna frequency can be simplified as:

$$f_r = \frac{1}{2\pi\sqrt{L_{equi}\ C_{equi}}} \tag{11}$$

It should be noted that in expression (11) capacitance C_{equi} and inductor L_{equi} can be expressed in terms of the reactive PIN diode components C_T and L_S and medium parameters (ε_f and μ_f), ε_f is the relative permittivity of YIG substrate and μ_f the dispersing quantity, their values depends on the properties of YIG and effectively on the applied magnetic bias.

III. RESULTS AND DISCUSSION

Figure 3 depicts the numerical study of the proposed antenna using full wave analysis under HFSS software. The use of a YIG substrate for several magnetic fields while applying an external bias field on the y-axis (0, 180 and 251 Gauss) can result in a compact dualband antenna device with interesting frequency agility that covers the frequency ranges of 2.6GHz to 3.65GHz and 5.25GHz to 5.8GHz. The first band's maximum tuning range is near to 250MHz, while the second band's maximum tuning range is close to 550MHz. It's worth noting that with lower magnetic fields and higher frequencies, the tuning range expands slightly.

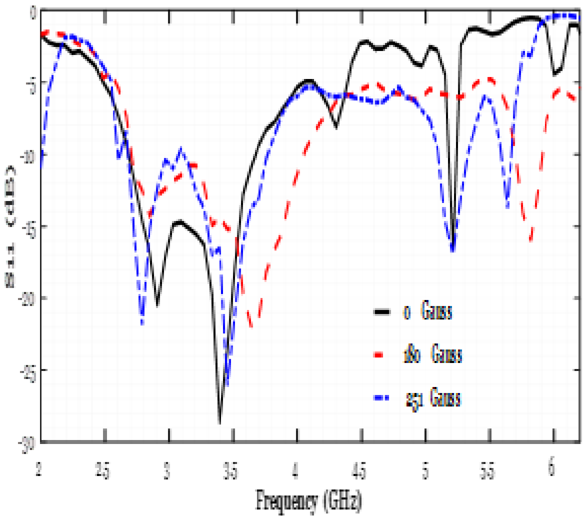


Figure 3. Simulated S11 triangular patch antenna on YIG for ON state and different magnetic bias

At -10dB, an intriguing bandwidth ranges from 150MHz at 0Gauss to 1300MHz at 180Gauss, which is considered higher when compared to previous reported results for various magnetic fields and resonant frequencies, as shown in Table 2. Peak gain results for the considered bias fields show a contrast, with a maximum value of 2.5 recorded at 180 Gauss at 5.8GHz.

Table 2. Results of bandwidth and peak gain for various magnetic fields

External magnetic field (Gauss)	0	180	251
f_{res} first band (GHz)	3.4	3.65	3.47
Bandwidth first band (MHz)	870	1300	1008
Peak Gain	0.16	1.2	1.17
f_{res} second band (GHz)	5.25	5.8	5.25
Bandwidth second band (MHz)	150	220	200
Peak Gain	0.23	2.5	1.33

Table 3 shows a summary of the comparison of some parameters patch antennas produced on YIG with our simulated results.

We can determine whether the proposed structure fulfil the requirements of patch antennas by comparing the values of various parameters stated in previous research and our own. When the same field is applied, our results are close to those of (ref 3) with the added benefit of increased bandwidth and peak gain. Although the radiation efficiency has improved since the reference 3 finding, which is the closest to our study, it remains lower than in previous research. However, Table 3 indicates that finding a compromise between the many parameters patch antenna constituent and the desired qualities based on the applications is always important.

Table 3. Comparison between published fabricated patch antennas on YIG substrate and proposed structure

Parameters	**Our results**	**(Ref 1) (Saxenaa *et al.*, 2011)**	**(Ref 2) (Hasan *et al.*, 2018)**	**(Ref 3) (Andreou *et al.*, 2016)**
Magnetic field	180	2200	$12.69\ 10^{-3}$	180
Fres (GHz)	3.65; 5.8	10.01	5.6	4.83
Gain (dB)	1.58; 7.96	1.94	2.406	-

Return loss (dB)	-22; -17	-14.02	-35.74	-21
Bandwidth at -10dB (MHz)	1300- 220	400	400	450
Max Radiation Efficiency (%)	32	89.2	45.1	30
Axial ratio at f_{res} (dB)	22; 28	-	-	0.98
Max agility (MHz)	550	-	200	570

By reconsidering the aforementioned principle as a basic theory, the use of PIN diode as a switch operating in OFF states, should offer the option to separate the two parts of the triangular patch.

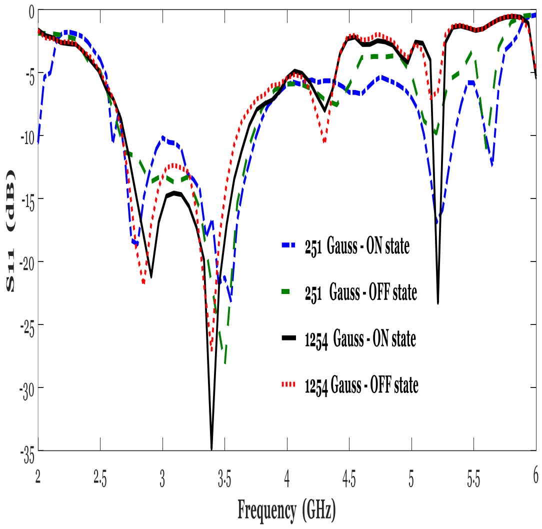
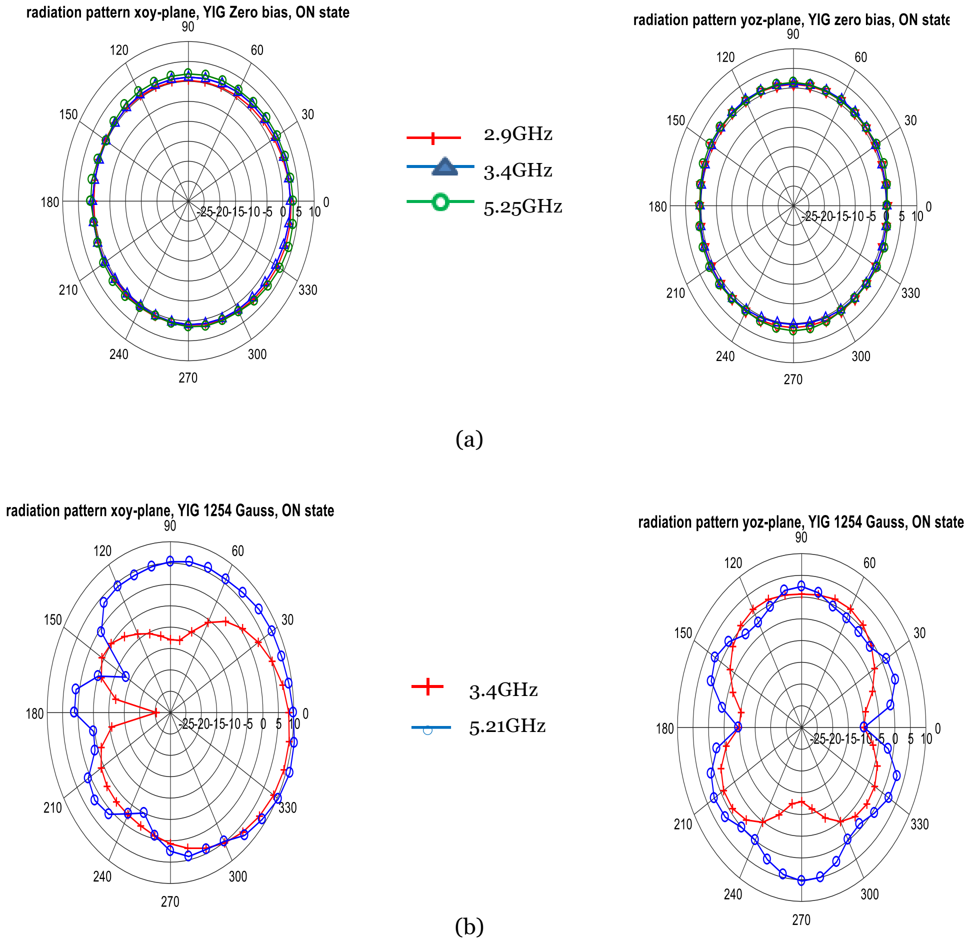


Figure 4. Simulated S_{11}Triangular patch antenna on YIG substrate, for ON and OFF states and different bias

In this case, we have tested 251 Gauss and 1256 Gauss bias at ON and OFF states of PIN diode. When the switch is at OFF state, the antenna presents only one band, which is the lower, the higher bands for instance are inhibited (return loss at higher frequencies 5.25GHz and 5.21GHz is less than -10dB), since only one part of the patch is radiating. This makes the antenna automatically tunable in different wireless frequency bands in addition to its agility due to the use of YIG.

Figures 5(a) and (b) presents the far-field radiation patterns as a function of antenna frequency and magnetic bias in y-direction for both ON and OFF states at selected resonant frequencies, for unbiased, 251 and 1254 Gauss. E-plane (co-polarization) were representing by yoz-coordinates and H-plane (cross-polarization) by xoy-coordinates.



(a)

(b)

Figure 5. E and H-plane radiation patterns: (a) unbiased, and (b) 1254Gauss

It should be noted that our antenna generates an omni-directional vertical plane radiation pattern, it indicates a strong and stable cross-polarized radiation pattern over the entire selected bands especially for ON state situation.

At zero bias, gain is constant for all frequencies and directions, we have an isotropic propagation in the transverse plane. For given bia 1254 Gauss, it is clear from Figure 5(b) that at operating frequencies (3.4 GHz and 5.21 GHz) the device generates an omni-directional pattern with good co-polarization isolation. For both frequencies 3.4 GHz and 5.21 GHz in case of 1256 Gauss- at ON state and at ‘xoy direction’, gain is maximum in OZ axis for an opening angle of -30°, on the other side gain is minimum in the opposite direction.

Table 4 summarises the maximum radiation efficiency values obtained in percent. As a result, changing the bias and state of the PIN diode should change the radiation efficiency. At the ON state, 1254 Gauss has the highest efficiency (70.2%). Although, improvement in radiation efficiency of the proposed antenna compared to some reported results is not significant such as bandwidth and gain, it is still reasonable in light of the structure's complexity.

Table 4. Maximum radiation efficiency values versus bias for ON and OFF states

Bias	0	180	251	1254
ON	40%	32%	25.6%	70.2%
OFF	47.5%	31%	26.32%	38%

IV. CONCLUSION

A multiband V- slotted triangular microstrip antenna was implemented on a ferrite substrate (YIG) and loaded with PIN diode to ensure good agility and dual reconfigurability was investigated in this paper. The device can offer a multiband system from 2.6GHz to 5.8GHz, with an optimal bandwidth of 1300 MHz and a maximum tuning range close to 550 MHz.

The application of in-plane magnetic fields (zero, 180, 251 and 1254 Gauss) tunes the operable resonant frequencies and manipulate the radiation characteristics. The investigation reveals that the proposed patch antenna structure can offer a maximum omnidirectional radiation in vertical plane, with stable cross-polarized radiation pattern and maximum achieved peak gain of 7.96dB for 180 Gauss of bias. Furthermore, it is noticed that efficiency increased by increasing magnetic field, an optimal value of 70.2 % were observed for 1254 Gauss of bias magnetic field. Finally, we confirm that the proposed antenna will be capable of being reconfigured to assume a wide range of circuit functions and would be interesting for WiMAX applications.

V. REFERENCES

Abdulraheem, YI, George, A, Oguntala, Abdulkareem, SA & Husham JM 2017, 'Design of Frequency Reconfigurable Multiband Compact Antenna using two PIN diodes for WLAN/WiMAX Applications', IET Microwaves, Antennas & Propagation, vol. 11, no. 8, pp. 1098-1105.

Andreou E, Zervos T, Varouti E, Alexandridis, AA, Lazarakis F & Fikioris, G 2016, 'A Reconfigurable Patch Antenna Printed on YIG-Epoxy Composite Substrate', IEEE European Conference on Antennas and Propagation (EuCAP*)*, 1–5.

Bahl IJ & Bhartia, P 1982, 'Microstrip Antennas', Artech House, vol. 2, pp. 139-147.

Bernhard, JT 2003, 'Reconfigurable antennas and apertures: State-of-the-art and future outlook', Proceedings of SPIE Conference on Smart Electronics, MEMS, Bio MEMS, and Nanotechnology, 5055, pp. 1-9.

Christo, GC, Tawk, Y, Youssef, A, Lane, AS & Scott, RS 2012, 'Reconfigurable Antennas for Wireless and space applications', Proceedings of IEEE, 100, pp. 2250-2261.

Costa, AP, Fontgalland, G, Neto AG & Sombra ASB 2021, 'YIG Matrix Based Multiband Magneto-Dielectric Cylindrical Resonator Antenna', Journal of Microwaves, Optoelectronics and Electromagnetic Applications, vol. 20, no. 2, pp. 348-358.

Das, SN & Chowdhury, SK 1982, 'Rectangular microstrip antenna on a ferrite substrate', IEEE Trans. Antennas Propag, vol. 30, no. 3, pp. 499-50.

Elfergani, IT, Abd-Alhameed, RA, See, CH, Sadeghpour, T, Noras, JM & Jones, SMR 2012, 'Small Size Tuneable Printed F-Slot Antenna for Mobile Handset Applications', Microwave and Optical Technology Letter, vol. 54, pp. 794-802.

Haider, H, Caratelli, D & Yarovoy, AG 2013, 'Recent developments in Reconfigurable and Multiband Antenna Technology', International Journal of Antennas and Propagation, vol. 10, no. 14.

Hasan, IH, Hamidon, MN, Ismail, I, Mekki, AS, Kusaimi M A, Azhari, S & Osman, R 2018, 'YIG Thick Film as Substrate Overlay for Bandwidth Enhancement of Microstrip Patch Antenna', IEEE Access, vol. 6, pp. 32601-32611.

Horestani, AK, Shaterian, Z, Naqui, J, Martín, F & Fumeaux, C 2016, 'Reconfigurable and Tunable S-Shaped Split-Ring Resonators and Application in Band-Notched UWB Antennas', IEEE Transaction on Antennas and Propagation, vol. 64, no. 9.

Kasahara, K, Sueda, S & Manago, T 2022, 'Thickness dependences of the dynamicmagnetic properties of epitaxial YIGfilms prepared by a metal–organic decomposition method', AIP Advances, vol. 12, p. 015204

Lai, MI 2009, 'Design of reconfigurable antennas based on an L-shaped slot and PIN diodes for compact wireless devices. IET Microwaves', Antennas & Propagation, vol. 3, no. 1, pp. 47–54.

Lee, B & Harackiewicz, FJ 1996, 'The RCS of a microstrip antenna on an in-plane biased ferrite substrate', IEEE Trans. Antennas Propag, vol. 44, pp. 208–211.

Makiyyu, AM, Rabaah, SA, Nurul, HO, Jumiah, H & Tasiu, Z 2017, 'Structural and magnetic properties of yttrium iron garnet (YIG) and yttrium aluminum iron garnet (YAlG) nanoferrite via sol-gel synthesis', Results in Physics, vol. 7, pp. 1135-1142.

Menezes, FL, Neto, DMA, Rodrigues, MLL, Lima, HLS, Paiva, DV M, da Silva, MAS, Fechine, LMUD, Sombra, ASB, Freire, RM, Denardin, JC, Rosa, MF, Filho, MM, Mazzetto, SE & Fechine, PBA 2020, 'From Magneto-Dielectric Biocomposite Films to Microstrip Antenna Devices', mdpi, J. Compos. Sci, vol. 4- 144.

Mohamadzade, B, Simorangkir, RBVB, Hashmi, R, Gharaei, R, Lalbakhsh, A, Shrestha, S, Zhadobov, M & Sauleau, R 2021, A Conformal, Dynamic Pattern-Reconfigurable Antenna Using Conductive Textile-Polymer Composite', IEEE Transactions on Antennas and Propagation, vol. 69, no. 10, pp. 6175-6184.

Nikolaou, S, Bairavasubramanian, R, Lugo, C, Carrasquillo, I, Thompson, DC, Ponchak, GE *et al.* 2006, 'Pattern and frequency reconfigurable annular slot antenna using pin diodes', IEEE Transactions on Antennas and Propagation, vol. 54, no. 2, pp. 439-448.

Polder, D 1949, 'On the theory of ferromagnetic resonance', Philos Mag, vol. 40, p. 99-115.

Pozar, DM 1988, 'Magnetic tuning of a microstrip antenna on a ferrite substrate', Electron. Letter, vol. 24, no. 12, pp. 729-73.

Rainville, PJ & Harackiewicz, FJ 1992, 'Magnetic Tuning of a Microstrip Patch Antenna Fabricated on a Ferrite Film Magnetic Tuning of a Microstrip Patch Antenna Fabricated on a Ferrite Film', IEEE Microwave and Guided Wave Letters, vol. 2, no. 12.

Ramli, N 2013, 'Aperture-coupled frequency-reconfigurable stacked patch microstrip antenna (FRSPMA) integrated with PIN diode switch', Progress in Electromagnetics Research C, vol. 39, pp. 237–254.

Saxenaa, NK, Singha, B, Kumarb, N & Pourusha, PKS 2011, 'Microstrip triangular patch antenna fabricated on LiTiZn ferrite substrate and tested in the X band range', International Journal of Electronics and Communications, vol. 66, no. 2, pp. 140-142.

Shah, AH 2014, 'different ferrite material used as substrate in microstrip patch antenna', International Journal of Engineering Science & Advanced Technology, vol. 4, no. 1, pp. 043-048.

Zermane, A, Sauviac, B, Djouablia, L & Benghalia, A 2019, 'Tunability of metamaterial compact band-stop filters using YIG substrate', Journal of Electromagnetic Waves and Applications, vol. 33, no. 13, pp. 1726-1734.