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Compact Power Divider Integrated with Coupler and Microstrip Cavity Filter for X-band Surveillance Radar System

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Abstract

This paper present the compact power divider integrated with coupler and microstrip cavity filter for x-band surveillance radar system. These modules consist of several devices (splitter, filter and coupler) it is integrated in a single module aims to reduce the loss in the joint connectors. The bandpass filter is use microstrip cavity filter for operating on X-Band Frequency and deployed on RT/duroid 5880. The power divider and coupler is designed using quarter wavelength transformer. A theoretical analytical circuit model will be presented, from the theoretical model; a compact integrated module will be designed and simulated. The proposed compact integrated module is small in dimension and performs a compact size. The compact integrated devices design on X-Band frequency is simulated and the result is presented.

Keywords: Integrated, filter, power divider, X-Band, radar

1. Introduction

Radio Detecting and Ranging (Radar) is a technology that is very famous and reliable for identifying unknown objects. The Radar were developed and widely used in many applications such as for air surveillance, weather predictions, traffic controlling, military applications and so on [1, 2]. The basic functions of radar are to detect the presence of electromagnetic scatterers (radar targets) in the antenna beam and to determine their positions. The antenna radiates the transmitter output into space, typically in a directional pattern that concentrates most of the power into a major lobe or beam which is narrow in one angular dimension (fan beam) or in both angular dimensions (pencil beam).If there is a target in the beam, the radar receives an echo from it following each transmitted pulse. The target range or distance is readily determined by multiplying half the time delay between the transmitted and received pulses by the speed of light [3].

Surveillance Radar and Polarimetric Synthetic Aperture Radar [4] is a technology that is need for an archipelagic nation like Indonesia. Other than that, antenna suitable for coastal surveillance radar is looking at a beam of the antenna, as in previous research circularly symmetric shaped beams [5]. In the research that has been done [6], the preparation of radar components is still using separate modules and connected with a semi-rigid cables and adapters. In this case, lead to the dimensions of the radar to be large. The large dimensional of radar that lead to weight also increased, so in this research is to design a devices from several modules integrated into one of a compact form aims to reduce the effect of loss connections between the connected ports.

In this proposed design, performed the design and simulation of the three component modules that is will integrated into one device so that it becomes compact form. Other than that, this proposed design suitable to be applied to the front-end array antenna that generates a beam forming [7].

The output of proposed design be expected have good insertion loss and the same phase on output port because a collection of sources (the antenna) and the radiated field caused by these sources [8]. These modules are 2 Way Power Divider, Directional Coupler and

Bandpass Filter as shown in the block diagram of the radar depicted on Figure 1 with the focus of research in this paper is on the components which is in the red circle.
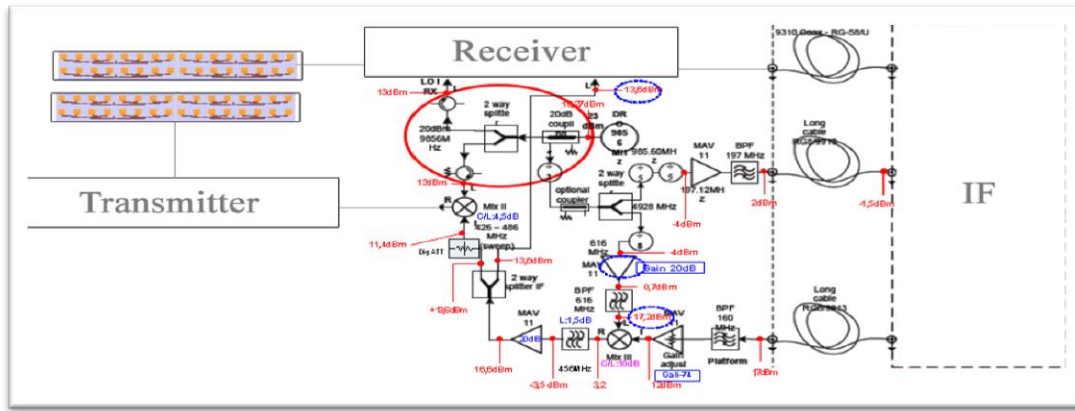

Figure 1. Diagram Block of the Surveillance Radar

2. Theory and Design RF Module
2.1. Microstrip Cavity Bandpass Filter

A band-pass filter (BPF) is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range. An example of an analogue electronic band-pass filter is an RLC circuit (a resistor–inductor–capacitor circuit). These filters can also be created by combining a low-pass filter with a high-pass filter [9].
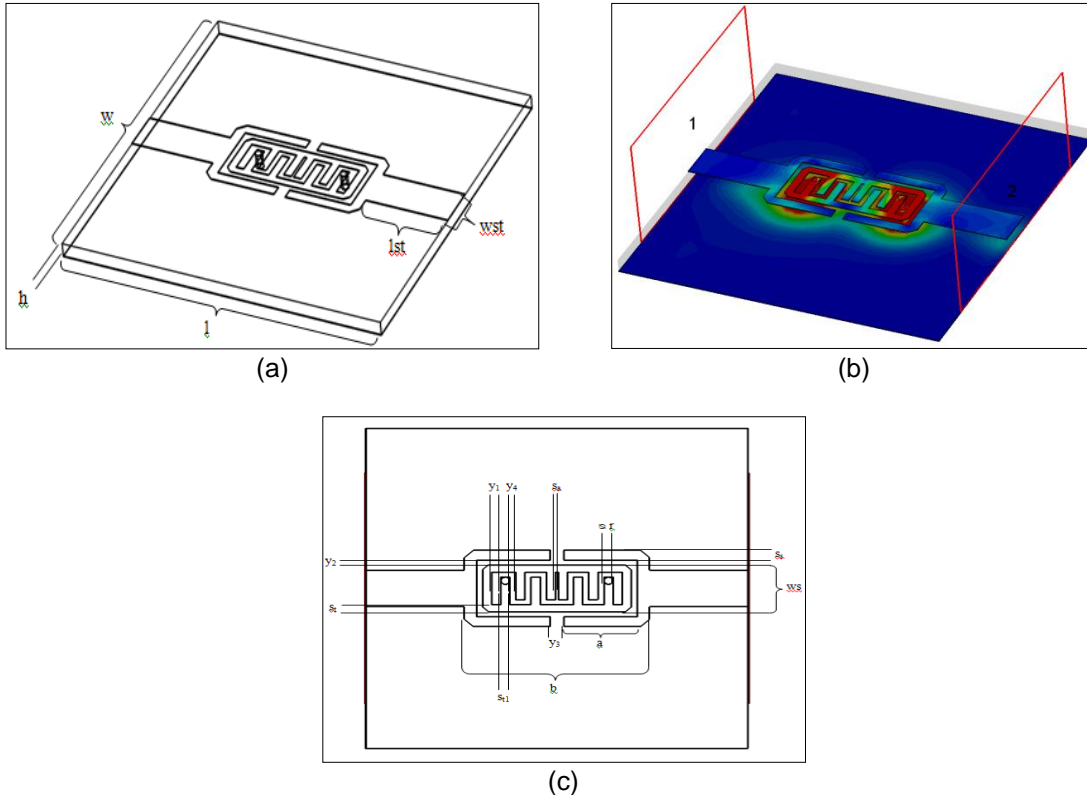

(a)

(b)

(c)

Figure 2. (a) The Geometry of Filter with N=10, (b) Field Simulation Result,
(c) The Dimensional of Filter

Bandpass is an adjective that describes a type of filter or filtering process; it is to be distinguished from passband, which refers to the actual portion of affected spectrum. Hence, one might say "A dual bandpass filter has two passbands". A bandpass signal is a signal containing a band of frequencies not adjacent to zero frequency, such as a signal that comes out of a bandpass filter [10].

Bandpass filter design using cavity method in microstrip with the resonator that is connected to ground. This aims to increase the value of resistance in the filter, related to good matching on input and output ports. In this paper the comparison about pole of the filter (N) with N = 10 and N = 14, aimed for the different bandwidth on the filter.

The proposed design of bpf module with N=10 is depicted in Figure 2. The values of parameter in this filter design as follows: S_t = 0.25 mm; S_{t1} = 0.4 mm; y_1 = 0.3 mm; y_2 = 0.2 mm; y_3 = 0.45 mm; y_4 = 0.2 mm; a = 2.425 mm; b = 6.1 mm; w_s = 1.93 mm; s_s = 0.4 mm; ⊗ r = 0.3 mm; w_{st} = 1.5 mm; l_{st} = 3.25 mm; w = 13.3 mm; l = 12.6 mm; h = 0.51 mm.
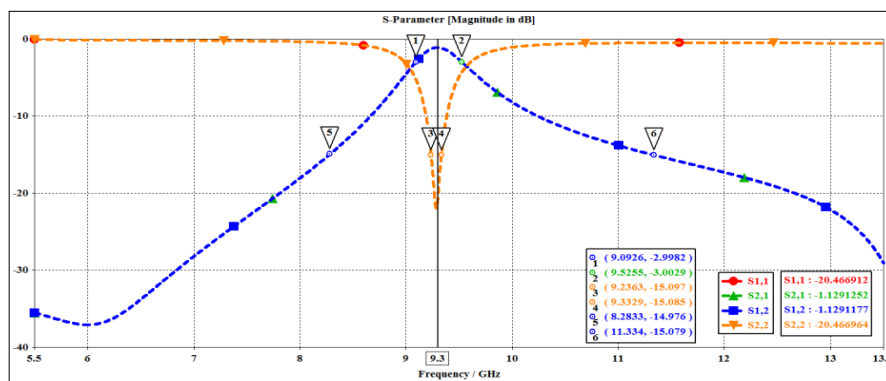

Figure 3. Simulation Result S-Parameter of Band Pass Filter N=10

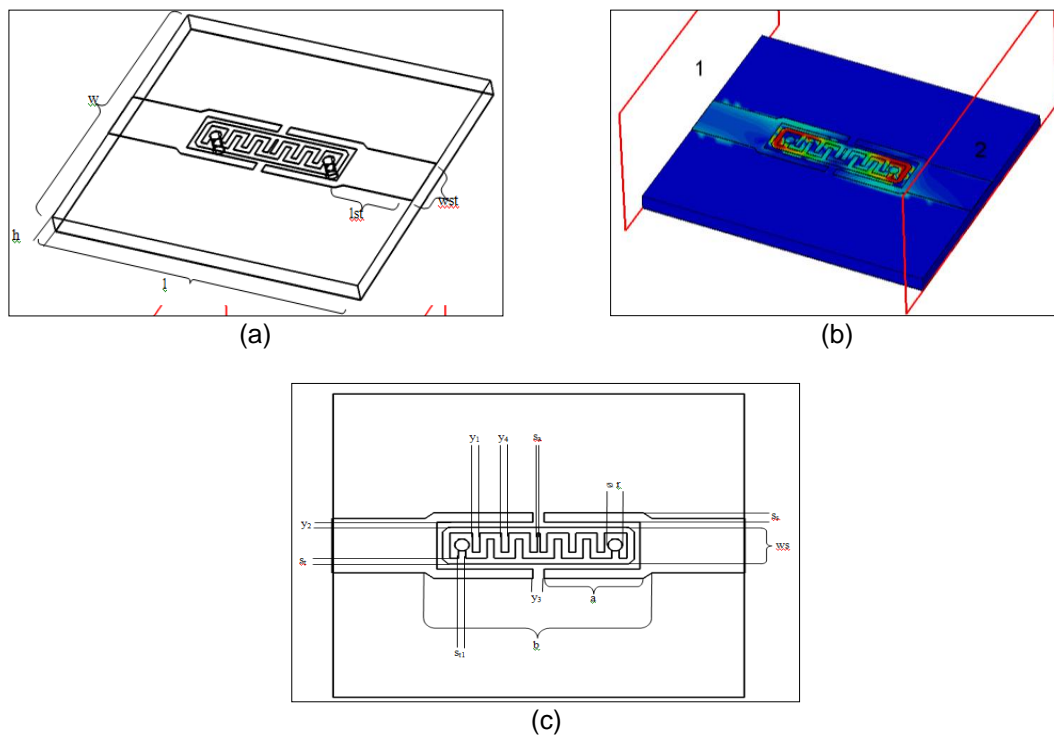(a)   (b)

(c)

Figure 4. (a) The Geometry of Filter with N=14, (b) Field Simulation result, (c) The Dimensional of Filter

BPF by using pole N=10 is produces a bandwidth about 3 GHz shown by the value under -15dB (<-15dB) is depicted on Figure 3. The cutoff of filter (-3dB down) at the frequency of 9.0926 GHz to 9.5255 GHz and the bandwidth of passband is 432.9 MHz. The value of return loss on each port (S_{11}-S_{22}) at 9.3GHz is -20,4669 dB.

The proposed design of bpf module with N=14 is depicted in Figure 4. The values of parameter in this filter design as follows: S_t = 0.25 mm; S_{t1} = 0.25 mm; y_1 = 0.25 mm; y_2 = 0.2 mm; y_3 = 0.4 mm; y_4 = 0.25 mm; a = 3.343 mm; b = 7.9 mm; w_s = 1.55 mm; s_s = 0.4 mm; ⌀ r = 0.5 mm; w_{st} = 2.3 mm; l_{st} =3.25 mm; w = 12.75 mm; l = 14.386 mm; h = 0.51 mm.
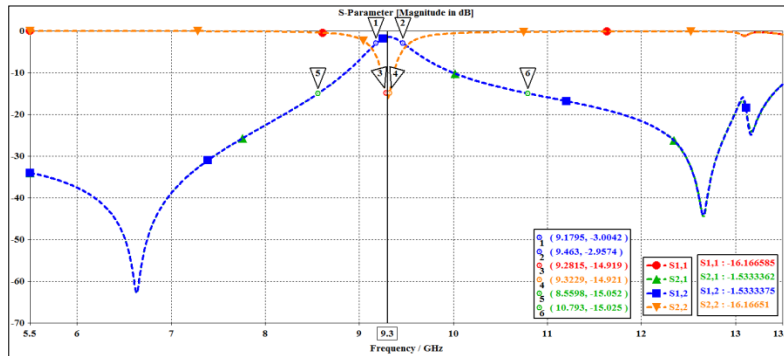

Figure 5. Simulation Result S-Parameter of Band Pass Filter N=14

BPF by using pole N=14 is produces a bandwidth about 2.2332 GHz shown by the value under -15dB (<-15dB) is depicted on Figure 5. The cutoff of filter (-3dB down) at the frequency of 9.1795 GHz to 9.463 GHz and the bandwidth of passband is 283.5 MHz. The value of return loss on each port (S_{11}-S_{22}) at 9.3GHz is -16.16651 dB.

BPF with different pole N = 10 and 14 produce a different characteristics, the more of poles (N) is smaller bandwidth, this can be proved BPF with N = 14, resulting smaller bandwidth compared to BPF with N = 10. In the compact integration module, BPF used pole N = 10 in terms of the return loss is better than BPF with pole N = 14

2.2. The 2-way Wilkinson Power Divider Design and Simulation

The 2-way Wilkinson Power Divider (WPD) usually work at quarter-wavelength transmission line (λg/4) section at the design center frequency and Wilkinson power consists of two quarter-wavelength line segments at the center frequency (f_c)with characteristic impedance $\sqrt{2}Z_o$, and a 2*Z_o lumped resistor connected between the output ports [11]. From the explanation can be seen that the type of power divider has four sections as follows [12]:
1. Input port
2. Quarter-wave transformers
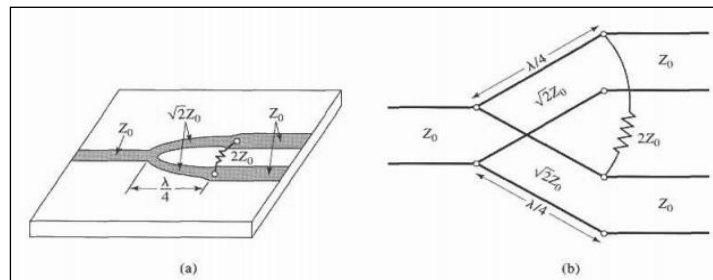3. Isolation resistors
4. Output ports

Figure 6. The Wilkinson Power Divider; (a) An Equal-Split Wilkinson Power Divider in Microstrip form, (b) Equivalent Transmission Line Circuit

The smallest insertion loss result depends on designing of the width of λg/4 section (W) at frequency center (f_c). Based on Figure 6, the 2-way WPD has some ideal parameters that can be implemented into a microstrip transmission line. We designed the 2-way WPD with 9.3 GHZ Fc, Z_o = 50Ω and deploy isolation resistor (R1= 100 Ω) between 2 port output.

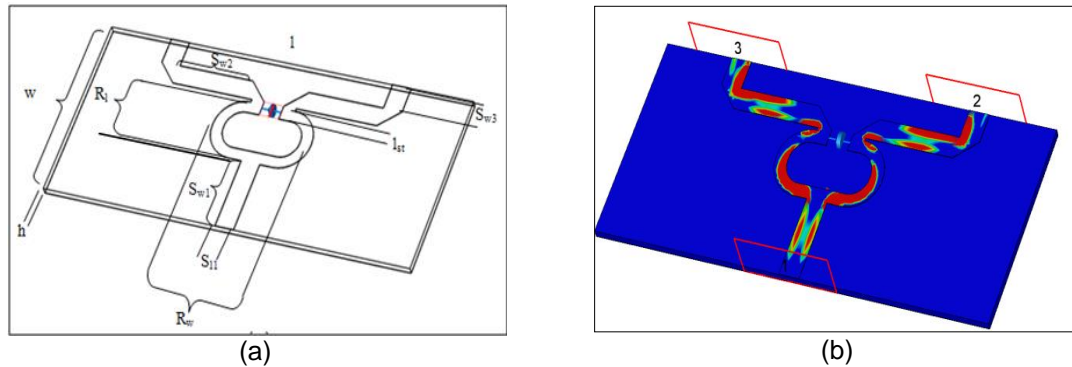(a)   (b)

Figure 7. (a) Layout for Simulation 2-way WPD, (b) Field Simulation result

The design of 2-Way WPD depicted in Figure 7. The values of parameter in this filter design as follows: S_{w1} = 5.5 mm; S_{w2} = 6 mm; S_{w3} = 2 mm; l_{st} = 0.9 mm; R_1 = 4.8 mm; R_w = 8 mm; S_{l1} = 1.5 mm, w = 14 mm; l = 29.6 mm; h = 0.51 mm.
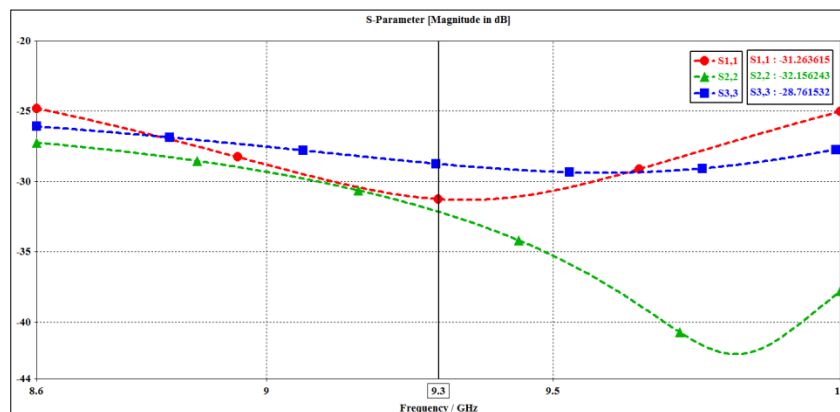

Figure 8. Simulation Result Return Loss of 2-Way WPD(S_{11}, S_{22}, S_{33})

The result of this simulation contains graphs of the return loss, insertion loss and isolation of the proposed design of 2-way WPD. From the simulation result, the input S_{11} (red line) and output port S_{22} (green line) S_{33} (blue line) depicted in Figure 8 have a good return loss is less than -28 dB this is indicating less than 0.158% of the power is reflected back. Figure 9 show the bandwidth of 2-way WPD is about 2 GHz categorized as wide band. These specifications do not meet to apply on our radar, which requires a bandwidth of 60-150 MHz at Fc 9.3 GHz therefore the output port needs to add a narrowband BPF.

Figure 9 show the insertion loss, reverse transmission line S_{12} (red line) S_{13} (green line) showed that this device as combiner have equal power with transmission loss about -3.183 dB, it's indicate the signal power will be transmitted only have a loss approximately 0.183 dB. The graph also show for forward transmission line S_{21} (blue line) S_{31} (yellow line) showed that this device as power divider have equal power with transmission loss about -3.192dB, its indicate the signal power will be transmitted only have a loss approximately 0.192 dB from ideal split

power of 2-Way WPD is. This 2 Way WPD have a good insertion loss refers to calculation 10 log 2 (the number of ports divided).
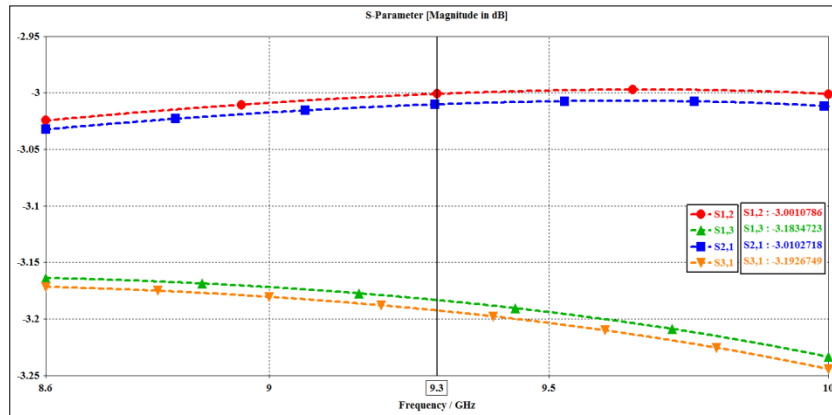

Figure 9. Simulation Result Insertion Loss (S_{12}, S_{13}, S_{21}, S_{31})
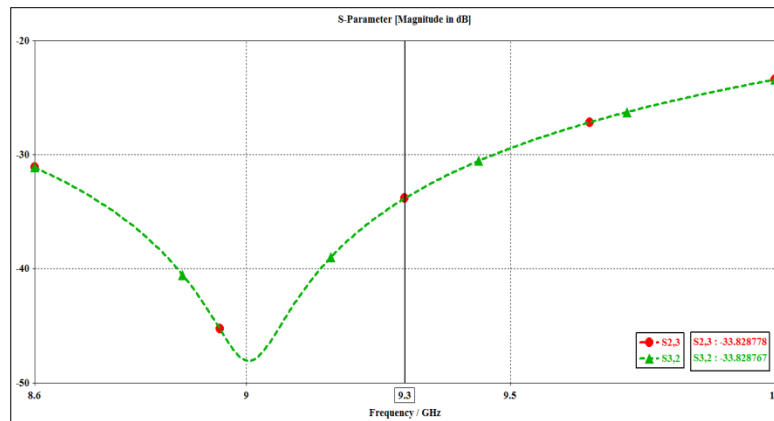

Figure 10. Simulation Result Isolation between 2 ports (S_{23}, S_{32})

Figure 10 show the isolation between the both output ports S_{23}(red line) S_{32} (green line) has good isolations about -33.828 dB, this value is better than the desired planning that is -20dB. The isolation value of the proposed design is enough to prevent cross-talk between the both output ports.

2.3. Directional Coupler Design and Simulation

The coupler designed using the coupled line directional couplers method. Basic configuration of directional coupler shown in Figure 11, the characteristics from a directional coupler can be describe by its coupling factor, directivity, reflection loss, isolation and the impedance matching of port.

The design of coupler needed for coupling level accuracy -3 dB at 9.3 GHz and have a phase different 90º on the output port. The length of transmission line on directional coupler usually designs with quarter-wavelength. Directional couplers are most frequently constructed from two coupled transmission lines set close enough such that energy passing through one is coupled to the other. This technique is favored at the microwave frequencies where transmission line designs are commonly used to implement many circuit elements. However, lumped component devices are also possible at lower frequencies. Also at microwave frequencies, particularly the higher bands, waveguide designs can be used. Many of these

waveguide couplers correspond to one of the conducting transmission line designs, but there are also types that are unique to waveguide.
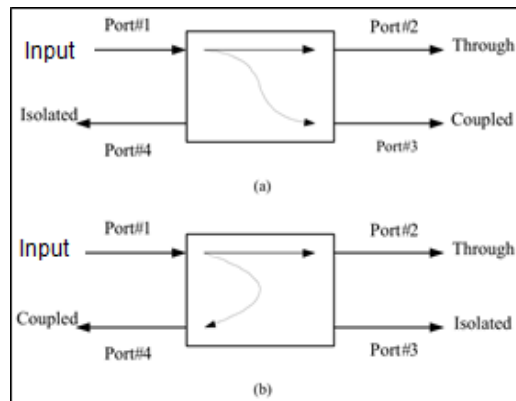

Figure 11. A coupler model with Four – port; (a) forward, (b) backward

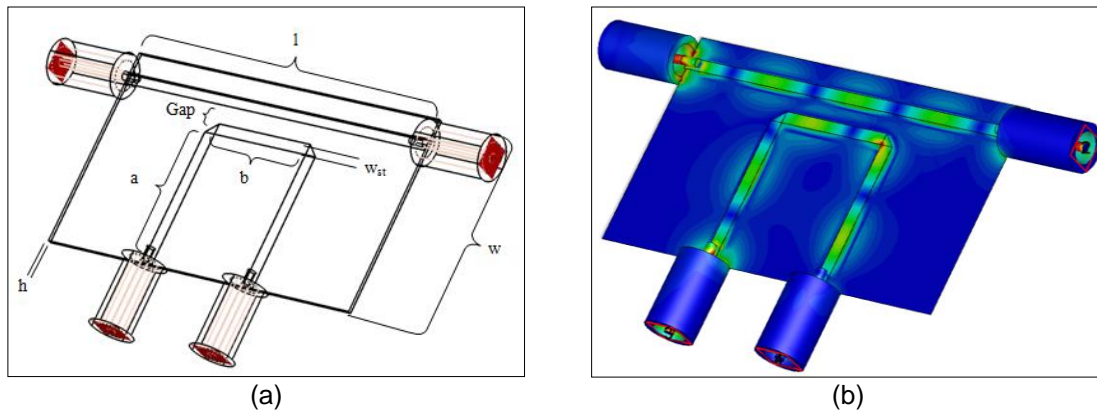(a)   (b)

Figure 12. (a) Layout for Simulation Directional Coupler, (b) Field Simulation result

The proposed design of directional coupler depicted in Figure 12. The values of parameter in this coupler design as follows: w = 27.7 mm; l = 46.2 mm; Gap = 2.6 mm; w_{st} = 1.5 mm; b = 14 mm; a = 19 mm; h = 0.51 mm.

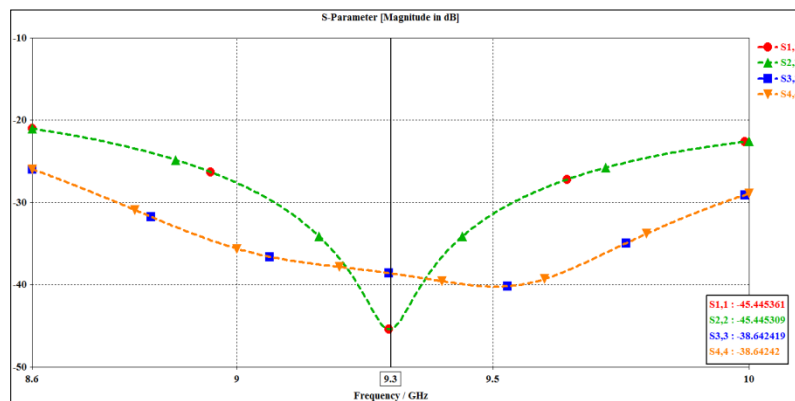Figure 13. Simulation Result Return Loss of Coupler (S_{11}, S_{22}, S_{33}, S_{144})

The result of this simulation contains graphs of the return loss, coupling and isolation of the proposed design of coupler. From the simulation result, it have four port of coupler for directivity port S_{11} S_{22} (green line) and for output port (coupling and isolation) S_{33} S_{44} (orange line) depicted in Figure 13. The return loss on four port shows a value is below -38dB is good and acceptable.
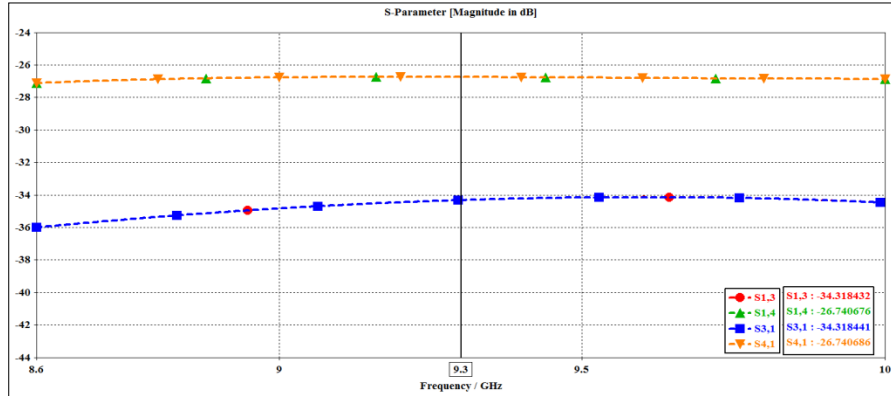

Figure 14. Simulation Result Isolation (S_{13}) and Coupling (S_{14}) of Coupler

Figure 14 show the isolation value and the couple value of directional coupler. The isolation value S_{14} S_{41} (orange line) has good isolations about -26.74 dB. The couple value S_{13} S_{31} (blue line) has good value about -34.31 dB. The value of isolation and couple is considered as good and acceptable for application on FWCM Radar.

3. Power Divider Integrated with Coupler and Microstrip Cavity Filter Design and Simulation

The design of this Integration designed using microstrip calculation. Prior to integration of each RF module, designed it first of each module (BPF, Power divider 2 way and Coupler). The design integration is depicted on Figure 15 and 16 shows a compact form by combined several RF module. Figure 17 shows the filters are used in the design. The Integrated module design with 9300MHz frequency center (f_c), Z_o = 50Ω will be designed on a 0.51mm thick Roger Duroid 5880 substrate which has relative permittivity of 2.2, the dissipation factor is 0.0009 and conductor thickness of 35μm. The frequencies used for X-Band radar applications on the part of transmitter and receiver.
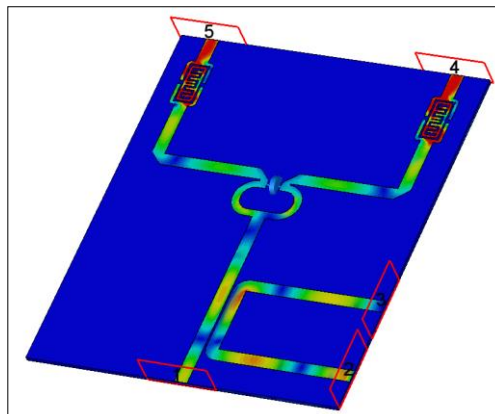

Figure 15. Surface Current Simulation Result

There are some important parameters to consider in this design such as Return Loss, Insertion loss and narrow bandwidth. The functional of narrow bandwidth will eliminate the harmonic signal from the antenna to the receiver components and vice versa from the transmitter to the antenna components.

Figure 15 is the result of a simulation of the movement electric field on the surface of the conductor material. The movement field starts from port 1 with effect of coupling to the output port (port 4 and port 5) with the same power divide and same phase (red color on the port 4 and port 5).
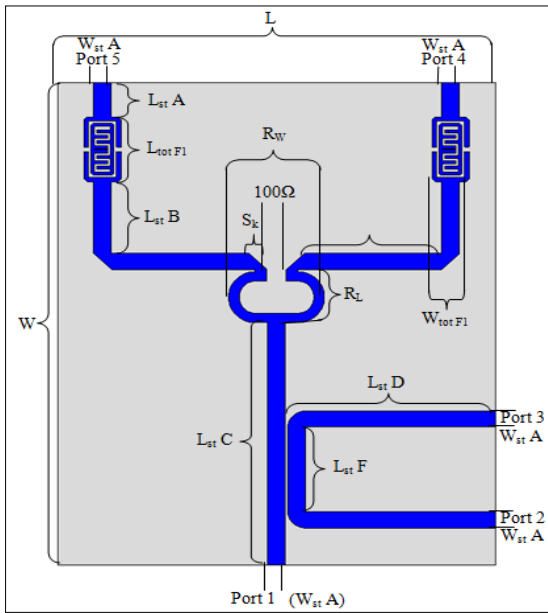

Figure 16. Power Divider Integrated with Coupler and Microstrip Cavity Filter Design
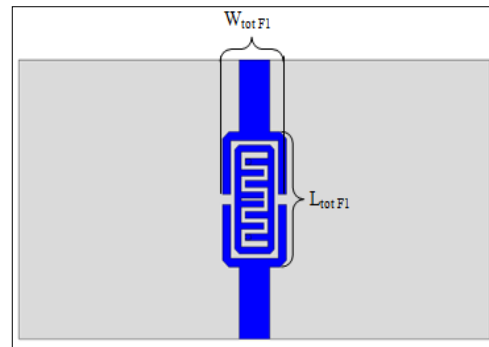
Figure 17. Filter Design with Pole N = 10

The proposed design of integrated system depicted in Figure 16 and BPF used on integrated module depicted in Figure 17. The values of parameter in this design as follows: L = 45.5 mm; W = 36.6 mm; W_{st} A = 1.5 mm; L_{st} A = 3.25 mm; L_{tot} F1 = 6.1 mm; W_{tot} F1 = 3.13 mm; L_{st} B = 6.75 mm, S_k = 2.12 mm, R_w = 8 mm, R_L = 4.8 mm, L_{st} C = 22.8 mm, L_{st} D = 15.85 mm, L_{st} D = 8 mm.
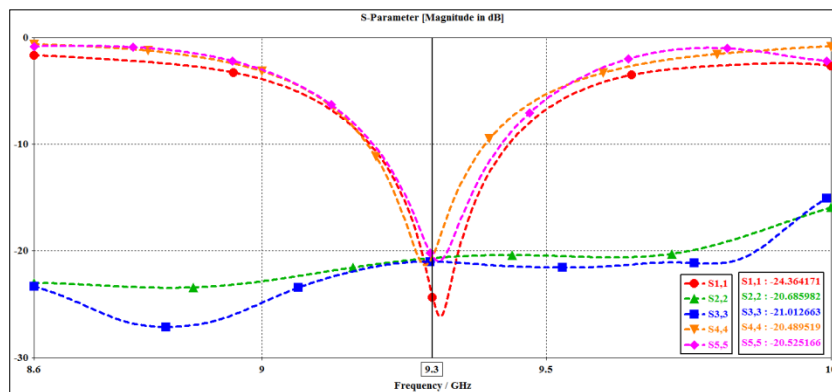

Figure 18. Simulation Result S-Parameter of Compact Integrated Module

Figure 18 show S-Parameter simulation result on each port. From the simulation result, the input S_{11} (red line) and output port S_{22} (green line) S_{33} (blue line) S_{44} (orange line) S_{55} (pink line) depicted in Figure19 have a good return loss is less than -20 dB this is indicating less than 1.01% of the power is reflected back. The value of return loss is good and acceptable for application on FWCM Radar.
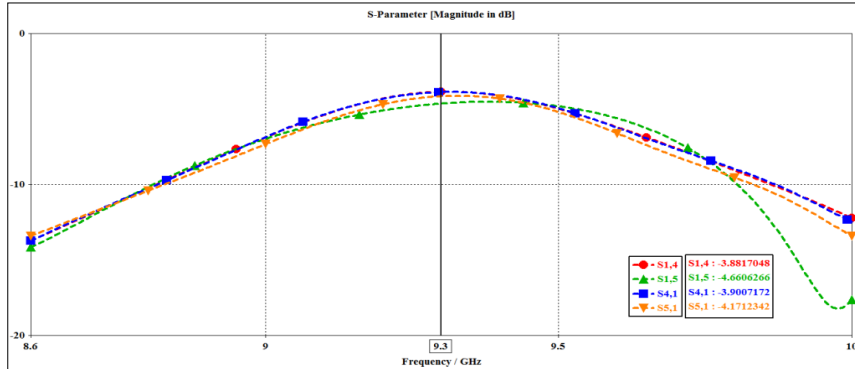

Figure 19. Simulation Result of Input Signal after a Power Divider to BPF (S_{14} and S_{15})

Figure 19 show the simulation result of Insertion loss, where the input signal after a power divider will pass through a band pass filter. The resulting value (S_{14}, S_{41}, S_{15}, S_{51}) is about -3.8 dB is good value approaching the design results (-3 dB). The output after BPF is produces a bandwidth about 1.4 GHz shown by the value under -15dB (<-15dB) is depicted on Figure 20.
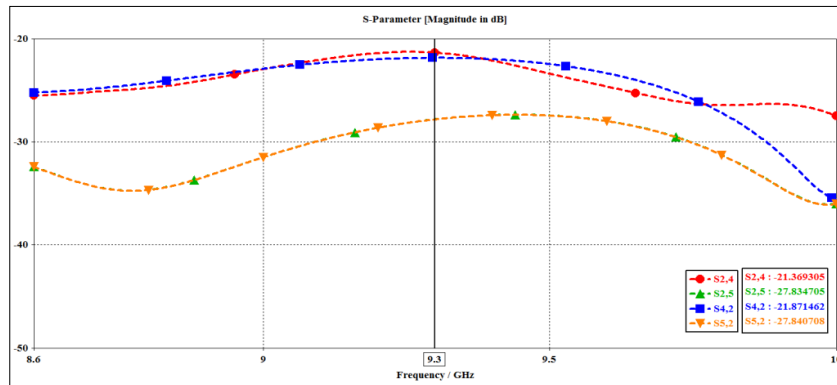

Figure 20. Simulation Result of Input Signal from Coupler to BPF (S_{24} and S_{25})

Figure 20 show simulation result of Input Signal from Coupler to the output passes of BPF. The resulting value (S_{24}, S_{42}, S_{25}, S_{52}) is bellow -21 dB is good value approaching desired planning is must bellow -20dB these specifications suitable to be applied on our radar.

Figure 21 show the isolation between the both output ports through BPF S_{45}(red line) S_{54} (green line) has good isolations about -27.27 dB. The value is better than the desired planning that is -20dB these specifications suitable to be applied on our radar. The isolation value of the proposed design is enough to prevent cross-talk between the both output ports.
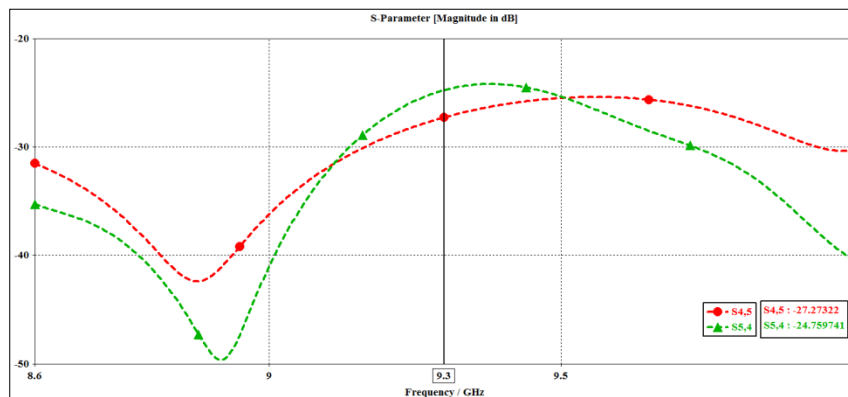
Figure 21. Simulation Result of Isolation between Output Port through BPF (S_{45} and S_{54})

4. Conclusion

The compact integrated module of the proposed design has been designed and simulated on Duroid RO5880 substrate which operates at 9.3 GHz frequencies. The modules have a good return loss is less than -20 dB both on input (S_{11}) and on output Port (S_{44}-S_{55}) which indicates the VSWR in are less than 2. The value of return loss is good and acceptable for application on FWCM Radar. The bandpass filter that used in integrated module have a narrow bandwidth is applicable used in receiver and transmitter system. The proposed design has eliminated three conventional devices (power splitter, coupler and BPF) integrated in a single module aims to reduce the loss in the joint connectors. This proposed design is meet the good specifications it will be installed on LPI (Low Probability of Intercept) Radar; Indonesia Institute of Sciences PPET - LIPI.

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