The impact of dielectric materials on patch antenna efficiency in the 2 and 5 GHz bands

#Lingjian Li, Geoffrey.S.Hilton, Dominique.L.Paul
Centre for Communication Research, the University of Bristol
1.31, Merchant Venturer Building, Woodland Road, Bristol, BS8 1UB, UK
Lingjian.li@bristol.ac.uk

Abstract

This paper presents a robust and repeatable method to determine patch antenna efficiency in relation to its dielectric material. Measured results show that antenna efficiency varies significantly with both dielectric materials and frequency. Replacing cheap dielectric materials can improve antenna efficiency by up to approximately 5dB.

Keywords: Antenna Efficiency Dielectric materials

1. Introduction

In recent years, one of the major research topics on mobile networks is energy consumption reduction. Efficient antenna solutions can significantly improve system efficiency, thus reducing the power consumption in the whole network. Dielectric loss is determined as a dominating force in dictating antenna efficiency performance in [1]. By using air as the substrate for planar antennas, dielectric loss will be minimised and the antenna efficiency will be maximised. However, for many applications, dielectric substrates are still desirable because of their many advantages including the simplicity for commercial manufacturing and the capability of the direct integration with RF circuits through PCB technologies [2] [3]. Therefore, it is important to study the impact of dielectric materials on antenna efficiency to achieve a balanced performance on efficiency and costs.

This paper compares the efficiency performance of patch antennas fabricated on different dielectric substrates. Experiments have been carried out at 2.15GHz, 2.4GHz and 5.25GHz. The three frequencies are within bands of important applications: 3G Mobile networks operate in the range of 2.11-2.17GHz for downlink communications. Wireless network of IEEE 802.11b and 802.11g standards use the 2.4 GHz band, while WLAN IEEE 802.11a occupies the frequency bands around 5.2GHz. Three typical commercially-available dielectric materials were selected as the antenna substrates for the comparison experiment. Details of the materials are presented in Table 1. Note that the figures for loss tangent are approximate values and might vary slightly with frequency.

Table 1: Dielectric properties of materials used in the experiment

Dielectric material	Dielectric constant	Loss tangent
Rogers RT/Duroid 5880	2.2	0.0009
Arlon AD320	3.2	0.0044
FR4	4.7	0.0160

2. Measurement results of input response and radiation patterns

Fig.1 shows the geometry of the microstrip antennas used in the experiment. All antennas were fed by single probes. The thickness h for all substrates is 1.6mm. The dimensions ($W \times L$) and feed position d of each antenna were determined by FDTD simulations to give a good matching performance at the specific frequency. In order to determine the antenna efficiency, the input response and three-dimensional radiation patterns have been measured. The full results for 2.4GHz and 5.25GHz are presented. The results for 2.15GHz are similar to those for 2.4GHz and a summary will be given at the end of the paper.

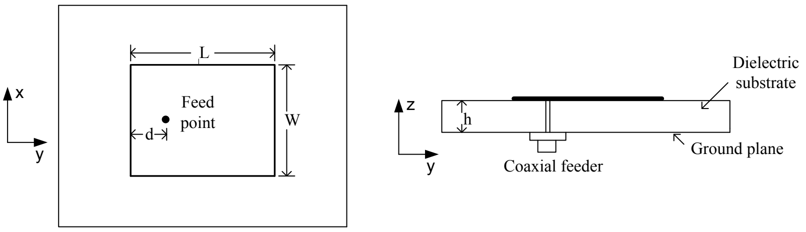


Figure 1: Configuration of the patch antennas used in the experiment

2.1 Measurement results for 2.4GHz

Fig.2 shows the input response for the patch antennas resonating at around 2.4GHz. All antennas are well matched at 2.4GHz, with the reflection coefficients all better than -13dB.

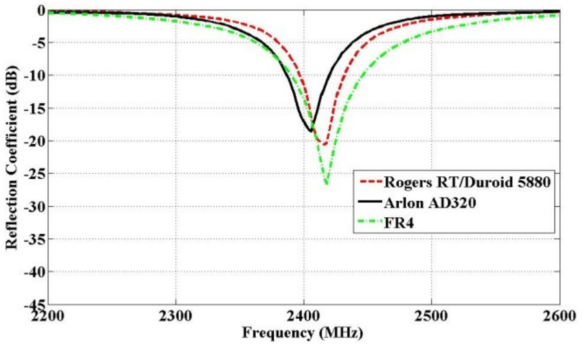
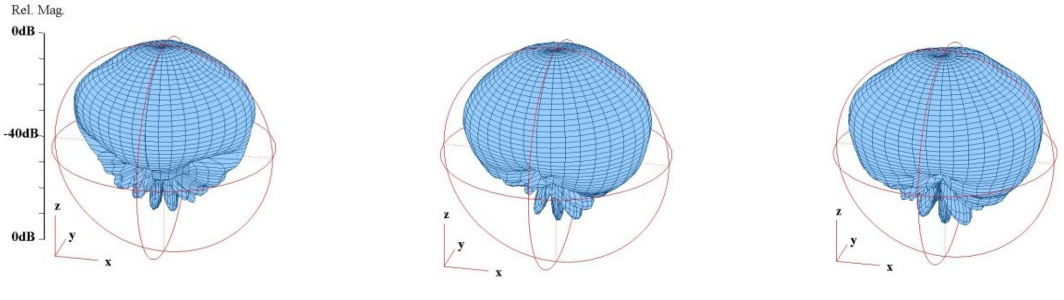


Figure 2: Input response of patch antennas resonating at around 2.4GHz

Fig.3 shows the 3-D radiation patterns of co-polarisation measured at 2.4GHz. All antennas have good polarisation purity. Cross polarisation was also taken into account for the efficiency measurements but only contributes up to 3% of the total radiated power. All three patterns are similar to each other, indicating that these antennas are suitable for comparison measurements.



(a) Duroid patch antenna (b) Arlon patch antenna (c) FR4 patch antenna

Figure 3: Co-polarisation radiation patterns measured at 2.4GHz

2.2 Measurement results for 5.25GHz

The input response of patch antennas fabricated for a resonance at around 5.2GHz is shown in Fig.4. The reflection coefficients for all antennas are below -15dB at 5.25GHz.

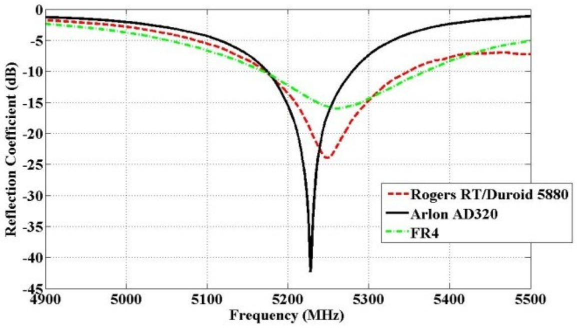
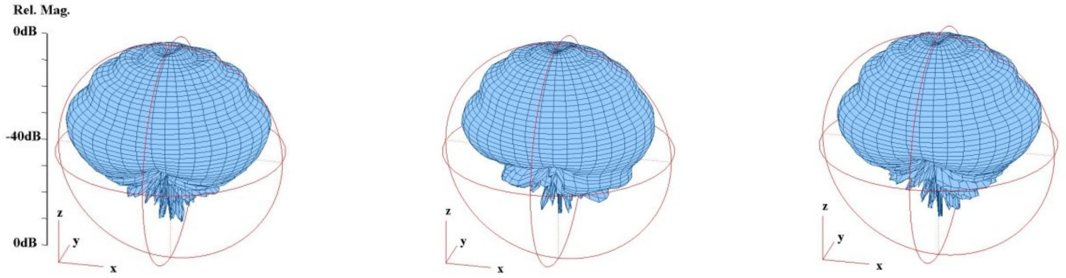


Figure 4: Input response of patch antennas resonating at around 5.2GHz

Fig.5 shows the radiation patterns of the three patch antennas measured at 5.25GHz. Again, a high level of similarity has been achieved for all patterns. Cross-polarisation levels for all antennas are below 6% of the total transmitted power.



(a) Duroid patch antenna (b) Arlon patch antenna (c) FR4 patch antenna

Figure 5: Co-polarisation radiation patterns measured at 5.25GHz

3. Efficiency comparison results

Various antenna efficiency measurement techniques have been recorded in the literature, such as the widely used Wheeler Cap method [4] and the Gain/Directivity method [5]. In this experiment, the purpose was to measure the efficiency of patch antennas relative to a benchmark. Patch antennas with the lowest dielectric loss tangent (i.e. with Duroid substrate) were used as the reference/benchmark antenna at all frequencies. The efficiency of other patch antennas was measured by comparing their total radiated power to that of the reference antenna, provided that all antennas were measured under the same condition. The antennas were mounted on a circular ground plane with a diameter of 60cm. Equation (1) summarises this method, in which the total radiated power of an antenna is measured by integrating the electric fields on its full radiation pattern. In equation (1), the electric fields of the radiation patterns of the tested antenna and reference antenna are represented by E_t and E_r respectively. Input response was considered in the calculation to exclude the effect of mismatch loss. Reflection coefficients are represented by $\mathit{\Gamma}_t$ and $\mathit{\Gamma}_r$ for the tested and reference antenna respectively. Since all antennas are well-matched at the measured frequencies, the effect of mismatching is minimal.

$$\eta_r = \frac{\oiint_s |E_t|^2 d\Omega}{\oiint_s |E_r|^2 d\Omega} \times \frac{(1-\mathit{\Gamma}_r)}{(1-\mathit{\Gamma}_t)} \qquad (1)$$

It is also very important to determine the error margins in the final efficiency results. As a result of the triple travel due to cabling mismatch, periodical ripples of an approximate level of ±0.3dB occur in the measured transmission response. Through method in [1], the error margin in the efficiency results for 2.15GHz and 2.4GHz is determined to be ±8%, while the maximum error margin is ±10% for the 5.25GHz results. Note that this is the worst-case-scenario analysis by adding up all possible errors in the system. The realistic error margin may be smaller than the values given in the paper.

The efficiency of the FR4 and Arlon antennas relative to the Duroid antennas, η_r is shown in Table.2. The efficiency values are shown both in percentage and decibels. It can be concluded that dielectric materials play a significant role in determining antenna efficiency. Rogers RT/Duroid 5880, with the lowest dielectric loss tangent, shows significant advantages in terms of efficiency performance at 2.15GHz and 2.4GHz. At the higher frequency of 5.25GHz, however, the benefits of using Duroid become less obvious. Considering the availability and price of these materials, there might not be an advantage of replacing very cheap FR4 substrate with Duroid. Arlon AD320 is the most cost-effective material for antenna substrate at 5.25GHz. Note that although the size of the patch was scaled down from 2GHz resonance to 5GHz resonance, the substrate thickness was not scaled. The same substrate thickness of 1.6mm was used for all frequencies in this experiment. These figures might vary if different substrate heights were used for the 5.25GHz antennas.

Table 2: Measured efficiency of FR4 and Arlon patch antennas relative to Duroid patch antennas, η_r

Frequency(GHz) Dielectric	2.15	2.4	5.25
FR4	35±8% -4.6±0.9dB	44±8% -3.6±0.8dB	57±10% -2.5±0.8dB
Arlon AD320	60±8% -2.3±0.5dB	67±8% -1.8±0.5dB	96±10% -0.2±0.4dB

4. Conclusions

The results of the comparison experiments in the 2 and 5 GHz bands show that patch antenna efficiency varies significantly with the selection of dielectric materials, while the efficiency performance of the same dielectric material varies in relation to frequency. Rogers RT/Duroid 5880 ($\mathcal{E}_r$=2.2) with the lowest dielectric constant and loss tangent demonstrates good efficiency performance at 2.15GHz and 2.4GHz. Measurement results show that the use of Arlon AD320 ($\mathcal{E}_r$=3.2) as the antenna substrate will result in a power reduction of approximately 2dB relative to the use of Duroid in the 2GHz band. However, provided that a substrate of the same thickness is used at 5.25GHz, the efficiency performance of Arlon is very close to Duroid in the higher band. Therefore Arlon has a better overall performance in terms of both efficiency and cost for 5GHz applications. FR4 ($\mathcal{E}_r$=4.4) is the cheapest and most widely used material for antenna substrate. However, employing FR4 as the substrate will cost a power reduction of approximately 3-5dB in the 2GHz band and 2-3dB in the 5GHz band respectively compared to the use of Duroid. Future research will investigate the variation of antenna efficiency in relation to the substrate thickness.

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Acknowledgments

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