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<td><strong>Citation</strong></td>
<td>IEEE Antennas and Wireless Propagation Letters, 8 MAY 2012 (Journal), 2012</td>
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<td><strong>Issued Date</strong></td>
<td>2012</td>
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Multiband and Wideband Monopole Antenna for GSM900 and Other Wireless Applications

Hattan F. Abutarboush, Member, IEEE, H. Nasif, R. Nilavalan, Senior Member, IEEE, and S. W. Cheung, Senior Member, IEEE

Abstract—In this letter, the design of a compact monopole antenna for multiband and wideband operations is proposed. The antenna has three distinct frequency bands, centered at 0.94, 2.7, and 4.75 GHz. The antenna has a compact size of only $30 \times 40 \times 1.57 \text{ mm}^3$ including the ground plane. The multiband and wideband operations are achieved by using an E-shaped slot on the ground plane. The design procedure is also discussed. The frequency bands can be independently controlled by using the parameters of the E-slot. The impedance bandwidth, current distributions, radiation patterns, gain, and efficiency of the antenna are studied by computer simulation and measurements.

Index Terms—E-shaped slot antenna, independent control, multiband antenna, small antenna, wideband antenna.

I. INTRODUCTION

DESIGN of compact antennas to support several standards simultaneously for wireless devices has been an interesting research topic for studies in industry and academia. The demand for smaller wireless devices to work in different standards has increased significantly. Compact antennas with multiple-band and wideband operations are vital for future wireless system. The antennas in future must be able to have not only multiband operation, but also wide bandwidths, simple structures, compact sizes, and the ability to easily integrate with RF circuits. Achieving these requirements is quite a challenge. The monopole antenna, with its attractive advantages of low weight, low cost, and wide bandwidth, is one of the preferred technologies to satisfy these requirements.

In literature, different ways of generating multiband and wideband operations in a single antenna have been proposed, e.g., using a trapezoid conductor on the backside of the antenna [1], inductive slot [2], additional sleeve [3], shorting wall [4], U-slot antenna [5], double L-slit [6], coupled V-slot [7], split-ring monopole antenna [8], inverted-L monopole antenna [9], defected ground plane [10], and using single-cell metamaterial loading [11]. However, most of these antennas could not cover the Global System for Mobile Communications (GSM900) band, which, at such a low frequency, requires a relatively large antenna size for which to cater.

In this letter, a planar monopole antenna with an E-shaped slot cut on the ground is proposed for multiwideband operation that includes the GSM900 system at low frequency and other different wireless systems such as the Wireless Local Area Network (WLAN) IEEE 802.11 b/g, Bluetooth, Satellite Digital Multimedia Broadcast (S-DMB), IEEE 802.11y, Worldwide Interoperability for Microwave Access (WiMAX), and free licensed WLAN at 5-GHz band. The novelties of the design include: 1) using an E-slot to create the GSM900 or GSM800 band on a single-band antenna without the need to increase the antenna size; 2) creating two wide frequency bands at higher frequencies using the same E-slot; and 3) achieving independent control on the frequency bands, which allows the antenna to be easily designed for other applications. In addition, the proposed antenna has the advantages of small size, low profile, simple configuration, and cheap production. The low profile of the antenna makes it a promising candidate for future compact and slim wireless devices.

II. DESIGN OF WIDEBAND AND MULTIBAND ANTENNA

A. Antenna Geometry

Fig. 1. (a) Layout and (b) prototype of antenna.

The structure of the proposed monopole antenna with a microstrip feed is shown in Fig. 1(a), which consists of a rectangular radiator, a 50-$\Omega$ microstrip feed line, and a ground plane. The antenna is designed on an FR-4 substrate with an overall area of $30 \times 40 \text{ mm}^2$ and a thickness of 1.57 mm.
An E-shaped slot is cut on the ground plane to create a longer current path to excite a narrow band at 0.94 GHz and, at the same time, to achieve two wide bands for other systems. The design of the antenna is optimized using the High Frequency Simulation Software (HFSS) with the main dimensions listed in Table I.

### Design Steps

The design procedure can be described using Fig. 2 as follows.

**Step 1:** A monopole antenna with microstrip feed as shown in Fig. 2 is first designed to operate in a single band at approximately 3.7 GHz and optimized in terms of minimizing the reflection coefficient. The result is shown in Fig. 2.

**Step 2:** An inverted T-shaped slot is cut on the ground plane as shown in Fig. 2 to perturb the current path and so to create dual-band operation. It can be seen from the result of Fig. 2 that adding the inverted T-shaped slot shifts the 3.6-GHz frequency band to about 4.25 GHz and, more importantly, creates a low-frequency band at around 1 GHz without requiring increasing of the antenna size.

**Step 3:** Two vertical slots are cut at both ends of the horizontal slot of the inverted T-shaped slot to form an E-shape (rotated anti-clockwise by 90°) as shown in Fig. 2. The result in Fig. 2 shows that cutting these two vertical slots lowers the low-frequency band from 1 to 0.94 GHz without requiring increasing of the antenna size.

### Current Distributions

The behavior of the antenna is further studied using current distribution. The resonant frequencies of 0.94, 2.7, and 4.75 GHz, as indicated in Fig. 2, have been used for studies. The results obtained by using HFSS are shown in Fig. 3(a)–(c).

**D. Parametric Analysis and Independent Control**

In our design, we aim to have the ability to independently control the individual frequency bands so that we can easily change them for other applications without the need to redesign the whole antenna again. To have independent controls, we need to identify the current paths responsible for the individual bands as discussed in our previous works [12]–[14], and then find out along the edge of the whole E-shaped slot on the ground plane. The length of this current path can be changed using parameter $S_6$ (i.e., the width of the middle slot of the E-slot) shown in Fig. 1(a), which in turn can be used to control the resonant frequency. Although other parameters could also help to serve the same purpose, they would change the current paths responsible for resonances of the other two bands. The major current path at the resonant frequency of 0.94 GHz as indicated in Fig. 3(a) has a length of about 2.75 mm, which is corresponding to approximately 0.5&lambdabar, where $\lambda$ is the wavelength at the resonant frequency given by $\lambda = \lambda_0 / \sqrt{\varepsilon_r + 1}/2$, with $\lambda_0$ being the free-space wavelength. At the higher frequency of 2.7 GHz, Fig. 3(b) show that the current concentrates more at the edges of the E-slot on the left-hand side. The length of this current path can be changed using parameter $S_7$ as shown in Fig. 1(a). Since the resonances at 2.7 and 3.6 GHz together form a single wide band, $S_7$ can be used to control this band. At 2.7 GHz, the current path indicated in Fig. 3(b) has a length of about 32 mm, corresponding to approximately 0.5&lambdabar. The simulation results in Fig. 4(b) show that this current path along $S_7$ has the strongest distribution and so is the main current path. Although $S_7$ has strong current distribution, it is much less than that of $S_1$ and so is not the main current path for radiation. As a result, $S_2$ is not used in calculating the current path. At 4.75 GHz, Fig. 3(c) shows that the current concentrates more at the edges on the right-hand side of the E-slot, thus the length of the current path can be altered by using parameter $S_3$. The major current path indicated in Fig. 3(c) has a length of about 19 mm, corresponding to approximately 0.5&lambdabar. Note that at these resonances, the slot serves as the major radiating element.

### TABLE I

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<td>S_3</td>
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<td>9</td>
<td>6</td>
<td>17.5</td>
<td>14.6</td>
<td>5.1</td>
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Fig. 2. Steps of designing proposed antenna.

Fig. 3. Simulated current distribution at (a) 0.94, (b) 2.7, and (c) 4.75 GHz.
Fig. 4. Effect of changing some parameters of antenna on the 
performances at (a) 0.94, (b) 2.8 and 3.6, and (c) 5 GHz.

the corresponding structural parameters to independently alter
the lengths of these individual current paths. From the current
distribution discussions in Section II-C, we have identified
the current paths responsible for the frequency bands and the struc-
tural parameters, i.e., \( S_8 \), \( S_7 \), and \( S_5 \), used to change these cur-
rent paths and hence the frequencies. A parametric study has
been carried out to determine the effects of these parameters on
the resonant bandwidths and frequencies. Fig. 4(a) shows that
\( S_8 \) can be used to independently control the lower frequency
band without affecting the other bands, as expected. Fig. 4(b)
shows that \( S_7 \) can be used to control the two middle wide bands,
and Fig. 4(c) shows that \( S_5 \) can be used to shift the highest fre-
quency band over a wide range without affecting the other two
bands.

III. MEASURED RESULTS

A. Reflection Coefficient and Bandwidth

The antenna has been fabricated as shown in Fig. 1(b). The simu-
lated and measured reflection coefficients \( S_{11} \) of the anten-
a are shown in Fig. 5 and in good agreement. The little
discrepancies might be due to factors such as fabrication and mea-
surement tolerances. It can be seen that the antenna can
operate in three distinct frequency bands centered at 0.94, 2.8,
and 5 GHz with impedance bandwidths (\( S_{11} < -10 \) dB) of
5.29% (912–972 MHz), 54% (2.390–3.943 GHz), and 44%
(4.689–5.324 GHz), respectively. These frequency bands
can cover the applications listed in Table II. Although the
allocated bands for the GSM systems in the US and Europe
are 824–894 MHz (GSM800) and 880–960 MHz (GSM900),
respectively, the frequency band 912–972 MHz in our current
design can be easily tuned to match the either GSM systems
using parameter \( S_8 \) as demonstrated in Fig. 4(a). Moreover,
simulation results have shown that the bandwidth of the
frequency band can be improved to cover the GSM800 or
GSM900 systems by using parameter \( S_8 \). For example, with
\( S_8 = 0.35 \) mm and \( S_5 = 18 \) mm, the frequency band obtained
has a bandwidth of 80 MHz, which can cover the GSM900
band as shown in Fig. 4(a). The other two distinct bands of the
proposed antenna form a wide frequency band that can cover
the other applications listed in Table II. Other applications in
the 5-GHz band can also be possibly covered by adjusting the
key parameters of the antenna as demonstrated in Fig. 4(c).

B. Radiation Patterns, Gain and Efficiency

The radiation patterns, gain, and efficiency are measured
using the antenna measurement equipment StarLab, manu-
factured by Satimo [15]. Before any measurement is done,
calibration is carried out by using the standard antennas pro-
vided. For radiation pattern and gain measurements, it is just
like other antenna measurement equipment. For power ef-
ciciency measurement, the equipment first measures the gain,
radiation intensity, and reflection coefficient of the antenna
and automatically computes the directivity using the radiation
intensity using software. The efficiency of the antenna is then
computed using the equation

\[
\text{Efficiency} = \frac{G(\theta, \phi)}{D(\theta, \phi)(1 - \Gamma)}
\]
where $\Gamma$ is the voltage reflection coefficient, and $G(\theta, \phi)$ and $D(\theta, \phi)$ are the gain and directivity, respectively, of the antenna and are functions of spherical coordinate angles $\theta$ and $\phi$. The directivity is calculated by using the radiation intensity [16]. The simulated and measured radiation patterns for co- and cross polarizations in the $xz$- and $xy$-planes at the frequencies of 0.94, 2.8, 3.6, and 5 GHz are shown in Fig. 6(a)–(d), respectively. Again, they show fairly good agreements. The measured peak gain and radiation efficiency of the antenna are shown in Fig. 7. The measured efficiencies are about 55%, 72%, and 82% in the 0.94-, 3.25-, and 5-GHz bands, respectively, with the corresponding peak gains of −3.67, 1.34, and 4.94 dBi.

Considering the small size of the antenna, these efficiency and gain values are acceptable. Computer simulations on efficiency and peak gain of the antenna have also been carried out. The simulated results (which are not shown in here to save space) have shown that, in these frequency bands, the gains of the antenna are about 0.5 dBi higher than those of the measured results, and the simulated efficiencies are about 6% higher.

IV. CONCLUSION

The design of a monopole antenna with a compact size of only $30 \times 40 \times 1.57$ mm$^3$ for multiband and wideband operations has been presented. An E-shaped slot cut on the ground plane is used to generate a low frequency band for GSM900 and two other high frequency bands with much wider bandwidths for many other applications. These frequency bands can be independently controlled by using the structural parameters of the E-slot. Simulation and measurement results have shown that the antenna has stable radiation pattern, high efficiency, and high gain in all the operating frequency bands.

REFERENCES