2-Bit, 1-4 GHz Reconfigurable Frequency Measurement Device

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Abstract—A Reconfigurable Frequency Measurement (RFM) device operating from 1 to 4 GHz has been designed, simulated, fabricated and tested. The RFM device can identify an unknown signal by assigning it to one of the four sub-bands defined by a switched circuit. The 2-bit design is formed by switching between two branches, where each branch corresponds to one bit. The RFM device is made using PIN diodes and other surface mounted components, integrated on the same dielectric substrate in microstrip technology. Simulated and measured results are shown with a very good agreement.

Index Terms—frequency measurement, PIN diode switch, resonator, delay line.

I. INTRODUCTION

Instantaneous frequency measurement (IFM) circuits have been widely used for electronic warfare (EW) in radar monitoring, communications and weapon guidance systems. IFM receivers present high dynamic ranges, frequency measurement with high accuracy, high probability of intercept over wide instantaneous RF bandwidths, and relatively low cost [1].

IFM circuits are large due to the fact that each bit in the design is formed by a branch, allowing for an instantaneous readout through a set of parallel outputs. The main part of this branch is the discriminator, which usually consists of an interferometer based on delay lines. IFM circuits also need detection and analogue to digital conversion (ADC) stages for each branch of the design [1–4].

In this paper, a Reconfigurable Frequency Measurement (RFM) circuit which is a two-port device is described. The RFM device operates as a reconfigurable interferometer and does not provide an instantaneous readout, the RFM scans for the frequency of an unknown signal by switching between its states; the readout is through a serial output. PIN diodes are used to switch between states; the switching time is determined by the PIN diode switching speed, which is approximately 10 ns.

Table 1 shows a comparison between the proposed RFM design and relevant frequency measurement systems available in the literature [4, 5]. The comparison is made in terms of frequency of operation, resolution, power consumption, size, and other characteristics. From the comparison, it is apparent that the RFM design presents some advantages over other non-reconfigurable designs made on microwave laminates [4], such as: a reduced number of electronic components (since only one detector, one amplifier, and one ADC stage are needed to identify an unknown frequency, independently of the number of bits) resulting in low power consumption. The RFM has a reduced size, due to the use of less electronic components and a two port configuration, e.g. the implementation in [4] is bulky compared to the RFM, due to the fact that it has a multiport configuration, while the RFM has only two ports, independently of the number of bits (scalable design). To the best of our knowledge this is the first RFM device, built on a PCB with surface mounted components, resulting in a low cost implementation; other available designs on PCBs are non-reconfigurable.

Another reconfigurable frequency measurement device uses microwave photonics [5]; this design provides a continuous frequency and resolution tuning. The RFM device presented in this letter is a discreetly tuned device, designed to identify an unknown signal by switching between its states. The detected signal is then allocated to one of four sub-bands.

Non reconfigurable frequency measurement implementations using microwave photonics include a design operating on the polarization domain [6]. The design in [7] derives frequency information based on an amplitude comparison of the power fading function; the design presented in [8] can measure frequency and power. These designs focus on a single fixed discriminator.

II. DESIGN CONCEPT

The RFM device shown in Fig. 1 consists of a reconfigurable interferometer, able to switch between two different branches with distinct delays, combined with a reference branch. The device is composed by wideband power...
The RFM device shown in Fig. 1 operates from 1 to 4 GHz. For State 1, a resonator is coupled to line \( l_1 \) to yield a transmission zero at 3.8 GHz. The open loop resonator contains inner stubs to achieve size reduction. State 1 produces the output for bit 1 after the detection and conversion stages.

### Table 1. Comparison between frequency measurement devices

| Frequency Bandwidth (GHz) / Resolution (MHz) | Technology / Type of System | No. of Bits | DR* | Size (mm) | Ref. |
|---------------------------------------------|----------------------------|-------------|-----|-----------|-----|
| 1-4/600-940                                | Microstrip / R             | 1/2         | Based on delay lines | 45 x 65 | This work |
| 2-4/62.5                                   | Microstrip / F             | 5/5         | Open-loop resonator based bandstop filters | 199 x 113 integrated device | [4] |
| 1-12/120                                   | Microwave photonics / R    | 1/1         | Dual-parallel Mach-Zehnder modulator | Not informed | [5] |
| 2-13/250                                   | Microwave photonics / F    | 1/1         | Dual-parallel Mach-Zehnder modulator | Not informed | [6] |

Type of System (R: Reconfigurable, F: Fixed), *DR: Discriminator

For State 2, the delay line \( l_2 \) is selected and the combined signal produces the output for bit 2, after the detection and conversion stages. Line \( l_0 \) has a length of \( \lambda_g/2 \) and lines \( l_1 \) and \( l_2 \) have lengths of \( \lambda_g/6 \) and \( \lambda_g/3 \), respectively, where \( \lambda_g \) is the guided wavelength of the microstrip lines for a center frequency of 2.5 GHz.

### IV. DEVICE FABRICATION AND OPERATION

The RFM device shown in Fig. 1 was fabricated using a LPKF Protolaser S Machine on an ARLON AD1000 substrate with a dielectric constant of 10.2, loss tangent of 0.0023, conductor thickness of 0.035 mm, and dielectric thickness of 1.27 mm. Dimensions of the complete device are as small as 45 mm x 65 mm.

Each power divider uses two resistors of 100 Ω and 220 Ω for a good impedance match from 1 to 4 GHz. The two SPDWT switches use the diode BAR50-02V by Philips Semiconductors, which has an insertion loss of 0.1425 dB and an isolation of 9.32 dB at the frequency of 2.5 GHz and can handle a maximum RF signal power of 30.17 dBm, which is determined by its power dissipation capability of 250 mW considering a series resistance of 3 Ω. The maximum RF power handling of the RFM is limited by the PIN diode. The PIN diode equivalent circuits used in simulations are defined as a series RL, \( R=4.82 \), \( L=41.6 \) pH (forward bias) and a series RC, \( R=76.1 \) Ω, \( C=1294.75 \) pF (reverse bias).

These equivalent circuits were obtained from regressions after measuring a single PIN diode and fitting RLC models to experimental data.

DC 1, DC 2 and DC 3 are DC bias ports. A choke inductor of 82 nH with a self-resonance of 1.7 GHz is used to isolate all DC bias ports from the microwave circuit. The inductor presents a measured isolation of -20 dB at 1GHz, -50 dB at 1.7 GHz and -15.7 dB at 4 GHz. A resistor of 100 Ω is used in series with the choke inductor to provide a current of 10 mA, using a 1 V bias voltage at the DC ports to operate the diodes.

The two RFM states are achieved by biasing the diodes that form the SPDWT switches. Switch 1 is formed by Diodes 1 (D1) and 2 (D2), and Switch 2 is formed by Diodes 3 (D3) and 4 (D4). State 1 of the device is obtained when D1 is reversed biased, while D2, D3 and D4 are forward biased. State 2 is obtained when D1 and D2 are forward biased, while D3 and D4 are reversed biased.

### V. RESULTS AND DISCUSSIONS

Fig. 2 shows the simulated and measured transmission for each state of the device. These responses define the bits for frequency identification, where the incoming unknown signal is assigned to one of four possible sub-bands. The measurements were taken after a SOLT calibration, using an Agilent PNA Network Analyzer model E8361A.

State 1 includes a transmission zero at 3.8 GHz in the simulated response and 3.6 GHz in the measured response. The frequency shift is believed to be caused by a modified coupling to the resonator caused by the solder used to embed the multiple surface mounted components that surround the resonator (two pin diodes and a choke inductor).
This transmission zero added to the delay of $l_1$ combined with $l_o$ produces the first bit (bit 1) of the design, after stages of detection and conversion. The second bit (bit 2) is obtained by combining the delay of $l_2$ with $l_o$.

For an input level of 0 dBm, a threshold of -8 dBm is defined for the circuit, thus, after the detection stage, an ADC process generates a logic level 1 (one) when $|S_{21}| \geq -8$ dB and 0 (zero) when $|S_{21}| < -8$ dB. Fig. 2a shows the analogue signals for each state of the device and Fig. 2b shows the bits generated after the ADC stage, considering a threshold of -8 dB for $S_{21}$.

These bits when combined, divide the frequency range from 1 to 4 GHz in four sub-bands for frequency identification. Table 2 provides details of the four sub-bands defined by Bit 1 and Bit 2 and their resolution. The resolution of the proposed device varies from 660 to 940 MHz, with an average resolution of 750 MHz. This parameter can be reduced by increasing the number of bits and maintaining the operation band of the system fixed. For example, a 4-bit system has an average resolution of 187.5 MHz, an 8-bit system, approximately 11.7 MHz, and a 10-bit system has 2.9 MHz of average resolution. The resolution depends on the longest delay in the circuit, according to (2). It is possible to switch to a longer delay line, if required. The overall resolution of the system is not a problem of technology; it is a cost-benefit problem of a given project. In practical implementations, a limiter amplifier is added before the device to fix the input level to the RFM to a required value (for this design the input level is set to 0 dBm). This limiter amplifier can also work as a bandpass filter rejecting frequencies out of the operation band of the system.

### VI. CONCLUSIONS

The RFM device presented in this letter is a new approach to frequency measurement circuit design. The device has only one output port and switches between two states to identify an unknown signal at the input port. This RFM device reduces considerably the number of electronic components used in traditional IFM systems, resulting in low power consumption and smaller size due to reconfiguration. The concept presented in this letter can be scaled to other RFM designs with a larger number of bits, always generating a two-port device.

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