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5. CONCLUSION

In this letter, as a new design method of a filter, a closed form equation of tapped feeding has been presented and discussed. Also, a $\lambda_g/2$ stub BPF and $\lambda_g/4$ stub BPF with narrow bandwidth have been presented using the equivalent circuits of the tapped-line geometry. The parameters of the tapped-line geometry are obtained by input (output) admittance toward source (load) of the filter prototype, and the proposed tapped-line geometry is composed of the open-stub and the additional transmission-line which have a negative electrical length.

The proposed design method using the equivalent circuit of the tapped-line geometry can be applied to several filters’ design such as an edge-coupled filter, a combline filter, an interdigital filter, and so on. Because stub filter doesn’t need coupling mechanism, its design procedures are simple. Also, the suggested stub filter design allows narrower bandwidth implementation compared to the conventional stub filter which is typically provided only with wide bandwidth. The proposed filter is easily implemented and integrated with other devices and circuits.

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monopole element and a coupled-fed shorted monopole element, different from the design in [15] and also capable of generating two wide operating bands covering GSM850/900/1800/1900/UMTS for penta-band WWAN operation. In addition, the antenna studied in this article is printed on a 0.4-mm thick FR4 substrate, thinner than that in [15], making it more attractive for thin-profile laptop computer applications. Further, a more realistic system ground plane consisting of the display ground plane (or the supporting metal frame of the laptop display) and the keyboard ground plane (or the main ground plane) is used in the study, which can provide more informative results for the internal WWAN antenna employed in the laptop computers.

For considering the case of the laptop computer equipped with a touch panel, the user’s hand effects are also analyzed, because the user’s hand can be very close to the embedded internal WWAN antenna, when it is pointing close to or at the top edge of the touch panel. In this case, since the user’s hand is a very glossy material [16–20], its effects on the antenna performances, especially on the radiation pattern and radiation efficiency, may not be negligible. The obtained results based on the user’s hand model provided by SPEAG SEMCAD [21] are presented and discussed.

2. STUDIED ANTENNA

Figure 1(a) shows the geometry of the studied uniplanar printed WWAN laptop computer antenna. Detailed dimensions of the antenna’s metal pattern are given in Figure 1(b). The studied antenna is printed on one surface of a 0.4-mm thick FR4 substrate. The antenna comprises a shorter radiating strip, a longer radiating portion and an antenna ground. For application in the laptop computer, the antenna is mounted along and at the center of the top edge of the display ground plane. Through the fixing points C and D in the antenna ground, the antenna is electrically connected to the display ground plane, which is further connected to the keyboard or main ground plane to be considered as the system ground plane in this study. Both the display and keyboard ground planes are of the same dimensions 200 × 260 mm², which are reasonable for general laptop computers. The two ground planes are fabricated using a 0.2-mm thick copper plate in the experiment, and the angle between the two ground planes are denoted as α, which is set to be 90° in the experiment.

In the studied antenna, the shorter radiating strip (section JA in Fig. 1(b)) is a simple direct-fed monopole of length about 36 mm, close to a quarter-wavelength at about 1900 MHz. One end of the shorter radiating strip is the feeding point A, which is spaced 0.2 mm to the antenna ground. Across the 0.2-mm spacing, a 50-Ω mini coaxial line is applied with its central conductor and outer grounding sheath connected to point A and point B (the grounding point in the antenna ground), respectively, for testing the antenna.

The longer radiating portion consists of a longer radiating strip (section IE) short-circuited to the antenna ground and a coupling part. The longer radiating strip has a length of about 98 mm (about a quarter-wavelength at 900 MHz) and is capacitively excited through the coupling part which comprises two coupling strips (sections GE and GF) and a feeding strip of length \( t \) 14 mm. The coupling excitation mechanism is applied to achieve a dual-resonance excitation in the 900 MHz band to obtain a wide operating band covering GSM850/900 operation [15, 22–25]. Also note that to enhance the coupling in the condition of a thin (0.4 mm only) dielectric substrate used, there are two coupling strips applied, both spaced a coupling gap of 0.3 mm to the feeding strip to achieve the required coupling effect. Through adjusting the length \( t \) of the feeding strip (the length of the two coupling strips fixed to be 13.5 mm), the desired coupling effect can be controlled.

3. RESULTS AND DISCUSSION

The antenna was fabricated and tested. Figure 2 shows the measured and simulated return loss of the fabricated prototype. Good agreement between the measured data and the simulated results obtained using Ansoft HFSS [26] is verified. Two wide operating bands at about 900 and 1900 MHz are seen to be generated. With the 3:1 VSWR or 6-dB return loss definition, the bandwidths of the

![Figure 2](image-url)
two operating bands easily cover GSM850/900/1800/1900/UMTS operation.

Figure 3 shows a comparison of the simulated return loss and input impedance of the studied antenna and the reference antenna (corresponding PIFA with a direct feed). Both the two antennas are of the same size. From the simulated return loss shown in Figure 3(a), it is observed that the lower operating band at about 900 MHz cannot be excited with good impedance matching for the reference antenna. For the upper operating band, there are very small differences for the two antennas. This can be explained from the simulated input impedance shown in Figure 3(b); it is seen that the very high input impedance level for the reference antenna at around 900 MHz is greatly decreased to be about or smaller than $100 \Omega$ with two resonances (zero reactance), which results in the successful excitation of a dual-resonance excitation for the desired lower operating band to cover GSM850/900 operation. As for the input impedance level at around 1900 MHz, very small differences are seen, which agrees with the results observed in Figure 3(a).

Effects of the longer radiating portion and the shorter radiating strip are studied in Figure 4. The results indicate that for the case with the shorter radiating strip only, the 900 MHz band cannot be excited and there is one resonant mode occurred at about 1900 MHz for the upper-band operation. As for the case with the longer radiating portion, the desired lower-band operation can be ob-

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Figure 3  Comparison of the HFSS simulated (a) return loss and (b) input impedance of the studied antenna and the reference antenna (corresponding PIFA with a direct feed). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Figure 4  Simulated (HFSS) return loss of the studied antenna and the two cases with the longer radiating portion or the shorter radiating strip only. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Figure 5  Simulated (HFSS) return loss as a function of the length $t$ of the feeding strip; other dimensions are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]
tained, and in addition, a higher-order resonant mode is excited at about 2000 MHz. This higher-order resonant mode at about 2000 MHz and the resonant mode at about 1900 MHz contributed by the shorter radiating strip are formed into the desired wide operating band for GSM1800/1900/UMTS operation.

Effects of the length \( t \) of the feeding strip are analyzed in Figure 5. The simulated return-loss results for the length \( t \) varied from 10 to 14 mm are presented. Large effects on the impedance matching of the 900 MHz band are seen. This behavior is reasonable, since the variations in the length of the feeding strip will result in variations in the capacitive excitation of the longer radiating portion. However, this also indicates that by adjusting the length \( t \), good excitation of the desired dual-resonant lower operating band can be fine-tuned. It is also noted that very small effects are seen on the upper operating band. This behavior indicates that the desired lower and upper bands can be separately controlled by the longer radiating portion and the shorter radiating strip, respectively.

Figure 6 shows the simulated return loss as a function of the angle \( \alpha \) between the display and main ground planes. Results show that there are very small variations for the angle \( \alpha \) varied from 90° to 120°. This indicates that the orientation between the display and main ground planes has small effects on the impedance matching of the embedded internal WWAN antenna studied here.

Radiation characteristics of the antenna are also studied. Figure 7 plots the simulated and measured three-dimensional (3-D) total-

\[ \begin{align*}
\text{Figure 6} & \quad \text{Simulated (HFSS) return loss as a function of the angle \( \alpha \) between the display and main ground planes. Other dimensions are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]}
\end{align*} \]

\[ \begin{align*}
\text{Figure 7} & \quad \text{(a) Simulated (HFSS) and (b) measured 3-D total-power radiation patterns of the studied antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]}
\end{align*} \]

\[ \begin{align*}
\text{Figure 8} & \quad \text{Measured antenna gain and radiation efficiency of the studied antenna. (a) Lower band for GSM850/900 operation. (b) Upper band for GSM1800/1900/UMTS operation. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]}
\end{align*} \]
power radiation patterns of the antenna at 860, 925, 1795, 1920,
and 2045 MHz, about the central frequencies of the five operating
bands. The measured and simulated radiation patterns are gener-
ally seen to be in agreement. Figure 8 shows the measured antenna
gain and radiation efficiency of the antenna. Over the lower band
for GSM850/900 operation [Fig. 8(a)], the antenna gain is about
1.7–2.8 dBi, and the radiation efficiency is ranged from about
60–74%. Over the upper band for GSM1800/1900/UMTS opera-
tion [Fig. 8(b)], the antenna gain is about 2.9–4.7 dBi, whereas the
radiation efficiency is all better than 70%.

To analyze the user’s hand effects on the studied antenna, the
simulation model using SEMCAD [21] shown in Figure 9 is applied.
The user’s hand is pointing at the top edge of the touch panel and is
assumed to space 8 mm to the display ground plane and 5 mm below
the antenna as shown in the simulation model. The simulated (SEM-
CAD) return loss for the studied antenna with and without the user’s
hand is shown in Figure 10. It is interesting to see that there are very
small variations between the two cases of with and without the user’s
hand. That is, the user’s hand shows very small effects on the
impedance matching of the studied antenna embedded inside the
laptop computer casing. However, as seen from the 3-D total-power
radiation patterns at 925 and 1795 MHz for the studied antenna shown
in Figure 11, large variations in the radiation patterns owing to the
presence of the user’s hand are seen. In addition, the radiation effi-
ciency is decreased by about 10% at the two frequencies, when the
user’s hand is present. This efficiency decrease is mainly owing to the
user’s hand being a very lossy material [16–20] for the antenna.

4. CONCLUSION

A uniplanar printed monopole antenna easy to fabricate on a very
thin (0.4 mm) FR4 substrate at low cost for GSM850/900/1800/
1900/UMTS operation in the modern thin-profile laptop computer
has been proposed. The antenna is formed by a simple direct-fed
monopole element and a coupled-fed shorted monopole element.
Two wide operating bands at about 900 and 1900 MHz have been
obtained for the desired penta-band operation. In addition, the
capacitive coupling mechanism between the two monopole ele-
ments in the studied antenna allows the two generated wide bands
to be adjusted separately, which makes the antenna easy to fine-
tune in practical applications. For the case of the laptop computer
with a touch panel, the user’s hand effects have also been ana-
lyzed. Results have shown that there are large effects on the
radiation pattern and radiation efficiency of the antenna embedded
inside the laptop computer, owing to the presence of the user’s
hand in the vicinity of the antenna. This behaviour is similar to the
user’s hand effects observed for the internal mobile phone anten-
as [16–20].

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