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Receiver with Collerator Designed for Instantaneous Frequency Measurement (IFM)

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Abstract: Along with its widespread use in electronic warfare (EW), the Instantaneous Frequency Measurement (IFM) receiver has piqued the interest of RF system designers. The delay line, Wilkinson power divider, 90° hybrids, and 180° hybrid correlator components were developed using Agilent's Advanced Design System (ADS). Microstrip technology was used to design the circuit. As a connection crossing constraint, the 90° hybrid and 180° hybrids were built on separate printed circuit boards. In the simulation, the developed correlator was able to monitor the RF input signal from 2GHz to 5GHz in real-time. Between the physical measurement and the modeling results, there was a reasonable agreement. As a result, the correlator prototype is deemed acceptable, but further research is required to improve it.

Keywords: *Delay Line IFM receiver, Hybrid Couple, Phase Correlator, and Wilkinson Power Divider*

INTRODUCTION

Radar has rapidly expanded its applications since its invention for military purposes during World War II (Tsui, 1986). In military applications, radar has become a vital piece of equipment. In order to effectively interfere with radar, one must at least know whether one is a radar target. Therefore, electronic warfare (EW) receiver (also referred to as an intercept receiver) is needed to detect the existence of an RF signal and provide information of either a friendly or hostile signal(Pozar, 2000). Usually, detailed information about hostile radar is not available, thus it is impossible to design an intercept receiver as effective as the receiver in the radar system. However, the signal strength at the input of the intercept receiver is much stronger than at the radar receiver because the distance traveled by the radar signal from the source to the intercept receiver is half the distance from the source to the radar receiver. Therefore, if an intercept receiver is properly designed, it can detect the radar signal effectively. The IFM receiver is prominent among system designers since it I s commonly used in modern EW systems.

An IFM receiver uses a correlation method (Chang, 1989) to measure the phase difference between the delayed and undelayedversions of an input signal. Since the introduced delay time is known, the frequency of the input signal can be measured.

The IFM receiver has many of the desired qualities of an EW receiver: very wide bandwidth, moderately high sensitivity, small size, and relatively low-costSullivan & Electronic, (2002). The IFM receiver manipulates the fact that when a signal with carrier frequency ω passes through a delay line with a time delay τ, it experiences a phase shift of θ (which is equal to ωτ). The multiplication of the delayed signal with the undelayed version of the signal simultaneously produces outputs of the form sin ωτ and cos ωτ. The ratio of these two outputs represented in tan-1 is then be manipulated and processed to determine the desired RF signal frequency (Kai Chang, 1989).

MATERIAL AND METHODS

The Wilkinson power divider, the microstrip delay line, the 90° hybrid couple, and the 180° hybrid couple are the four main components that make up the correlator for IFM receivers (Tsui, 1986).Each component will be built and simulated independently for the greatest performance at 4GHz, based on theoretical principles and calculations, prior to the integrity of a complete correlator. Fig. 1 depicts the research technique flowchart.

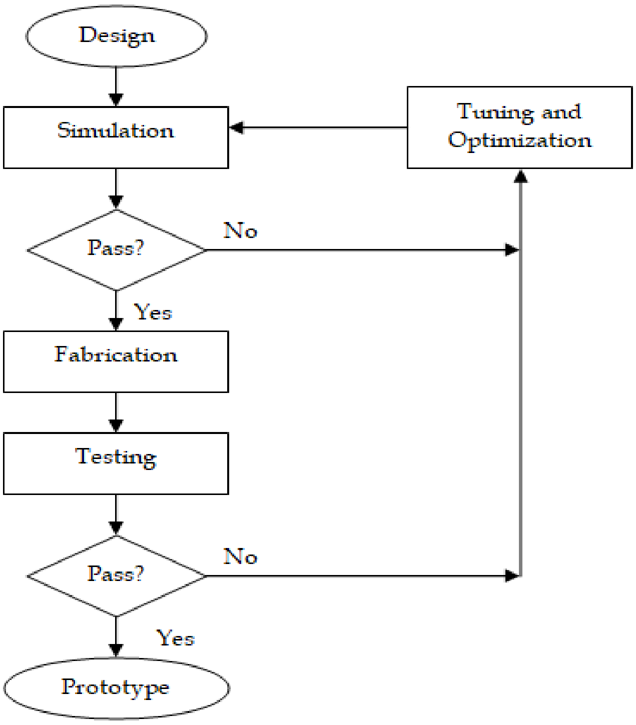


Fig. 1 Research Methodology Flowchart

RESULTS AND DISCUSSION

A. Principle of Operation

The basic measurement technology for RF frequency encoding is the microwave correlator (East, 2012). An IFM receiver uses delay lines to compare the phase of the input signal to measure its frequency. A sinusoidal wave is considered split into two paths.Lee *et al.,* (2008), one path delayed a constant time with respect to the other one as shown in Fig. 2.

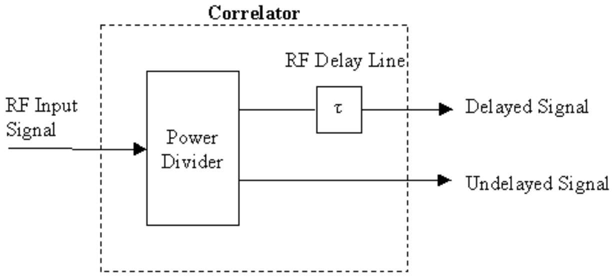


Fig. 2 Phase Relation of Sinusoidal Waves with Constant Time Delay

There is a phase difference between the two outputs caused by the constant time delay. The relative phase angle between the delayed and the undelayed waves is in Equation (1).

$$\theta = \omega\tau \tag{1}$$

In an IFM receiver, the frequency of the input signal is determined by measuring this phase difference. If the phase angle is measured and the delay time τ is known, the frequency can be determined through Equation (1). The phase angle θ is measured using the relations in Equation (2)

$$E = A\sin\theta \tag{2}$$

$$F = A\cos\theta \tag{3}$$

Where *E* and *F* are two voltages and *A* represents the amplitude of the input signal. The phase angle can be measured from the amplitudes of *E* and *F*. In a practical IFM receiver, the major portion of the circuitry is to produce the above relations. In some of the earlier IFM receivers, the voltages *E* and *F* are measured on the *X* and *Y* axes of an oscilloscope. The trace of the point (*X*, *Y*) is a circle. The radius of the circle represents the amplitude of the signal, and the angle in the polar display represents the phase angle because

$$\theta = \tan^{-1}\left(\frac{E}{F}\right) = \omega\tau \tag{4}$$

B. **Phase Correlator**

A phase correlator is also referred to as a frequency discriminator. It is the key component in an IFM receiver. A phase correlator consists of 4 components: power divider, delay line, 90° hybrid couple, and 180° hybrid couple. The power divider splits the input signal into two paths. The delay line produces the necessary time delay required. The 90° and 180° hybrid couple provides the proper phase shift.

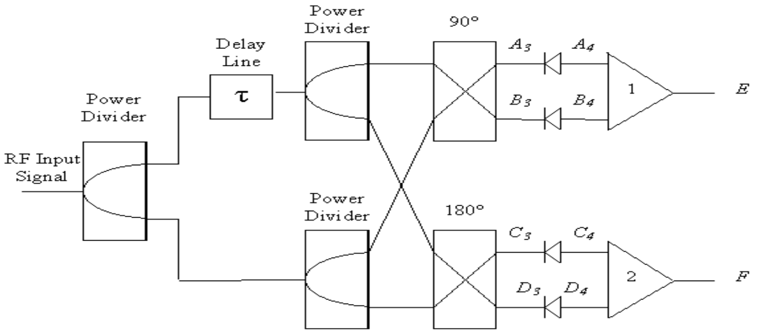


Fig. 3 Basic Diagram of Microwave Correlator with Two Hybrids

The phase correlator uses microwave components to perform autocorrelation as shown in Fig. 3. Delay is accomplished through a microwave delay line and multiplication is accomplished through the square law of a diode detector. The diode detector produces the autocorrelation term, as well as some other undesirable terms which are removed by filtering.

C. Wilkinson Power Divider

Power dividers are passive microwave components used to divide input power into differential parts, and also for combining input power. The Wilkinson power divider is a three-port component. It can be made to produce equal-division (3*dB*) of the output ratios as well as arbitrary power division (Wang & Lü, 2010). Employing the microwave laminate TLX-9-0310 from Taconic Advanced Dielectric Division, with *H*=0.7878*mm* and ε_r=2.5, the design at 4*GHz* was simulated using ADS.

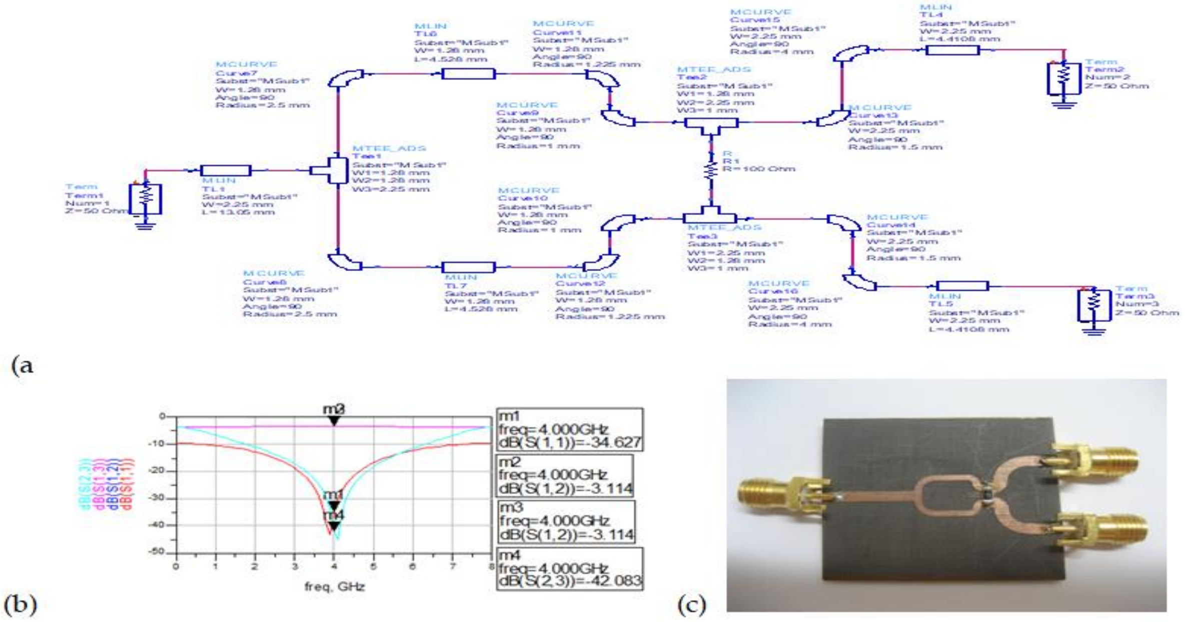


Fig. 4 Wilkinson Power Divider:(a) Schematic Diagram (b) the S-Parameter Response (c) Fabricated Wilkinson Power Divider

The design was well-performed as the value of S(1,1) and S(2,3) shows in Fig.4 that all ports are matched with isolation between the output ports. Then, the design was fabricated and tested using a signal generator and oscilloscope.

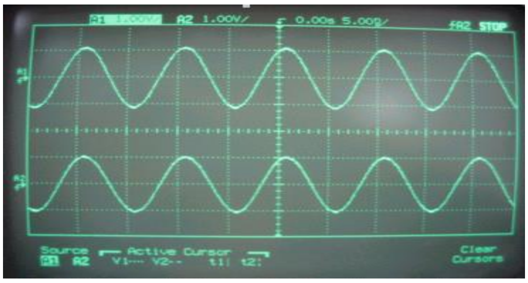


Fig. 5 Output Waveform of Wilkinson Power Divider Displayed on an Oscilloscope

By observing the oscilloscope in Fig. 5, we can know that the Wilkinson power divider divides the input waveform into two output waveforms with the same characteristics.

D. Delay Line

The relationship between the input signal frequency *f*, and the phase difference between the outputs θ, can be determined by manipulating the time delay τ (Gruchalla, *et al.*, (2014). Knowing the value of τ of one input signal frequency, we can determine the phase difference, and then measure the frequency of other input signals, for τ is a constant value.For a 2 GHz input signal, $\theta = 72°$, the time delay can be calculated as the following:

$$\theta = 2\pi f \tau$$

$$72° = 2(180)(2\times10^{9})\tau$$

$$\therefore \tau = 0.1ns$$

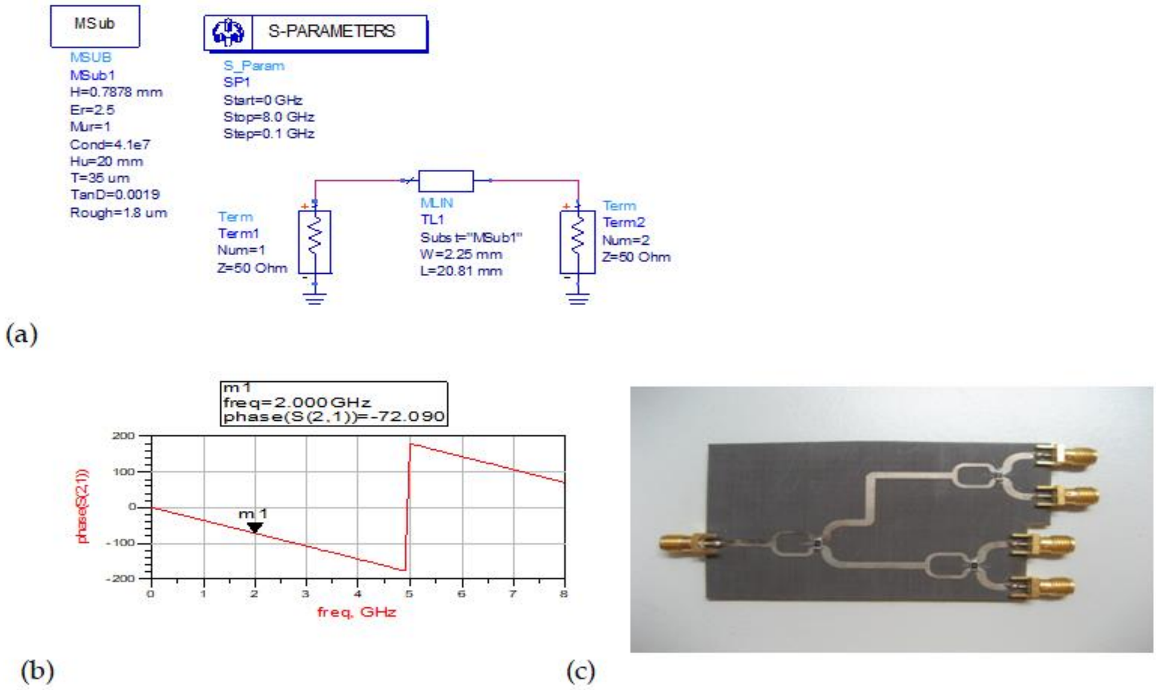
The length of a 0.1ns delay line is obtained by the following calculation:

$$v_p = \frac{c}{\sqrt{\varepsilon_{eff}}} = \frac{3\times10^{8}}{\sqrt{2.0780}} = 0.2081\times10^{9}\, m/s$$

We know that 1ns = 10^{-9}s:

$$\therefore v_p = \frac{0.2081\times10^{9}}{10^{9}} = 0.2081 m/ns$$

Thus, for 0.1ns, the length of the microstrip delay line is l_d= 20.81*mm*. The delay line with the dimensions determined was simulated using ADS and tested.



(a)

(b)

(c)

Fig. 6 Delay Line: (a) Schematic Diagram (b) Phase of Delay Line Output (c) Fabricated Delay Line

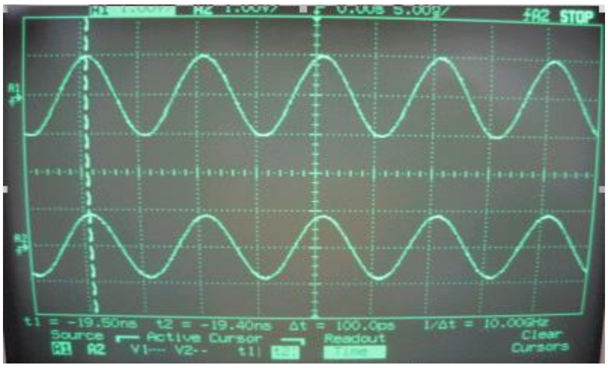


Fig. 7 Output Waveform of Delay Line Displayed on Oscilloscope

From oscilloscope in Fig. 7, there is a phase shift between the ports. By using active cursor, we find out that the time delay, $\tau = 100.0ps = 0.1ns$.

E. Hybrid Couple

90° hybrid and 180° hybrid produces the phase difference of 90° and 180° respectively at the output arms.The characteristic impedance of the quarter wave branch line with $Z_0 = 50\Omega$ is:

$$\frac{Z_0}{\sqrt{2}} = \frac{50}{\sqrt{2}} = 35.4\Omega$$

In order to determine the dimensions of the microstrip line, the following calculation was done:

$$B = \frac{377\pi}{2(35.4)\sqrt{2.5}} = 10.5801$$

$$\frac{W}{H} = \frac{2}{\pi}\left[9.5801 - \ln(20.1601) + \frac{1.5}{5}\left\{\ln(9.5801) + 0.39 - \frac{0.61}{2.5}\right\}\right]$$

$$\therefore \frac{W}{H} = 4.6461 > 2$$

$$\therefore W = 4.6461(0.7878) = 3.6602mm$$

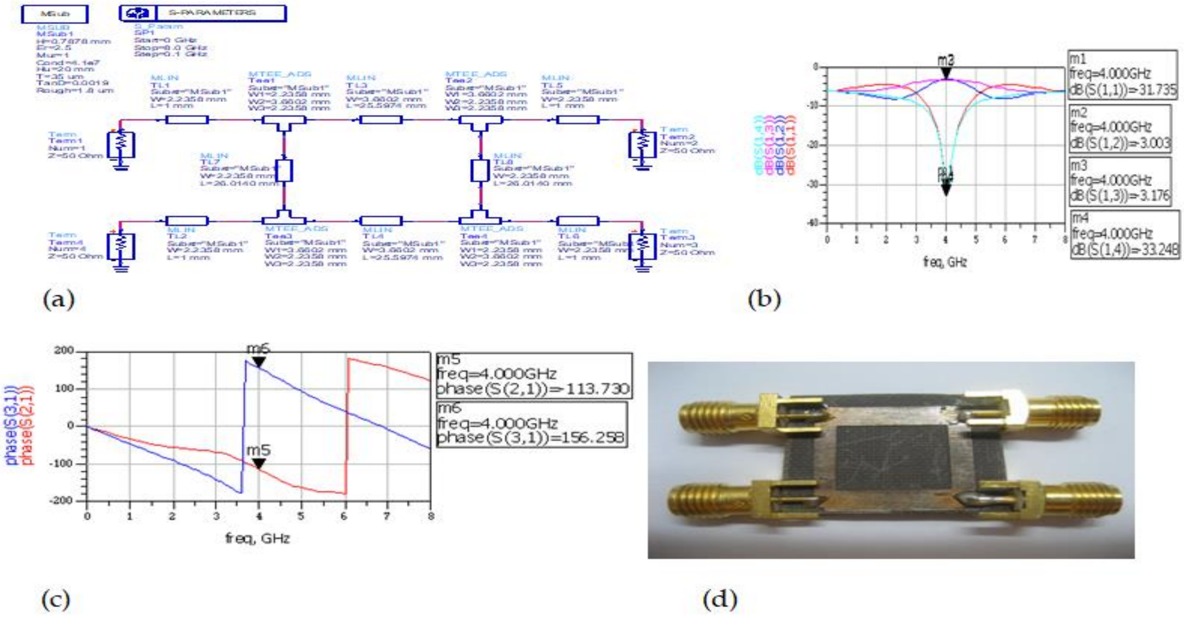
For the 35.4Ω line length:

$$\varepsilon_{eff} = \frac{3.5}{2} + \frac{1.5}{2}\frac{1}{\sqrt{1+12\left(\frac{1}{4.6461}\right)}} = 2.1462$$

Substituting $k_0 = 83.7758m^{-1}$ calculated previously, the line length is calculated as

$$\therefore l = \frac{90^\circ\left(\frac{\pi}{180^\circ}\right)}{\sqrt{2.1462} \times 83.7758} = 12.7987mm$$

The dimensions for a 50Ω quarter wave line is $W = 2.24mm$ and $l = 13.01mm$.



(a) (b)

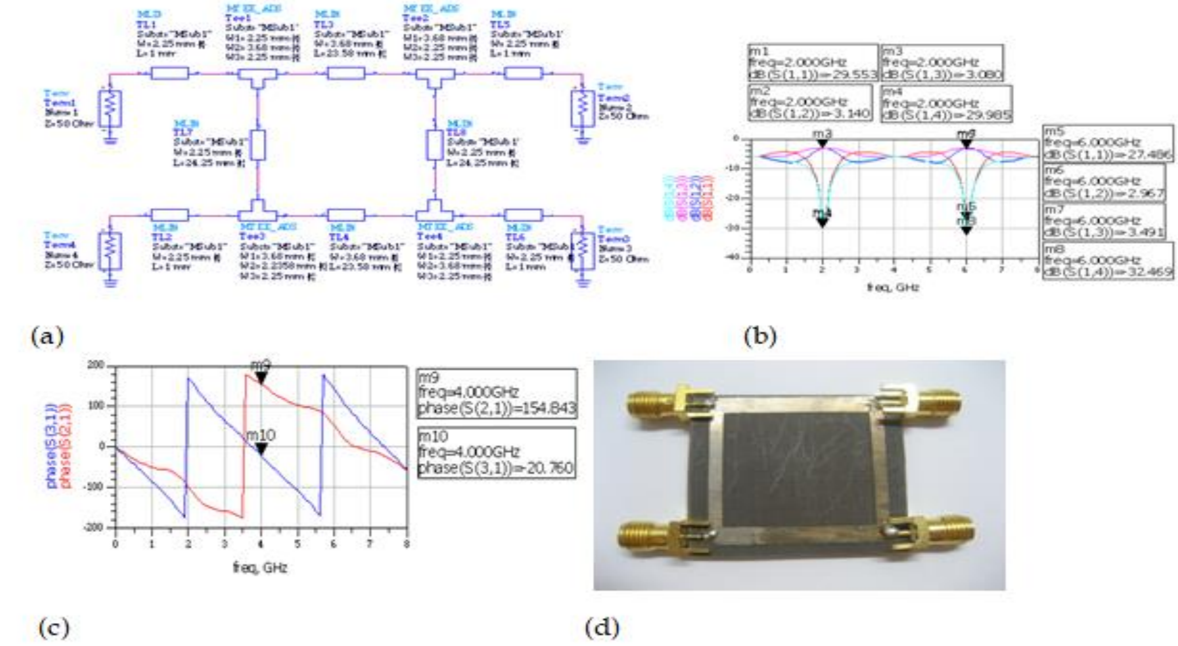
(c) (d)

Fig. 8 90° Hybrid: (a) Schematic Diagram (b) S-parameter Response (c) Phase of Output (d) Fabricated 90° Hybrid

The S-parameter response shows that the design was matched at 4*GHz* as shown in Fig. 8 Besides that, the phase difference between both outputs (m5-m6= -113.730°-156.258°=-269.988°) was accurate.The same calculations were implemented for 180° hybrid where the dimensions determined is as follows:-

For 35.4Ω, W=3.6602*mm* and *l*=25.5974*mm*

For 50Ω, *W*=2.2358*mm* and *l*=26.0140*mm*



(a) (b)

(c) (d)

Fig. 9 180° Hybrid: (a) Schematic Diagram (b) S-Parameter Response (c) Phase of Output (d) – Fabricated 180° Hybrid

The 180°hybridswere properly matched as shown in Fig. 9. The phase difference between both outputs is m9-m10=154.843°- -20.760°=175.603°.However, the fabricated hybrid couple cannot be tested due to equipment problems as the oscilloscope is testing for an output waveform with a frequency below 100*MHz*. The components were designed at 4*GHz* are shown in figure 8a. Further research is needed in testing the design for circuit improvement.

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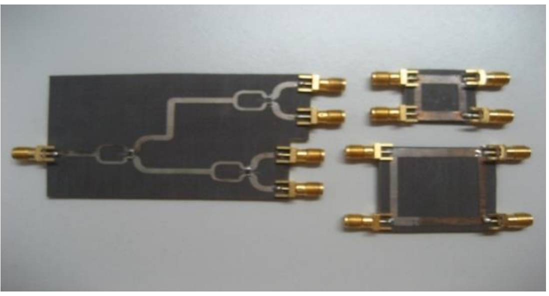

Fig. 10 Fabricated IFM correlator

CONCLUSION

The microwave correlator is the IFM receiver's measuring component. It performs the mathematical function of dividing the RF input signal into two routes, delaying one path relative to the other, and multiplying the two signals. The purpose of the microstrip delay line is to provide proper time delay. It is the most important element in the correlator. The microstrip delay line's main purpose is to offer accurate time delay. The correlator's most crucial component. As a result, it's crucial to know the exact length of the delay line so that only the time delay that's required is generated.The correlator's components were well-designed and modeled. However, the fabricated PCB board should be tested over a wide variety of frequencies to ensure that the designed component can be used in practice.

RECOMMENDATION

The operating band for electronic warfare purposes is from 2*GHz* to 18*GHz*. Research can be carried out in order to produce an IFM receiver that can track the full 2*GHz* to 18*GHz* of the RF input signal frequency. This work was designed for a correlator that tracks the full 2*GHz* to 5*GHz* of RF input signal frequency. As a suggestion, the correlator can be designed at a design frequency of 10*GHz* for input sweep frequency of 6*GHz* to 18*GHz*.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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REFERENCES

Chang, K. (1989). Microwave Passive and Antenna Components, vol. 1. Handbook of Microwave and Optical Components, 688-692.

David M. Pozar: *Microwave Engineering, 2nd Edition*, John Wiley & Sons, New York, 1998.

East, P. W. (2012). Fifty years of instantaneous frequency measurement. IET Radar, Sonar & Navigation, 6(2), 112-122.

Gruchalla, H., Czyzewski, M., &Slowik, A. (2006, May). The Instantaneous Frequency Measurement Receiver with Simultaneous Signal Capability. In 2006 *International Conference on Microwaves, Radar & Wireless Communications* (pp. 554-557). IEEE.

Helton, J., Chen, C. I. H., Lin, D. M., &Tsui, J. B. (2008, March). FPGA-based 1.2 GHz bandwidth digital instantaneous frequency measurement receiver. In 9th *International Symposium on Quality Electronic Des*ign . (pp. 568-571). IEEE.

Lee, Y. H. G., Helton, J., & Chen, C. I. H. (2008, May). Real-time FPGA-based implementation of digital instantaneous frequency measurement receiver. *In 2008 IEEE International Symposium on Circuits and Systems* (pp. 2494-2497). IEEE.

Pozar, D. M. (2000). Microwave and RF design of wireless systems. John Wiley & Sons.

Sullivan, W. B., & Electronic, J. (2002). Instantaneous frequency measurement receivers for maritime patrol. *Journal of Electro*nic Defense, 25(10), 55-62.

Tsui, J. B. Y. (1986). Microwave Receivers with Electronic Warfare Applications. John Willey & Sons. Inc., USA.

Wang, H., &Lü, Y. (2010, October). A digital instantaneous frequency measurement receiver based on sub-Nyquist sampling. In IEEE 10th International Conference On Signal Processing Proceedings (pp. 1902-1905). IEEE.

Sullivan, W. B., & Electronic, J. (2002). Instantaneous frequency measurement receivers for maritime patrol. Journal of Electronic Defense, 25(10), 55-66