4-bit, 1 to 4 GHz Reconfigurable Discriminator for Frequency Measurement

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***Abstract*—This paper presents a novel 4-bit reconfigurable discriminator for frequency measurement, operating from 1 to 4 GHz. The discriminator is a two-port device used to identify the frequency of an unknown signal by switching between its 4 states. The device is formed by a fixed reference line and a switchable delay line. The device is implemented using microstrip lines and PIN diodes. Simulated and measured results are presented for the four states of the reconfigurable discriminator.**

Keywords*— *Frequency measurement, radar, delay lines, electronic countermeasures, switches

I. INTRODUCTION

Instantaneous Frequency Measurement (IFM) receivers are widely used for Electronic Warfare (EW) [1, 2]. IFMs identify with accuracy the frequency of an unknown RF signal. Conventional IFM receivers, shown in Fig. 1, are fixed systems with a parallel configuration and provide an instantaneous readout; the IFMs are formed by n-branches to produce n-bits. Each branch contains a discriminator, a detector, a frequency converter and an amplifier [3, 4], resulting in large subsystems with high power consumption due to the large number of electronic components used in the designs.

In this paper, we propose a reconfigurable discriminator (RD) circuit, with its block diagram shown in Fig. 2, for use in a Reconfigurable Frequency Measurement (RFM) receiver. The circuit is a two-port device that can produce 4 bits, operating from 1 to 4 GHz. An RFM operates in series by switching between a set of 4 delay lines. Using the RD only one amplifier and detector is needed, resulting in a compact design compared to traditional IFMs [3-4], that use an amplifier and detector per branch. The use of fewer electronic components also results in low power consumption.

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The main circuit of an RFM is a 4-bit RD stage, which uses PIN diodes to switch between states to achieve the 4-bit readout. The RFM does not provide an instantaneous readout like traditional IFMs [3-4], since it should switch between states before identifying the incoming signal. The switching time depends on the switching speed of the PIN diode used, which is 10ns.

II. DESIGN CONCEPT

A component diagram of the proposed RD is shown in Fig. 3. The device is formed by using a pair of wideband power dividers, two Single Pole, Quadruple Throw (SP4T) switches, a reference line (l_0) and 4 delay lines (l_1, l_2, l_3 and l_4) with their respective phase shifts $\theta_0(\tau_0)$, $\theta_1(\tau_1)$, $\theta_2(\tau_2)$, $\theta_3(\tau_3)$ and $\theta_4(\tau_4)$, where τ is the delay of the line.

The RD switches between four states, starting with delay line l_1 (State 1) and ending with delay line l_4 (State 4). The four delay lines are selected using the SP4T switches. The four delay lines are combined with the reference line to form a state of the RD.

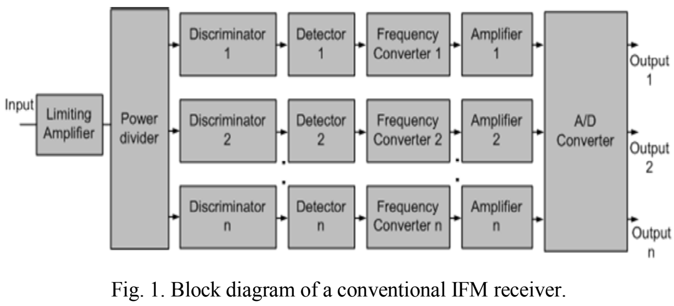


Fig. 1. Block diagram of a conventional IFM receiver.

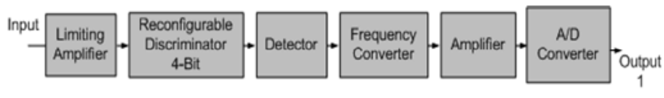


Fig. 2. Block diagram of a reconfigurable FM receiver.

The reference line is the same for the four states of the device. The resulting combined signals are defined by (1)

$$S_{0n}(t)=\sin\left(\frac{2\omega t-\omega(\tau_0+\tau_n)}{2}\right)\cos\left(\frac{\omega(\tau_n-\tau_0)}{2}\right) \qquad (1)$$

where $S_{0n}(t)$ is the combined output signal, ω is the carrier angular frequency of the input signal, τ_0 and τ_n are the delays of the reference line and delay lines (n = 1, 2, 3 and 4), respectively. At times t_0, t_1, t_2, and t_3, the four combined signal have a phase $\theta_{01}(\tau_0,\tau_1)$, $\theta_{02}(\tau_0,\tau_2)$, $\theta_{03}(\tau_0,\tau_3)$ and $\theta_{04}(\tau_0,\tau_4)$, respectively.

III. 4-BIT DISCRIMINATOR DESIGN

The core of an RFM device is formed by a reference line (l_0), which has a length of $\lambda_g/2$ and four delay lines (l_1, l_2, l_3 and l_4) with lengths of λ_g, $3\lambda_g/2$, $2\lambda_g$ and $5\lambda_g/2$, respectively. λ_g is the guided wavelength at 2.5 GHz, the center frequency of the device. The RFM is a two port device that can produce a 4-bit output to identify an unknown signal, after the SPQT switches sweep all four lines l_1, l_2, l_3 and l_4 at t_0, t_1, t_2 and t_3, respectively.

IV. DEVICE FABRICATION AND OPERATION

The RD device shown in Fig. 4(a) was fabricated using a LPKF Protolaser S machine to pattern an Arlon AD1000 substrate, with a dielectric constant of 10.2 and a loss tangent of 0.0023. Each power divider uses two resistors of 100 Ω and 220 Ω to achieve a good impedance match over the 1 to 4 GHz band. The SP4T switches use BAR 50-02V diodes by Philips Semiconductors. A single diode has an insertion loss of 0.1425 dB and an isolation of -9.32 dB at the frequency of 2.5 GHz. The diode can handle a maximum RF signal power of 30.17 dBm, limited by its power dissipation capability of 250 mW and a serial resistance of 3 Ω for a bias current of 10 mA.

Switch 1 is implemented by 6 diodes, namely Diode 1 (D1) through Diode 6 (D6), a close-up to Switch 1 is shown in Fig. 4(b). Similarly, Switch 2 is implemented by 6 diodes, from Diode 7 (D7) through Diode 12 (D12), see Fig. 4(a). Both switches use choke inductors with a self-resonance at 1.7 GHz to isolate the bias circuitry from the microwave circuit. A 100 Ω resistor in series with the choke inductor provides a 10 mA current to the diodes using a 1 V bias source. Both switches include two 100 nF broad band capacitors as DC blocks, in order to achieve the diode polarizations required for operating the device. The 12 bias ports are shown in Fig. 4(a), with labels starting with DC 1 and ending with DC 12.

Table 1 shows the bias required for each diode to select the different delay lines (l_1 to l_4) of the design, corresponding to the four states of the RD. Fig. 5 shows the PIN diode equivalent circuit models for forward-bias and reverse-bias. These models were obtained from measurements, and used in simulations using Momentum.

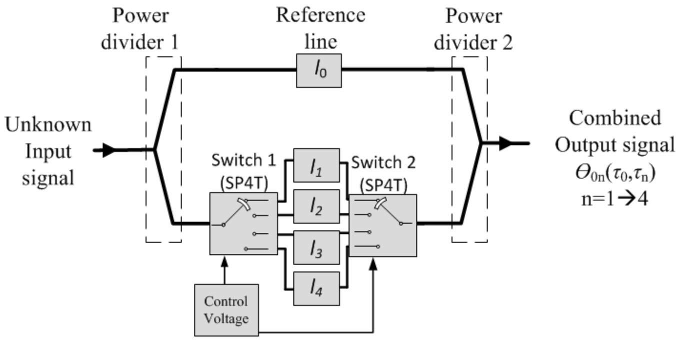
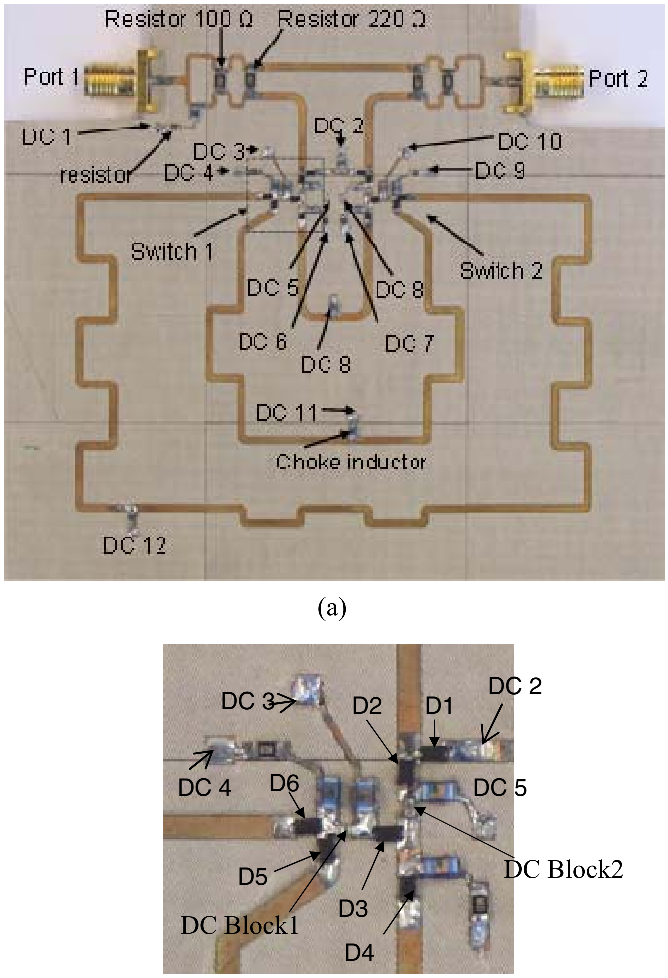


Fig. 3. Component diagram of the RD



(a)

(b)

Fig. 4. Photograph of the fabricated circuit: (a) RD device; and (b) close-up to Switch 1.

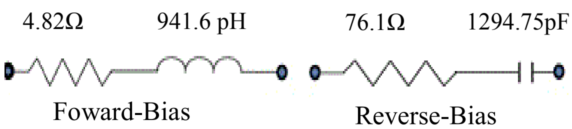


Fig. 5. PIN Diode equivalent circuit models.

Table 1. Diode biasing for each state

Line	Switch 1						Switch 2					
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
l_1	FB	RB	FB	RB	FB	RB	FB	RB	FB	RB	FB	RB
l_2	RB	FB	FB	RB	FB	RB	RB	FB	FB	RB	FB	RB
l_3	RB	FB	RB	FB	FB	RB	RB	FB	RB	FB	FB	RB
l_4	RB	FB	RB	FB	RB	FB	RB	FB	RB	FB	RB	FB
FB = Forward-Bias, RB = Reverse-Bias												

V. Results and Discussions

Fig. 6 shows the simulated and measured transmission signal for each of the four discrete states of the RD device. Each of these responses corresponds to a bit for signal identification in an RFM receiver. The measurements were done with an Agilent PNA Network Analyzer model E8361A after a SOLT calibration.

In an RFM receiver, analogue to digital conversion takes place after the RD stage. By setting a threshold, it is possible to define the bits to be recovered from the analogue signals generated by the RD. By combining all the digital outputs generated by the RD, an unknown signal can be identified into a slot defined by the resolution of the receiver. For a four bits design, using the RD presented in this paper, the resolution is 187.5 MHz. The RD resolution is defined by [3]

$$f_R = BW/2^N \tag{2}$$

where BW is the frequency range and N is the number of bits of the RD.

Fig. 6 shows the analogue signal produced by each discriminator. The signals start with the most significant bit, generated when l_1 is selected (as one can see in Fig. 6(a)) and ends with the less significant bit, generated when l_4 is selected (see Fig. 6(d)).

The simulated and measured responses agree well, however there is a slight frequency shift of 27.96 MHz for State 1, 112.17 MHz for State 2, 65.84 MHz for State 3 and 50.59 MHz for State 4. This shift might be due to a slight dielectric constant variation of the substrate.

The bits identified by the circuit are processed in series, and stored in a buffer. Transient ripples observed while switching from state to state do not affect the reading of the bits.

VI. Conclusions

The RD presented in this paper is a two-port device, which allows the use of less electronic components compared with conventional IFM implementations. The device consumes 40 mW to operate, and conforms the core part of an RFM receiver. The RFM can handle a maximum RF power signal of 30.17 dBm, which is limited by the PIN diode.

The design switches between four delay lines, which are combined with the same reference line to achieve four discriminator states for serial frequency identification. The new design looks promising.

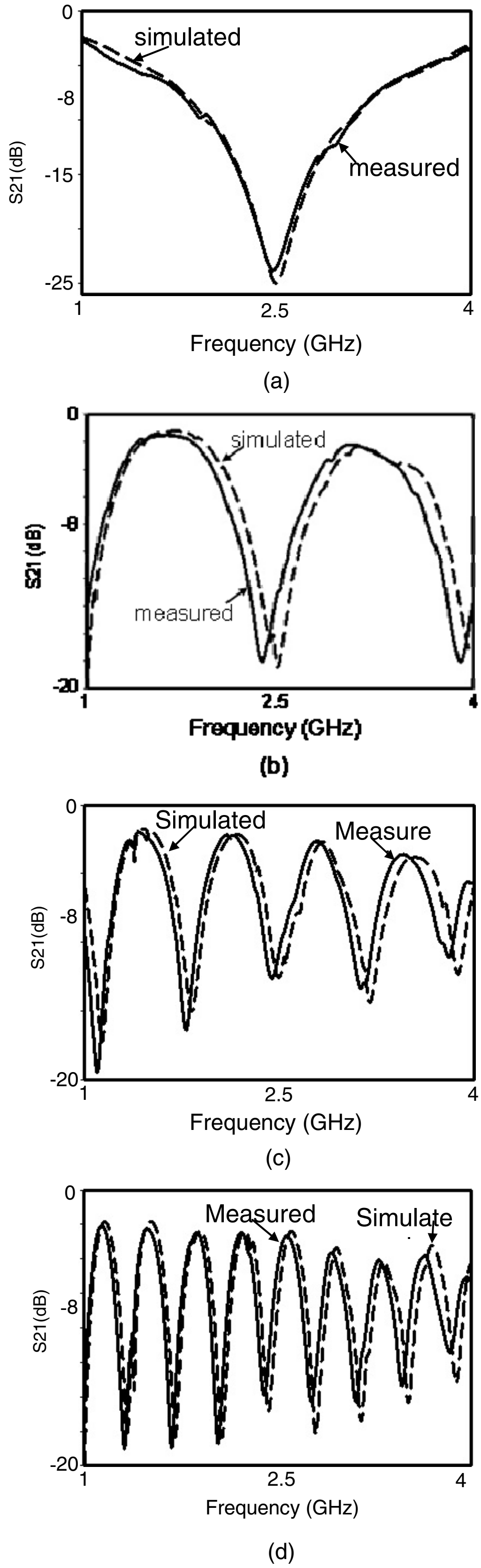


Fig. 6. Simulated and measured transmission for each RD state: (a) State 1 (delay line l_1 is selected); (b) State 2 (delay line l_2 is selected); (c) State 3 (delay line l_3 is selected); and (d) State 4 (delay line l_4 is selected).

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