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ULTRAWIDE BAND POWER DIVIDER BASED ON SUBSTRATE INTEGRATED WAVEGUIDE (SIW) FOR S-BAND APPLICATIONS

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ABSTARCT

This paper proposes a novel design of power divider based on SIW with extra via. Simulation and measurement are done to investigate the characteristic of the power divider. Characteristic dependence to the power divider structure parameters are investigated, such as: diameter of via, thickness of substrate, and feeding transition. The power divider is designed by using substrate with high constant dielectric (ϵ_r = 6.15). The design obtain minimum structure of 64×95 mm which is reduced the size up to 80% comparing with the previous design. The measurement result is satisfied to requirement parameters target of return loss (S11) less than –14.3 dB, insertion loss (S21 and S31) more than –4.3 dB with at frequency range of 2-3.5 GHz of fractional band width at 54.5%.

Keywords: microstrip, ultra-wide band, SIW, power divider.

INTRODUCTION

Power divider is wide used in millimeter wave and microwave applications. The conventional wave-guide power divider has low losses but it has large size and weight, it may difficult to be integrated into circuit. In other side of general talking, the using of microstrip technology for develop millimeter and microwave circuit such as power divider allows to have a compact size, enable to integrated into microwave circuit, easy to fabricate, and low-cost. Most of microstrip gives high losses as its disadvantage [1]. More advance technology, SIW promise some advantages in implementation such as have a compact and planar structure, low cost, and give lower losses compare with microstrip. As a compact and planar structure of SIW, it enables to be integrated into circuit easily, for example integrated to the antenna [2]. Some researchers develop the power divider based on SIW in various purposes [2]-[8] such as power divider integrated with a Vivaldi antenna to decreasing the return loss [2], T-junction and Y-junction [3], for miniaturization structure proposed the half mode SIW (HMSIW) [4]-[6], for enhance the bandwidth rejection by using a slot [7], for enlarge the bandwidth by using ridge SIW (RSIW) [8]. All of the mentioned power dividers are operate at high frequencies for radar applications.

In ultra-wide band (UWB) radar system, a power divider work on RF front-end sub system as divider the input power and distributes to each array antenna elements. In radar system, the power divider is also used for picking a signal for in time domain analysis and then comparing with the reflected signal. One of the radar applications is Ground penetration radar (GPR).GPR is a promising technology to detect buried objects beneath or near ground surface. The complexity is mainly due to various fields of research such as electromagnetic wave propagation in loss media, UWB power divider, UWB antenna design, and signal processing which are incorporated in this technology. In order to supporting front-end of GPR technology, we develop a UWB power divider which works in frequency range of 2-4 GHz.

GPR design has a specific problem than other radar application. GPR operate at lower frequencies in order to have capability to penetrate ground layers. Lower frequency gives a consequence to the power divider structure to the large enough size. This is giving a challenge to propose a novel design of power divider with small structure design base on SIW for GPR application.

This work is include the simulation, optimization, fabrication, and measurement of proposed three port power divider base on SIW to accomplishing the targeted parameter to fulfilling the specification for GPR application. The basic characteristic of power divider also investigated in this report. The proposed power divider is operates at 2-3.5 GHz to support ultra wide band GPR with small structure and have a compact size.

The rest of contents of this paper are organized as follows; In Section II, parameters of the designing process as a target of the three ports power divider in design and fabrication are described. In Section III, details design and investigation of the proposed power divider including the transition feeding are reported. The previous work is also reviewed in this section. In Section IV, the results of measurement of proposed power divider are discussed. Finally, the conclusions of the work are provided.

DESIGN PARAMETERS

Operating frequency

Theoretically, lower frequency will increase the ability to penetration but it will be enlarger the structure of the power divider. In accordance with what is mentioned above, it is good to obtain the optimum value in achieving a tradeoff among the parameters. Power divider base on SIW have the similar characteristic with a waveguide, it should be set at a single mode in order to avoid signal distortion. It divider is designed to operate in frequency range of 2-4 GHz in order to fulfil the specification of the

GPR application. Ultra-wide band (UWB) has more than 20% of fractional bandwidth determined from the following equation (1)

$$FBW = \frac{2(f_h - f_l)}{(f_h + f_l)} \quad (1)$$

where f_h and f_l are higher and lower frequency of the power divider.

Scattering parameter

The return loss can be calculated by using S11 when the output port of power divider in match condition with the load. Scattering parameters must be specified as targeted design parameters to achieve good performance of the divider. The targets of scattering parameter of the three port power divider are S11 of −10 dB for the input, S12 and S13 for each should be least than -3 dB for the output.

SIW STRUCTURE

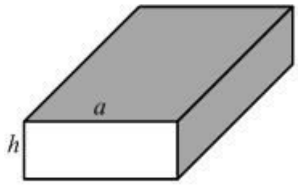

Figure-1. Basic structure.

Basic structure of the SIW and the parameter are shown on Figure-1. Frequency cut-off f_c at TE_{mn} mode can be determine by using

$$f_{c\text{-}mn} = \frac{v}{2\pi\sqrt{\epsilon_r}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{h}\right)^2} \quad (2)$$

where v is velocity of light in free space, ϵ_r is dielectric constant of the used substrate, a and h are width and the thickness of substrate respectively. Because of the structure of SIW is very thin, so that the suitable operation mode isTE_{m0}. Therefore the dominant mode of (TE_{10}) is determinate from equation (3) as derivation of the equation (2) [9].

$$a = \frac{v}{2f_{c\text{-}10}\sqrt{\epsilon_r}} \quad (3)$$

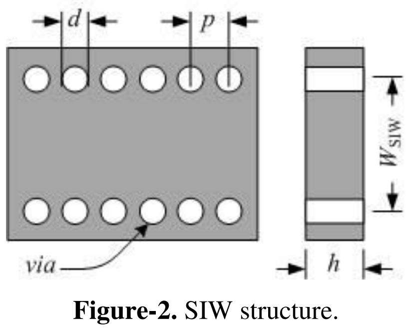

Figure-2. SIW structure.

Physically, width of the structure can be obtain by using equation (4) as follows

$$W_{\rm SIW} = 0.5\left[a + \sqrt{(a + 0.5d)^2 - 0.4d}\right] + 0.27d \quad (4)$$

where d is the diameter and p is the adjacent distance between two vias of SIW structure. The distance of two via is twice of the diameter.

Simulation of basic structure

The design of power divider is base on SIW involving permittivity as dielectric constant of the used substrate ϵ_r. Figure-3 shows the dependence of width of $W_{\rm SIW}$ to dielectric constant with various frequency cut-off, plotting from equation (3) and (4) with variation of ϵ_r of 1.05, 2.2, 3.48, 4.3, and 6.15. We set the diameter of via is unity. These dielectric constants are referring to the commercial products specification. The higher ϵ_r give smaller size at same frequency cut-off. The lower frequency with smaller size is preferred over the other, which is substrate with ϵ_r of 6.15.

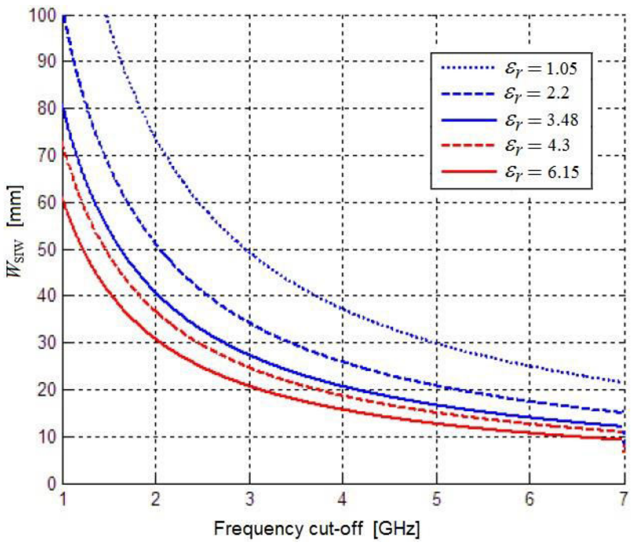

Figure-3. $W_{\rm SIW}$ size gains to frequency in various ϵ_r.

Figure-4 shows the numeric simulation result of S-parameter for S11 and S21 of the SIW basic structure at $W_{\rm SIW}$ = 30.8 mm, W = 35 mm, L =40 mm h =35 µm, d =1 mm, and ϵ_r = 6.15. Frequency cut-off rising at 2.07 GHz for insertion loss of −3 dB and close to 0 dB at frequency above 2 GHz. Return loss (S11) is less than −20 dB for higher frequency above 2 GHz.

Dependence of return and insertion loss

Effect of various diameter of via d to the S-parameter of the SIW is also investigated. We sweep the diameter for 0.5, 1.5, 2.5, and 3.5 mm to observe the affect to return-loss and insertion loss. The S-parameter as a result of numeric simulation is shown in Figures 5 and 6. Minimum return-loss is increasing when the diameter of d become bigger, see in Figure-5.

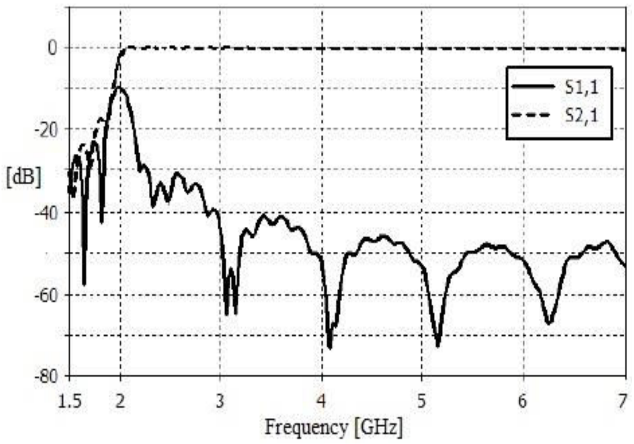

Figure-4. S-parameter of the SIW basic structure.

Dependence of insertion-loss to the diameter size of d is demonstrated in Figure-6, which the frequency cut-off at insertion-loss at -3 dB shifts to higher frequency when d becomes bigger. Both figure shows that for bigger diameter of d give higher return loss or return loss. While changes in substrate thickness h do not has significant impact on return-loss and insertion-loss.

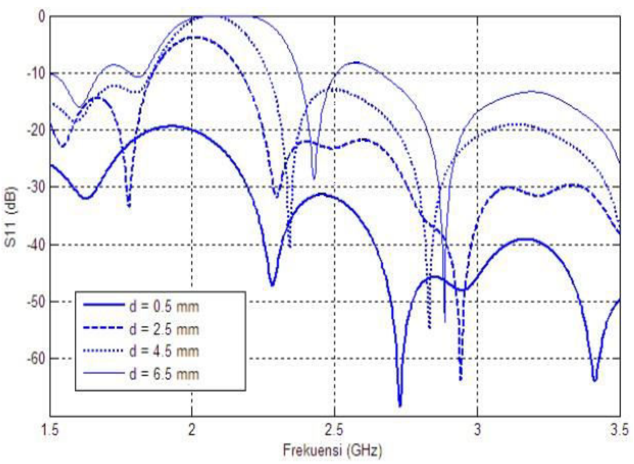

Figure-5. S11 for various d.

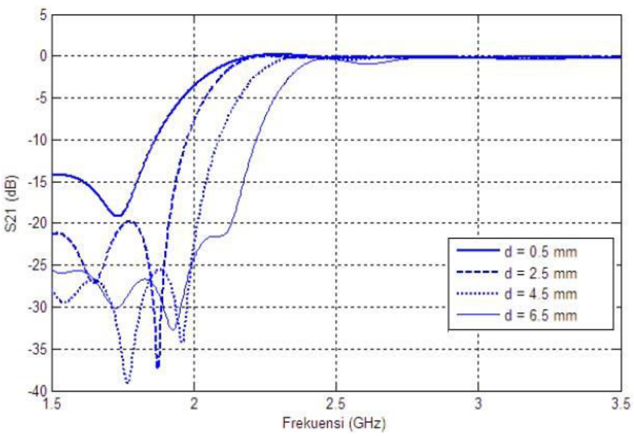

Figure-6. S21 for various d.

Transition feeding

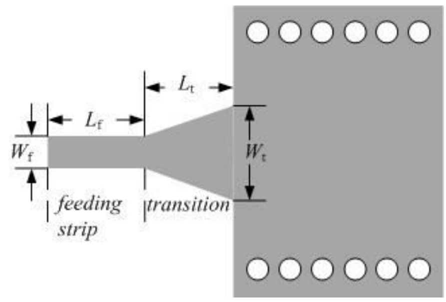

Figure-7. Structure of transition feeding.

The SIW basic structure is an ideal form of SIW structure which has very large impedance at its both edges. Therefore, need to design the transition feeding at the edges of the structure in order to match the impedance between transmission line and SIW structure. The structure of the transition feeding is shown in Figure-7; dimension of the transition feeding is determine by using equations (5) and (6). Factor A is involving some parameters are impedance of microstrip inputZ_0, impedance of the airZ_f, and dielectric constant relative ϵ_r. The equations of factor A for $W/h \leq 2$ is expressed as follow

$$A = 2\pi \frac{Z_0}{Z_f} \sqrt{\frac{\epsilon_r+1}{2}} + \frac{\epsilon_r-1}{\epsilon_r+1}\left(0.23 + \frac{0.11}{20}\right) \tag{5}$$

using of the result of equations (5), we can obtain the width of the transition feeding as follows:

$$W_t = h\frac{8e^A}{e^{2A}-2} \tag{6}$$

The length of the transition feeding L_t determined byλ_s, where the wavelength of the substrate λ_s is expressed as follows:

$$\lambda_s = \frac{v}{f\sqrt{\epsilon_{\text{eff}}}} \tag{7}$$

where the permittivity effective ϵ_{eff} is determined by using

$$\epsilon_{\text{eff}} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r+1}{2\sqrt{1+12\frac{h}{W}}} \tag{8}$$

The width of feeding and output strip W_{fm} is calculated by using the equation (9). We setting the impedance input and output are at Z_0 for 50Ω.

$$Z_0 = \frac{80}{\sqrt{\epsilon_{\text{eff}}}} \ln\left[\frac{8h}{W_{\text{fm}}} + \frac{W_{\text{fm}}}{4h}\right] \tag{9}$$

Final dimension of the microstrip transition feeding of the SIW structure is shown in Table-1. Numeric simulation result of the transition feeding structure shown in Figure-8. The structure demonstrate minimum value to return-loss and good insertion-loss in the range frequency of 2–4 GHz.

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Table-1. Dimension of transition feeding.

Variable of the dimension	**in** (mm)
W_{fm}	6.5
W_{tm}	13
L_{fm}	2.24
L_{tm}	6.5

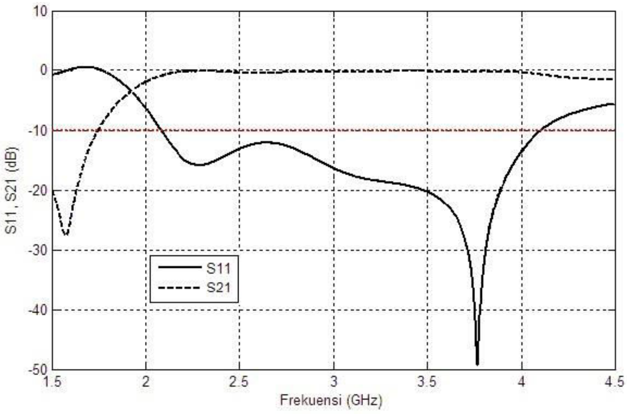

Figure-8. S-parameter of the transition feeding.

Design of simple three port power divider

The previous design of the three port power divider is consist of one port input (denoted as port 1) and two port output (denoted as port 2 and 3). The structure is built on 3 layers with copper layer on the top and bottom layer, and a dielectric layer between the two copper layers as shown in Figure-9. The substrate have ϵ_r= 6.15. Total dimension of the designed structure is 71 × 99 mm square. The simple three port divider give the return loss less than -10 dB and insertion loss (S21 and S31) less than -3 dB for frequency range in 2-3.6 GHz. The plotting of the performance as a result of numeric simulation shown on Figure-10, as reported in [10].

Table-2.

Variable of the dimension	**in** (mm)
W_{fm}	6.5
W_{tm}	13
L_{fm}	2.24
L_{tm}	6.5
L	99
W	71
$L_{SIW\text{-}basic}$	40
$W_{SIW\text{-}basic}$	29
d	1
h	0.35
p	2
W_{edge}	35

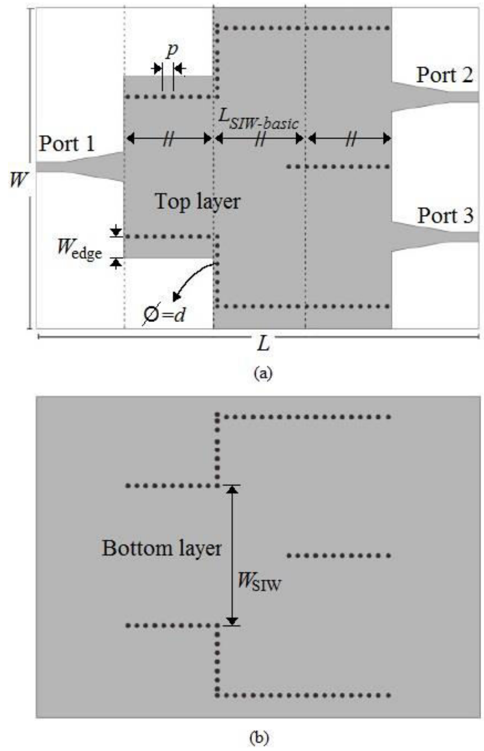

Figure-9. A simple power divider structure: (a) Top layer, (b) Bottom layer.

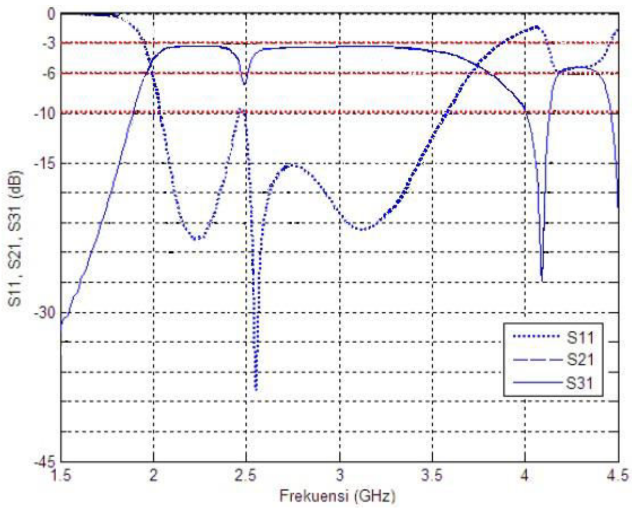

Figure-10. S-parameter of simple power divider.

Modified design of power divider

In order to miniaturization the dimension of structure, we modified the previous design by adding extra via at the transition area that are at input and output side. Two via are added to the transition area, two on the input and two on each the output. The new structure of the modified divider has designed. The diameter size of extra via at transition structure d_t = 1.5 mm. Distance between extra via of transition feeding and via of the power divider structure p_t= 0.66p, where p is via pitch of the power divider structure. Adjacent distance between two extra via on transition structure $W_{t\text{-via}}$=31 mm, $W_{SIW-basic}$= 29 mm, and $L_{SIW-basic}$ =40 mm. Finally the total dimension of the divider structure $W \times L$ is 64×95 mm^2. The final structure can be seen on Figure-11. The modified power divider has reduced the size of 14% compared with previous work [10].

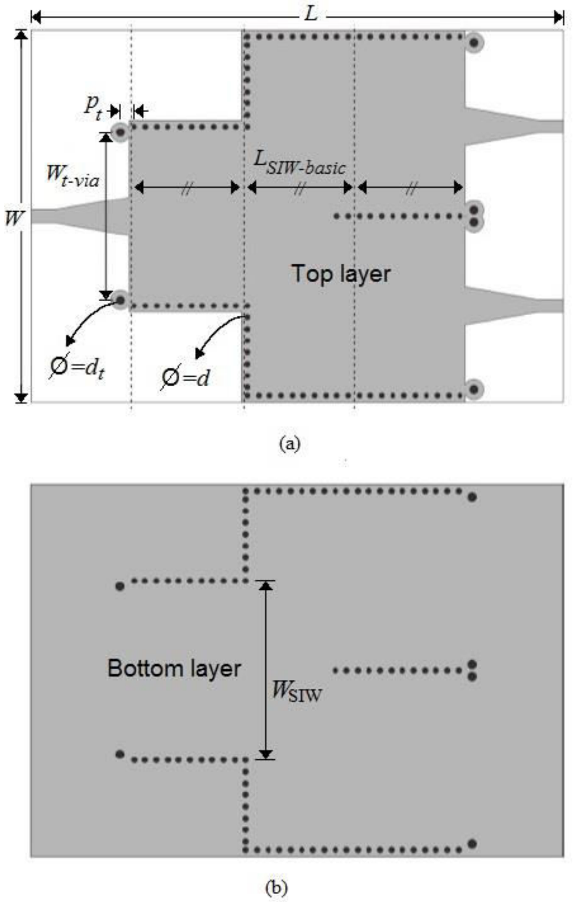

Figure-11. New power divider structure: (a) Top layer, (b) Bottom layer.

Performance parameters of the novel power divider are shown in Figure-12. The curve of the denoted as solid line demonstrate similar performance to the previous work, but it gives better return loss on frequency around 2.4 GHz compare with previous work. Previous work shows the return loss on 2.4 GHz more than −10 dB, current work give return loss less than -17 dB. Insertion loss curve of S21 and S31 denoted as dotted line and dashed line, respectively. Similar with previous work both of insertion loss curve are coincide. The same behavior as return loss happens to the insertion loss; both demonstrate better performance on around frequency 2.4 GHz. Previous work shown that the insertion loss give least than −6 dB (see Figure-11) and the modified design perform more than −3 dB at 2.4 GHz. Generally all the curve shows that the novel power divider operates in the same frequency range of 2−3.6 GHz, it is similar to the previous design.

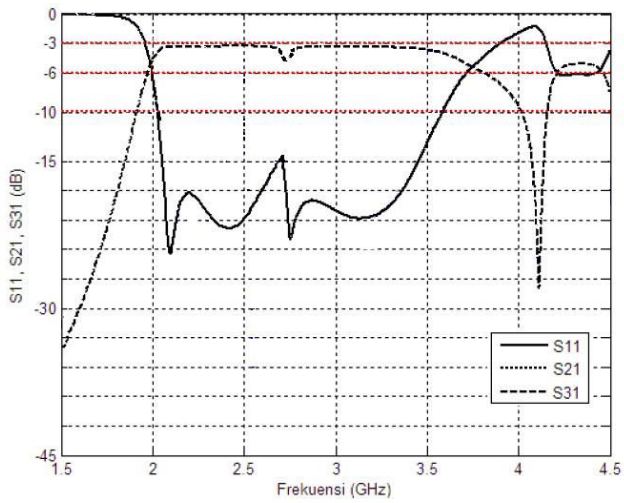

Figure-12. S-parameter of new power divider.

The comparison between the simple power divider as previous work and the modified one is shown in Table-3. Frequency range, return loss, and insertion loss are perform slight similar for both divider, but the modified structure reduce the total size to be 86% of previous structure and gives better insertion loss.

Table-3. Comparison between the previous and modified power divider.

Parameter	Previous	Modified	Difference
Range freq. [GHz]	2 – 3.6	2 – 3.6	–
S11 [dB]	– 10	– 15	5
S21 [dB]	– 7	– 4	3
S31 [dB]	– 7	– 4	3
Dimension [mm^2]	71 × 99	64 × 95	86%

MEASUREMENT

Fabricated three ports power divider follows the specification which it is as result of the design and simulation. Table-4 shows physical parameters as a specification of the novel power divider. All of the values of the dimension parameters are in millimetre.

The physical form of the novel three ports power divider is printed on the top layer and bottom layer of the substrate are shown in Figures 13 and 14, respectively. The bottom layer is as ground plane of the power devider.

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Table-4. Dimension of new power divider.

Variable of the dimension	in (mm)
W_{fm}	6.5
W_{tm}	13
L_{fm}	2.24
L_{tm}	6.5
L	95
W	64
$L_{\mathrm{SIW\text{-}basic}}$	40
$W_{\mathrm{SIW\text{-}basic}}$	29
d	1
h	0.35
p	2
W_{edge}	1
$W_{\mathrm{t\text{-}via}}$	36.5
d_t	2.5
p_t	1.5

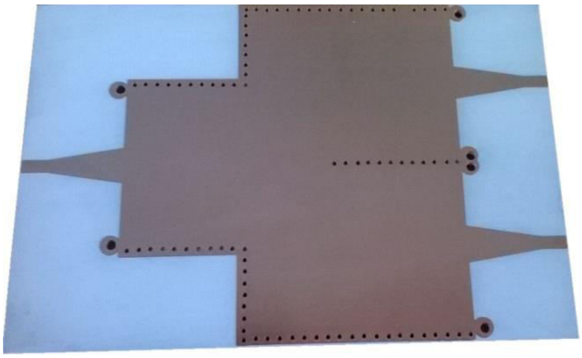

Figure-13. Top layer of power divider.

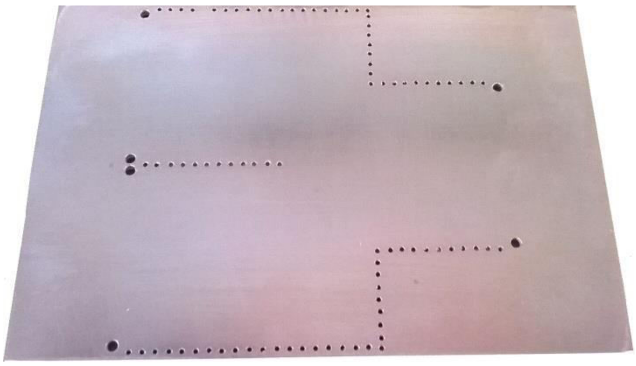

Figure-14. Bottom layer of power divider.

Measurement are done for the parameter and compared with the numeric simulation result to observe the performance of the new power divider. Figure-15 shows the comparison of return loss between numeric simulation and the measurement of the new power divider. Lower frequency cut-off of both curve are quite similar, but higher frequency cut-off shift to lower at 3.5 GHz compared to the result of the numerical simulation at 3.6 GHz. In general, the curve of return loss gives the similar performance, less than 14 dB for all the S11 in the range of the desired bandwidth.

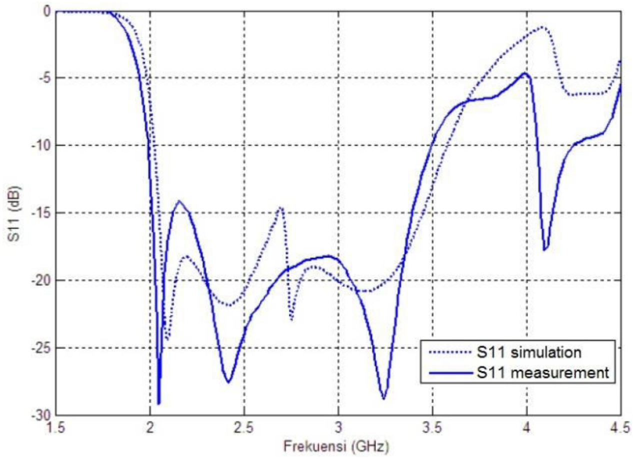

Figure-15. S-parameter of simple power divider based on SIW.

Figure-16 shows the comparison between numeric simulation and measurement of insertion loss. Numeric simulation result of S21 and S31 shows that both curve are slightly similar. There is little bit difference between S21 and S31 for measurement result, but in general both give the same bandwidth. The insertion loss for both simulation and measurement results are quite similar, but there is difference in bandwidth.

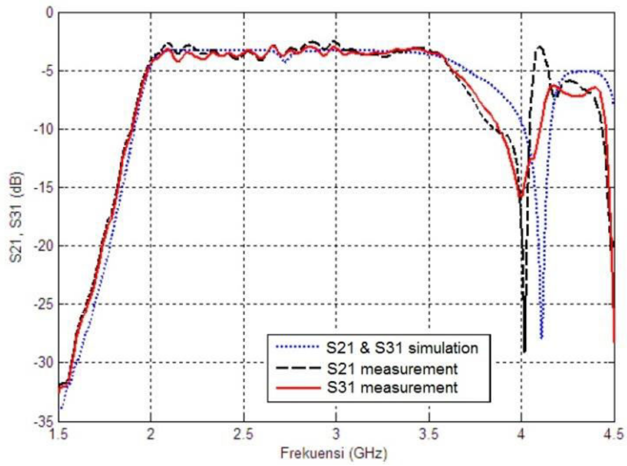

Figure-16. S-parameter of single power divider based on SIW.

4. CONCLUSIONS

Prototype of the novel three ports power divider based on SIW had designed, simulated, fabricated and measured. Total final dimension of the new power divider has reduced the size to be 86% than the previous. In General, return loss (S11) and insertion loss (S21 and S31) demonstrate similar behavior for result of simulation and measurement. The parameter gives a good performance to the novel power divider, that are frequency in range of 2-3.5 GHz, return loss less than -14 dB, insertion loss more than −3 dB, and the fractional bandwidth 54.5%. The novel power divider is fulfilling the specification requirement of the ultra-wideband ground penetration radar.

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