3D Directional Coupler for Impulse UWB

3D Electromagnetic Simulation and Prototyping

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ABSTRACT. The AWS Group developed a UWB radar and UWB transceiver for indoor people location and tracking. A radar concept has been developed. This paper will describe step by step the realization of a UWB directional coupler with a novel 3-D architecture. This paper gives a walkthrough of our design of the 3-D directional coupler.

KEYWORDS: Microsptrip directional couplers, Radar, Scattering parameters, Vertically Installed Planar Structure.

1. Introduction

The AWS Group was developing a UWB radar and UWB transceiver for indoor people location and tracking. A radar concept has been developed. The radar is composed of a pulse generator, a channel model, a low-noise amplifier, a matched filter, two pulse shapers, a flip-flop circuit and an integrator. This paper will focus on the design of the directional coupler. The development of the broadband directional coupler aims to create a separation between the pulse generator and the Low Noise Amplifier. This enables the radar system to connect both so that only one antenna is necessary for the radar system; also it will avoid triggering the pulse detection. For the design of the coupler, the technology used is microstrip. The specifications for the coupler design are shown in Table I. The Software used for the design is AWR Microwave Office and CST Microwave Office. First the development of the 3D directional coupler will be detailed. Then the manufacturing process of the prototype will be described. Finally the measured performances of the prototype will be presented.

Frequency Band	3.1-10.6 GHz
Maximum Dimensions	20mm x 20mm
Reflection	< -20dB
Isolation	< -25dB
Coupling	= 10dB ±0.5dB
Transmission Losses	< 1dB
Constant Group Delay	As small as possible

Table 1. ***Directional coupler specifications***

2. Development of the 3D directional coupler

The substrate is the CER10-250, because of its high relative dielectric coefficient εr = 9.5, the circuit will have a relatively small size.

2.1. *First Approach*

From the study of [3-5], it was decided that the directional coupler should be designed with two asymmetric elements. This is to ensure bandwidth efficiency and the best isolation possible. On the other hand, the phase difference between the coupled waves at the ends of the coupler is not 90° at all frequencies as opposed to symmetric couplers. As a first approach, a perfect coupler design was dimensioned using tables with broadband Chebyshev equal-ripple coupling response. The values were picked for a bandwidth ratio of 4 and a coupling factor of 10dB. The parameters were entered in AWR Microwave Studio into ideal coupled microstrip line @ 6.85GHz. These ideal elements showed perfect coupler behavior.

Coupled Microstrip Line Parameters	Coupler 1 ideal / physical	Coupler 2 ideal / physical
Width	418.3μm	568.2μm
Gap	80.83μm	591.9μm
Z_{0e}	78.6485Ω / 81.94Ω	57.8896Ω / 60.38Ω
Z_{0o}	31.7902Ω / 25.975Ω	43.2133Ω / 41.85Ω

Table 2. ***Dimensions of the directional coupler and even and odd mode impedances for ideal and physical model***

The dimensions of the physical layout, shown in Table 2, were calculated with TX-Line Calculator embedded in AWR. The simulation results of the S-parameters, obtained with CST microwave, are very different from what was expected: stronger transmission losses, reflections, strong isolations and the bandpass ripple is uneven. To understand, what is causing these discrepancies, the impedance of the elements needs to be studied. From the CST simulation of the coupler elements, the physical impedances differ from the expected values at 6.85GHz, shown in Table 2. The effect is more noticeable in element 1 due to the stronger coupling. Also the frequency dispersion of the effective permittivity is the source of the differences between even and odd mode impedances and phase velocities. This explains the unevenness in the bandpass. The odd mode is travelling faster because it propagates mostly above the substrate in the air. The even mode is travelling slower because it propagates mostly in the substrate with a higher dielectric constant hence slowing down the phase velocity. Ideally the phase velocities of both modes should be equal. Some tweaks were brought to the dimensions to improve the closeness of the ideal components and the physical layout. However there is a dimension constraint on the gap, due to limitations in manufacturing accuracy at the AWS group. A noticeable error remains between the desired values and the observed values especially with element 1. The first element being the most problematic, its evolution will be treated first.

2. 2. ***Evolution of the first element***

The 1st element went through two evolutions before reaching its final design state. These evolutions aimed at countering the effect of the difference in phase velocity between the two modes of propagation by slowing down the odd mode propagation. The 1st evolution was the design of a meander in the 1st element, and the second the implementation of a vertically installed planar circuit. Thus it is needed to slow down the odd mode propagation to equilibrate the phase velocities. Two shapes of meander were studied: triangular and circular. However they were both unsuccessful. Thus I chose to implement a vertically installed planar circuit for the 1st element.

The VIP adds a new degree of freedom in the design and allows finer adjustments of the parameters. This structure affects the transmission of the electric fields in even and odd mode. The value of the odd mode impedance is strongly related to the characteristics of the vertical substrate, since the odd mode electric flux is concentrated in the vertical substrate. As for the even mode, its impedance is related to the main substrate. The paper recommends the use of a substrate of lower dielectric constant than the main substrate for the VIP. However it is dealing with stronger coupling coefficients and substrates with much lower dielectric coefficients. A study of the effects of the substrate dielectric coefficient on the studied structure led to the conclusion that the same substrate should be used for the VIP to obtain maximum performances. Considering manufacturing, the implementation shown in figure 1 (left) was designed. The solder was also taken in consideration because the VIP cladding thickness influences the impedances. The dimensions of this element are as follow: gap = 388.311µm, width (W1) = 286.854µm, VIP Height = 375.664µm. The simulation results on the effective dielectric constants are shown in figure 2. The even and odd mode impedances in this case are close to ideal values and the phase velocities have been about equalized. Now let us take care of the 2nd element's evolution.

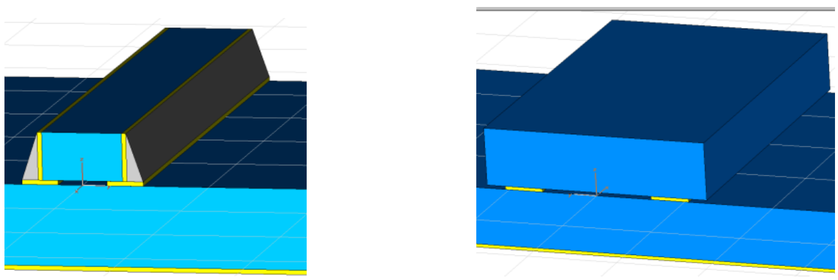

Figure. 1. ***1st element final state (left), 2nd element final state (right)***

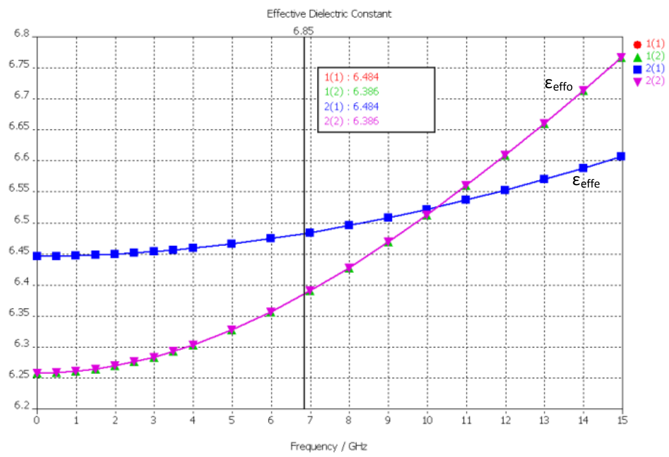

Figure. 2. ***Even and Odd mode effective dielectric constant (ε_{effe}, ε_{effo}) for element 1from our design***

2. 3. *Evolution of the second element*

The coupling factor of the 2nd element is lower than for the 1st element. This makes the use of the VIP technique unfeasible in this case. Instead a piece of uncladded substrate was added horizontally on the second element. Hence the odd mode is travelling in a medium with the same dielectric constant as for the even mode. The new layout for the 2nd element is shown in figure 1 (right) and its dimensions are as follow: gap = 1170μm, width (W2) = 424.90μm , width of substrate = 1252.39μm. The even and odd mode impedances in this case are close to ideal values and the phase velocities have been about equalized. Now let us move on to transitions.

2. 4. *Evolution of the transitions*

The design of the transition between the two elements of the coupler has become problematic. The elements of the coupler aren't in direct contact. Hence particular attention had to be given to the design of the transition to reduce reflections and isolation coefficients and also optimize energy transfer. The first consideration is to implement a transition at 45º inclination to suppress the coupling effect in the transition. A few designs for the transition where studied. The evolution of the transition is shown in Figure 5. The simulation of the last transition shows the best performances out of all those tested. The transitions to port 1 and 4 need some adjustments to optimize the coupler's performance. The transitions to port 2 and 3 are just regular steps. The dimensions for the transitions to port 1 and port 4 are b1 = 210μm, b4 = 250μm. The transition to port 1 is illustrated in Figure 6, the transition to port 4 is similar.

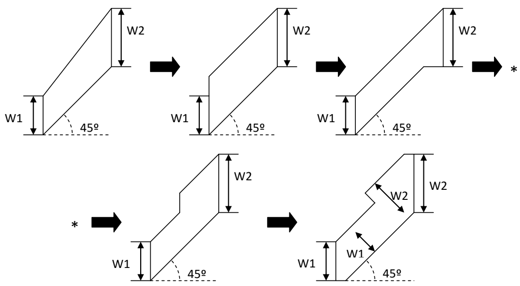

Figure. 5. ***Evolution of the transition between both elements***

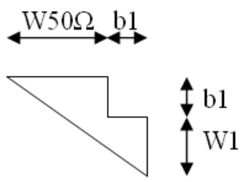

Figure. 6. ***transition to port 1***

The transitions to port 2 and 4 are steps from the width of the line to a 50Ω-line.The full design of the directional coupler is almost complete. Some adjustments were brought to the length of the elements. The physical size of the connectors was taken in account for the size of the board. And the length of the added piece of substrate on element 2 was adjusted by reducing the length by 200um on each side symmetrically relatively to the length of the second element. The resulting layout is shown in Figure 3. The S-parameters' performances are shown in Figure 5.The design doesn't meet fully the requirements but is satisfactory to move on to the prototyping part. The simulqted coupling factor is purposely stronger than it should be to compensate errors in manufacturing which usually result in a lower coupling factor.

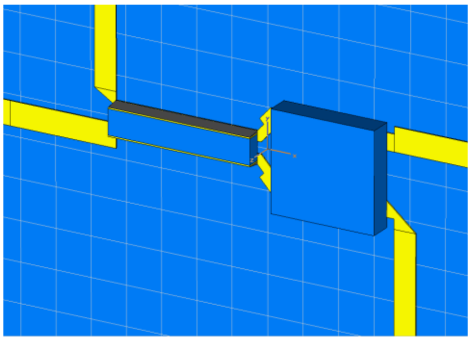

Fig. 3. ***Directional coupler final layout***

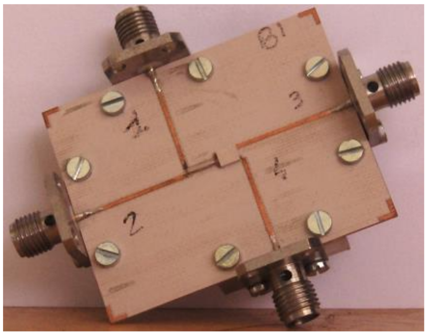

Fig. 4. ***Prototype of the Directional coupler's final layout***

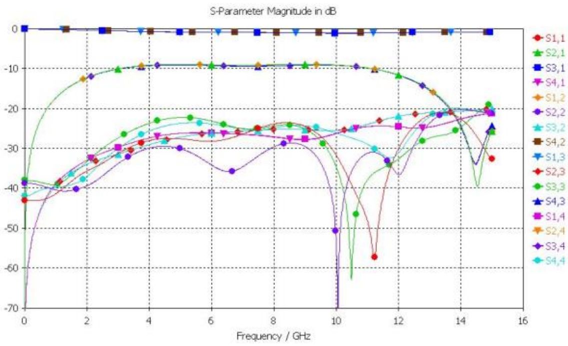

Fig. 5. ***S-parameters' performances of the directional coupler final layout***

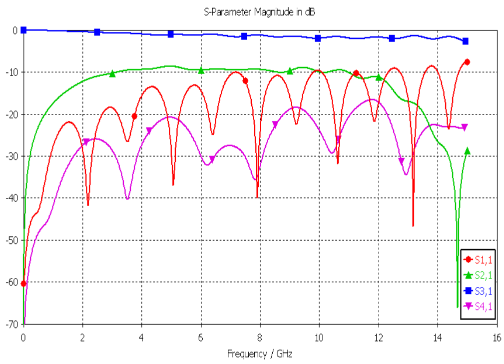

Fig. 6. ***S-parameters' measured performances of the directional coupler final layout @ port 1***

3. Manufacturing process of the prototype

The prototype (figure 4) of the coupler was produced using precision machinery. The board layout was produced in University College Dublin. A precision milling machine: LPKF-C60 was used to mechanically etch the pattern on the CER-10. The assembly of the board was carried out in Tyndall National Institute. The assembly involved cutting 2 CER-10 VIP bricks X 4mm x Y 0.705mm x Z 0.375mm and X 2.9mm x Y 2.5mm x Z 0.67mmu sing a Disco DAD6H/T dicing saw. They were both positioned and fixed using a microscope and a Finetech flip chip aligner bonder. The 1st brick (double cladded) was soldered with Alpha Metals SAC387 solder paste. The 2nd brick (uncladded) was glued on the board.

S11 (reflection)	S12 (bandpass)	S13 (transmission)	S14 (isolation)
<-11.102dB	-10.89dB @ 3.1GHz -9.85dB @ 10.6GHz R = ±0.87dB C = -10.12dB	>-3.83dB	<-21.68dB
S21 (bandpass)	**S22 (reflection)**	**S23 (isolation)**	**S24 (transmission)**
-10.98dB@3.1GHz -9.78dB@10.6GHz R = ±0.88dB C = -10.13dB	<-12.53dB	< -20.62dB	>-2.46dB
S31 (transmission)	**S32 (isolation)**	**S33 (reflection)**	**S34 (bandpass)**
>-3.81dB	<-20.7dB	<-10.683dB	-11.05dB@3.1GHz -10.68dB@10.6GHz R= ±0.7dB C = -10.3dB
S41 (isolation)	**S42 (transmission)**	**S43 (bandpass)**	**S44 (reflection)**
<-21.69dB	>-2.45dB	-11.07dB@3.1GHz -10.54dB@10.6GHz R = ±0.8dB C = -10.3dB	<-13.83dB

Table 3 ***Directional coupler measured S-parameter performances***

4. Performance Measurements of the prototype

The S-parameters were measured using the VNA HP8720C. While two ports where connected to the VNA, the other two ports where equipped with 50Ω-load impedances. The VNA was calibrated using Agilent Calibration Kit guaranteeing the validity of S parameters up to 9GHz. In figure 6 and table 5, we show the measured S-parameters of the directional coupler manufactured using precision machinery. The S-parameters are different from the to the simulation results, the coupling is lower than expected but it fits the requirement of -10dB. However the ripple is about one and half or twice as high as required. The isolation in the coupler is satisfactory <-20dB but higher than the specifications required. The losses and the reflection in the circuit are on the other hand higher than expected.

5. Conclusion

Following the unsatisfactory experimental results, we incorporated the SMA connectors to the simulation and obtained results matching the measurements. So this means that we have to redesign the transition between SMA connectors and the microstrip line. Also regarding the higher transmission losses of the real directional coupler, the substrate has probably a higher loss tangent of dielectric than its model. Thus the measured insertion losses are mainly due to losses of the feeding transmission lines. An improved model of the substrate has to be incorporated to the model and some modifications to decrease overall losses, insertion losses and increase isolation have to be brought before this 3D architecture can be considered viable.

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