Microstrip Patch Antenna with Defected Ground Structure for Bandwidth Enhancement

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ABSTRACT
In this paper, a new Defected Ground Structure (DGS) consisting of I-shape slot in ground has been presented to enhance the bandwidth of the Microstrip Patch Antenna (MPA). The parameters such as Bandwidth, Return loss and VSWR are much improved in proposed antenna than simple MPA without defected ground structure. Finite Element Machine (FEM) based High Frequency Structure Simulator (HFSS) software Version-13.0 is used to obtain the performance parameters of the proposed antenna. A comparison is also shown for the proposed antenna with the antenna structure without defect. The proposed antenna resonates in C-band at frequency of 6.0718 GHz with bandwidth of 132.3 MHz. A very good return loss of -46.75 dB is obtained for I-Shaped Defected Ground Structure (DGS). Also I-shaped DGS in the ground plane found to give a size reduction of about 5%.

General Terms
Bandwidth (B.W.), Voltage Standing Wave Ratio (VSWR), return loss (S_{11}), gain and directivity.

Keywords
Defected Ground Structure (DGS), Microstrip Patch Antenna (MPA).

1. INTRODUCTION
Recently, a growing demands of microwave and wireless communication systems in various applications resulting in an interest to improve antenna performances. Therefore, the selection of microstrip antenna is suitable to apply at various fields such as telecommunication, medical application, satellite and military system. However, microstrip antenna has its inherent shortcomings such as narrow bandwidth, typically 5% of centre frequency and half space radiation [1]. Many kind of miniaturization techniques, such as using of dielectric substrate of high permittivity [2], slot on the patch, DGS at the ground plane or a combination of them have been proposed and applied to microstrip patch antennas.

Conformal microstrip antennas are applied for a wide variety of higher frequency, such as the cylindrical microstrip antenna, has been paid more attention by many researchers [3-5], which can reduce the size, widen the radiation beam. The surface wave restricts the wide use of microstrip antenna, electromagnetic bandgap (EBG) or photonic bandgap (PBG) structure is a method to reduce the surface waves, which exhibit band-gap feature [6] too. EBG has been applied in the field of antenna to improve the performance of antenna [7-12], such as suppression of surface wave propagation, increasing the gain of antenna and improving the radiation pattern by inserting the EBG structure into the substrate [13-15]. However, in implementing EBG, a large area is needed to implement the periodic patterns and it is also difficult to define the unit element of EBG.

Defected ground structure (DGS) has similar microwave circuit properties as EBG, it can also modify guided wave properties to provide a band-pass or band-stop like filter and can easily define the unit element. The geometry of DGS can be one or few etched structure which is simpler and does not need a large area to implement it [16]. DGS structure disturbs the shield current distribution in the ground plane [17], [18], which influences the input impedance and current flow of the antenna.

Many shapes of DGS slot have been studied in planar microsrip antenna designs [19-21], which provides many good performances such as size reduction (resonant frequency lower), impedance bandwidth enhancement (quality factor lower) and gain increasing. The compact, broadband microstrip antenna with defective ground plane has been realized in [22]; the impedance bandwidth of the proposed antenna could reach about 4.3 times that of the conventional microstrip antenna. Several slots are embedded in the ground of the microstrip antenna so that the size is reduced, the impedance band and gain is enhanced [20]. By utilizing a slot-load technique [22], the microstrip slot antenna excites two resonant frequencies. By combining with a defective ground plane, the bandwidth is augmented and the resonant frequency is lowed simultaneously.

In this paper work, a notable ground structure named defected ground structure (DGS) has recently been investigated and found to be a simple and effective method to reduce the antenna size. Proposed antenna design incorporates I-Shaped Defected Ground Structure in ground plane. Etching this DGS underneath the simple microstrip feedline, impedance bandwidth broadening can be obtained.

2. ANTENNA DESIGN
Both MPA and proposed antennas are designed on Rogers RT/Duroid 5880 (tm) substrate with thickness (h_s) of 0.794 mm having relative permittivity (ε_r) of 2.2. The patch has the dimensions of 15.236 mm × 25.236 mm with height (h_p) of 0.05 mm. The ground has the dimensions of 20 mm × 30 mm with height (h_g) of 0.05 mm. Antenna is excited with microstrip feed having characteristics impedance of 50 Ω. The feed has dimension of 2.382 mm × 2.2 mm with height (h_f) of 0.05 mm. The complete geometry of simple MPA is shown in Fig. 1.

In order to improve the Bandwidth and Return loss, ground is defected with I-Shape slot. The width of slot along Y-axis is 3 mm and the length of slot along X-axis is 10 mm as shown in Fig. 2. Also this slot made on ground helps in the reduction of overall weight and size of proposed antenna.

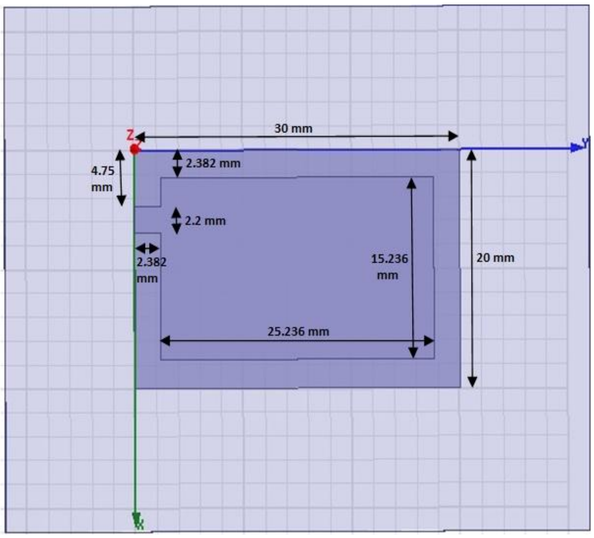

Fig 1: Geometry of simple MPA antenna

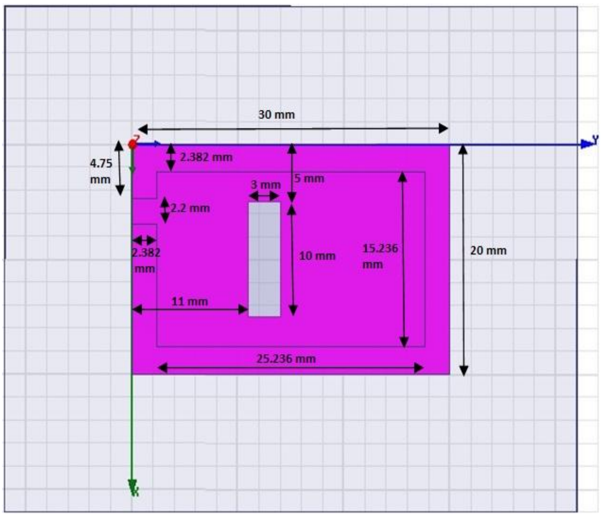

Fig 2: Geometry of G-shaped DGS antenna

Table 1 shows some common design parameters or specifications for both antennas i.e. simple MPA and I-slot DGS antenna.

Table 1. Common design specifications for both antennas

Sr. No.	Specifications	Dimensions (mm) / Values
1.	Ground (L_g×W_g×h_g)	20×30×0.05
2.	Substrate (L_s×W_s×h_s)	20×30×0.794
3.	Patch (L_P×W_P×h_p)	15.236×25.236×0.05
4.	Feed (L_f×W_f×h_f)	2.382×2.2×0.05
5.	Permittivity of substrate material "Rogers RT/Duroid 5880 tm" (ε_r)	2.2

The Proposed antenna resonates at frequency (f_r) of 6.0718 GHz. The resonant frequency, also called the center frequency, is selected as the one at which the return loss is minimum. For a specific resonant frequency (f_r) and dielectric constant of substrate (ε_r), the width (W), length (L) of patch of MPA are expressed as follows:

$$W = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (1)$$

$$L = L_e - \Delta L \qquad (2)$$

where, L_e and ΔL are the effective and extended Length of patch and are expressed as:

$$L_e = \frac{c}{2 f_0 \sqrt{\varepsilon_e}} \qquad (3)$$

$$\Delta L = 0.412\, h \frac{(\varepsilon_e + 0.3)(\frac{W}{h} + 0.2664)}{(\varepsilon_e - 0.258)(\frac{W}{h} + 0.8)} \qquad (4)$$

where, ε_e is the effective dielectric constant of substrate and is expressed as:

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{\frac{-1}{2}} \qquad (5)$$

Similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery [14]. Hence, for this design, the ground plane dimensions would be given as:

$$L_g = 6\, h + L \qquad (6)$$

$$W_g = 6\, h + W \qquad (7)$$

where, "h" is the height of substrate. L_g and W_g are length and width of ground plane respectively.

In order to improve the Bandwidth and Return loss, ground is defected with I-Shape slot. Also this slot made on ground helps in the reduction of overall weight and size of proposed antenna.

3. RESULTS AND DISCUSSIONS

Finite Element Machine (FEM) based High Frequency Structure Simulator (HFSS) software Version-13.0 package is used to obtain the performance parameters of the proposed antenna.

3.1 Return loss (S_{11}) and bandwidth

It is evident from Fig. 3 that when I-shaped defect in ground plane is introduced, the proposed antenna resonates in C-band at resonant frequency f_r = 6.0718 GHz. A very good return loss of -46.75 dB at f_r = 6.0718 GHz is obtained for this structure. At this resonant frequency, it gives a maximum bandwidth of 132.3 MHz (i.e. $MX_1 – MX_2$).

While the Fig. 4 depicts that MPA without slotting in ground also resonates in the C-band but at resonant frequency f_r = 6.2051 GHz. The bandwidth of the microstrip patch antenna with same dimensions as mentioned above but without slotting is 126.2 MHz at f_r 6.2051 GHz. The value of return loss (S_{11}) obtained from MPA is -27.72 dB.

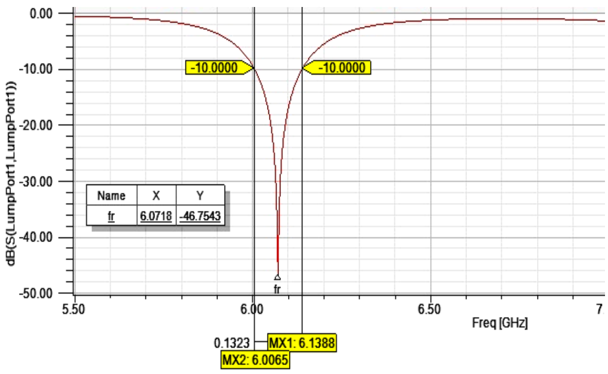

Fig 3: Return loss (S_{11}) of I-slot DGS antenna

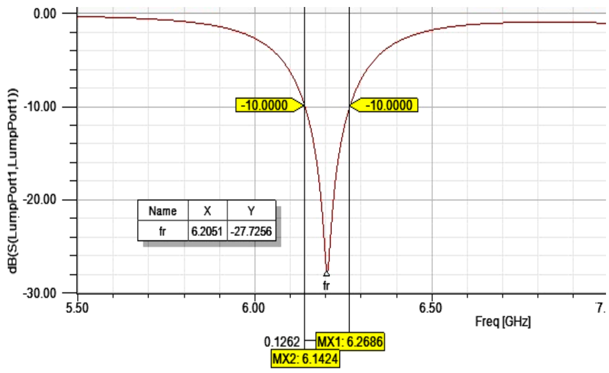

Fig 4: Return loss (S_{11}) of MPA

Thus it has been concluded that with I-Shape DGS, the bandwidth of the microstrip patch antenna (MPA) can be increased by 6.1 MHz (i.e. 132.3 MHz – 126.2 MHz = 6.1 MHz).

3.2 VSWR

Fig. 5 shows VSWR plot of the proposed antenna. At frequency of 6.0718 GHz, the VSWR is 1.009. As the value of VSWR is approximately equal to 1 at resonant frequency (f_r), proposed antenna results in perfect impedance matching.

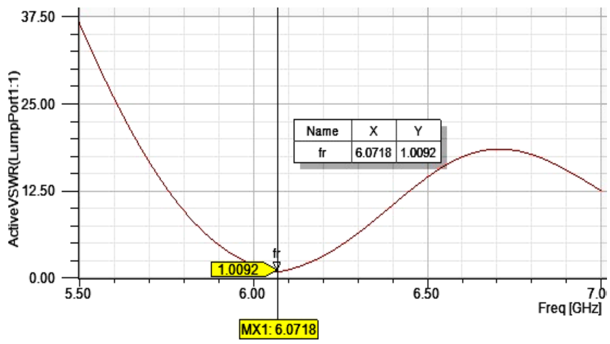

Fig 5: VSWR Plot of I-Shaped Antenna

While the VSWR, in case of simple MPA i.e. without defected ground at resonating frequency f_r= 6.2051 GHz is 1.085 as shown in Fig. 6.

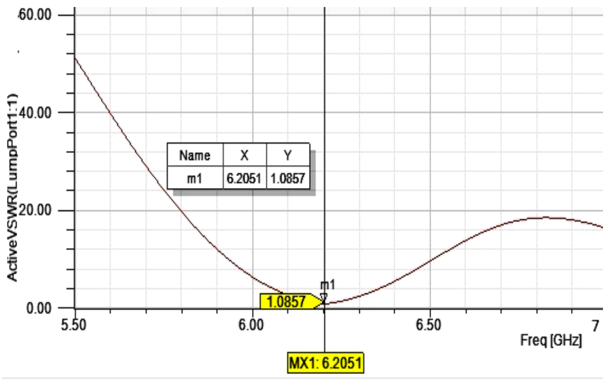

Fig 6: VSWR Plot of MPA

3.3 Total gain

Fig. 7 shows the Polar plot for gain, obtained from I-shaped DGS Antenna. The Total Gain provided by proposed antenna at f_r 6.0718 is 7.91 dB.

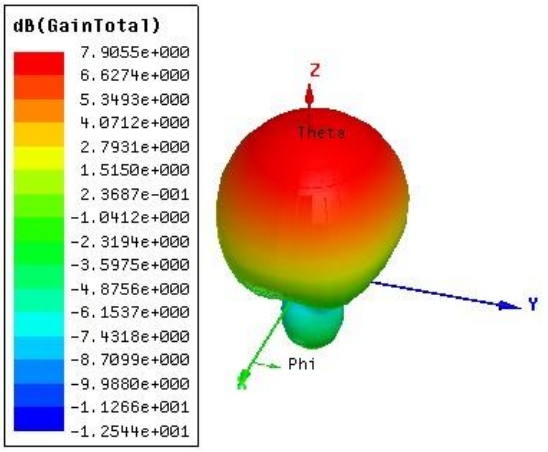

Fig 7: 3D Polar Plot of Total Gain of I-Slot DGS antenna

While the obtained gain, in case of MPA i.e. without defected ground at resonant frequency f_r= 6.2051 GHz is 7.96 dB as shown in Fig. 8.

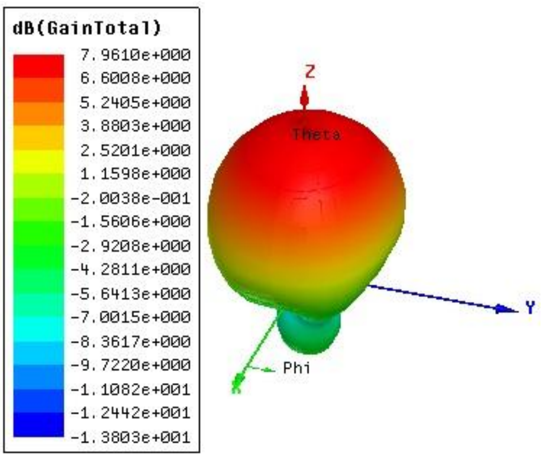

Fig 8: 3D polar plot of Total Gain of simple MPA

3.4 Directivity

Fig. 9 shows the 3D Polar Plot of Total Directivity obtained from I-shaped DGS Antenna. This figure shows that the Total Directivity of the proposed antenna at f_r = 6.0718 is 7.92 dB.

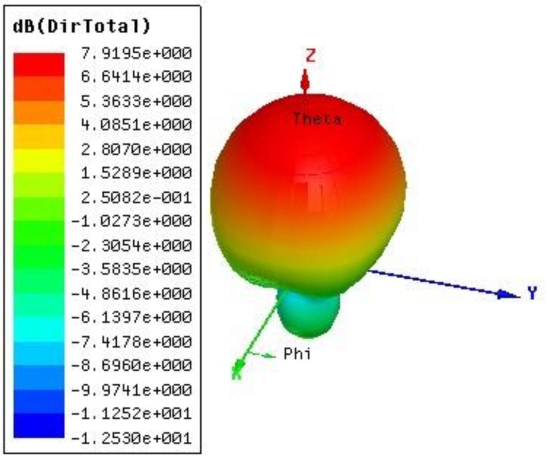

Fig 9: 3D Polar plot of total directivity of I-slot DGS antenna

While the simulated directivity, in case of simple MPA i.e. without defected ground at resonant frequency f_r= 6.2051 GHz is 7.995 dB as shown in Fig. 10.

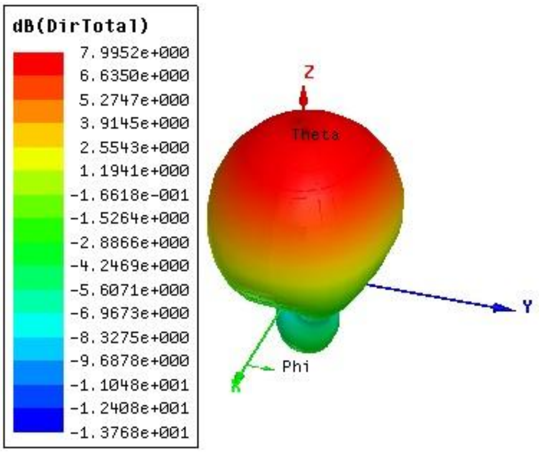

Fig 10: 3D polar plot of total directivity of MPA

Table 2 summarizes the obtained simulation features of the designed antennas.

Table 2. Comparison of simulated results of both antennas

Sr. No.	Parameters	MPA Antenna	I-Shaped DGS Antenna
1.	Resonating Frequency (GHz)	6.2051	6.0718
2.	Bandwidth (MHz)	126.2	132.3
3.	Return Loss (dB)	-27.72	-46.75
4.	VSWR	1.085	1.009
5.	Gain	7.96	7.91
6.	Directivity	7.99	7.92

4. CONCLUSION

A novel antenna design working in C-band has been successfully implemented in this paper. The bandwidth of the microstrip patch antenna with same dimensions as mentioned above but without slotting is 126.2 MHz at f_r 6.2051 GHz with return losses (S_{11} = -27.72 dB) as shown in Fig. 4. While microstrip patch antenna with I-Shape DGS provides bandwidth of 132.3 MHz and return losses reaches up to -46.75 dB as shown in Fig. 3. Thus it has been concluded that with I-Shape DGS, the bandwidth of the microstrip patch antenna is increased by 6.1 MHz. with reduction in ground plane area by 5%.

The proposed antenna design is useful for satellite communications as well as in RADAR.

5. REFERENCES

[1] Islam, Mohammad Tariqul, Mohammed Nazmus Shakib, Norbahiah Misran, and Tiang Sew Sun. "Broadband microstrip patch antenna." *European Journal of Scientific Research* 27, no. 2 (2009): 174-180.

[2] Lo, Terry Kin-chung, and Yeongming Hwang. "Microstrip antennas of very high permittivity for personal communications." In *1997 Asia Pacific Microwave Conference*, pp. 253-256. 1997.

[3] Wong, Kin‐Lu, and Jin‐Sen Chen. "Cavity‐model analysis of a slot‐coupled cylindrical‐rectangular microstrip antenna." *Microwave and Optical Technology Letters* 9, no. 3 (1995): 124-127.

[4] Chen, Jin‐Sen, and Kin‐Lu Wong. "Input impedance of a slot‐coupled cylindrical‐circular microstrip patch antenna." *Microwave and Optical Technology Letters* 11, no. 1 (1996): 21-24.

[5] Dahele, J. S., R. J. Mitchell, K. M. Luk, and K. F. Lee. "Effect of curvature on characteristics of rectangular patch antenna." *Electronics Letters* 23, no. 14 (1987): 748-749.

[6] Yablonovitch, Eli. "Inhibited spontaneous emission in solid-state physics and electronics." *Physical review letters* 58, no. 20 (1987): 2059.

[7] Qu, D., L. Shafai, and A. Foroozesh. "Improving microstrip patch antenna performance using EBG substrates." *IEE Proceedings-Microwaves, Antennas and Propagation* 153, no. 6 (2006): 558-563.

[8] Jin, Nanbo, Ang Yu, and Xuexia Zhang. "An enhanced 2×2 antenna array based on a dumbbell EBG structure." *Microwave and Optical Technology Letters* 39, no. 5 (2003): 395-399.

[9] He, Wei, Ronghong Jin, Junping Geng, and Guoming Yang. "2×2 Array with UC‐EBG ground for low RCS and high gain." *Microwave and optical technology Letters* 49, no. 6 (2007): 1418-1422.

[10] Geng, Jun-Ping, Jiajing Li, Rong-Hong Jin, Sheng Ye, Xianling Liang, and Minzhu Li. "The development of curved microstrip antenna with defected ground structure." *Progress In Electromagnetics Research* 98 (2009): 53-73.

[11] Brown, E. R., C. D. Parker, and Eli Yablonovitch. "Radiation properties of a planar antenna on a photonic-crystal substrate." *JOSA B* 10, no. 2 (1993): 404-407.

[12] Radisic, Vesna, Yongxi Qian, Roberto Coccioli, and Tatsuo Itoh. "Novel 2-D photonic bandgap structure for microstrip lines." *Microwave and Guided Wave Letters, IEEE* 8, no. 2 (1998): 69-71.

[13] Beaky, Matthew M., John B. Burk, Henry O. Everitt, Mansoor A. Haider, and Stephanos Venakides. "Two-dimensional photonic crystal Fabry-Perot resonators with lossy dielectrics." *Microwave Theory and Techniques, IEEE Transactions on* 47, no. 11 (1999): 2085-2091.

[14] Qian, Yongxi, Dan Sievenpiper, Vesna Radisic, Eli Yablonovitch, and Tatsuo Itoh. "A novel approach for gain and bandwidth enhancement of patch antennas." In *Radio and Wireless Conference, 1998. RAWCON 98. 1998 IEEE*, pp. 221-224. IEEE, 1998.

[15] Wang, Xiaojing, Yang Hao, and Peter S. Hall. "Dual-band resonances of a patch antenna on UC-EBG substrate." In *Microwave Conference Proceedings, 2005. APMC 2005. Asia-Pacific Conference Proceedings*, vol. 1, pp. 4-pp. IEEE, 2005.

[16] Zulkifli, Fitri Yuli, Eko Tjipto Rahardjo, and Djoko Hartanto. "Radiation properties enhancement of triangular patch microstrip antenna array using hexagonal defected ground structure." *Progress In Electromagnetics Research M* 5 (2008): 101-109.

[17] Arya, A. K., M. V. Kartikeyan, and A. Patnaik. "Efficiency enhancement of microstrip patch antenna with defected ground structure." In *Recent Advances in Microwave Theory and Applications, 2008. MICROWAVE 2008. International Conference on*, pp. 729-731. IEEE, 2008.

[18] Zulkifli, Fitri Yuli, Eko Tjipto Rahardjo, and Djoko Hartanto. "Mutual coupling reduction using dumbbell defected ground structure for multiband microstrip antenna array." *Progress In Electromagnetics Research Letters* 13 (2010): 29-40.

[19] Lin, Xian-Chang, and Ling-Teng Wang. "A wideband CPW-fed patch antenna with defective ground plane." In *Antennas and Propagation Society International Symposium, 2004. IEEE*, vol. 4, pp. 3717-3720. IEEE, 2004.

[20] Wong, K. L., J. S. Kuo, and T. W. Chiou. "Compact microstrip antennas with slots loaded in the ground plane." In *Antennas and Propagation, 2001. Eleventh International Conference on (IEE Conf. Publ. No. 480)*, vol. 2, pp. 623-626. IET, 2001.

[21] Lin, Shun‐Yun, and Kin‐Lu Wong. "Effects of slotted and photonic bandgap ground planes on the characteristics of an air‐substrate annular‐ring patch antenna in the TM21 mode." *Microwave and Optical Technology Letters* 31, no. 1 (2001): 1-3.

[22] Geng, Jun-Ping, Jiajing Li, Rong-Hong Jin, Sheng Ye, Xianling Liang, and Minzhu Li. "The development of curved microstrip antenna with defected ground structure." *Progress In Electromagnetics Research* 98 (2009): 53-73