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Research Article

Hexagonal Monopole Strip Antenna with Rectangular Slot for 100–1000 MHz SFCW GPR Applications

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A printed ultra wideband (UWB) monopole antenna is proposed for applications on stepped frequency continuous wave (SFCW) ground penetrating radar (GPR) within a frequency range of 100–1000 MHz. The proposed antenna consists of a hexagonal strip line with resistive loading and a rectangular slot that is added to the ground plane side of the printed antenna implemented on FR4 epoxy materials. The resistive loading at the hexagonal monopole is effective to increase bandwidth in the higher frequency region, while the rectangular slot is used to improve bandwidth characteristic in the lower frequency region. This paper investigates the characteristic improvement in the lower frequency region by applying a parametric study on the rectangular slot that is added at the ground plane side of the UWB monopole antenna. Computer simulation was conducted and measurements were carried out to validate the result.

1. INTRODUCTION

GPR systems are used for subsurface investigations. They are used for detection of objects buried beneath the earth surface such as landmines, cables, pipes, and hidden tunnels. One important component in any GPR system is the transmitter and receiver antennas [1]. Desired features of a GPR antenna include UWB operation capability, good impedance matching, and small or compact in size. For SFCW-GPR applications, it is also important that the antenna has a flat transfer function in the frequency domain. In this paper, the antenna was designed for transmitting a monocycle pulse generated by a 100–1000 MHz SFCW system. The antenna should have low VSWR (VSWR $\leq$ 2), flat transfer function in the entire bandwidth, and exhibits very small late-time ringing (in time domain).

There are several methods previously published that have been used to improve bandwidth. Broadband antennas can be achieved by implementing a flare shape aperture [2–5]. An array of several antenna elements with different dimensions has also been proposed for bandwidth improvement [4, 6]. Resistive/capacitive loading was also reported to increase antenna bandwidth in [2, 5, 7].

In this paper, we proposed a new antenna design. The design uses a resistive loading at the end of a hexagonal monopole strip (HMS) that is utilized for bandwidth improvement. However, resistive loading is only effective to increase the antenna bandwidth in the higher frequency region. An additional rectangular slot at the ground plane side is required in an attempt to improve the antenna bandwidth in the lower frequency region.

A parametric study of a rectangular slot has been conducted in order to investigate the influence of the rectangular slot dimension/configuration, such as the length of the slot, the position of the slot, and the optimal value of resistive loading on the antenna bandwidth. This will provide valuable information for optimizing the antenna characteristics to meet the required specifications.

This paper presents the simulation to obtain the optimal dimensions of the rectangular slot that is added at the ground plane side of the UWB HMS antenna. Simulation has been performed both in frequency and time domains. The method of moment (MoM) has been chosen for the numerical method. Measurements have been carried out to verify the simulation results.

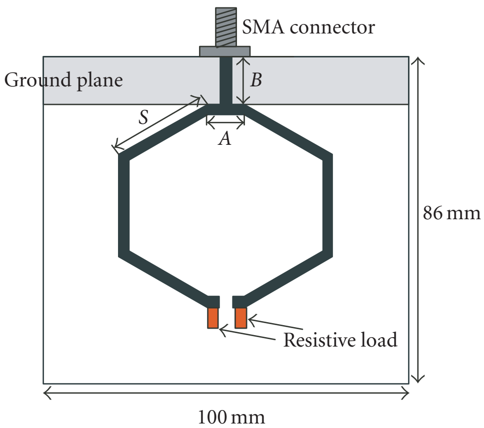


Figure 1: HMS antenna with resistive loading. $A = 10$ mm, $B = 8$ mm, and $S = 28$ mm.

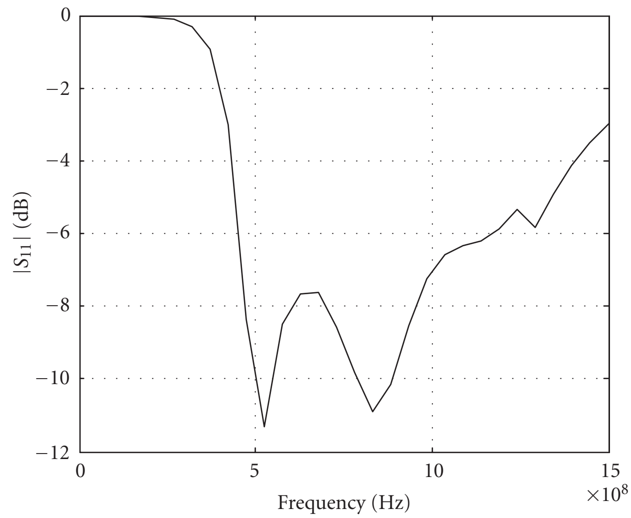


Figure 2: Simulated return loss characteristic of the HMS antenna in Figure 1.

The rest of the paper is organized as follow. Section 2 presents the antenna design. Section 3 discusses parametric study, measurement setup, and antenna characteristic in optimum dimension. Conclusion of this research is given in Section 4.

2. ANTENNA DESIGN

The UWB antenna has been designed to have a dimension of $100 \times 86\,\mathrm{mm}^2$ and printed on an FR-4 epoxy dielectric substrate. The dielectric substrate has thickness of 1.6 mm and a relative dielectric constant of 4.4. Antenna is designed with resistive loading at the end of the HMS that is used to improve bandwidth and to reduce the ringing level. Metal film resistor is used as a resistive load. Applying resistive loading will of course reduce the antenna efficiency. This has been shown in [8], that Wu-King loading profile reduces the antenna efficiency until 50 percent. Simulation shows that resistive loading reduces the antenna efficiency below 60 percent, as shown in Figure 13. In addition, low ringing level (in time domain) is also important in GPR applications. Therefore, despite the reduction of antenna efficiency, resistive loading is used to obtain wide bandwidth and to suppress the ringing level.

The previous research shows that a modified dipole antenna with a number of sharp edges increased the efficiency [9]. At the sharp edges, radiation occurs more effectively because of increasing displacement current. It becomes the reason why a hexagonal shape was selected for the antenna discussed in this paper. The total length of the HMS is related to the wavelength of the central frequency which corresponds to the spectrum of the monocycle pulse that will be transmitted. The feed point was connected with SMA connector.

The bandwidth of the antenna in Figure 1 should meet the requirement of 100–1000 MHz SFCW GPR application. The resistive loading at the end of the hexagonal strip is only effective to enhance the bandwidth in the higher frequency region.

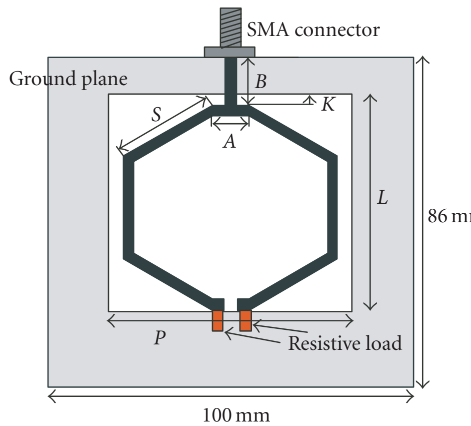


Figure 3: HMS antenna with rectangular slot.

Figure 2 shows the simulated return loss of the antenna in Figure 1. It can be seen that, the antenna transmits only the high-frequency part in the 100–1000 MHz range. Thus, theoretically it will differentiate the transmitted monocycle pulse.

The rectangular slot is added at the ground plane side of UWB HMS antenna in order to improve the bandwidth characteristic in the lower frequency region. The rectangular slot will perform as an effective resonator in the lower frequency region. Therefore, the dimensions of the rectangular slot must be larger than the dimensions of HMS.

3. RESULT AND DISCUSSION

Parametric study was carried out to investigate the influence of some important parameters such as the length of the slot (P, L), the position of the slot (K), and the resistive load (R).

When the rectangular slot position from the feed line is the same as the HMS position from feed line $(K = 0)$, the

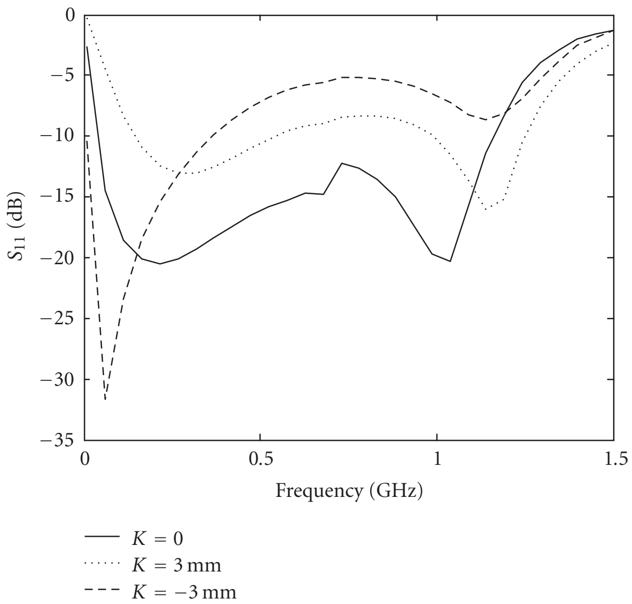


FIGURE 4: Effect of varying K to the antenna characteristic.

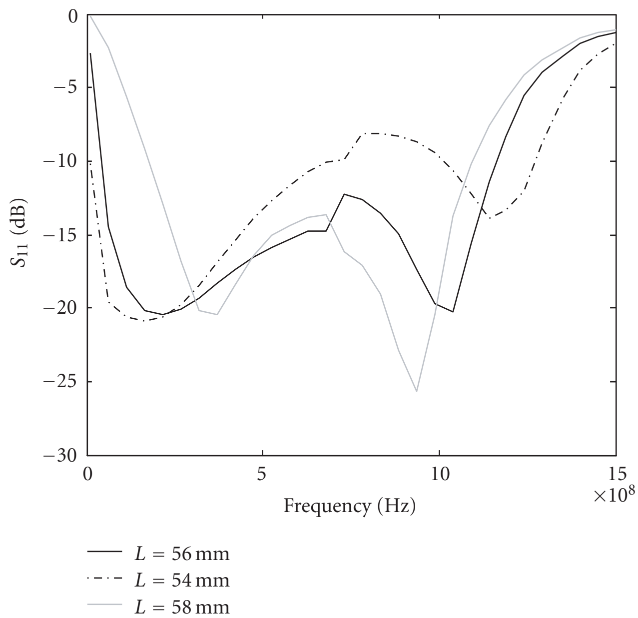


FIGURE 6: Effect of varying L to the antenna characteristic.

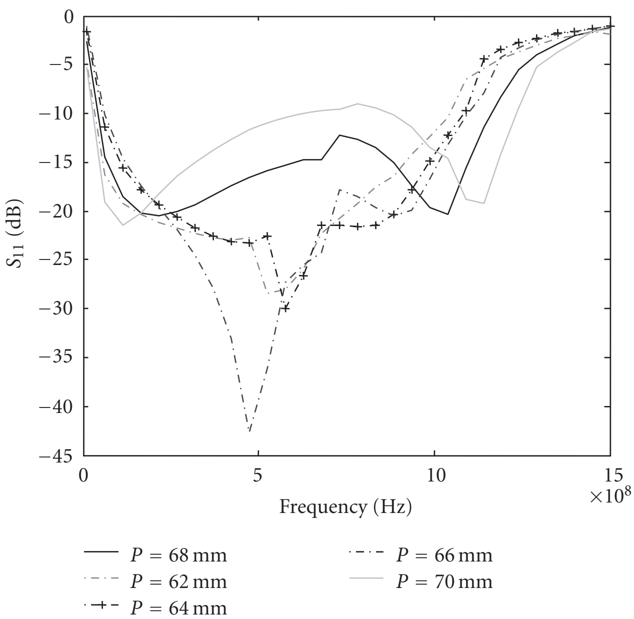


FIGURE 5: Effect of varying P to the antenna characteristic.

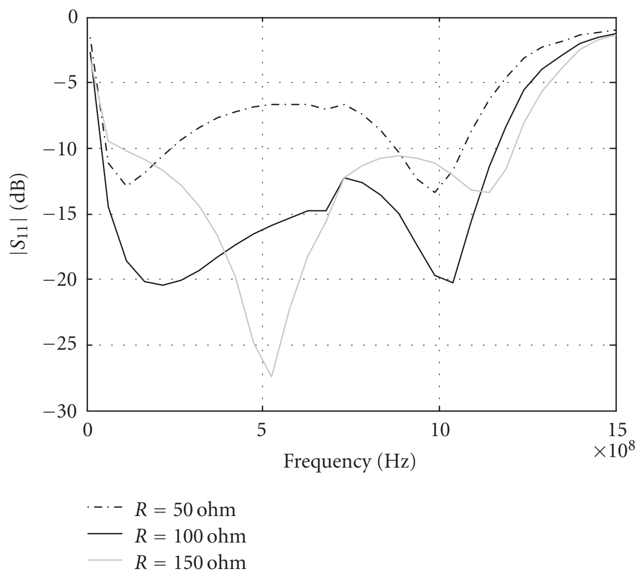


FIGURE 7: Effect of varying resistive loads value to the antenna characteristic.

optimal position of the rectangular slot is achieved. Figure 4 shows the effect of varying K.

Adjustment of P has a significant influence on the antenna characteristic at high frequencies and impedance matching the pass band. Figure 5 shows the effect of varying P. It can be seen that lager P does not affect the low frequency edge, but has much larger impact on the high-frequency edge. Furthermore, it is observed that an increase in impedance matching will be followed by a decrease in bandwidth.

Adjustment of L has significant influence on the antenna characteristic at both low and high frequencies. Figure 6 shows the effect of varying L. An increase in L will decrease the low-frequency edge and will consequently cause a decrease in bandwidth.

Figure 7 shows the effect of varying the resistive load value to the antenna in Figure 3. Adjustment of the resistive load has an influence on the antenna impedance matching.

The complete dimensions for optimum design of the HMS antenna with rectangular slot are $S = 28$ mm, $A = 10$ mm, $B = 10$ mm, $K = 0$, $L = 56$ mm, $P = 68$ mm, and $R = 100$ Ohm. The optimum dimension of UWB HMS antenna can be found by performing parametric study for rectangular slot after determining the total length of the

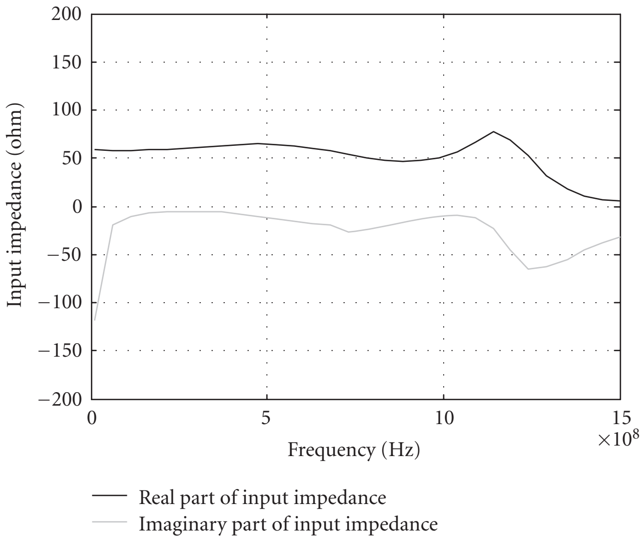


Figure 8: Simulated input impedance HMS UWB antenna with rectangular slot.

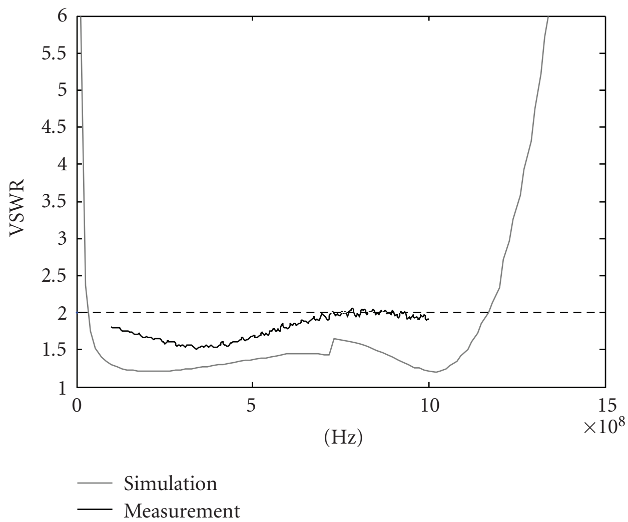


Figure 9: VSWR HMS UWB antenna with rectangular slot.

HMS. The dimensions of the rectangular slot must be larger than the dimensions of HMS as discussed in Section 2. The parametric study is started from K and followed by L and P.

The optimum design of the HMS antenna with rectangular slot has bandwidth from 97 to 1200 MHz at the return loss level less then −10 dB. Therefore, its bandwidth meets the bandwidth requirement of the 100–1000 MHz SFCW GPR application. The simulation and experiment results show that the antenna has relatively constant transfer function between 100 MHz to 1000 MHz, as shown in Figures 8 and 9. It produces minimum distortion to the individual frequency series from the synthesizer. Figure 9 shows that the antenna has relatively constant input impedance within the frequency range of the SFCW GPR, and which would minimize the ringing level.

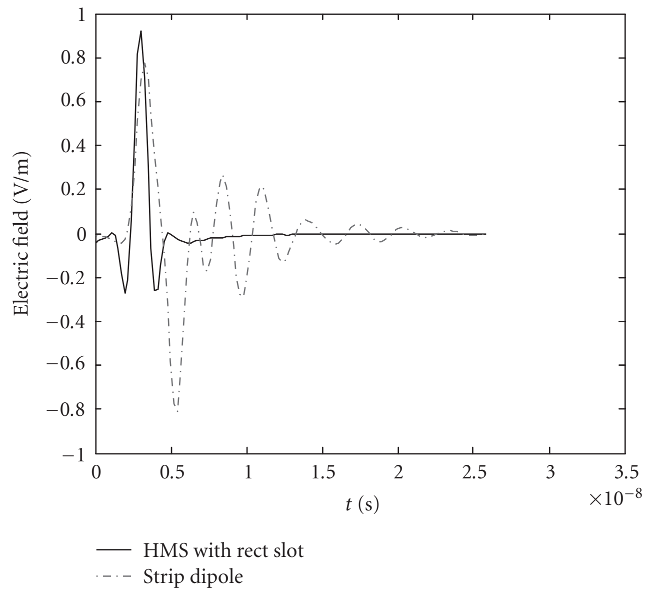


Figure 10: Transmitted waveform comparison between the HMS antenna and strip dipole.

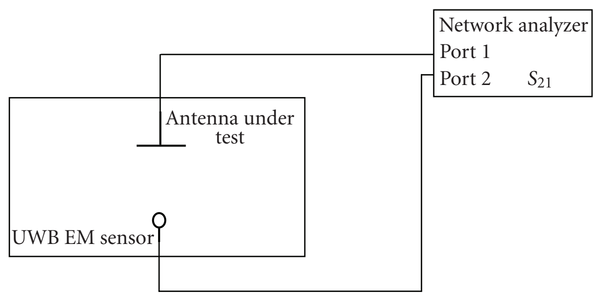


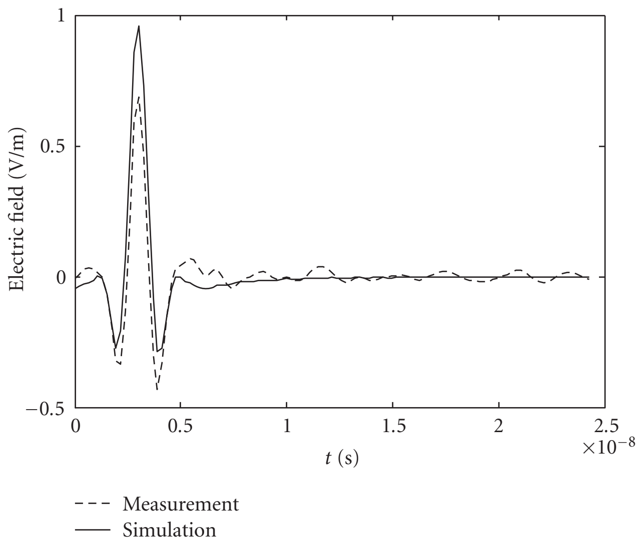
Figure 11: Transmit waveform measurement setup.

Figure 10 shows a comparison of transmitted waveform between the HMS antenna and a strip dipole with the same length when excited by a 5-nanoseconds pulse. It can be seen that the HMS antenna with rectangular slot contributes to a lower ringing level in comparison with the strip dipole.

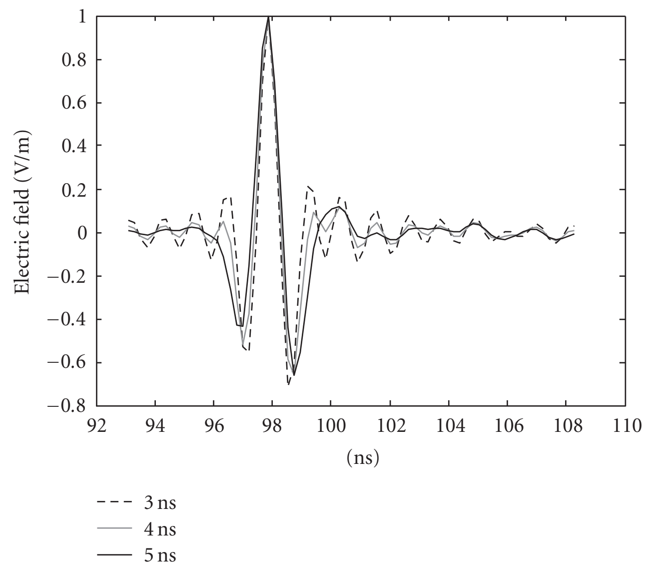
The antenna system can be modeled as a linear time invariant system. Therefore, the transmitted signal (E_t) can be obtained as a product of the measured S_{21} and the spectrum of the exciting pulse (S_f) followed by inverse FFT operation [10]. The monocycle pulse that is synthesized by the 100–1000 MHz SFCW has duration of 5 nanoseconds. E_t can be written as

$$E_t = \mathrm{IFFT}[S_{21} \cdot S_f]. \tag{1}$$

The transmit waveform of the antenna is shown in Figure 12(a). The simulation result has been verified with experiments measurements. The HMS antenna with rectangular slot was measured at both frequency and time domain using Vector Network Analyzer. The measurement setup in time domain is illustrated in Figure 11. The measurement result at frequency domain shows that the HMS antenna with rectangular slot meets the bandwidth requirement. The time

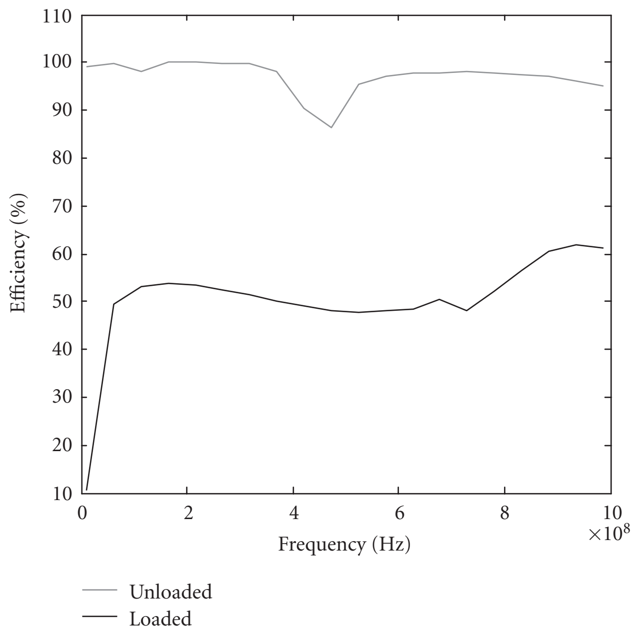


(a)

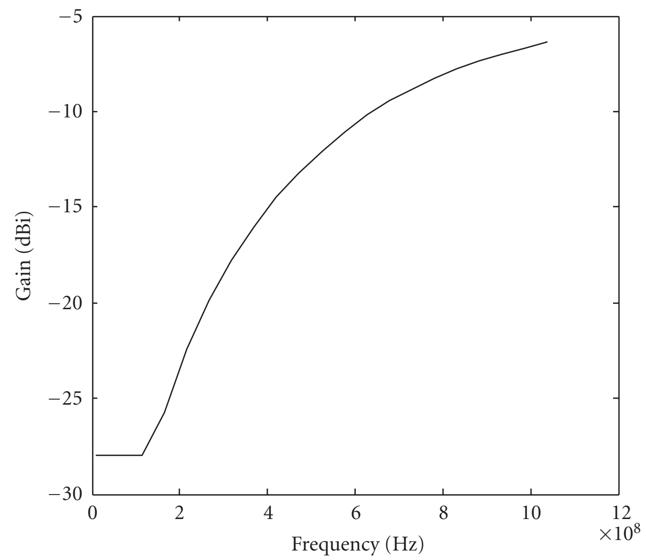


(b)

Figure 12: Transmitted waveform measurement (a) comparison between simulation and measurement results, (b) comparison of transmitted waveforms with different excitation pulses.



(a)



(b)

Figure 13: Simulated antenna efficiency and gain (a) simulated antenna efficiency, (b) simulated antenna gain.

domain measurement result is shown in Figure 12. As shown in Figure 12(a), the transmitted waveform measurement result agrees with simulated transmitted waveform.

In Figure 12(b), the antenna is excited with 3-nanoseconds, 4-nanoseconds, and 5-nanoseconds pulse and the transmitted waveform is shown. The 3-nanoseconds pulse has higher distortion and produces higher ringing level. This implies that the operation bandwidth of 100–1000 MHz is only effective for 5-nanoseconds pulse transmission as a narrower pulse requires larger bandwidth.

4. CONCLUSION

The UWB HMS antenna has been proposed for SFCW GPR application. The proposed antenna meets the 100–1000 MHz SFCW GPR requirements and has good performance for

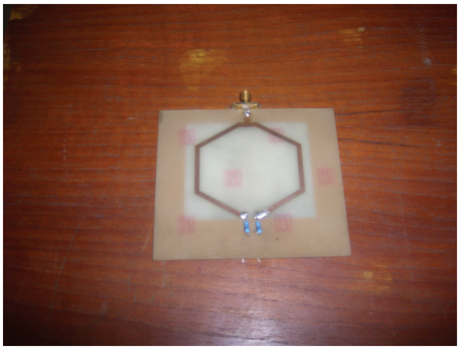


Figure 14: Photo of the HMS antenna with rectangular slot.

transmitting a 5-nanoseconds monocycle pulse excited by the SFCW synthesizer.

The rectangular slot that is added at the ground plane side of the UWB HMS antenna improves the bandwidth characteristic in the lower frequency region. Parametric study was carried out to investigate the influence of the dimensions of the slot (P, L). Adjustment of P has significant influence on the antenna characteristic at high frequencies and impedance matching in the pass band. A larger P does not affect the low-frequency edge, but has much larger impact on the high-frequency edge. An increase in L is able to decrease the low-frequency edge and will be followed by a decrease in bandwidth. Increasing L also increases the impedance matching in the high-frequency edge.

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