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Self-Complementary Bowtie Antenna with Resistive Loading for Increasing Bandwidth and Reducing Ringing Level

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ABSTRACT

Ground Penetrating Radar (GPR) is a method facilitating effective detection of buried object underground surface by utilizing the ultrawideb and (UWB) electromagnetic wave without damaging the soil structure. Antenna is an important part of GPR System. In order to obtain its best performance, an antenna must fulfil the UWB characteristic and has a low ringing level. One type of the antennas which is best applied to GPR application is bowtie antenna. The bowtie antenna with a self-complementary design aimed to get ultrawide bandwidth, on the other hand the antenna also produces relatively large ringing level. To cope with this matter, a resistive loading is performed to minimize the large ringing level. The research involves designing the antenna according to the required specification. A simulation is conducted to investigate the characteristic of the proposed antenna and to obtain the design that fulfil the intended specification and is followed by realization of self-complementary bowtie antenna with resistive loaded. The antenna is realized using a dielectric substrate FR-4 with a relative permittivity value of 4.3 and the thickness of 1.6 mm. The designed antenna produces a bandwidth 1300 to 2200 MHz and ringing level value which are less than -30 dB.

Key words :GPR, self-complementary bowtie antenna, resistive loaded, ringing level, UWB

1. INTRODUCTION

Traditionally observations of underground utilities and facilities such as electrical, communication and water supplies including pipelines and underground fibre optic, is carried out using ground digging process. This method has been considered to be not effective and inefficient because it contributes delays in the service and not to mention potential damages to the soil structure as well as excavation errors during the service. Nowdays, to facilitate the detection of underneath objects can use one of Radar technology which is Ground Penetrating Radar (GPR).The GPR is used to mainly to facilitate the works of detection and observation of the location, depth, and the shape of an underground object. The information about the objects and their condition can be obtained more easily and quickly and furthermore, damages on the soil can be avoided as it is non-destructive[1].

The working principle of the GPR is by radiating electromagnetic waves through transmitter antenna and penetrating the waves into the soil. When the electromagnetic wave hits a buried object, it will be reflected and will produce an “echo” signal which is then received by a receiving antenna. The “echo” signal will pass through the amplifier filter, then it will be processed by the signal processing and the data result will be displayed[1]. Detecting the position and shape of the object can be done optimally if the GPR has a high-resolution value and uses impulses of a certain duration. The required resolution is affected by antenna bandwidth which part of GPR system.

Antenna is one of the most important parts for the accuracy and performance of GPR. The antenna must be able to transmit and receive time pulse with short duration, because the duration of the antenna pulse in the time domain is related to the range of resolution and the depth of penetration, but short duration pulses can produce tail transmit pulses which is called late time ringing. Late-time ringing is caused by unwanted internal reflection which can cause masking effects and later will affect the level of resolution and accuracy of the results of GPR detection[2]. Based on[3], the width of main pulse that use around 6 ns with the minimum value of the ringing is below -30 dB to get the good performance of GPR. Therefore, the required antenna is the one which has a wide bandwidth but minimum late time ringing level.

There are many type of antenna that used for UWB applications such as monopole antenna [4], vivaldi antenna, bowtie antenna, etc . Based on the previous study, the double-side bowtie antenna design can cover a bandwidth of 7.5 GHz from the frequency range of 3.1 GHz to 10.6 GHz which is suitable for UWB applications[5]. Bowtie antennas are suitable for GPR applications because it fulfils ultrawide-bandwidth specifications[6]. Broadening the antenna bandwidth can be done by various methods, which are uses defected ground structure [7], fractal antenna method [8]and self-complementary. In research [9]comparing the design of a bowtie planar antenna without and with the self-complementary method for UWB applications, the comparison results show that the bowtie antenna with a self-complementary antenna has a simple design and does not require complex matching to get wide-bandwidth and detail bandwidth obtained was 8.75 GHz. Self-complementary antennas that are designed and are realized produce bandwidth from 2.8-10 GHz which is proposed for UWB application[10]. Based on[11][12] proposed an antenna design using resistive loading to reduce the value of the ringing level obtained and also be able to widen the bandwidth.

In this paper, we proposed a design of self-complementary bowtie antenna with resistive loaded method to fulfil the specification of the GPR Application. The material used for this antenna is FR-4 (ε_r = 4.3) with a material thickness of 1.6 mm. Antennas that are designed must meet the frequency range 1300 -2200 MHz and minimum ringing level of -30dB.

2. RESEARCH METHOD

In the process of designing antenna for GPR application, a bowtie antenna is design used with additional method which are self-complementary and resistive loaded method. The self-complementary bowtie antenna is a development of a triangular monopole antenna which is mirrored on the back side, in which the triangular monopole is as the radiating structure and the triangular shaped slot is on the ground. Most of the movement of electromagnetic fields in the antenna bowtie occurs along the edge of the bowtie so that modifying the length and angle of the bowtie antenna will affect the bandwidth [13]. Based on the research [10][14]if patches and ground slots possess identical dimensional shapes then the values of the magnetic field and the electric field will also be the same, therefore the input impedance will be constant and it does not depend on the source frequency and shape of the structure. Resistive loading is a method performed both to minimize the value of late time ringing and to enlarge the bandwidth [11][12]. In the designing of the self-complementary bowtie antenna with resistive loading, two resistors will be installed to connect the patches and the ground parts of the self-complementary bowtie antenna. The first resistor is installed connecting the end of the patch to the middle of the ground and the second resistor is placed between the slots on the ground, the details can be seen in Figure 1.

The design begins with determining the range frequency which is 1300-2200 MHz, selecting of FR-4 substrate as the materials and determining the dimension of the antenna. The finalization of the dimensions of the self-complementary bowtie antenna is based on modification calculations from the triangular monopole. The lower frequency is used because it can estimate the dimensions of the monopole patch which functions as a cylindrical monopole.

The length of the monopole patch is equal to the length of the cylindrical monopole and the cylindrical radius is obtained

a b

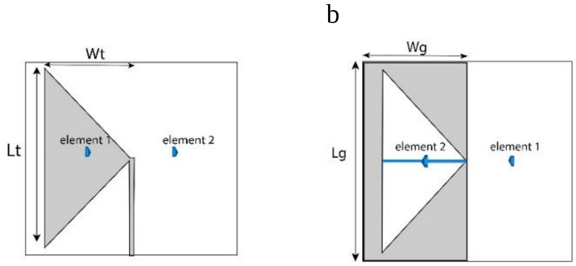

Figure 1: Self-complementary bowtie antenna with resistive loaded method (a)front side; (b) back side

from equating the surface area of the monopole patch. To find the value of the length and the radius, the equation are as follows (Sayidmarie & Fadhel, 2012)

$$\lambda = \frac{c}{f_L} \quad (1)$$

$$L = \frac{\lambda}{4} \quad (2)$$

$$f_L = \frac{7.2}{(L_T + r + p) \times k} GHz \quad (3)$$

$$L_T = \frac{\sqrt{3} \times W_T}{2} \quad (4)$$

$$k = \sqrt{\varepsilon_{eff}} \quad (5)$$

where λ is wavelength (m), c is speed of light (m/s), f_L is the lower frequency (GHz), r is radius of the cylindrical monopole (cm), .p is the gap between radiating structure and the ground (cm), L_T is the height of the cylindrical monopole which equal to triangular monopole patch (cm), W_T is the width of the triangular monopole patch (cm), ε_{eff} is effective dielectric constant, which can be found using the relative constant of the substrate (ε_r), the value can be calculated using equation :

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \quad (6)$$

3. DESIGN AND SIMULATION OF THE ANTENNA

The simulation is performed using the dimensions of the self-complementary bowtie antenna which has been calculated using equation (1) - (6). A simulation is used to observe the antenna characteristics based on the specified specifications. If the simulation results of the antenna characteristics do not meet these specifications, an additional optimization process will be performed on the antenna dimensions to get the optimal simulation results. The optimizing process of the antenna is done by change the value of dimensions the antenna become bigger, such as patch, substrate and ground plane by characterization process or trial error. However, the dimensions of the feed line width are smaller because the dimensions of the feed are related to the compatibility of the antenna supply impedance with the antenna impedance. The results of optimization on the parameters substrate width (Wg), substrate length (Lg) , patch width (Wt) and patch length (Lt) obtained indicate that if the size of the Wg and Wt is reduced or increased, it will affects the antenna bandwidth. The changes take place when the size of Wg and Wt is increased, the bandwidth obtained is getting wider. The increase or the decrease on size of Lg and Lt will affect the waveform. The addition of the dimensions of Lg and Lt makes the frequency shift to the left causing the antenna bandwidth to become narrower. The final dimensions of the self-complementary bowtie antenna is shown on Table 1.

The bandwidth results achieved after the optimization process is 600 MHz that cover from 1200 – 1800 MHz with a minimum value of Voltage Standing Wave Ratio (VSWR) 1.08 at a frequency of 1745.5 MHz.

Table 1: The dimension of the self-complementary bowtie antenna

Component	The Initial value of the component (mm)	The final value of the component (mm)	Information
h	1.6	1.6	thickness of substrate
t	0.035	0.035	thickness of copper
Wf	3.1	2	width of the feedline
Wt	39.11	68	width of bowtie antenna
Lt	33.622	73	length of bowtie antenna
Wg	48.71	83	width of the substrate
Lg	43.277	78	length of the substrate
Ws	24.352	41.5	width of the ground

In addition, ringing level indicates a widening of the pulse duration due to an increase in the dimensions of the antenna. The duration of ringing results was 7.1073 ns with the duration of main pulse is 5.1567 ns.

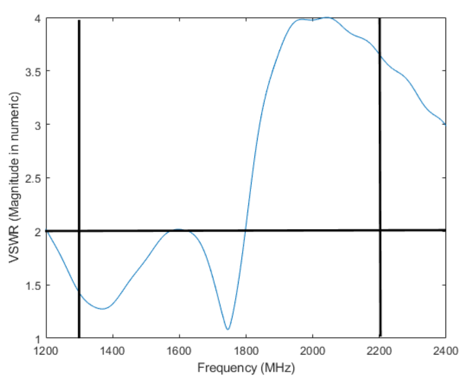

Figure 2: VSWR result from self-complementary bowtie antenna

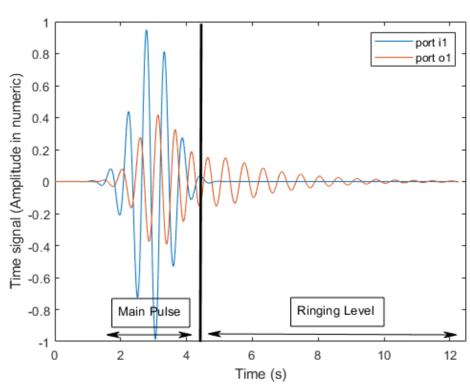

Figure 3: Ringing level result antenna design in numeric

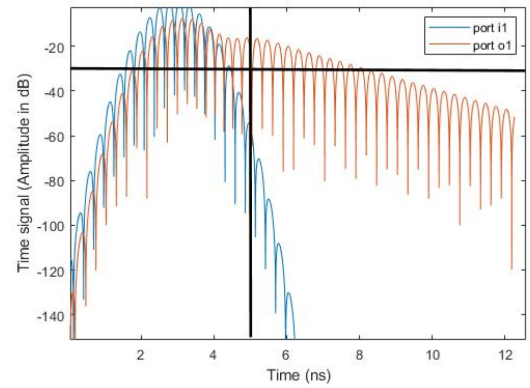

Figure 4: Ringing level result antenna design in dB

The Figure 3shows the ringing level value in numeric and Figure 4 show the ringing level value in dB. Antennas with optimized the dimensions of self-complementary bowtie antenna still do not meet the planned specifications so another method, namely resistive loading, is needed.

The first resistor is installed connecting the end of the patch to the middle of the ground and the second resistor is placed between the slots on the ground, the details can be seen in Figure 1. The resistor value used in element 1 and element 2 is the characterization of the resistor value of which the simulation results come close to the planned bandwidth and ringing level specifications. In this research, the resistor values observed were as follows: 33, 47,75, 100,220,330 390 and 470 ohms. Those values were chosen because the resistor value is characterization process and based on the resistor value is too large, the antenna frequency will shift to the right, while the resistor value will be too small, the antenna frequency will shift to the right and will also affect the dimensions of the antenna. The simulation of resistor values by pairing resistor values that have been determined sequentially in element 1 and element 2. The first resistor value on element 1 which was simulated is 33 ohms, then the resistor value on element 2 was replaced sequentially starting from 33 to 470 ohm, then repeatedly until the value on element 1 is 470 ohm. It can be concluded that the characterization to the combination of the resistor at element 1 and element 2 is done 64 times.

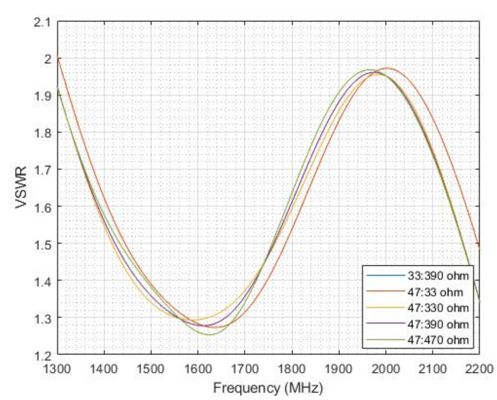

Figure 5: Result bandwidth of antenna resistive loaded design

The simulation results which are reviewed first are the bandwidth based on to the specifications. This is done to eliminate the value of the mismatched resistor then followed by reviewing the ringing level duration and ringing level value to get the optimal resistor value to conform with the intended

specifications. Based on the simulation results and that have been done, the installation of resistors with large values on element 1 affects the resulted waves to become sharper and the shifts to the left causing the narrowing of the bandwidth. Whereas the element 2 with a large value affects the antenna frequency to shift to the right which causes wider bandwidth There are several resistor values that meet the bandwidth specifications, those are R33:R390; R47: R33; R47: R330; R47: R390; R47: R470 ohms. The detail of simulation results of those resistors are shown in Figure 5. Based on the results of the review on the bandwidth that have been obtained, a review of the value of the ringing level is then carried out.

Figure 6 and Figure 7 shows the ringing level results that the minimum ringing level value and the detail value shown in Table 2. Based on the Figure 6 and Figure 7 and Table 2 detail result of duration of ringing and ringing value and based on that the resistor pair which have the shortest duration and minimum ringing value is the resistor value at element 1: 47 and the resistor value at element 2: 390 ohms.

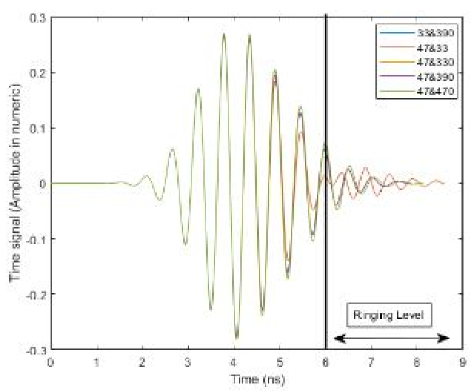

Figure 6: Result ringing level of the antenna with resistive loaded in numeric

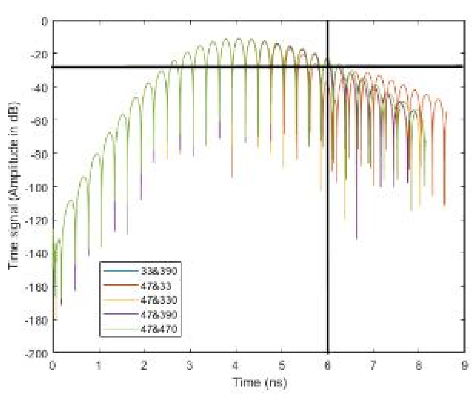

Figure 7: Result ringing level of the antenna with resistive loaded in dB

Table 2: The Comparison Ringing Value

No	Resistor value element 1:2 (ohm)	Pulse Duration	Duration of the ringing	Ringing Level (dB)
1	33:390	8.1001520 15686	2.1001520 15686	-119.9 to -24.71
2	47:33	8.5980634 689331	2.5980634 689331	-111.2 to -31.11
3	47:330	8.1001 52015686	2.1001520 15686	-119.9 to -24.71
4	47:390	7.9671087 265015	1.9671087 265015	-131.6 to -30.01
5	47:470	8.1373929 9774169	2.1373929 9774169	-144.9 to -22.81

Based on the above simulation results, the final dimensions and resistor values that meet the 900 MHz bandwidth specifications and ring level values below -30 dB are shown in Table 1 with additional resistor are element 1 and element 2 with the value 47 and 390 ohm.

From the result, the bandwidth that obtained after added resistive loaded increase 84.2% compared to the self-complementary antenna without resistive loaded and the ringing level decrease 13.15 dB from -16.86 become -30.01 dB. The comparison bandwidth and ringing result between the self-complementary bowtie antenna without and with resistive loaded show in Figure8, Figure9 and Figure 10.

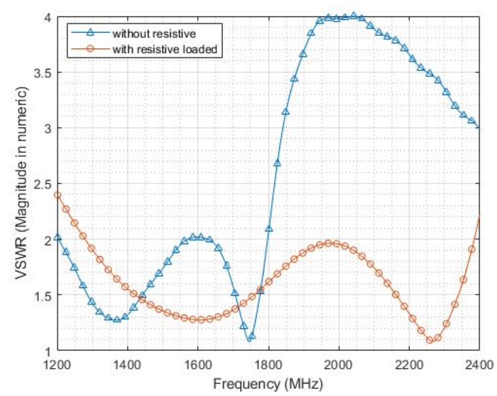

Figure 8: The comparison of bandwidth result between with and without resistive loaded

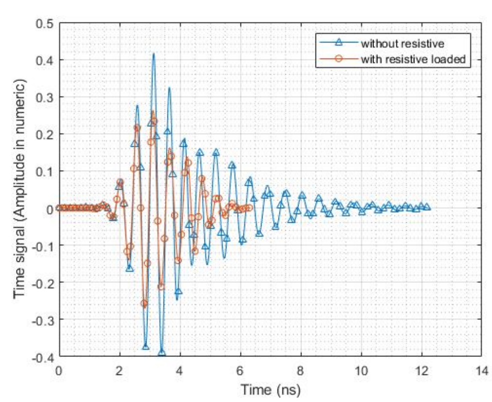

Figure 9: The comparison of ringing level result between with and without resistive loaded in numeric

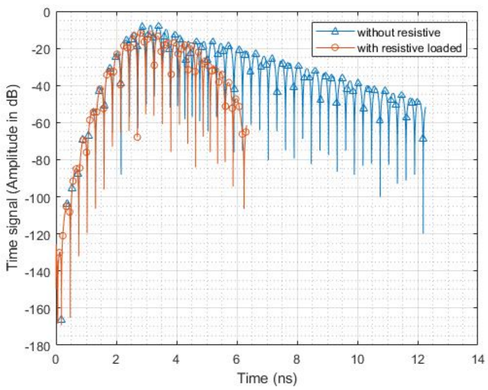

Figure 10: The comparison of ringing level result between with and without resistive loaded in dB

The antenna design is then fabricated following its measurements to get the actual condition data in the branch of the designed antenna. The antenna material used is printed circuit board (PCB) FR-4 with dielectric permittivity value of 4.3 and the detail dimensions antenna that fabricated show on Table 1.The dielectric permittivity value in the substrate affects the maximum amplitude value of the transmitted pulse, so the antenna fabrication process must be done with high accuracy and precision, because errors in the dimensions and the order of the antenna will affect the characteristics of the antenna that has been designed and simulated. Figure 11shows the fabricated antenna that has been installed using connector which has a 50ohm impedance.

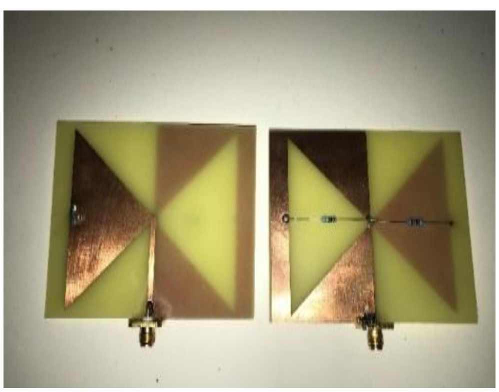

Figure 11: Realization Antenna

4. MEASUREMENT AND ANALYSIS

The parameters to be measured at this antenna are VSWR, Bandwidth and Ringing level. The VSWR measurement is applied because it is related to the comparison between the reflected and incoming waves and is also used to see the compatibility between the transmission line impedance and the antenna which causes the number of waves to be reflected to the source to a minimum so as to produce a good performance. Antenna bandwidth is related to detection resolution, so it is essential to measure the bandwidth to find out if the antenna has met the specifications. The antenna bandwidth lies in the lower frequency and upper frequency which is limited by the VSWR value. Measurement of these parameters is carried out using the Vector Network Analyzer (VNA) as a measuring tool with a range of frequencies from 300 KHz to 8 GHz). In this measurement, the implemented frequency range is 1200 MHz-2400 MHz. The scheme of the measurement is shown in Figure 12.

VSWR values for antennas with good performance have range value 1 until 2. VSWR analysis is carried out to compare the results from the simulation to those of the measurement. The realized antenna indicates a VSWR value of 1.759, while the antenna simulation has a VSWR of 1.897 at a frequency of 1300 MHz. The comparison reveals a different value of 0.138, the difference is considered not too significant. The VSWR measurement results from the realization of the antenna experience a frequency shift to the left, but it does not have much effect because both the VSWR results of the measurement and the simulation below 2 that means the antenna still has a good performance.

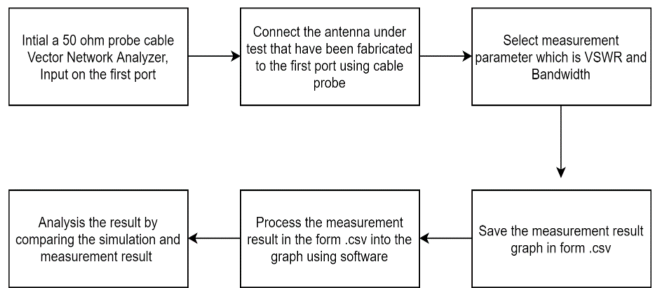

Figure 12: The scheme of VSWR and bandwidth measurement

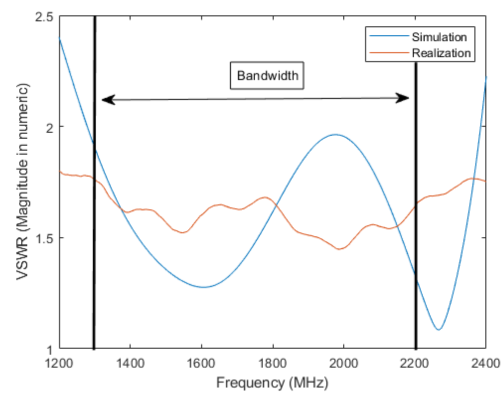

Figure 13: Comparison simulation and measurement result

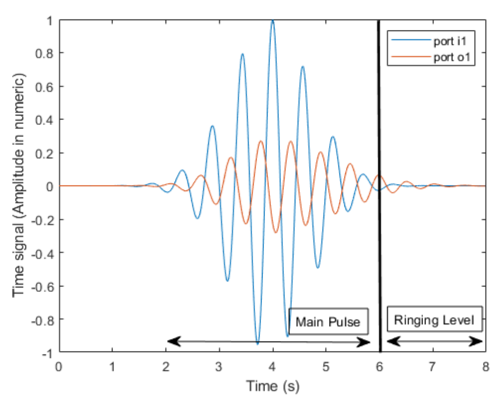

Figure 14: Simulation result of ringing level in numeric

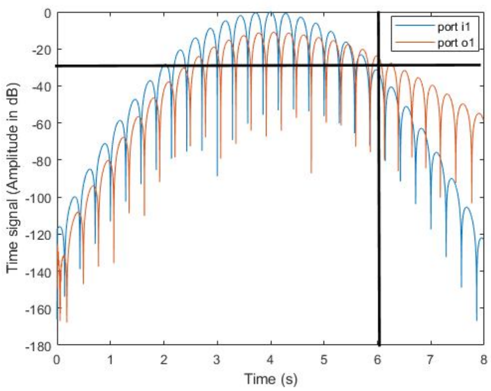

Figure 15: Simulation result of ringing level in numeric

The shift and the difference in value are influenced by many factors such as the precision of the fabricated antenna, the antenna measurement results changes when the condition of measurement instrument shifts or moves. Figure 13 shows the detailed comparison of the simulation and the measurement results.

In this paper, the bandwidth value is viewed from the VSWR curve. Based on the VSWR curve which is under 2, the bandwidth results that obtained from measurement and the simulation are 1105.1 and 1200 MHz, respectively which is cover the desired range frequency, namely 1300 – 2200 MHz. The fractional bandwidth that achieved from measurement result is 66.6% and for the simulation result is 60.3%. The comparison result show that the bandwidth from measurement result is wider 0.085 % than the bandwidth from simulation result. The results of the comparison of the simulation and the measurement bandwidth are in Figure 13.

From the simulation results it is seen that the pulse width on the transmitting signal is 6 ns and the pulse width on the receiving signal is 7.9671087265015 ns. Therefore the ringing level width of 1.9671087265015 ns (pulse width difference of the transmitting and receiving signals) confirms that the width of the ringing duration is small and it is in accordance with the specifications for the GPR application, the details are shown in Figure 14. In Figure 15 the range ringing level value obtained is -131.6 to -30.01 dB which meets the specified specifications to be below -30 dB.

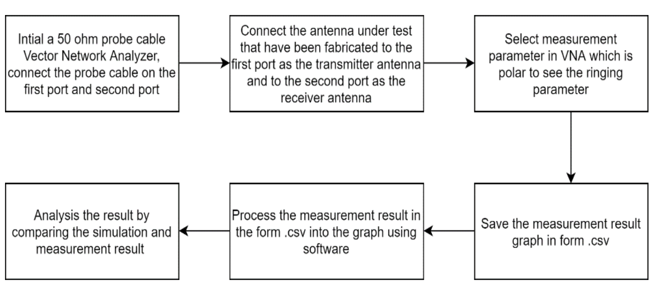

Figure 16: The scheme of ringing level measurement

Ringing level measurements are carried out using 2 antennas, the first antenna is connected to the S11 VNA which acts as a transmitter antenna, then the receiver antenna is connected to the VNA on S21 and same as the measurement of the VSWR and bandwidth, the implemented frequency range is 1300 MHz-2200 MHz, detail measurement process shown in Figure 16.In this measurement, the results will be reviewed from S21 and the distance between the two antennas is 12 cm.

Figure 17 shows that the result of ringing level measurement are in numeric and Figure 18 shows that the result of ringing level measurement is in dB. The width of the main pulse transmitted in measurement and simulation have same value which is 6 ns and the ringing value range obtained is -30.09 dB to -128 dB. The difference the range ringing level between measurement and simulation not too significant which are for the maximum value 0.08 dB and for minimum value 3.6 dB and both results still meet the specified specifications. The difference occurs due to several factors such as attenuation, fabrication accuracy, imperfect connector connection and measuring instrument condition.

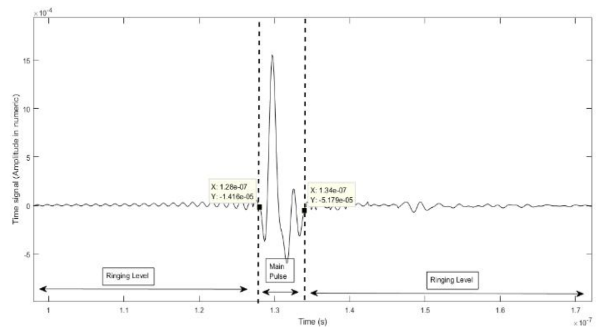

Figure 17: Measurement result of ringing level in numeric

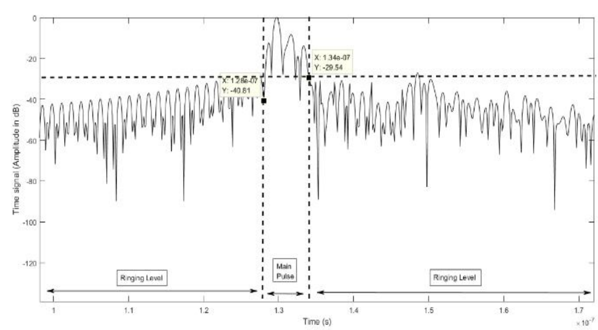

Figure 18: Measurement result of ringing level in dB

Based on measurement results that obtained, the bandwidth and the fractional bandwidth of measurement and the simulation fulfil the characteristic of ultra wide bandwidth because the value of fractional bandwidth that obtained from of both result are bigger than 20%. The range of ringing value that obtain also fulfill the specification of ringing level which is below -30 dB. From that, it was concluded that the realized antenna suitable for GPR application.

5. CONCLUSION

After completing all the processes comprising of the design, simulation, optimization, realization and measurement of the bowtie antenna with self-complementary bowtie and resistive loading for the GPR application, it can be concluded that the addition of the self-complementary method widens the resulting bandwidth value. The optimization which is done by enlarging the antenna dimensions affects the antenna frequency shift and bandwidth widening. The optimization that is done to widen the antenna bandwidth affects the width of the pulse duration of the antenna ringing level. The addition of the method of resistive loading is the result of characterization of some resistor values which suggest a conclusion that the bigger the resistor value in element 1 affects the narrowing of the bandwidth and the height of the amplitude increases. Contradictory to the resistor in element 2, the bigger the value results in wider bandwidth resistance and lower amplitude height. The results of bowtie antenna measurements with self-complementary and resistive loading are 1200 MHz for bandwidth and the range ringing level of -128 – 30.09 dB. The measurement results confirm that the design of the antenna has met the antenna specifications for the GPR application.

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