Compact coplanar interferometer for a 5-6 GHz IFM system

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Abstract. The authors present a new compact coplanar interferometer for application in an IFM system with 4 bits that operates in a frequency band from 5 to 6 GHz. This interferometer consists of a couple of coplanar two-way Wilkinson power dividers connected to two CPS lines with different signal delays. This interferometer presents smaller dimensions when compared to other designs. Details of this compact coplanar interferometer are provided along with a comparison between theoretical, simulated and measured results.

Keywords: electronic warfare, frequency estimation, microwave devices, RF signals

1. Introduction

IFM (Instantaneous Frequency Measurement) systems are widely used in EW (Electronic Warfare) and electronic intelligence systems for real-time determination of the unknown signals over a broad frequency band. Moreover, the growing amount of radiant systems results in an increased interest for identification of unknown signals. The IFM system monitors, at the same time, all the frequencies of the band for which it was designed without the need of spectrum scanning, instantly detecting the unknown signals [1-5].

A typical microwave IFM system includes a limiter amplifier, a power divider, interferometers, detector set, and an A/D (Analog/Digital) conversion stage. Figure 1 shows the architecture of a 4-bit IFM system based on interferometers.

A limiter amplifier is used in IFM system input to control the signal gain, increase sensitivity and clean up the signal within the band of interest. The output of the limiter amplifier is connected to a power divider with 4 balanced outputs. Each output of the divider is connected to an interferometer.

The interferometers provide the mathematical function of dividing the RF input into two paths, delaying one path with respect to the other one, then comparing the delayed signal to the other one. Because of this comparison, each interferometer produces a signal proportional to the phase difference between delayed and no-delayed signals, as shown in Figure 2(a). Each interferometer provides one bit of an output binary word that is assigned to a certain frequency sub-band. The output of each interferometer is connected to a microwave detector. The A/D conversion stage receives the signals from the detectors, and attributes “0” or “1” to form the digital word, as shown in Figures 2(b) and (c). These values depend on the power level of the signal received, expressed in Figure 2(a) by $V_{TH}$ (Value of Threshold). For instance, a signal below $V_{TH}$ of power will give “0” at the output. On the contrary, the output will give “1”.

A new compact coplanar interferometer layout, for application in a 5 to 6 GHz frequency band IFM system with 4 bits, was proposed, fabricated and measured.

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Fig. 1. Architecture of an IFM system based on interferometers with 4 bits of output.

Fig. 2. A 4-bit IFM system based on interferometers: (a) desired responses for the interferometers; (b) digital outputs; (c) binary code.

2. Interferometer Design

The new interferometer consists of a couple of coplanar two-way Wilkinson power dividers connected to two CPS (Coplanar Strips) lines with different signal delays. The frequency interval between consecutive minima of responses shown in Figure 2(a) is related to the signal delays according to
\[ \Delta f = \frac{1}{\Delta \tau_{2,1}} \]  

(1)

where \( \Delta \tau_{2,1} = \tau_2 - \tau_1 \) is the delay difference between the two branches of each interferometer.

As one can observe in Figure 3, the presented interferometer has two CPS transmission lines, in which the upper is the reference line and the lower is the delay-line. The reference line is made to have approximately 0.1 ns of group delay. On the other hand, the delay-lines are determined according to (1), with 0.6 ns, 1.1 ns, 2.1 ns and 4.1 ns of group delay for interferometers 1, 2, 3 and 4, respectively. These values are obtained by changing the length of the delay-lines. These are the necessary intervals to implement the desired responses from Figure 2(a). Both the lines have characteristic impedance of 100 \( \Omega \). The authors realized that such impedance would fit best the intended dimensions of the whole interferometer. A full wave EM simulator was used to optimize the length and position of the CPS lines.

Wilkinson power dividers were used to split and combine the signal before and after the CPS lines, respectively. Such power dividers have, in this case, characteristic impedance of 141 \( \Omega \) in each branch and a resistor of 200 \( \Omega \) to improve the isolation between outputs. These values give input and output impedance of 100 \( \Omega \). Then, quarter wavelength matching sections were added to connect the interferometer to 50 \( \Omega \) ports.

The same procedure was applied in the design of the four interferometers of the IFM system. The interferometers basically differ by the length of the delay-line. The interferometers were simulated and fabricated on Arlon substrate AD1000, whose dielectric constant is 10.2 and the thickness is 1.27 mm. The overall dimensions of the interferometers 1, 2, 3 and 4 are as small as 42 mm x 27 mm, 62 mm x 30 mm, 46 mm x 58 mm and 50 mm x 98 mm, respectively. The thinnest line width is 0.25 mm.

### 3. Results and Discussions

For the simulation, CST EM Studio was used. Some simulated results presented unwanted resonant points, caused, probably, by stationary waves in some structure sections or by box resonances specified by the simulation. These unwanted points are minimized by both adjusting the delay-lines geometries and the feeder sections lengths. The interferometers were fabricated by a PCB Prototype Machine on Arlon AD1000 with dielectric constant 10.2, loss tangent 0.0023, dielectric thickness 1.27 mm and conductor thickness 0.035 mm. Measurements were realized using the Agilent E5071B vector network analyzer, as one can see in Figure 4. The theoretical, simulated and experimental results for the four interferometers are presented in Figure 5 (each plot corresponds to one bit of the IFM system).

In Figure 5(a), concerning to the interferometer 1 (Bit 1), all the results are in good agreement with each other. For input power of 0 dBm, a threshold level of -5 dB at 5.500 GHz was considered for \( |S_{21}| \), as the A/D converter needs it to convert the incoming signal into logical levels “0” and “1”, to make the digital word. Thus, one has level “0” from 5.000 to 5.500 GHz and “1” from 5.500 to 6.000 GHz, at the IFM system Bit 1 output.

In Figure 5(b), concerning to the interferometer 2 (Bit 2), the results are a little different at some frequencies. These differences may be due to the fabrication procedure and the additional microwave losses in the process of soldering the connectors and chip resistors. Excess solder also may cause impedance mismatches damaging the final response of the device. Considering an input power of 0 dBm and threshold level of -8.35 dB for \( |S_{21}| \), one has level “1” for frequencies from 5.250 to 5.730 GHz, and “0” for the rest of the operating band at the Bit 2 output.

Interferometer 3 (Bit 3) responses are shown in Figure 5(c). Assuming input power of 0 dBm and a threshold level of -5 dB, one has level “0” for frequencies in the intervals 5.100-5.375 GHz and 5.650-5.875 GHz; and “1” for the rest of the operating band at the Bit 3 output.

Finally, interferometer 4 (Bit 4) responses are shown in Figure 5(d). The results are in good agreement with each other once more. Assuming input power 0 dBm and threshold level of -5 dB for \( |S_{21}| \), one has level “0”, for intervals 5.050-5.1875 GHz, 5.300-5.435 GHz, 5.535-5.6875 GHz and 5.825-5.960 GHz; and level “1” for the rest of the operating band at the Bit 4 output.
Fig. 3. New coplanar interferometer layout. The desired responses of Figure 2(a) are obtained by changing the length of the delay-line.

Fig. 4. Experimental setup used to measure the interferometer 4.
Fig. 5. Theoretical, simulated and experimental results for: (a) Interferometer 1 (related to Bit 1 output system); (b) Interferometer 2 (related to Bit 2); (c) Interferometer 3 (related to Bit 3); (d) Interferometer 4 (related to Bit 4).
The losses of these interferometers are far lower than the ones presented in [5], which regards maximum values of $|S_{21}|$ around -10 dB. It is always possible to trigger the A/D converter with a different threshold level, not strictly -5 dB. It just depends on the necessity of the project.

4. Conclusions

A new interferometer based on CPS delay-line for application in a 5-6 GHz IFM system was designed, simulated, implemented and measured. The theoretical, simulated and experimental results are in good agreement for the majority of the interferometers of a 4-bits IFM system. This shows that the proposed design is useful for small-dimensions planar IFM systems.

All the interferometers are coplanar, allowing a large-scale commercial production by the integration of different devices on the same substrate. Miniaturization techniques can be applied in the development of the interferometers. Besides, the interferometers can be implemented in superconducting version and used in satellite communication systems.

It is important to notice that the use of equal output impedance power splitters simplify the design. For the implementation of other interferometers it is basically necessary to vary the length of the delay-line. As a whole, the results presented here look promising as far as IFM system application is concerned.

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