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Design of Quad-bandAntenna for Wireless Communications

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Abstract:The project includes the design of multi-band microstrip antennaforGSM 900MHz, GSM 1800MHz,ISM 2.4GHz and WiMax 3.5GHz frequencies.The multi-band operation is achieved by etching rectangularslots on the ground plane of a Microstrip antenna.The simulation is performed with commercial electromagnetic software IE3D, using FR4 substrate. To demonstrate the effect of substrate parameters on the dimension of the antenna structure and multi-resonant operation, simulations are carried out with TMM10i and RO 4350 substrates. Antenna parameters are tabulated and compared for all the substrates. Antenna with RO4350 substrate performance is found to be better compared to other substrates considered.

Keywords: Quad Band Antenna,Microstrip slot Antenna, Multiband antenna, Simulation, IE3D.

I. INTRODUCTION

The wireless communication devices such as cell phones, handheld devices use Worldwide Interoperability for Microwave Access (WiMax), Global system for mobile communications (GSM), Wireless Local Area Network (WLAN), and Industrial Scientific and Medical (ISM), Code division multiple access (CDMA) frequency bands. Conventional antenna designed in a wireless communication system will operate in any one frequency band. However there is a need to design a multiband antenna which can work at multiple frequencies.Rapidgrowth in the communication field lead towards the configuration of minimized gadgets with multi-functionalities. Wireless sensors are outfitted with various applications like ISM, GSM, DCS, GPS, WiMax range of frequencies. As antenna being the key segment of wireless communication devices, the requirement is to design small, lightweight, inexpensive and conformal antennas with multi-resonant features.

Printed designs are well known because of their conformal aspects which permit simple combination with the planar PCBs. It has been noted that a wireless communication device provides the ability to integrate multiband operation. Therefore, a multiband antenna is attractive in many commercial applications as it is designed to have a single radiator with a capability to transmit and receive multiple frequencies.In high-performance aircraft, spacecraft, satellite, and missile applications, where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints, and low-profile antennas may be required. Presently there are many other government and commercial applications, such as mobile radio and wireless communications that have similar specifications. To meet these requirements, microstrip antennas can be used. The idea of Microstrip slot antenna is developed from slot antenna fed by a strip line which has various guaranteeing features, for example, capability to create unidirectional and bidirectional radiation pattern with larger bandwidth for data transmission. Strip and slot synthesis offers extra level of opportunity in configuration of multi-resonant antenna [1]. A Microstrip antenna with slot contains a rectangular cut in the ground plane such that the rectangular cut is normal to the Microstrip line conductor. The field of Microstrip line energize the rectangular slots. For efficient excitation of the slot, the strip is either short circuited through the dielectric substrate to the edge of slot or strip line is ended in an open circuited stub outside the edge of the cut slot [2].

The Microstrip exited rectangular slot antenna has been studied theoretically and experimentally by many researchers. The full wave rigorous analysis is the most accurate so far. These techniques are computationally very intensive and are based on the use of reciprocity theorem and integral equation in a manner similar to the waveguide exited by slot. The analysis is carried out in spectral domain is found in [3-4]. For the given slot size, resistance observed at the feed line can be made small in three possible ways [5]. The first possible way is off-centred feeding suggested by Yoshimura. The second is tuning of the slot by employing stubs as suggested by the Pozar [6]. This technique is very similar to previous one except that the length L_m of the Microstrip stub is longer than a quarter wavelength. The rectangular slot to accomplish single and dual resonance frequency of operations on the ground plane is discussed in [7-8].

The proposed antenna is designed and optimized for multi-resonant operation by etching the slots on the ground plane. The simulations are performed with commercial electromagnetic software IE3D for substrates FR4, RO4350 and TMM10i.

II. ANTENNA GEOMETRY AND DESIGN

A. Antenna Geometry

The geometry of quad band slot antennahasfour rectangular slots which provide four different resonant current paths. The length of each slot is just half of the guided wavelength calculated at corresponding frequency of interest. Horizontal and vertical slots have been designed of same size of 0.25λg and the total length of slot 0.5λg.The width of slot decides bandwidth, higher the slot width, higher is the bandwidth [8]. Offset distance is provided to slot for impedance matching. The geometry of proposed antenna is shown in fig.1. The specification of antenna design and optimized dimension of the antenna structure are depicted in table1.

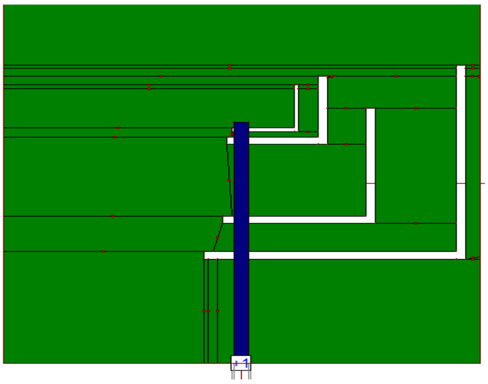

Fig.1The proposed quad band Microstrip antenna Simulation Model

TABLE I
ANTENNA DESIGN PARAMETERS

Parameters	Specification
Frequencies of resonance (f_r)	900MHz,1800MHz,2.4GHz,3.5GHz
Dielectric constant (ε_r)f substrate	4.4
Thickness of substrate	1.6 mm
Feeding method	Microstrip line feed
Ground plane Width (W)	50mm
Ground plane Length(L)	50mm

B. Calculation of slot length

The geometry of antennahas horizontal slot length A_n and vertical slot length $B_n$given in [8]. The total length of slot is first estimated by using equation (1).

$$A_n+B_n \cong \frac{\lambda_g}{2} \qquad (1)$$

Where,

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \qquad (2)$$

$$\lambda_0 = \frac{c}{f} \qquad (3)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{W}\right)^{1/2} \qquad (4)$$

From equation (1), the slot length is half of the effective wavelength that is inversely related to effective dielectric constant of antenna. So higher the dielectric constant lesser will be the slot length so antenna will be compact. Table II shows the optimized slot parameters for proposed quad band antenna design for various frequencies. Where L_{mn}represent position of the slot from top edge of microstrip feed line and r_n represent offset distance from centre y axis of microstrip feed line.S_n represents the slot width. Suffix 'n' is used to represent parameters values for n[th] resonant frequency.Based on the operating frequency, the overall effective inner slot length (A_n+B_n) is designed to be $(\lambda g)_n/2$, where $(\lambda g)_n$ is the guided wavelength corresponding to n[th] resonant frequency.The parameters L_{mn} and r_n are adjusted to satisfy the desired impedance matching. Since there is an inverse relationship between frequency and guided wavelength, the smallest slot length will corresponds to highest frequency.

TABLE II
DESIGN SLOT PARAMETERS AT VARIOUS FREQUENCIES OF QUAD BAND ANTENNA

$A_n+B_n \cong \frac{\lambda_g}{2}$			
Resonant Frequency f_n	**Width of slot S_n**	**Offset distance r_n**	**L_{mn}**
0.9 GHz	2mm	8mm	35 mm
1.8 GHz	2 mm	4mm	26 mm
2.4GHz	2mm	3mm	4 mm
3.5 GHz	1 mm	2 mm	1.6 mm

C. Calculation of Microstrip line width

The Microstrip line is designed for impedance of 50Ω in order to match the feed line impedance, which is given by equation (5) given in [9].

$$\frac{w}{h} = \frac{2}{\pi}\left[B-1-\ln(2B-1) + \frac{\varepsilon_r-1}{2\varepsilon_r}\left\{\ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}\right\}\right] \qquad (5)$$

Where, h is thickness of the substrate.
W is width of microstrip line.
ε_r is the dielectric constant of the substrate.
And B is defined in [9] as-

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}} \qquad (6)$$

III. SIMULATION RESULTS AND DISCUSSION

Simulation results of designed quad band antenna are discussed in this section.

A. S parameter v/s frequency

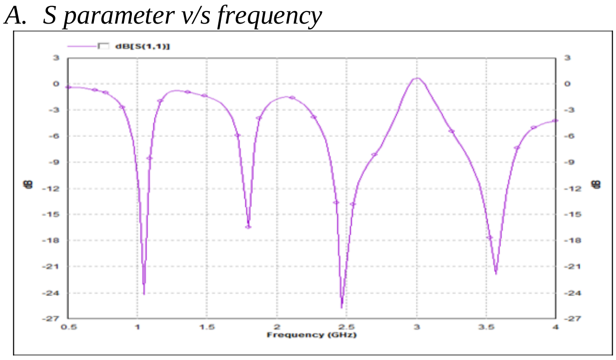

Fig.2S11(dB) v/s frequency

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B. *VSWR v/s frequency*

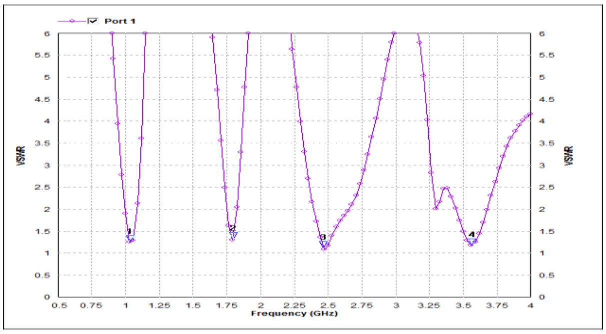

Fig.3 VSWR v/s frequency

C. *Total Field Gain v/s frequency*

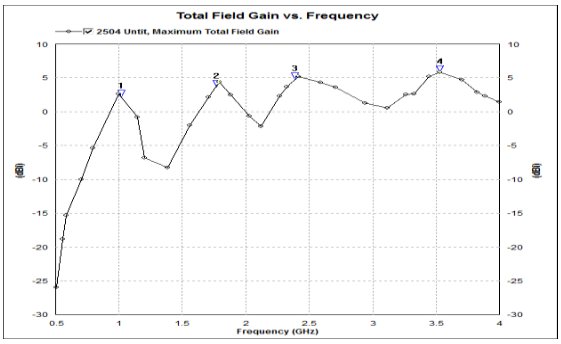

Fig.4Gain(dB) v/s frequency

D. *Elevation pattern plot at resonating frequencies*

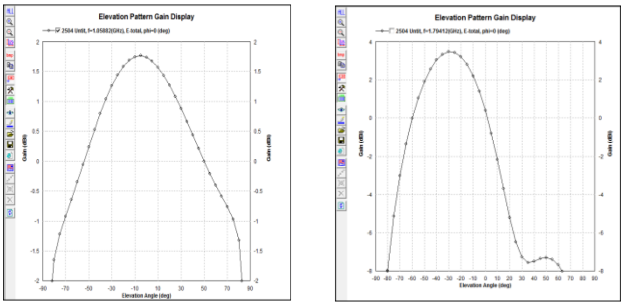

Fig.5Elevation pattern plot at first two resonating frequencies of 0.9GHz band and 1.8GHz band

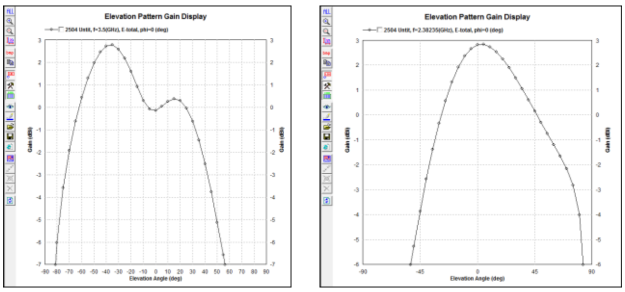

Fig.6Elevation pattern plot at last two resonating frequencies of 2.4GHz band and 3.5GHz band

Fig.2, Fig.3 and Fig.4 represent S11 (dB), VSWR, and Gain respectively. The antenna is resonating at four frequencies i.e. 1GHz, 1.8GHz, 2.4GHz and 3.5GHz. At 1000MHz, S_{11} parameter of -24dB, VSWR of 1.35 and gain of 2.2 dB is obtained. At 1800MHz, S_{11} of -16dB, VSWR of 1.38 and gain of 4.2dB is obtained. At 2400MHz, S_{11} of -25dB, VSWR of 1.04and gain of 4.9dB is obtained is shown in figure3.55. At 3500MHz, S_{11} of -21dB, VSWR of 1.2and gain of 5.1dB is obtained.

Fig 5 and 6 shows 2D radiation patterns at resonating frequencies. For all resonating frequencies S11 obtained is less than -10dB and ensuring multiband operation.Further simulations are carried out with two other substratesto demonstrate the effect of substrate parameters on antenna dimension and antenna characteristics. The simulated results are tabulated in table III.

TABLE III
SIMULATION RESULT OF QUAD BAND ANTENNA

Substrate Used (ε_r)	Frequency	Antenna Dimension (L*W) mm^2	S_{11} (dB)	VSWR	Gain (dB)
RO4350 (3.38)	900MHz	70*70	-15	1.6	2.3
	1800MHz		-35	1.8	2.5
	2.4GHz		-12	1.4	5.2
	3.5GHz		-18	1.2	5.4
FR-4 (4.4)	900MHz	50*50	-25	1.35	2.2
	1800MHz		-21	1.38	4.2
	2.4GHz		-24	1.04	4.9
	3.5GHz		-16	1.2	5.1
TMM10i (9.9)	900MHz	40*36	-13	1.9	1.8
	1800MHz		-11	1.8	1.8
	2.4GHz		-13	1.89	2.76
	3.5GHz		-20	1.3	3.2

From the table III, it is concluded that the designed antenna by using rectangular slot on ground plane can be used for various wireless communication applications. For all the three substrates which are used for simulations, the gain of greater than 2dB and return loss of less than -10dB is obtained for all the resonating frequencies. Among all three substrates considered, the performance of the antenna in terms of gain is better for RO4350 substrate. However the dimension of antenna structure is more.

IV. CONCLUSION

A Quad-band antenna with rectangular slots on the ground plane isdesigned.Theantenna structure is simulated and optimized to operate in GSM 900MHz and 1800MHz, ISM 2.4GHz and WiMax 3.5GHz frequencies. Antenna parameters are compared for various substrates. A substrate with higher dielectric constant can reduce the dimension of the antenna structure without compromising on the multi-resonant operation. The simulated antenna designs have to be fabricated and are to be tested for gain and S-parameters.

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