Printed Multiband Antenna for Mobile and Wireless Communications

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Abstract— **In this paper, a low profile printed multiband antenna is numerically investigated and experimentally measured. The antenna is proposed to be used for GSM-850, GSM-900, UMTS-2100, WiMAX-2.3 and WiMAX-3.3. It is developed from the existing tripleband microstrip antenna that works on frequency of 2GHz, 3.5GHz and 5.5GHz. To improve the coverage of frequency bands, the existing antenna structure is totally redesigned using FR-4 Epoxy substrate with permittivity of 4.3 and thickness of 0.8mm to produce a new antenna configuration that works at desired frequency bands. To have the proposed antenna to be as compact as possible, the meandering strip technique is applied to minimize the antenna dimension. Hence, to be possible being fed in planar, the microstrip line technique is used to feed the antenna. Prior to the fabrication, the proposed antenna is numerically designed in which some parameters of antenna including return loss, VSWR, bandwidth, gain, and radiation pattern are used as design indicators. Based on the design result, the antenna with total dimension of 32mm x 32mm is then realized to be experimentally characterized. From the measured result, it is shown that the proposed antenna has working bandwidths (VSWR<2) for frequency ranges of 800–920MHz, 1900–2400MHz and 3300–3420MHz that corresponds to frequency ranges of GSM-850, GSM-900, UMTS-2100, WiMAX-2.3 and WiMAX-3.3, respectively. In addition, the measurement results of antenna parameters show good agreements with the numerical results.**

Keywords-antenna parameters, meandering strip, microstrip line, multiband, printed antenna.

I. Introduction

In mobile communications, there is some technological function, namely cellular technology that is often used, such as GSM (Global System for Mobile communication) as 2nd generation and UMTS (Universal Mobile Telecommunications System) as 3rd generation. GSM has different frequency bands in every country, for example GSM-850 (uplink 824.0-849.0 MHz and downlink 869.0-894.0 MHz) is used mostly in the America, whilst primary GSM-900 (uplink 890.2-914.8MHz and downlink 935.2-959.8MHz) and DCS-1800 (uplink 1710.2-1784.8MHz and downlink 1805.2-1879.8MHz) are mainly used in several countries in Asia, Europe, Africa and Australia. UMTS frequency commonly used at several countries including Indonesia is at 2100MHz frequency band (uplink 1920-1980MHz and downlink 2110-2170MHz) [1].

This work is partially supported by the Asahi Glass Foundation Research Grant 2011, Japan.

Beside the cellular technology, some technology developed in wireless communications is WiMAX (Worldwide Interoperability Mobile Access) technology. Similar to the cellular technology, WiMAX technology that provides wireless transmission of data with different modes of transmission requires different frequency bands for each country. In terms of transmission speed, this technology is higher than UMTS. In Indonesia, two main frequency bands have been allocated for WiMAX services based on the decision of the Minister of Communications and Informatics in 2009, there are in frequency bands of 2.3-2.4GHz and 3.3-3.4GHz for fixed and mobile WiMAX services, respectively [2].

The different frequency bands used in mobile and wireless communications have driven the demand of antenna that can operate in multiband frequencies. Although, there is a fact that the size reduction levels remain unsatisfactory to the expectation, a microstrip-patch antenna is one of the antennas which may overcome this kind of demand due to its inherent capabilities such as low cost, low weight, low profile, and multi-band support [3]-[6]. Further, as the space in recent telecommunication devices is very limited, it is required a compacter antenna, therefore the type of microstrip-patch antenna is almost suitable for the purpose. Other kind of antenna that can accomplish the need and has similar capabilities as of microstrip-patch antenna is IFA (Inverted-F Antenna) and planar antenna [7]-[9]. However, these types of antenna have specific characteristics and can only be used for specific applications.

To cover all mentioned frequency bands in a radiating device, a multiband antenna is proposed to be designed and realized. The proposed antenna structure that is printed on FR-4 Epoxy substrate is developed from the existing structure in [9] with some enhancement in parameters to be able operate at desired frequency bands. In the design process, the structure of proposed antenna is investigated to obtain optimum design architecture. Some parameters of antenna as keys of design criteria are analyzed numerically. Hence, some techniques to minimize the antenna dimension and to feed the antenna input are discussed in order to have an antenna with the dimension as compact as possible. After the realization, the fabricated antenna is then characterized experimentally in which the results are compared with the numerical ones.

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II. Antenna Design

A. Multiband Antenna Design

Based on the existing antenna structure in [9], in order to operate at several frequency bands, the existing structure should be reconfigured by modifying each strip as well as its ground plane. The dielectric substrate for antenna deployment is also changed from RT/Duroid 5880 substrate (ε_r of 2.2 and thickness of 0.254mm) to FR-4 Epoxy substrate (ε_r of 4.3 and thickness of 0.8mm) to have a smaller antenna dimension compared to the existing one. In addition, the microstrip line feeding technique is applied for the antenna to be able feed by an SMA type connector. As the shape of each strip of antenna is in rectangular shape, to obtain its working frequency in TM_{mn} mode it can be numerically calculated using the following equation [5].

$$f_{mn} = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{\left(\frac{m\pi}{L}\right)^2 + \left(\frac{n\pi}{W}\right)^2} \qquad (1)$$

where ε_r, L, and W are the relative permittivity of used dielectric substrate, the length and the width of strip, respectively. The TM_{10} mode is commonly used for determining the working frequency of rectangular strip as it is a dominant mode. Therefore, the length of strip will play an important role in determination of working frequency.

To generate the frequency band of 900MHz to be used for GSM-850 and GSM-900, the most efficient technique is by adding the length of S-strip. This will shift the lowest frequency band of existing structure from 2GHz to 900MHz. Hence, to get frequency band on 2GHz for UMTS uplink, it is performed by making longer the length of T-strips. Then, the frequency band of 2.1GHz for UMTS downlink and WIMAX-2.3 will be produced by the V-strip, whilst the H-strip will produce the frequency band of 3.3GHz for WiMAX-3.3. The initial design of proposed antenna is illustrated in Fig. 1 where the height of S-strip (a) is 25mm and the length of V-strip (b) is 28.25mm, so the total antenna dimension including its feeding network is about 45.5mm x 29mm. By adjusting the length of each strip, the desired frequency bands of GSM-850, GSM-900, UMTS-2100, WiMAX-2.3 and WiMAX-3.3 can be obtained. The simulated result of return loss is depicted in Fig. 2. It is seem that the VSWR on frequency band of 3.3GHz needs to be improved.

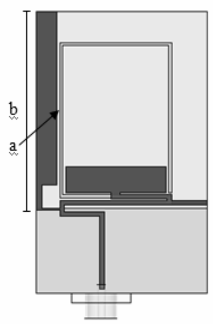


Figure 1. Initial design of multiband antenna for GSM-850, GSM-900, UMTS-2100, WiMAX-2.3 and WiMAX-3.3

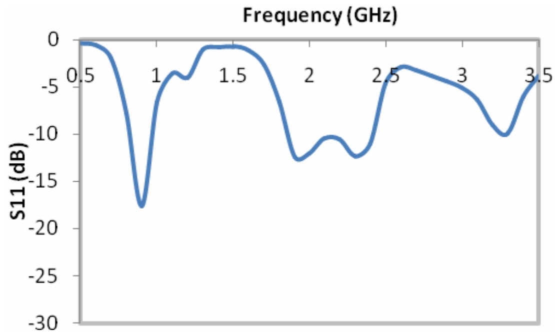


Figure 2. Simulated result of return loss for initial design of multiband antenna

B. Meandering Technique and Feeding Network

From Fig. 1, it can be seen that the dimension of initial design of multiband antenna is bigger than the existing antenna. Therefore, some effort to miniaturize the antenna should be conducted especially for V-strip and S-strip. Here, a meandering technique is applied to reduce the size of antenna by making the strips in a coil-like or snake-like shape. To perform the technique on V-strip as well as the S-strip, the strip width is made as small as possible to be more easily folded. The effect of varying the width of meandered V-strip to the antenna performance is plotted in Fig. 3. It seems that the width variation of meandered V-strip has no significant effect in the determination of working frequency. It should be noted that the length of meandered V-strip is more dominant to generate the working frequency around 2GHz instead of the width. This also applies for other working frequencies in connection with the length of each strip.

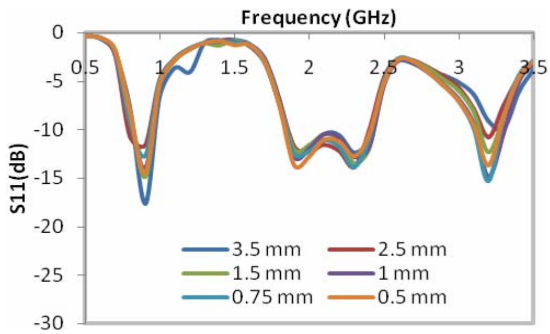
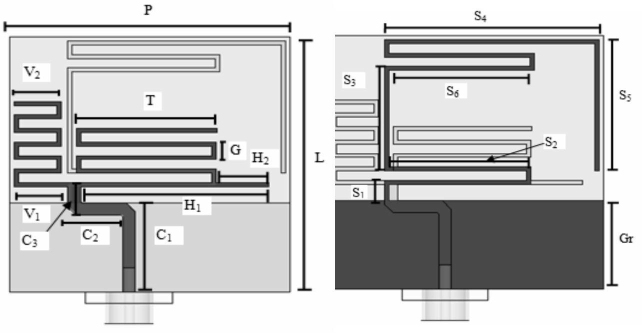


Figure 3. Simulated result of return loss as the width variation of meandered V-strip

As the next step, the similar treatment to make a compacter multiband antenna is also applied to the T-strip and H-strip. Here, as the H-strip is responsible to produce the frequency band of 3.3GHz, the length of H-strip is the shortest one compared to others. Hence, to feed the proposed antenna using an SMA type connector, a microstrip line technique is applied as the feeding network using a $\lambda/4$ transmission line with the impedance of 50Ω. The microstrip line is placed in planar to the antenna to be easier in the fabrication. Furthermore, in order to match with the impedance of feeding network, 2 strips connected to the microstrip line, i.e. T-strip and V-strip have to be 100Ω of each.

The width of 50Ω microstrip line and 100Ω strips can be obtained using equations in [3]-[5] in which the used material is FR-4 Epoxy substrate with ε_r of 4.3 and thickness of 0.8mm. From the calculation, the widths are 1.5mm and 0.4mm for 50Ω microstrip line and 100Ω strips, respectively. However, due to the issue of manufacturing process that limits the strip width no less than 0.5mm, although it will affect to the performance of antenna therefore the width for 100Ω strips is set to be 0.5mm. In addition, to avoid the higher-order mode excited by the feeding network, the 50Ω microstrip line is reduced by cutting the angle on its bended-corner. As a result, the final design of multiband antenna as shown in Fig. 4 has total dimension of 32mm x 32mm where its parameters are summarized in Table 1.



(a) (b)

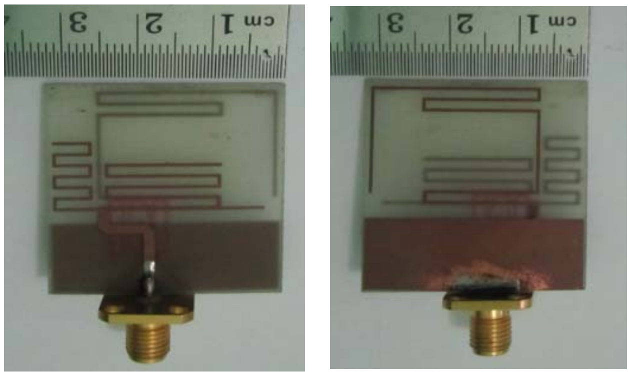
Figure 4. Final design of multiband antenna for GSM-850, GSM-900, UMTS-2100, WiMAX-2.3 and WiMAX-3.3 (a) front view, (b) back view

TABLE I. PARAMETERS OF PROPOSED MULTIBAND ANTENNA

Parameter	Dimension (mm)
P	32.00
L	32.00
C_1	11.10
C_2	6.25
C_3	4.10
G	2.20
V_1	6.10
V_2	5.40
H_1	21.50
H_2	6.00
T	16.00
G_r	11.10
S_1	2.60
S_2	16.50
S_3	13.20
S_4	24.90
S_5	16.60
S_6	16.90

III. FABRICATION AND CHARACTERIZATION

From the design result, the proposed multiband antenna is then deployed on a double-side FR-4 Epoxy substrate with ε_r of 4.3 and thickness of 0.8mm. Figure 5 shows the pictures of prototype fabricated multiband antenna to be characterized experimentally. The characterization includes the measurement of some basic parameters such as return loss, VSWR, gain and radiation pattern. Then, the results are verified and compared with the numerical design results.



(a) (b)

Figure 5. Fabricated multiband antenna for GSM-850, GSM-900, UMTS-2100, WiMAX-2.3 and WiMAX-3.3 (a) front view, (b) back view

A. Return Loss and VSWR

Figures 6 and 7 show the measured result of return loss and VSWR respectively. As comparison, the numerical design result of each is also depicted together consecutively. It is seen that from numerical design result plotted in Fig. 6, the frequency bands of GSM-850 and GSM-900 are covered by a band that has a bandwidth of 180MHz from 810MHz to 990MHz with the lowest return loss value of 24.64 dB at frequency 870MHz (VSWR = 1.12 shown at Fig. 7). However, from measurement result it shows that the working bandwidth only covers from 800MHz to 920MHz with the lowest VSWR of 1.081 at 820MHz, Fig. 7, so that the frequency band of GSM-900 is not completely covered. This is probably evoked by the inaccuracy of manufacturing process with some capability limitation in the fabrication of minimum strip width.

Hence, the frequency bands of UMTS-2100 and WiMAX-2.3 are covered by 2 adjacent bands each other for the numerical design result. Those bands are around 1900MHz used for the UMTS-2100 uplink, whilst the UMTS-2100 downlink is covered by another band which also includes the frequency band for WiMAX-2.3. Both these frequency bands has bandwidth of 490MHz from 1920MHz to 2410MHz with the lowest return loss value for the first band of 30.17dB at 1940MHz (VSWR = 1.06 shown in Fig. 7) and for the second band of 26.86dB at 2250MHz (VSWR = 1.10 shown in Fig. 7). In the measurement result, although the bandwidth response is only from 1900MHz to 2400MHz, Fig. 7, however it is still able to cover very well the frequency bands for UMTS-2100 and WiMAX-2.3 with VSWR value of 1.16 and 1.23 at frequencies of 1920MHz and 2240MHz, respectively.

Furthermore, in the numerical design result the frequency band of WiMAX-3.3 is covered by a band with bandwidth of 190MHz ranging from 3280MHz to 3470MHz with the lowest return loss value of 17.25dB (VSWR = 1.32 shown in Fig. 7) at center frequency of 3390MHz. Whilst in the measurement result, it is covered by a band with bandwidth of 120MHz ranging from 3300MHz to 3420MHz with the lowest return loss value of 13.32dB (VSWR = 1.55 shown in Fig. 7) at center frequency of 3360MHz. Again, the difference is probably affected by the inaccuracy of manufacturing process causes the narrower bandwidth response.

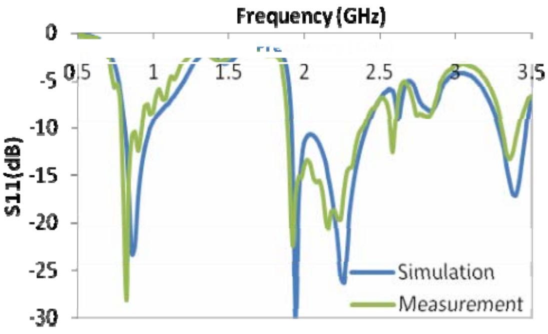


Figure 6. Simulated and measured results of return loss

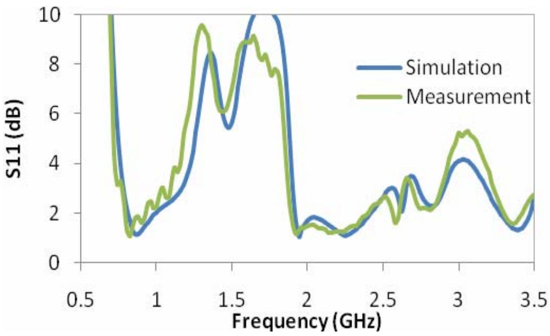


Figure 7. Simulated and measured results of VSWR

B. Gain and Radiation Patterns

The next step of experimental characterization is gain measurement for each frequency band. To obtain the optimum result, the gain measurement is taken at the maximum value. Figure 8 shows the measured gain for each frequency band, whilst Fig. 9 plots the gain of numerical design result as comparison. From the numerical design result, it shows the maximum gain value for each frequency band is -10.72dB for GSM-850, -10.17dB for GSM-900, -2.37dB for UMTS-2100, -1.58dB for WiMAX-2.3 and -0.02dB for WiMAX-3.3. While from measurement result, the maximum gain is -3.10dB for GSM-850 and GSM-900, 1.18dB for UMTS-2100, 0.14dB for WiMAX-2.3 and -2.69dB for WiMAX-3.3. From the results, it is indicating that the gain of proposed antenna is quite low almost for all frequency bands. This occurs as the dimension of antenna aperture is too small whilst the gain is proportional to the antenna aperture.

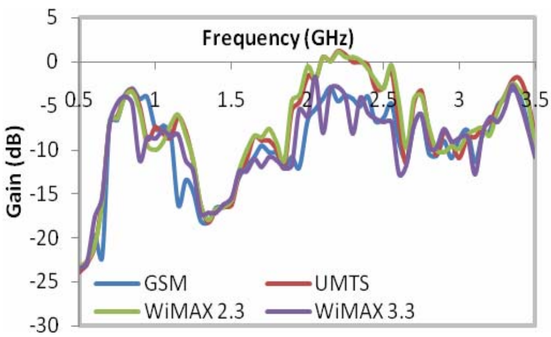


Figure 8. Measured gain of multiband antenna for each frequency band

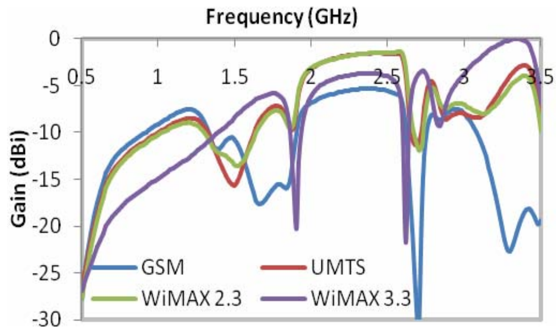
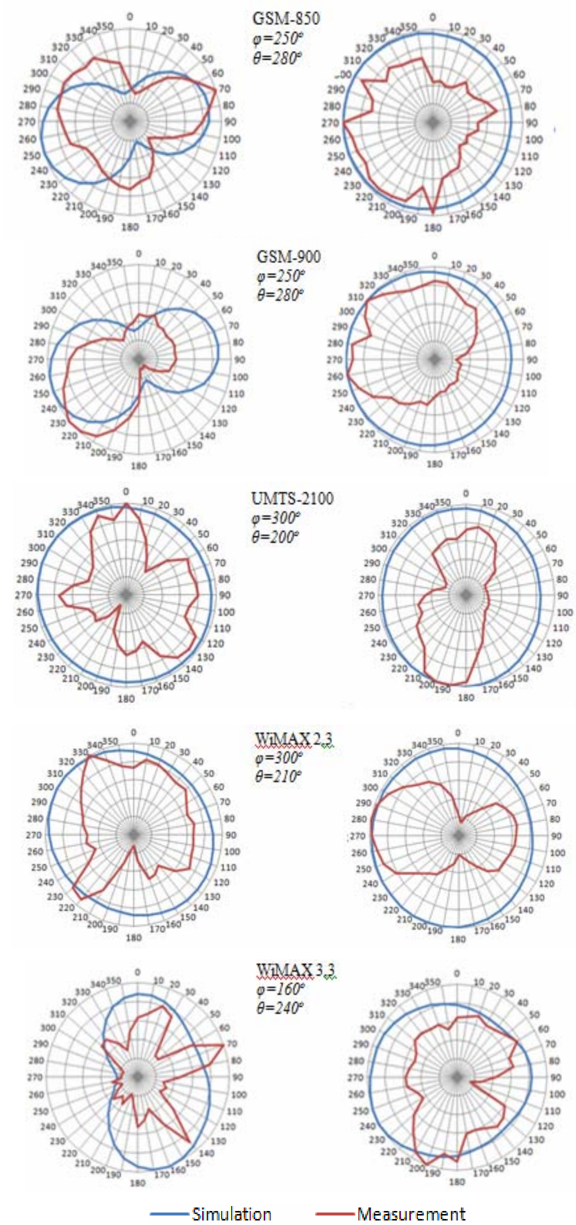


Figure 9. Simulated gain of multiband antenna for each frequency band



(a) (b)

Figure 10. Simulated and measured results of radiation patterns for each frequency band (a) *E*-plane and (b) *H*-plane

Figure 10 shows the radiation patterns of multiband antenna for *E*-plane and *H*-plane for each frequency bands at maximum gain. Both in the numerical design and measurement result, it shows that for each frequency band taken at the maximum gain has different angles both of φ and θ. This means that for each frequency band is dominated by its respective strip. From the measurement result, it is seen that the radiation patterns shows a different shape and not as smooth as to the numerical design result because of the manufacturing issue, however it is still acceptable for some far-field distance and can resemble the simulation results qualitatively.

IV. CONCLUSIONS

A printed multiband antenna for mobile and wireless communications has been numerically designed and experimentally characterized. The antenna that has a compact dimension of 32mm x 32mm including its λ/4 transmission line as a feeding network was deployed on FR-4 Epoxy substrate with ε_r of 4.3 and thickness of 0.8mm. It consists of 4 meandering strips in which each of strips has designated for each frequency band. One of the strips was located at the ground plane side to produce the frequency band of GSM-850 and GSM-900, while other three strips were printed oppositely to the ground plane side to obtain the frequency bands of UMTS-2100, WiMAX-2.3 and WiMAX-3.3. From the results of numerical design and experimental characterization, although there was a slight different in the shape of radiation patterns and the overall gain was quite low, however it has been shown that the characteristics of proposed antenna had good agreements each other in terms of return loss, bandwidth, VSWR, and gain. It has also been demonstrated that the meandering technique could make the dimensions of proposed antenna to be smaller and compacter, whilst the microstrip line technique has made the proposed antenna ease for the fabrication. In addition, the gain improvement and size reduction of fabricated multiband antenna are still being investigated for the current research where the result will be reported in the near future.

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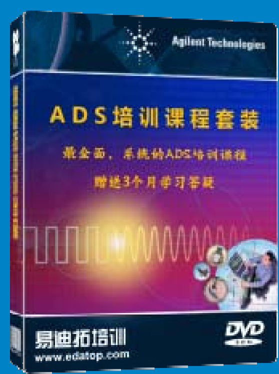

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