Design Considerations For Sub-GHz Multilayer Microstrip Antenna For Near Ground Communication Links In Rural Areas

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Abstract

This paper presents some preliminary results of design and development of sub-GHz multilayer microstip antenna for use in near ground communication applications. In design stage of the antenna, iterative approach was applied. Firstly, a two layer microstrip antenna design process is presented. Next, the corners of the patch were cut, and a vertical wall on all sides of the antenna were introduced. In this way, both the size and resonant freqeuncy can be tuned. Moreover, as an application specific requirement, it is intended to embed this antenna into a metal box in order to protect it from man-made and natural environmental effects. This was also studied, and effects of the embedding ground on the antenna characteristics were examined. It is shown that the designed antenna provides -27dB resturn loss, and 7.3dB peak gain at 915MHz with the dimension of 150x200x13mm. Some preliminary measurements have proven the simulations.

1. Introduction

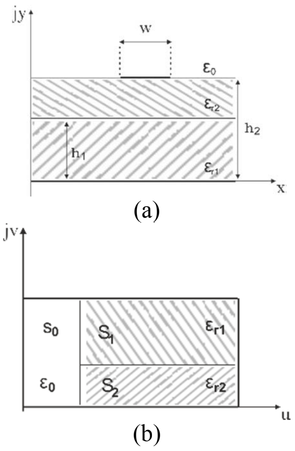
Antenna interaction with the environment is a critical issue in sub-GHz applications. Effects of the environment and neighboring objects on antennas have been studied in platform-mounted antenna applications. Substrate type materials can be used to protect antennas from environmental damage. Then, effect of dielectric substrate added on top of microstrip antenna has been reported in [1]. When the object on which the antenna is mounted is not planar, antenna should be embedded carefully to reduce perturbations on the antenna parameters, such as antenna impedance and radiation pattern [2]. A popular research topic is design of human body-embedded antennas (implant antenna). As the antenna efficiency and size are reduced greatly due to human body interaction, this problem has been studied extensively in the literature. Performance of microstrip antennas has been reported [3], and parametric changes are reported. One way to reduce these changes is to consider these effects in the design of the antenna from the scratch. In [4], MEMS based differentially fed dual band antenna has been demonstrated for use in medical applications. In all of these applications, as expected, microstrip antenna technology has been used. On the other hand, there has to be different techniques to increase the antenna performance for embedded applications at sub-GHz bands. The most efficient technique is to use multilayer structures [5]. This can be achieved by printing a variety of geometric slots and patches in between various numbers of multi-substrate structures. The theoretical basis and analysis methods of simplified multilayer microstrip antennas have been published several decades ago [6]. However, design challenges regarding with the environmental constraints have still been continuing. For example, design of sub-GHz high gain, low profile antenna for near ground communication applications, such as wireless sensor networks operating in rural areas, have still many challenges [7].

The authors have been dealing with design of low profile, high gain sub-GHz antenna for near ground communications in rural areas. Moreover, as application specific requirement, it is intended to embed this antenna into a metal box in order to protect it from environmental effects. For this purpose, the design requirements should include antenna to metal box interaction, and detailed analysis of perturbations of the antenna parameters. In this regard, the effect of the substrate that is necessary to cover the antenna for protecting from man-made and natural environmental effects should also be studied. As this is an ongoing research planned for two years period, only antenna design issues are presented in this conference paper. Then, the antenna design started with the choice of the best technology and antenna topology to achieve above requirements. For this purpose, one particular structure has been found very promising for improvements [8]. The proposed antenna consists of a microstrip patch on a low-dielectric constant substrate along with a vertical ground surrounding the rectangular the antenna. The substrate is spaced from the bottom ground by air which makes a multilayer antenna structure. It was demonstrated that this antenna provides resonance at sub-GHz, and achieves quite acceptable gain for near ground communication applications in rural areas. However, there needs to be improvements for the targeted application specific requirements. The paper deals with these improvements, and presents the first experimentally demonstrated findings.

The paper is organized as follows; section 2 provides a review for the theoretical basis of multilayer microstrip antennas as microstrip technology seems to be only choice for this targeted application. Section 3 presents design stages of the antenna, and its implementation details. Finally, the last section provides simulation and measurements results. As an ongoing research, the last section also provides incomplete and future works planned for the next year.

2. Methodology

The microstrip antenna considered in this paper consists of two dielectric layers. As the antenna has multiple dielectric layers, classical numerical methods do not provide sufficiently accurate results. According to the literature, the most effective analysis method for multilayer microstrip antennas is conformal mapping. It provides very realistic approximations to resonance frequency for microstrip based transmission lines as described in [6]. According to [6], the multilayer structure in the z-plane is mapped onto g-plane using Wheeler's transformations shown in Fig.1 (a) and Fig. 1 (b).



(a)

(b)

Fig. 1. Multilayer microstrip antenna model in (a) z=x+jy plane, (b) g=u+jv plane

If the antenna under investigation provides a ratio of $w/h \geq 1$ (wide microstrip line), the following applies for the quasi-static effective permittivity

$$\varepsilon_e = 1 - q_1 - q_2 + \varepsilon_{r_1}\varepsilon_{r_2}\frac{(q_1+q_2)^2}{\varepsilon_{r_1}q_2 + \varepsilon_{r_2}q_1} \qquad (1)$$

$$q_1 = \frac{S_1}{S_c} = \frac{1}{2}\frac{h_1}{h_2}\left[1 + \frac{\pi}{4} - \frac{h_2}{w_{ef}}\ln\left(\frac{\pi}{h_2}w_{ef}\frac{\sin\left(\frac{\pi}{2}\frac{h_1}{h_2}\right)}{\frac{\pi}{2}\frac{h_1}{h_2}} + \cos\left(\frac{\pi}{2}\frac{h_1}{h_2}\right)\right)\right] \qquad (2)$$

$$q_2 = \frac{S_2}{S_c} = 1 - q_1 - \frac{1}{2}\frac{\ln\left(\frac{\pi}{h_2}w_{ef} - 1\right)}{\frac{w_{ef}}{h}} \qquad (3)$$

where the effective line width w_{ef} is

$$w_{ef} = w + \frac{2h_2}{\pi}\ln\left[17.08\left(\frac{w}{2h_2} + 0.92\right)\right] \qquad (4)$$

ε_{r_i} denotes the dielectric constant of i^{th} substrate. h_1 denotes the height of the bottom substrate while h_2 denotes the height of both substrate.

On the other hand, dispersion model of effective dielectric constant has been developed using Getsinger's formula in [9]. It is given by

$$\varepsilon_{eff} = \varepsilon_r' - \frac{\varepsilon_r' - \varepsilon_e}{1 + P(f)} \qquad (5)$$

where

$$\varepsilon_r' = \frac{2\,\varepsilon_e - 1 + A}{1 + A} \qquad (6)$$

and

$$A = \left(1 + \frac{12h_2}{w}\right)^{-1/2} \qquad (7)$$

Here, the frequency dependent term, $P(f)$, is given as follows [10],

$$P(f) = P_1P_2[(0.1844 + P_3P_4)10fh]^{1.5763} \qquad (8)$$

With

$$P_1 = 0.27488 + \left[0.6315 + \frac{0.525}{(1 + 0.157fh)^{20}}\right]u - 0.065683\exp(-8.7513u) \qquad (9a)$$

$$P_2 = 0.33622[1 - \exp(-0.03442\varepsilon_r')] \qquad (9b)$$

$$P_3 = 0.0363\exp(-4.6u)\,(1 - \exp[-(fh/3.87)^{4.97}]) \qquad (9c)$$

$$P_4 = 1 + 2.751(1 - \exp[-(\varepsilon_r'/15.916)^8]) \qquad (9d)$$

It should be noted that *fh* is normalized in *GHz cm* and $u = w_e/h_2$.

Then, the resonant frequency (f_r) of the multilayer microstrip antenna with patch length L is given by [11],

$$f_r = \frac{c}{2\,L\sqrt{\varepsilon_{eff}}} \qquad (10)$$

where c is the velocity of light in free space.

The derivation given above does not take fringing effect into account Therefore, it is somehow inaccurate. As fringing effect is considered, it is known that the patch size of the microstrip antenna is greater than its physical size. This difference is represented by ΔL (open-end extension). This size has already been reported in the literature [12], as

$$\Delta L/h = \left(\xi_1\xi_3\xi_{5/}\xi_4\right) \qquad (11)$$

where

$$\xi_1 = 0.434907\frac{\varepsilon_{eff}^{0.81} + 0.26}{\varepsilon_{eff}^{0.81} - 0.189}\frac{(w/h)^{0.8544} + 0.236}{(w/h)^{0.8544} + 0.87} \qquad (12a)$$

$$\xi_2 = 1 + \frac{(w/h)^{0.371}}{2.358\varepsilon_r' + 1} \qquad (12b)$$

$$\xi_3 = 1 + \frac{0.5274\,arctan\left[0.084(w/h)^{1.9413/\xi_2}\right]}{\varepsilon_{eff}^{0.9236}} \qquad (12c)$$

$$\xi_4 = 1 + 0.0377arctan[0.067(w/h)^{1.456}]x\left[6 - 5\exp\left(0.036(1 - \varepsilon_r')\right)\right] \qquad (12d)$$

$$\xi_5 = 1 - 0.218\exp(-7.5\,w/h) \qquad (12e)$$

Then, the resonant frequency with open end extension (ΔL) arising from fringing effect is given [9] as,

$$f_r = \frac{c}{2\,(L + 2\Delta L)\sqrt{\varepsilon_{eff}}} \qquad (13)$$

3. Design and implementation

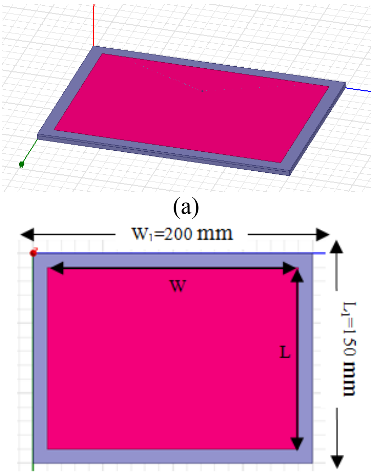
There have been various approaches to enhance gain of microstrip antennas in sub-GHz bands (~915 MHz). This is still a challenge. From the literature, one particular structure has been found very promising for improvements [8]. The proposed antenna consists of a microstrip patch on a low-dielectric constant substrate along with a vertical ground surrounding the rectangular the antenna. The antenna is proved to provide relatively higher with acceptable size and profile. However, it still needs improvements to fulfill the requirements of the target application in this work. In doing this, first of all, the effects of vertical ground and truncated corners of the patch are examined carefully using simulation tools. Moreover, interaction between the metal in which the antenna is to be embedded and the antenna is studied for possible perturbations on the antenna characteristics. Stages of the design is described as follows.

The multilayer antenna geometry proposed in this paper is already given in Fig.1(a). Here, the first layeris chosen as air ($\varepsilon_{r_1} = 1$) and the second one is dielectric (FR4 with $\varepsilon_{r_2} = 4.4$). Next, the dimensions are listed in Table I, which are determined for the targeted frequency band (900 MHz). Thecalculated resonant frequency using (13)is *901.6MHz*.Note that the vertical groundis still not considered here as the method described in previous section needs to be extended. However, the authors prefer to use simulation tools to design and optimize the antenna.

Table 1. Dimensions of the antenna

Dimensions	***Values***
Patch length (L)	130mm
Patch width (W)	180mm
Air height	3mm
FR4 height	1.6mm

Then, first of all, the antenna geometry is simulated using a commerical 3D EM solver in order to validate theoretical result (Fig.2). This is rather trivial but it is required as a benchmarking deisng for the improvements explained later.



(a)

(b)

Fig. 2. The geometry of the proposed multilayer microstrip antenna (a) 3-D view (b) top view (dimensions)

As shown in Fig. 2(b), the width and the length of the proposed antenna are 200 mm and 150 mm, respectively. Fig. 3 shows the return loss of the proposed antenna (~-25 dB at 895MHz). This proves that the resonant frequency calculated from the equations in previous section has slight deviation from the simulated result.

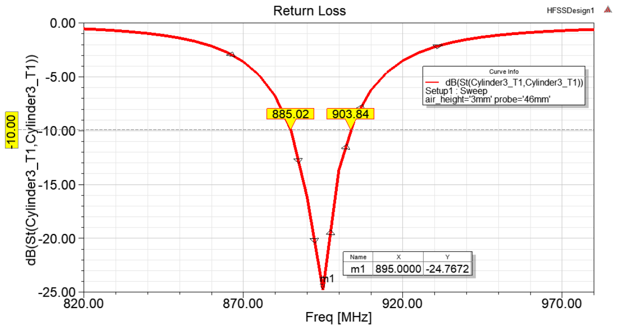


Fig. 3. Return loss (S_{11}) of the antenna.

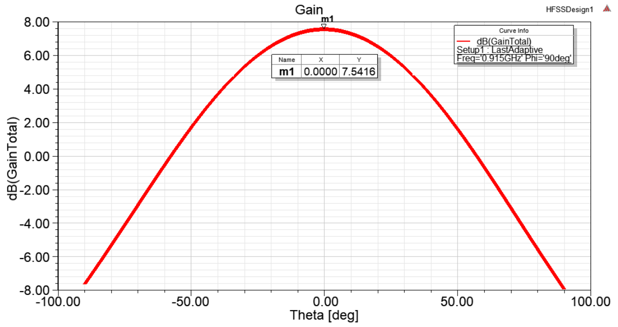


Fig. 4. Simulated gain of the multilayer microstrip antenna.

Next, the corner of the patch is cut firstly (truncated), and then a vertical ground is added to examine the effects. These are expected to shift the resonant frequency, to some extent, by keeping the antenna size small. In doing this, there have been recursive optimizations and parametric studies to achieve the targeted resonant frequency, and the gain performance. The optimized size of the cuts, (truncated corners)on the patch is found to be 41.86 mm. The best coax feeding is determined at position of (46,100). All other dimensions are kept as in in Table 1.Simulation results are provided in Fig. 7. It is shown that the return loss of~-42dB is obtained at 930MHz. The maximum gain in the targeted angle reaches 7.7dB at 915MHz in Fig. 8,

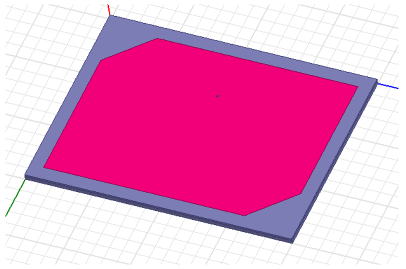


Fig. 5. The geometry of the antenna with truncated corners.

In the next step, the vertical ground is placed at four sides as shown in Fig. 6.Theoptimized height of the vertical groundis determined as 13 mm. Moreover, the tolerances in the fabrication facility and hardware implementations were also considered in the simulations (up to 0.5mm tolerances were simulated and their effects are studied).

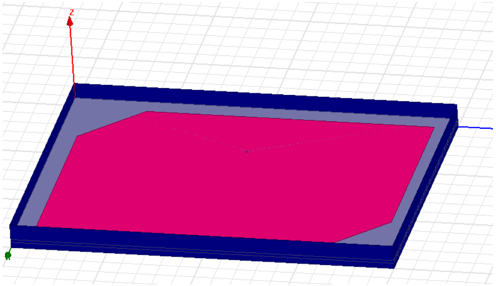


Fig. 6. The geometry of the antenna with vertical ground

Figure7, shows the return loss of the antenna with three different cases for comparison. As shown, the return loss is -27dB at 915MHz, and the peak gain reaches 7.3dB at 915MHz as seen in Fig.8. Finally, Fig.9 shows the simulated the radiation pattern of the antenna.

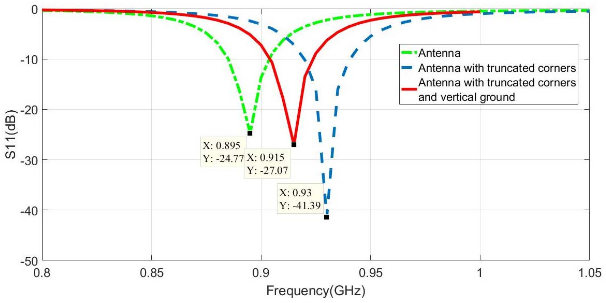


Fig. 7. Variation of the return loss (three cases)

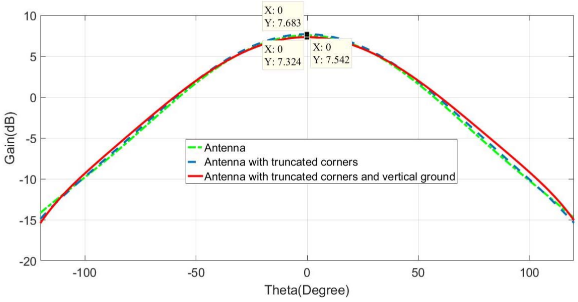


Fig. 8. Variation of the peak gain (three cases)

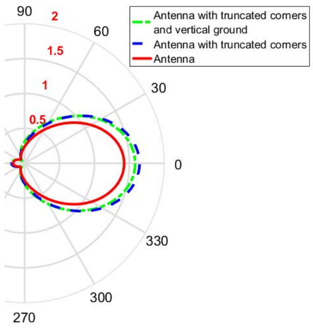


Fig. 9. Radiation pattern of the antenna (three cases).

In the following step,the antenna is embedded into a metal box as shown in Fig. 10. In this case, the size of the corner cuts are taken 42.4 mm after optimizations.

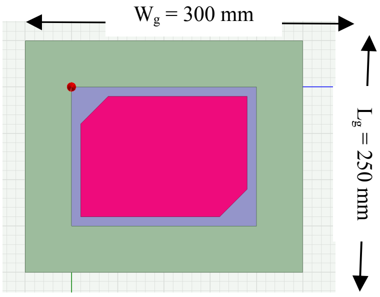


Fig. 10. Antenna embedded into a metal box (ground plane)

The effects of the metal box on the antenna parameters are shown in Fig.11 and Fig.12. It should be noted that the gain pattern is perturbed with the metal box but the peak gain increases slightly.

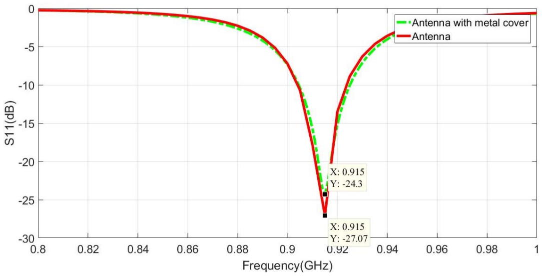


Fig. 11. Variation of the return loss with the metal box

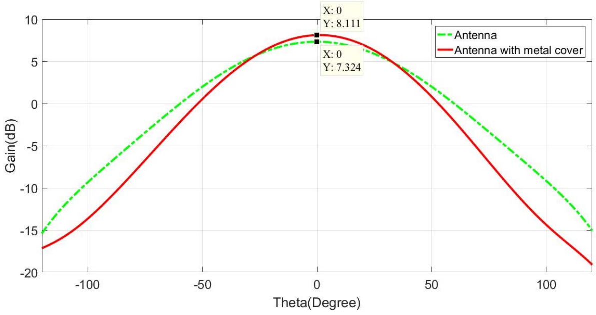


Fig. 12. Variation of the gain with the metal box

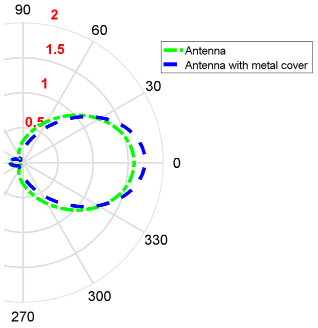
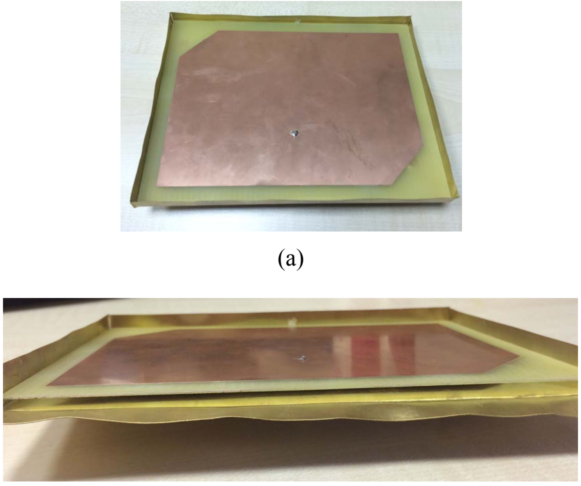


Fig. 13. Effect of the metal box on the radiation pattern

As a final step, the proposed antenna in Fig.6 was fabricated as it is shown Fig.14.



(a)

(b)

Fig. 14. The fabricated antenna (a) Front side, (b) cross section

The simulated and the measured return loss of the antenna is shown in Fig.15. However, the gain of the fabricated antenna has not been measured yet.

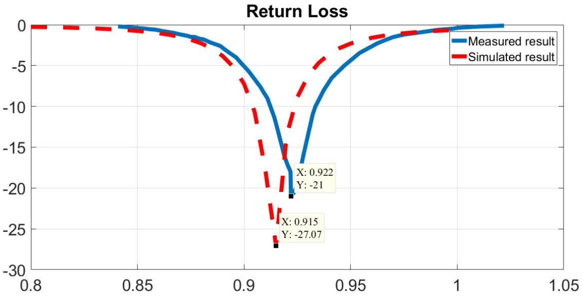


Fig. 15. Measured and simulated return loss of the antenna.

4. Results

In this paper, a multilayer microstrip antenna is designed, developed and fabricated at 900 MHz band. The effects of vertical ground and truncated corners of the patches on antenna performance is investigated by simulations and measurements. It is shown that the theoretical formulation provided, in the literature, for the resonant frequency quite agree with the simulations. Moreover, it is shown that the effect of metal box in which the antenna is embedded has very little effects on the antenna characteristics.

In future works, the antenna gain should be measured, and then possible improvements on the gain should be investigated. There is also a need to protect the antenna from man-made and natural environmental effects as it is planned to be used in a wireless sensor network (WSS) in rural areas. This may require a dielectric cover on the antenna. On the other hand, the link level performance of the antenna in peer to peer communication link should also be studied. For this purpose, the effects of the ground on the antenna and link performance needs to be studied. In this regard, the angular orientation of the antenna, the height from the ground should be examined.

5. Acknowledgment

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6. References

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