Frequency Reconfigurable Filtering Power Divider with A Single Varactor

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Abstract: This paper presents a compact frequency reconfigurable filtering power divider (FRFPD) designed with a single varactor. The proposed FRFPD consists of a “T” type input coupling line, a square loop resonator loaded with a single varactor, and a “π” type output coupling line loaded with a resistor. The tuning frequencies of the proposed FRFPD are analysed in theory. The simulated results demonstrate that the central frequency of the proposed FRFPD can be tuned from 1.85 to 2.10 GHz with insertion loss varied from 1.1 to 3.0 dB. Moreover, the isolation between two output ports is better than 20 dB. The effectiveness of the proposed FRFPD is verified by the measured results.

Keywords: Compact, frequency reconfigurable, filtering power divider. Classification: microwave and millimeter devices, circuits.

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1 Introduction

Nowadays, power divider is a key component and widely used in modern wireless communication and radar systems [1-3]. It can split the input power into several parts [4]. Usually, a filter is tandem with power divider to realize the good out of band suppression. In order to minimize the system size and reduce cost, filtering power divider is developed which integrates a filter and a power divider into a component [5-7]. However, this kind of filtering power divider only has fixed operating frequency band, which is not suitable for the cutting edge reconfigurable RF system. The frequency reconfigurable filtering power divider (FRFPD) is thus introduced to solve this problem [8-11].

In [8], the authors replaced a quarter-wavelength transmission line in the Wilkinson power divider with an electronically tunable lowpass structure to realize a FRFPD, where the electronically tunable lowpass structure is established with four ferroelectric BST-varactors. In [10], the authors utilized 8 varactors to achieve a two-way FRFPD that held nearly constant absolute bandwidth when operating frequency is changed by tuning the bias voltage of these varactors. In [11], A filtering power divider that owned high in-band isolation within the reconfigurable operating frequency band was proposed, where 12 varactors are employed. It is widely acknowledged that the more varactors are used, the more insertion loss they will introduce. The bias network design for multiple varactors is also complicated.

In this paper, a compact FRFPD with a single varactor is proposed. In order to analyse the working mechanism, the proposed FRFPD is divided into two identical parts by serving the symmetric plane as magnetic wall, where relation between tuning frequency with varactor is deduced. For demonstrate, a FRFPD whose
tuning range from 1.85 to 2.10 GHz with insertion loss from 3.0 to 1.1 dB is designed by loading one single varactor. The high isolation between two output ports is also obtained at the same time. Good agreements are observed between simulated and measured results.

2 Analysis and design of the FRFPD

Fig. 1 shows the geometries of the proposed FRFPD. It consists of a “T” type input coupling line, a square resonant loop loaded with a varactor and capacitor $C_s$, and a “π” type output coupling line with a resistor. The input and output coupling lines are indicated as CL-A and CL-B, respectively. A transmission line indicated as ML is used to achieve electrically connection between them. The characteristic impedance of the input and output ports is $Z_0$. $Z_{o1}$, $Z_{o2}$ and $\theta$ are the odd-mode impedance, even-mode impedance and electrical length of the CL-A and CL-B, respectively. $Z_m$ and $\theta_m$ are the characteristic impedance and electrical length of the microstrip transmission line (ML).

![Schematic of the proposed FRFPD](image)

In order to analyze the central resonant frequency $f_r$, the square resonant loop is divided into two identical parts as shown in Fig. 1. Every part has a varactor that derived from the original varactor $C$. The presence of varactor $C/2$ makes every part tunable resonator. The resistor $R$ and capacitor $C_s$ are used to improve the isolation between Port2 and Port3.

The input admittance of each tunable resonator can be derived as:

$$Y_{inC} = Y_{in3} + j2\pi fC.$$  \hspace{1cm} (1)

$$Y_{in3} = \left(\frac{Z_{o3}Z_{o2}Y_{in2} + j\tan \theta}{Z_{o3}Z_{o2} + jZ_{o2}Z_{in2}}\right)\tan \theta,$$  \hspace{1cm} (2)

$$Y_{in2} = Y_m \left(\frac{Y_{in1} + jY_m \tan \theta_m}{Y_m + jY_{in2} \tan \theta_m}\right),$$  \hspace{1cm} (3)

$$Y_{in1} = j\tan \theta / \sqrt{Z_{o1}Z_{o2}}.$$  \hspace{1cm} (4)

The relation between resonant frequency $f_r$ and varactor $C$ can be obtained when the imaginary part of $Y_{inC}$ satisfies the following formula:

$$\text{Im}[Y_{inC}] = 0.$$  \hspace{1cm} (5)

Based on Eq. (5), it is observed that the resonant frequency $f_r$ is closely related to the value of varactor $C$, the electrical length of ML $\theta_m$. Here, the parameters of
The proposed RFRPD is selected as follows: $Z_0 = 50 \, \Omega$, $Z_{0o} = 30 \, \Omega$, $Z_{0e} = 80 \, \Omega$, $Z_m= 30 \, \Omega$, $	heta = 35^\circ$, $\theta_m = 100^\circ$, $C_m = 20 \, \text{pF}$, $R = 100 \, \Omega$.

The impacts of different capacitance value of varactor on resonant frequency $f_r$ is investigated firstly. Fig. 2 shows the relation between resonant frequency $f_r$ and varactor capacitance value $C$, where it is observed that if a commercial varactor has tunable capacitance value from 0.5 to 6.5pF under different DC voltage bias, the resonant frequency $f_r$ is shifting from 2.26 to 1.53GHz with other parameters of the proposed RFRPD fixed. The other parameter $\theta_m$ is also studied to examine its impacts on resonant frequency. Fig. 3(a) compares the resonant frequency under different electrical length $\theta_m$, where the capacitance value of varactor is also varied. It is observed that the resonant frequency $f_r$ is shifting toward lower frequency band when the electrical length $\theta_m$ is becoming bigger.

The presence of resistor $R$ and capacitor $C_m$ will improve the isolation of output ports (port2 and port3). In order to illustrate it, the isolation between port2 and port3 $S_{23}$ is simulated under three conditions, namely, with $C_m$ and $R$, with $C_m$ and without $R$, without $C_m$ and with $R$. Fig. 3(b) presents the simulated results. It is shown that the in-band and out of band isolation between port2 and port3 is obtained with presence of resistor $R$ and capacitor $C_m$. 

![Fig. 2. The analysis of tunable resonator. (a) circuit prototype (b) Relationship between $f_r$ and $C$.](image1)

![Fig. 3. Theory performance of the FRFPD prototype. (a) Frequency reconfiguration with different $\theta_m$, (b) Isolation improvement by $R$ and $C_m$.](image2)
3 Fabrication and measurement

In this section, a prototype of proposed FRFPD is established and measured based on the explicit analysis in the aforementioned section. The structure and dimensions of the fabricated FRFPD are shown in Fig. 4(a). Fig. 4(b) shows its photograph. The size of the circuit is 33 mm × 27 mm. The circuit is printed on a Taconic RF-35 substrate with a thickness of 0.508 mm, relative permittivity 3.5 and dielectric loss tangent 0.0018. Infineon BB857 varactor is utilized as the tuning element. A bias resistor of 11 kOhm $R_b$ is used as a RF choke. $C_m$ is 20 pF and two tandem 50 Ω resistors are used to realize 100 Ω isolation resistor (R).

![Fig. 4. Fabricated FRFPD. (a) Physical layout and its dimensions (unit: mm), (b) Photograph of the proposed FRFPD.](image)

![Fig. 5. Simulated and measured results of the fabricated FRFPD prototype. (a) Simulated and measured $S_{11}$ and $S_{21}$, (b) Simulated and measured $S_{23}$, (c) Simulated and measured $S_{22}$, (d) Measured magnitude imbalance and phase difference.](image)

The responses of the fabricated FRFPD are shown in Fig. 4. Measured and simulated results are in great agreements with each other. It can be seen that the operating frequency of the FRFPD is tuned from 1.85 to 2.10 GHz when the bias...
voltage is varied from 10 to 30 V as shown in Fig. 5(a). The return loss of each port ($S_{11}$, $S_{22}$, $S_{33}$) is better than 12 dB within the tuning range. Moreover, the isolation between port 2 and port 3 is better than 20 dB at the operating frequency. Within the tuning range of the FRFPD, insertion loss of two output ports ($S_{21}$, $S_{31}$) are both better than 6.0 dB and reaches the top of 4.1 dB at 2.10 GHz. Within the passband, the magnitude imbalance and phase difference are about ± 0.6 dB and ± 2.2 deg as shown in Fig. 5(d), which can be improved by replacing the DC bias circuit ($R_b$) with a symmetrical one.

A factor called TPR is defined to evaluate number of tunable elements for per output port:

$$TPR = \frac{\text{Number of tunable elements}}{\text{Number of output ports}}. \quad (6)$$

The proposed two-way FRFPD in this paper has just one varactor which means that its TPR is just 0.5. Table I compares the proposed FRFPD and some reported FRFPDs. It is observed that our proposed FRFPD owns an extremely low TPR.

It should be noted that although the proposed FRFPD has a lowest TPR, the insertion loss is still larger than that of the filtering power dividers in [8-10]. This is due to the much larger bandwidth of the filtering power divider in [8] and the combining effect of lower working frequencies and smaller parasitic resistor of varactors in [9, 10]. Hence, an improvement of the insertion loss can be achieved by using varactors with small parasitic resistors or widening work bandwidth.

| Ref. | Freq (GHz) | IL (dB) | Isolation (dB) | Number of tunable elements | TPR |
|------|------------|---------|----------------|----------------------------|-----|
| [8]  | 1.7-2.1    | 0.6-1.2 | >25            | 4                          | 2   |
| [9]  | 0.71-0.82  | 1.2-2.5 | >20            | 4                          | 2   |
| [10] | 0.62-0.82  | 1.8-2.4 | >16            | 8                          | 4   |
| [11] | 1.3-2.08   | 2.9-5.3 | >26            | 12                         | 6   |
| This work | 1.85-2.10 | 1.1-3.0 | >20            | 1                          | 0.5 |

4 Conclusion

A FRFPD loaded with a single varactor is described. The two output ports share one varactor, which reduces the number of tuning elements. To verify the proposed theory, a FRFPD prototype has been fabricated and measured. Compared to the open FRFPDs, the proposed FRFPD owns a smaller TPR. The proposed FRFPD and tuning elements sharing technology can be applied in reconfigurable microwave system.

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