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بسم الله الرحمن الرحيم

Design of a Reconfigurable Microstrip Antenna with Defected Ground Structure for 5G System

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Abstract: The paper proposes the design of a reconfigurable microstrip antenna. Defected ground structure (DGS) has been developed to improve characteristics of many devices and enhanced bandwidth also DGS is adopted as an emerging technique for improving the various parameters of microwave circuit therefore in this paper, the antenna design of FR-4 with DGS. The designed antenna is expected to work in four modes depending on PIN state. The antenna operates at resonant frequency (2.6, 5.35,5.43,5.45) GHz. In addition, the VSWR value is between (1-1.4) at the resonant frequency with increase of XXX % in the realized gain compares to the antenna without DGS. DGS enhance the gain, bandwidth and improve the characterizes of the microstrip antenna radiation. The bandwidth reached (540MHz) when PIN 1 and PIN 2 is on. This antenna design, simulation, and performance analysis have been conducted using Computer Simulation Technology (CST) software. This paper focuses on using DGS to improve in the bandwidth, gain and return loss to make it suitable for 5G.

Keywords: reconfigurable, 5G, adaptive modulation, DGS

1. Introduction

Modern wireless communication introduces many day-to-day communication devices, which happen to be vital for human beings. All these devices operate in their own frequency of operation. Hence the need for single antenna operates in various frequency bands has been increased [1]. A reconfigurable antenna is an antenna capable of modifying its frequency and radiation properties dynamically, so it could simultaneously operate in different frequency bands for different communication services, in a controlled and reversible manner. Reconfiguring an antenna is achieved by rearranging the antenna currents or reconfiguring its radiating edges. PIN diodes have been used as the switching elements in the reconfigurable antennas for the purpose of multiple frequency bands operation [2].

Microstrip patch antennas are increasingly gaining popularity for usage in portable wireless system applications due to their light weight, low profile structure, and low cost. Reconfigurable antennas can support more than one wireless standard and deliver the same performance as that of multiple antennas. Hence, reconfigurable antennas have the following advantages: (i) low cost, low volume, simple integration, and good isolation between different wireless standards, (ii) low front-end processing that means no need for front-end filtering and good out-of-band rejection, (iii) best candidate for software-defined radios which can adapt to new surroundings, and (iv) change functionality as per the mission changes, act as a single element or as an array, providing narrow band or wideband as per the requirements. The reconfiguration techniques are presented in Fig. 1 [3].

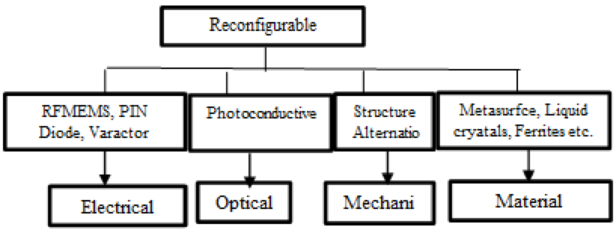


Fig. 1; Antenna reconfiguration techniques.

Reconfiguration is achieved through the integration of switches such as PIN diode, PIN diode, and MEMS switches. A PIN diode is a type of diode whose internal capacity varies with respect to the reverse voltage. It always works in reverse bias conditions and is a voltage dependent semiconductor device. PIN diodes possess the ability to tune the operating frequency continuously and can reduce the circuit complexity. But it provides limited usage due to its disadvantages such as nonlinearity, low dynamic range, and high-power losses. In addition to this, the integration of PIN diode varies the capacitance reactance of the whole antenna structure. Micro- electro- mechanical system (MEMS) switches are a special type of micromachined switches that control radio frequency (RF) signal paths in microwave and millimeter- wave circuits through mechanical motion and contact. RF MEMS switches are small, micromechanical switches that have low power consumption and can be produced using conventional fabrication technology, but it requires high control voltage and longer switching time. Thus, PIN diodes are most commonly preferred due to its fast-switching speed, availability, and easy integration [4]. In [5] designed a reconfigurable antenna that operates in two frequencies band:2.4 GHz the frequency allocated to Wi-Fi application and the 28GHz frequency band for 5G applications. The total size of the antenna is $30 \times 26.5mm^2$, it printed on the FR-4 substrate with a dielectric constant of 4.4 and thickness of 1.6 mm. A metal pad is used to switch the antenna between two frequencies 2.4GHz correspond to Wi-Fi application and 28GHz band for 5G application. In [6] they design and fabricate two proposed microstrip antenna covers multi-band microstrip patch antennas. These proposed antennas cover the useful frequency band of modern wireless communication systems. Antenna_1 covers tri-band frequency, for WiMAX band 2.53 GHz (2.51 – 2.55 GHz), WLAN/C-band band 3.86 GHz (3.80 – 3.87 GHz), and C-band 6.45 GHz (6.19 – 6.60 GHz) which has potential for C-band in 5G services. Antenna_2 covers dual-band for C- band, and X-band 6.92/ 7.707 GHz (6.72 – 7.92 GHz, 1420 MHz) which is serving for C- band and suitable for mid-band 5G application. The proposed design of microstrip patch antennas is characterized as simple structures to be manufactured ($94 \times 76 \times 3.18$ mm^3). Besides, Experimental results verified good conformity with simulation results such as return loss, gain, bandwidth, and radiation pattern of these antennas. In paper [7] has described a numerical analysis on antenna performance of flexible microstrip patch antenna for WBAN application whereas the primary approaches to use rubber material as substrate and the center frequency is 2.45 GHz.

In this paper, a small microstrip patch antenna has been proposed for 5G wireless standard. The stupendous increase in mobile data, technologies are approaching from 4G i.e., fourth generation to 5G, fifth generation. The antenna resonates at10.15 GHz with a return loss of -18.27dB and can be used in future 5G wireless devices. The proposed patch antenna shows good radiation pattern and good gain of 4.46dB. The structure of the antenna is very low profile i.e., 20 mm × 20 mm × 1.6 mm and can be easily integrated into devices where space is a major issue. Simulation results are presented and described. In this work an increment of 7.5% of the realized gain was observed using DGS method. DGS is a technique that can reduce the VSWR, improve the return loss, increase the surface current, so it can say the improvement of the antenna performance. In this work, the enhancement of antenna performance was achieved by using DGS. The inset fed microstrip patch antenna has designed in [8] with DGS structure for ISM band application. The antenna was constructed using Taconic (TLX-8) substrate where the material thickness was only 0.5 mm, the dielectric constant was 2.55 and the loss tangent (Tan δ) at 0.0019 (very few), respectively. In this paper, it has achieved very good, achieved gain at 7.04 dBi and the VSWR at 1.06 only where the material was very thick to use as substrate. With DGS, the reflection coefficient ($S11$) was around -30 dB where the return loss at the designed antenna without DGS at -13.5dB only with -10dB bandwidth of 21 MHz [9]. In [10] Low Profile Frequency Reconfigurable Tri-band antenna for WBAN application is presented. The percentage bandwidth obtained is 3.17, 1.83, and 2.69% at the operating frequencies respectively. Good agreement is observed between the simulated and measured results. A directional radiation pattern obtained at the operating bands becomes more suitable for off-body communication. The simulated SAR value is found within the FCC limit. Thus, the proposed antenna achieves frequency switching alternatively between the application bands individually or tri-band operation simultaneously with quintessential features such as compact size, thin profile, and low SAR values more preferable for real-time applications.

2. Proposed antenna design and configuration

The proposed antenna is designed and simulated using the Computer Simulation Technology (CST) software. The general methodology to model a patch antenna in CST is explained in the flow chart given below in Fig. 2 [4].

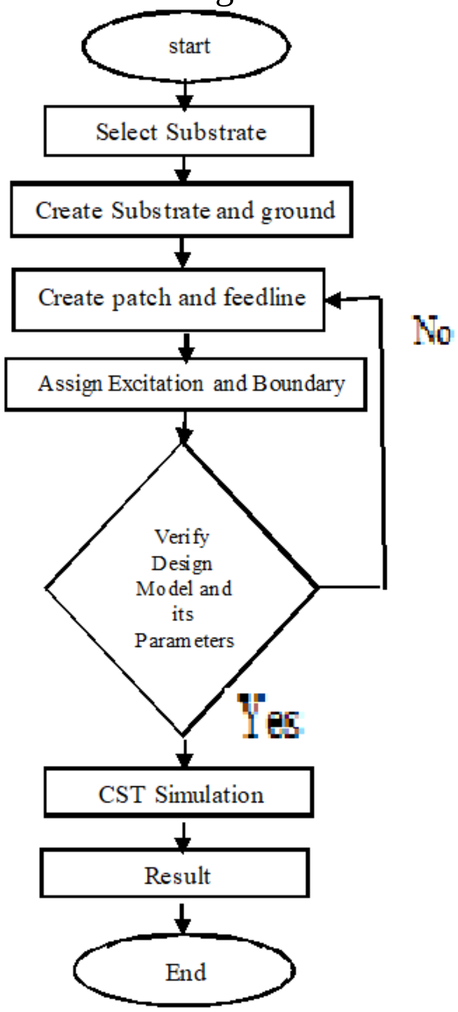
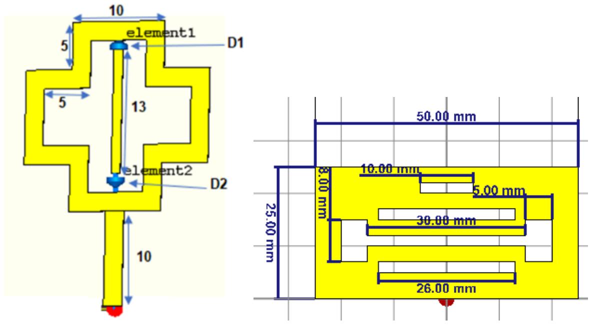


Fig. 2; The antenna simulation flow chart in CST.

The geometry of the proposed frequency reconfigurable antenna is depicted in Fig. 3.An FR-4 substrate is used with think (h=3mm), permittivity ($\varepsilon_r = 4.3$) and loss tangent tan δ=0.025. The patch and the ground of the antenna constructed using a 0.035 mm thick copper with conductivity of 5.710[8] S/m. t substrate dimension is $50 \times 50\ mm^2$. The ground dimension is $50 \times 25\ mm^2$. The patch dimension is $20 \times 20\ mm^2$. The feedline dimension is $10 \times 2\ mm^2$. The substrate dimension is $50 \times 50\ mm^2$ as shown in Fig. 3.



01. (b)

Fig. 3; Proposed Antenna Design: (a) Front view:consisting of patch dimension and (b) Back view (ground plane): including the height of the ground plane with DGS.

Dumbbell shape Defected Ground Structure is used as it improves the performance parameter of antenna based on gain. It increases gain thereby making the antenna more efficient. DGS gained popularity because of its simple structural design and low cost. It suppresses higher harmonics and mutual coupling in the antenna enhancing its bandwidth and gain []. A dumbbell shape DGS has been incorporated on the ground as shown in Fig. 4.

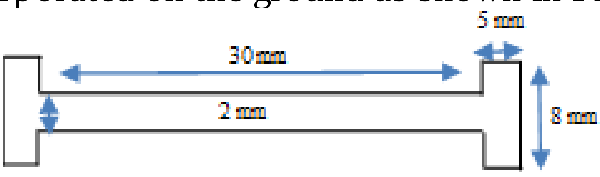


Fig. 4; Dumbbell shaped DGS with dimensions.

3. Operation Process and Theory

Adaptive modulation has the potential to increase the system throughput significantly by matching transmitter parameters to time-varying channel conditions. However, adaptive modulation schemes that rely on perfect channel state information (CSI) are sensitive to CSI imperfections induced by estimation errors and feedback delays [11]. The use of adaptive modulation allows a wireless system to choose the highest order modulation depending on the SNR. Different order modulations allow to send more bit per symbol and thus achieve higher data rate and better spectral efficiency [12]. For this cause, some form of adaptive modulation is projected. The adaptive modulation system is based on the variation in the transmitted power or symbol rate transmission or BER or coding rate/schemes, or any amalgamation of these parameters [13]. The disadvantages of the adaptive modulation need an exact channel estimate at the transmission, added hardware complexity to execute adaptive transmission, and buffering/delay of the input data because the transmission rate vary with channel condition. Fig. 5 shows the main units of (AM) system. The AM is based on SNR measurement and depending on the value of SNR selected the type of modulation [14].

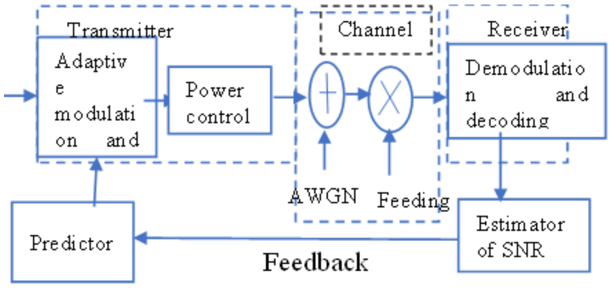


Fig. 5; Typical adaptive modulation system.

When the authors connected between the outer stub using two diodes the response in terms of S_{11} and gain spectra are changed according as seen in Fig. 6 the obtain result are summarized in table 1.

Table I: comparison between DSG and without DGS.

Case	Name of experiment	With DGS	Without DGS
00	Frequency	2.6, 5.35	3.35, 5.1
	Return loss S_{11} dB		
	Bandwidth MHz	65, 400	110
	VSWR	1.14, 1	1.88
	Gain dBi	-3.3, 5	2.9, 2.8
	Directivity	2.7, 6.22	3.6, 5.68
01	Frequency	5.43	4.7
	Return loss S_{11} dB		
	Bandwidth MHz	400	430
	VSWR	1.16	1.45
	Gain dBi	4.57	1.3
	Directivity	6.3	3.4
10	Frequency	5.35	4.8
	Return loss S_{11} dB		
	Bandwidth MHz	386	600
	VSWR	1	1.2

	Gain dBi	4.334	0.5
	Directivity	5.8	3.23
11	Frequency	5.4	4.6
	Return loss S_{11} dB		
	Bandwidth MHz	600	500
	VSWR	1.423	1.3
	Gain dBi	3.086	1.7
	Directivity	5.828	3.4

Table II: comparison between with DSG and without DGS and length of ground=25.

00	F1=2.6GHz	S11=-20	BW=100MHZ	GAIN=-3.254dBi	D=2.964 dBi
	F2=5.4GHz	S11=-35	BW=400MHZ	GAIN=4.82dBi	D=6.197 dBi
01	F1=5.4GHz	S11=-22	BW=400MHZ	GAIN=6.29 dBi	D=6.29 dBi
10	F1=5.4GHz	S11=-32	BW=400MHZ	GAIN=4.34 dBi	D=5.801
11	F1=5.45GHz	S11=-14	BW=600MHZ	GAIN=3.086 dBi	D=5.828

Table III: comparison between with DSG and length of ground=50.

00	F1=2.4GHz	S11=-41	BW=40MHZ	GAIN=-4dBi	D=6dBi
01	F1=2.4GHz	S11=-13	BW=70MHZ	GAIN=-6 dBi	D=5.5dBi
10	F1=2.4GHz	S11=-11	BW=600MHZ	GAIN=-6 dBi	D=5 dBi
	F2=5.4GHz	S11=-20	BW=50MHZ	GAIN=6 dBi	D=7 dBi
11	F1=5GHz	S11=-14	BW=60MHZ	GAIN=5 dBi	D=7 dBi

4. Results and Discussions

This section displayed the simulation results of proposed Antenna design in S-parameter. It is selected three frequency bands (5.35, 5.43 and 5.4 GHz) because they have good results in S11 and gain. The simulation is done by CST microwave studio software.

A- Return losses

A mount of power reflected from the antenna due to termination mismatch determines the performance of the designed antenna S_{11} is represents the return losses or back losses. S_{11} is achieve matching on equal or less than -10. As S_{11} become, much smaller antenna performance improves due to lower losses. From Fig. 6. We observed S_{11} is matching in 5.35, 5.43 and 5.4 GHz as operating frequencies in different PIN diode states.

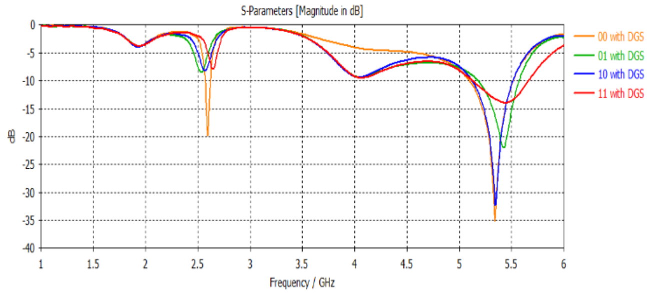


Fig. 6; S_{11} parameter of the proposal design.

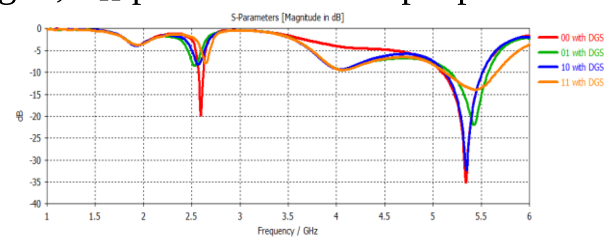


Fig. 7; S_{11} parameter of the proposal design with DGS and length of ground equal 25mm.

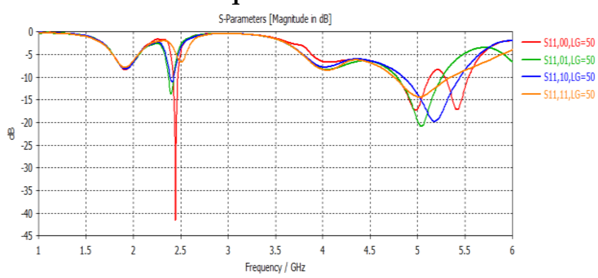


Fig. 8; S_{11} parameter of the proposal design with DGS and length of ground equal 50mm.

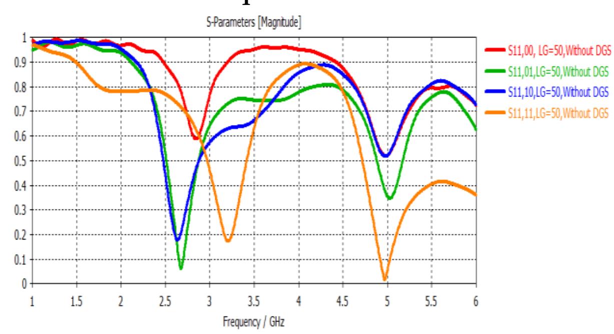


Fig. 9; S_{11} parameter of the proposal design without DGS and length of ground equal 50mm.

B- Gain spectra

Antenna gain of four cases results are shown in Fig. 10. the antenna gain is measured 3dBi, 2.8 dBi on 3.35GHz and 5.1 GHz respectively in case1. In case2 gain is measured 1.3 dBi on 4.7GHz, case3 realized 0.5 dBi on 4.8GHz and in the last case, the gain is 1.7 dBi on 4.6GHz.

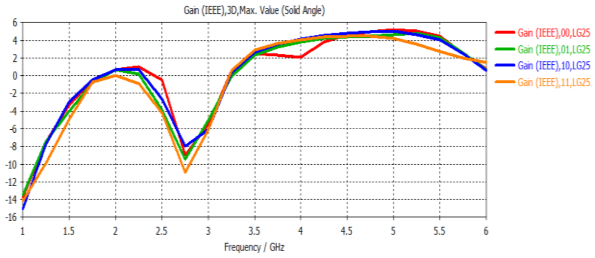


Fig. 10; Antenna gain spectra with DGS and length of ground=25mm.

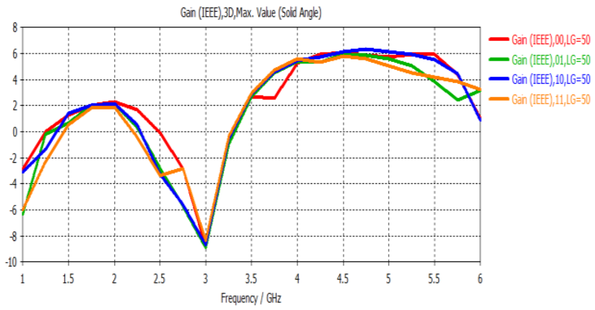


Fig. 11; Antenna gain spectra with DGS and length of ground=50mm.

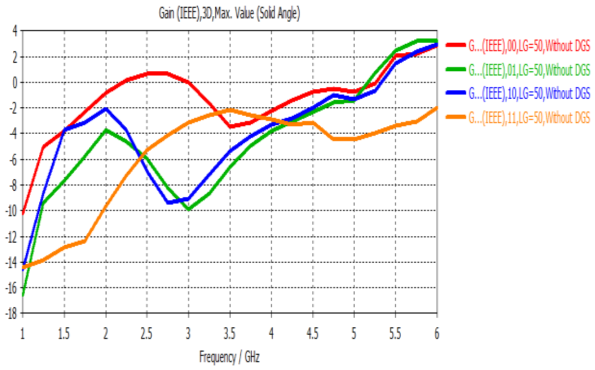


Fig. 12; Antenna gain spectra without DGS and length of ground=50mm.

B- Comparison with other studies

From Table 2, it can be observed analysis comparison between many references. The design recorded in [11] antenna works in multi-band frequency, but have two frequencies only but in this paper have four states to a chive five frequency.

Table 2: Comparison with other published results.

Ref.	No. of bands	Re-configurable	Size/mm	Frequency/GHz	BW	gain
[1]	Multi-band	Yes	30 × 26.5 × 1.6	2.4,2.8	32.5M 2.57G	___

[2]	Single -band	No	$20 \times 20 \times 1.6$	10.15	380M	4.46
[3]	Multi-band	TM_{01}, TM_{11}, TM_{12}, TM_{02}	--------	2.49	9%	6.5 8.8
[4]	Multi-band	No	$47 \times 38 \times 3.18$	2.51,2.55, 6.7,7.9	70, 410 M	7.31,8.81, 10.6, 5.56, 6.22
[7]	Single -band	Yes	$30 \times 30 \times 3.2$	3.35-3.77 3.4-3.73	11% 10%	4.8
[8]	Single -band	Yes	$62 \times 43 \times 1.6$	2.4	108M 105M	3.01 2.11
Proposed antenna	Multi-band	Yes	$50 \times 50 \times 50$	3.35,5.1,4.7, 4.8,4.6	110, 430, 600, 500M	3, 2.8, 1.3, 0.5, 1.7

4. Conclusion

In this paper, the proposed Reconfigurable antenna has been designed for 5G applications The antenna shows matching S11 less than -10. The antenna gain is found 3, 2.8 dBi on 3.35 and 5.1 GHz on case1. In case2 gain is measured 1.3 dBi on 4.7GHz, case3 realized 0.5 dBi on 4.8GHz and in last case, gain is 1.7 dBi on 5.6GHz. The simulation results are done by using CST microwave studio software.

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