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Performance Evaluation of Rectangular Microstrip Patch Antennas Loaded with Plastic and Barium-Titanate Substrates at GSM 1800 MHz Band

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Abstract

In this paper, the resonance and radiation characteristics of patch antennas fabricated with two different types of dielectric substrates have been investigated and compared at GSM 1800 MHz band. At first, the above-stated characteristics of a patch antenna loaded with conventional plastic substrate have been investigated. Later a high permittivity dielectric material (barium titanate) has been used as the antenna substrate. The main goal here is to reduce the antenna size with a high permittivity dielectric material and then to compare its resonance and radiation performance with the earlier low permittivity substrate loaded prototype. It is found that with the use of high permittivity substrate the antenna volume gets smaller (about 6% of the plastic substrate prototype) although the gain decreases by around 2.5 dB.

Keywords

Patch Antennas, Size Reduction, Barium Titanate, GSM Bands

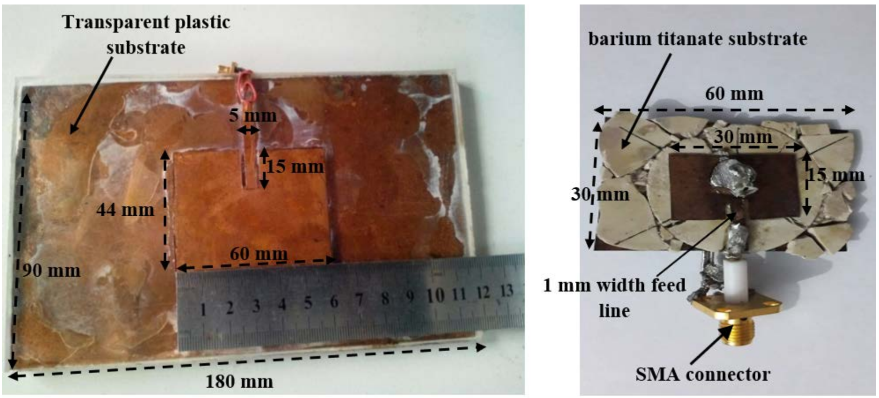
1. Introduction

Microstrip patch antennas are generally low-profile antennas which yield significant gain in the broadside direction. However, the resonance and radiation characteristics of these sort of antennas are mainly dependent on the dielectric materials used as the antenna substrates [1] [2]. Low dielectric permittivity materials (ε_r = 2.0 - 5.0) are generally less lossy, hence traditionally are being used as the substrates of the patch antennas [3] [4]. Another advantage of using low permittivity material is: radiation in patch antennas are caused by fringing fields from the edges, and the substrates having low permittivity enhances the fringing effect thus maintaining good radiation efficiency [5]. The drawback of using a lower permittivity material as the antenna substrate is the subsequent necessity of a relatively larger sized radiator, which might be an issue in sophisticated RF systems where space is a major concern. Deployment of artificial electromagnetic structures, such as metamaterials, metasurface etc. in the vicinity of an antenna can reduce its size by exciting unconventional resonant modes below the first order mode [6] [7]. However, the laboratory fabrication of process of metamaterial is quite cumbersome [8] [9]. When this is the fact, by using high permittivity material as the antenna substrate, the antenna size can be made compact. But high permittivity materials used as the antenna substrates induces surface waves which in turn causes the antenna's radiation efficiency to degrade significantly [10] [11]. Apart from this, high permittivity substrate causes the quality factor of the antenna to increase, which eventually yields poor resonance bandwidth [12]. Despite all these unconducive factors, high permittivity materials are still being used extensively in planar types of antennas for size reduction purpose [13] [14]. Moreover, high permittivity substrates used in microstrip transmission lines prevents spurious radiations since the electric fields become strongly bound there. To summarize things up, a trade-off has to be made among gain, bandwidth, and antenna size to harness the optimum performance from the antenna while choosing the substrates.

Modern communication systems are getting way to complicated, which necessitates the use of simultaneous high gain and compact antenna systems. Due to its high gain and planar nature, patch antennas are very suitable for use in the devices requiring GSM applications [15] [16]. Plastic is a low dielectric permittivity substrate whereas barium titanate possesses very high permittivity which is also ferroelectric in nature. In this paper, the resonance and radiation performance of patch antennas loaded with plastic and barium titanate substrates at GSM 1800 MHz band have been explicated. The organization of the paper is as follows: antenna geometry and structure has been described first; in the subsequent section, simulation and measurement results of the antennas have been shown; and in the final section, conclusion and scopes for future research with these sorts of antennas have been predicted. It is seen that the simulated and measured results of both the antennas are in good agreement with each other.

2. Antenna Geometry and Structures

The fabricated antenna structures and geometries are shown in **Figure 1**. The permittivities of both the substrates were measured by impedance analyzer. The permittivity of plastic was measured to be 3.101, while that of the barium titanate was 32.23. Based on the measured permittivities, the antenna dimensions were then fixed following relevant formulae [17]. The required sized (90 mm × 180 mm × 8 mm) plastic substrate was prepared from commercially available plastic slab to support the metallic structures of patch and ground. On the



(a) (b)

Figure 1. Fabricated patch antenna prototypes (a) with plastic substrate; (b) with barium titanate substrate.

contrary, barium titanate is usually available in powered form. So suitable shaped substrate discs were prepared in the laboratory. The discs were then glued to from a rectangular shaped substrate structure (30 mm × 60 mm × 4.5 mm) which was later sandwiched with metallic structures to form the antenna. The laboratory fabrication process of barium titanate has been described in [18].

As the first prototype, plastic loaded rectangular patch antenna was fabricated as shown in **Figure 1(a)**. The patch length and width are 44 mm and 60 mm respectively. The other dimensions of the antenna are also indicated in the figure. As the second prototype shown in **Figure 1(b)**, a GSM 1800 MHz patch antenna was fabricated by using barium titanate as the substrate.

The length and width of the patch and the ground are 14.7 mm and 28.9 mm respectively. The other dimensions are shown in **Figure 1(b)**. Due to the high dielectric permittivity of barium titanate, the antenna size shrinks drastically. In fact, this antenna occupies just 6.5% volume of the earlier prototype.

3. Simulation and Measurement Results

3.1. Resonance Characteristics

The primary important characteristic of an antenna is its resonance bandwidth. To say this, the reflection co-efficient (S_{11}) of the antenna has to fall below −10 dB. This is the acceptable limit for most antenna applications. However, this requirement is quite flexible for some applications, like mobile communications where −6 dB value of S_{11} is still fine [19]. It was not possible to measure the reflection coefficient for the fabricated antennas due to the unavailability of VNA (Vector Network Analyzer). However, the antennas were simulated by keeping the same dimensions and parameters in Ansys HFSS software [20]. The simulated reflection coefficients for both plastic and barium titanate loaded antennas are shown in **Figure 2**.

From **Figure 2(a)**, it is seen that the reflection co-efficient of the plastic loaded antenna falls well below −10 dB, which is quite satisfactory. However, in

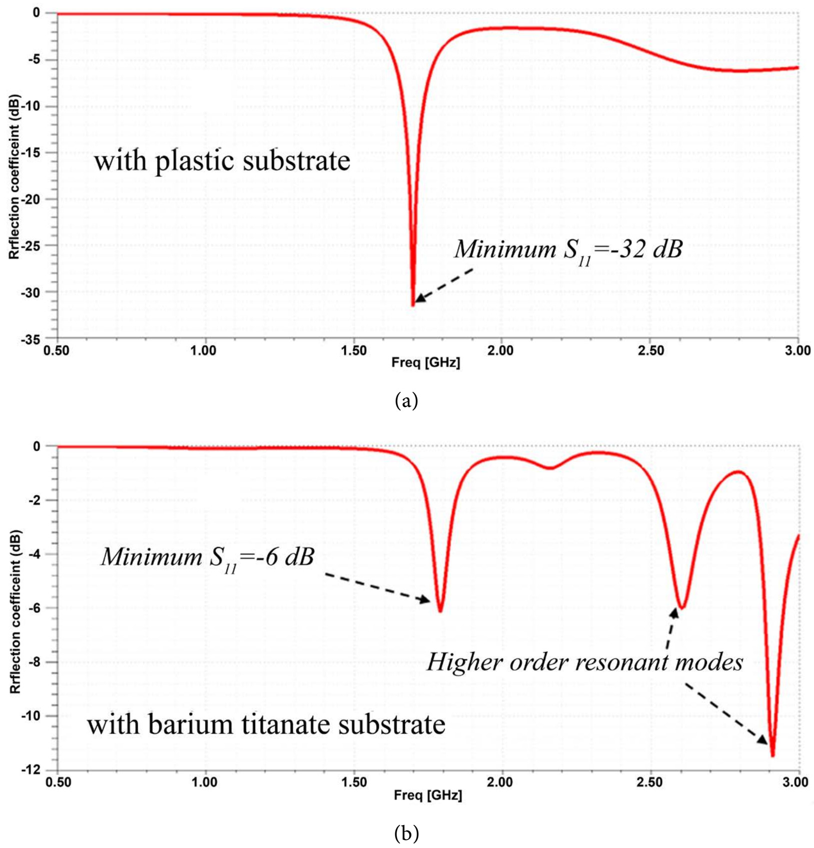


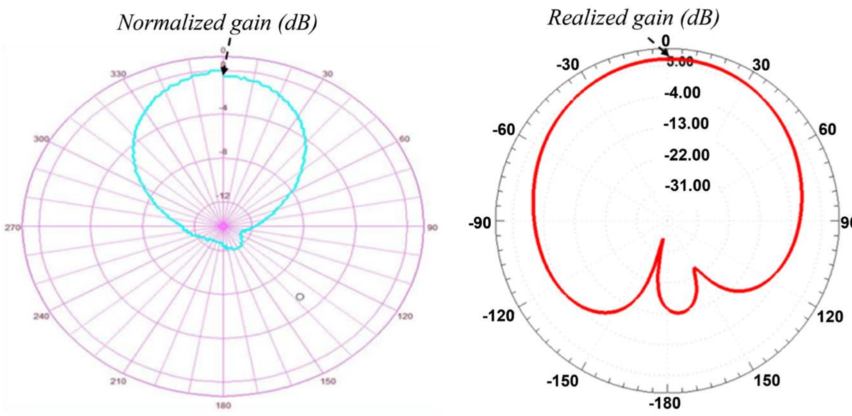
Figure 2. Simulated reflection coefficients (S_{11} parameters) of the patch antennas (a) with plastic substrate; (b) with barium titanate substrate.

case of the barium titanate loaded patch as shown in **Figure 2(b)**, the minimum S_{11} is −6 dB, which means around 75% of the incident power is still being delivered to the antenna. Considering GSM antenna applications, this amount of reflection co-efficient is normally acceptable. Moreover, several higher order resonant modes are also visible for this antenna. After investigating the radiation patterns of these modes, it was found that the radiation is mainly skewed from broadsided with a slightly reduced gain.

3.2. Radiation Characteristics

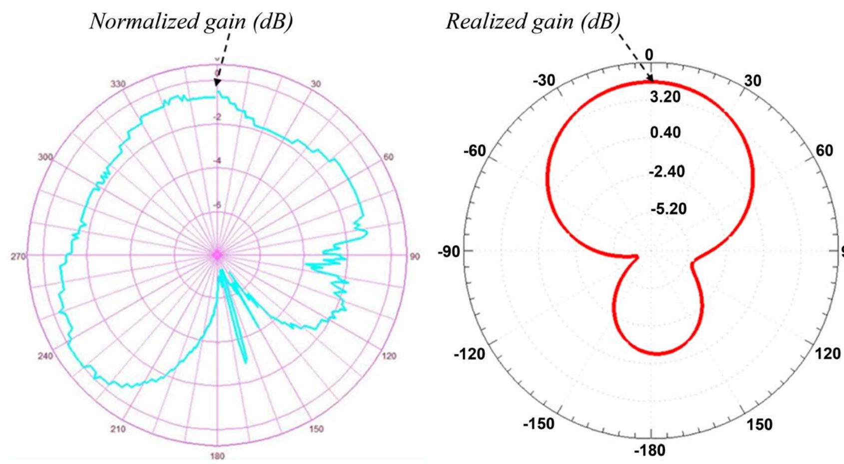
The radiation characteristics of the fabricated antennas were measured in the laboratory. Later these were compared with the simulation. **Figure 3** shows the comparison of radiation pattern of the patch antenna fabricated with plastic substrate in elevation plane. It is seen that at 1.8 GHz the gain in the broadside is 7.01 dB. Due to the presence of a low permittivity substrate, the side lobes are also minor which is always desirable in modern communication system.

The radiation characteristics of the antenna fabricated with barium titanate substrate is shown in **Figure 4**. It is seen that the gain of the antenna is comparatively low. The cause of low gain may be attributed to the surface waves created due to the high permittivity substrate. From the simulation result, it is



(a) Measurement (b) Simulation

Figure 3. 2-D radiation pattern comparison in elevation plane (phi = 90˚ cut) at 1.8 GHz for plastic loaded patch antenna, (a) Experimental result (normalized gain in dB); (b) Simulation result (realized gain in dB).



(a) Measurement (b) Simulation

Figure 4. 2-D radiation pattern comparison in elevation plane (phi = 90˚ cut) at 1.8 GHz for barium titanate loaded patch antenna, (a) Experimental result (normalized gain in dB); (b) Simulation result (realized gain in dB).

seen that the maximum gain seen at the broadside is 4.49 dB. Therefore, in this case also, both the experimental and simulation results showed good matching which was quite challenging for the case of such a small radiator.

Finally, the properties of the two antennas have been summarized in Table 1.

4. Conclusion and Future Work

In this research, two rectangular patch antennas have been simulated and fabricated by using two different types of dielectric substrates at GSM 1800MHz band. Comparing the performances of these antennas, it can be said that with the use of high permittivity barium titanate substrate, the volume of the antenna has been decreased to 6% of the volume with original plastic loaded patch, thus providing a compact sized radiator. However, the gain decreases by around 2.5

Table 1. Comparison of antenna performances for different substrates.

Properties	*Antenna Substrate Types*	
	Plastic	Barium Titanate
Antenna size	90 mm × 180 mm × 8 mm	30 mm × 60 mm × 4.5 mm
Resonant Frequency	1780 MHz	1790 MHz
Maximum realized gain (dB)	7.1	4.489
Minimum Reflection coefficient (dB)	−32 dB	−6 dB

dB due to the presence of high permittivity substrate. This is the trade-off that has to be made in order to implement a smaller sized antenna at the same desired frequency. The future works involve multiband, broadband, multi-polarization, and arrayed versions of these antennas.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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