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The Design of Frequency-tunable Mechanical Tuning Coupler Based on Coupled Line Structure

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Abstract: In the current study, a frequency-tunable mechanical tuning coupler based on coupled line structure is proposed, which shall have high stability and high flexibility of tuning. This mechanical tuning coupler is based on coupled line structure of microstrip technology. This coupler is composed by baseplate for signal transmission and mobile plate for mechanical tuning. By mechanically tuning the rotation angle, the coupling length is changed and tunability is achieved. The operating frequency can be tuned from 1.02 GHz to 1.27 GHz while the rotation angle is tuned from 180° to 135° approximately. The design principle is based on quarter-wave resonance phenomenon of coupled line.

Keywords: frequency-tunable, coupled line, mechanical tuning, microstrip

Načrtovanje mehanskega spojnika z možnostjo nastavitve frekvence na podlagi strukture sklopljene linije

Izvleček: V pričujoči študiji je predlagan frekvenčno nastavljiv mehanski sklopnik, ki temelji na strukturi sklopljene linije in ima visoko stabilnost in prilagodljivost uglaševanja. Ta mehanski nastavljiv sklopnik temelji na strukturi sklopljene linije mikropasovne tehnologije. Sestavljata ga osnovna plošča za prenos signala in premična plošča za mehansko nastavljanje. Z mehanskim nastavljanjem kota vrtenja se spreminja dolžina sklopke in doseže nastavljivost. Delovno frekvenco je mogoče nastaviti od 1,02 GHz do 1,27 GHz, kot vrtenja pa približno od 180° do 135°. Načelo zasnove temelji na resonančnem pojavu četrtvalovne resonance sklopljene linije.

Ključne besede: frekvenčno uglaševanje, sklopljena linija, mehansko uglaševanje, mikropasec

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1 Introduction

Coupler, known as an important communication electronics, plays an essential role in optical and microwave system [1-4]. Couplers are usually used for power distribution, phase shift and so on [5]. Among them, tunable couplers can realize further functionality for its tunability of coupling coefficients or frequency. Most tunable couplers realize tunablility by using reconfigurable components, such as tunable capacitors or Micro Electro Mechanical Systems (MEMS) switches [6-10]. Besides, some couplers also use magnetic material to realize tunablility [11].

Coupled line is a popular structure in microstrip industry. When two waveguides get close to each other, the function of power redistribution can be realized. This structure is popular in the application of couplers [12-13]. The principle of coupled line coupler is based on quarter-wave resonance phenomenon. Their operating frequencies depend on coupling length mostly.

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In this study, a frequency-tunable mechanical tuning coupler based on coupled line structure is proposed. This tunable coupler uses two-layer structure. Using two-layer structure can realize much functions like refining smoothness and reducing size [14]. In current study, the tunability of component is achieved by using this two-layer structure.

Mechanical tuning is a popular tuning way in the design of tuning resonators and filters [15-17]. Tuning screw structure is a popular structure in mechanical tuning. This coupler is made by printed circuit board (PCB) technology, which should have high stability and low manufacturing cost. This mechanical tuning coupler can be driven by a stepper micromotor [18]. By changing rotation angle of mobile plate, the coupling length of coupler can be changed leading to the shifting of operating frequency. The coupling lines is deformed into semicircle-ring type. It still obeys the law of quarter-wave resonance phenomenon, but some differences exist.

2 The simulation of miniature tunable inductor

The principle diagram of this frequency-tunable mechanical tuning coupler can be given by Fig. 1.

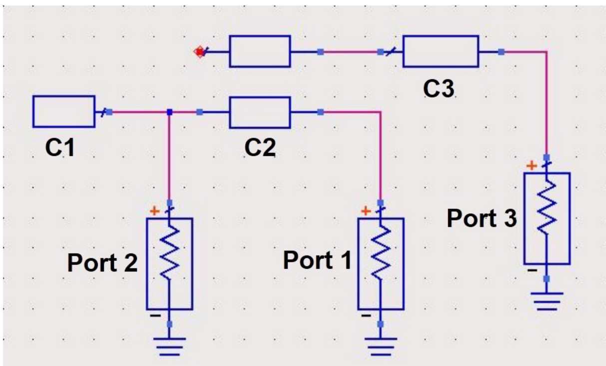

Figure 1: principle diagram of frequency-tunable mechanical tuning coupler

C1 means the length of microstrip which does not participate in coupling in signal transmission end. C2 means the length of coupling part. C3 means the length of microstrip which does not participate in coupling in coupling end. The coupling length C2 decides the operating frequency. By mechanically tuning the length of C2, tunability of frequency can be realized. According to the simulation of Advance Design System (ADS), the ratio of C2/C1 and C2/C3 is better to be larger than 300%, or the reflection coefficients S11 and transmission coefficient S21 will deteriorate gradually.

Fig. 2 shows the perspective model of frequency-tunable mechanical tuning coupler with a rotation angle at 135°.

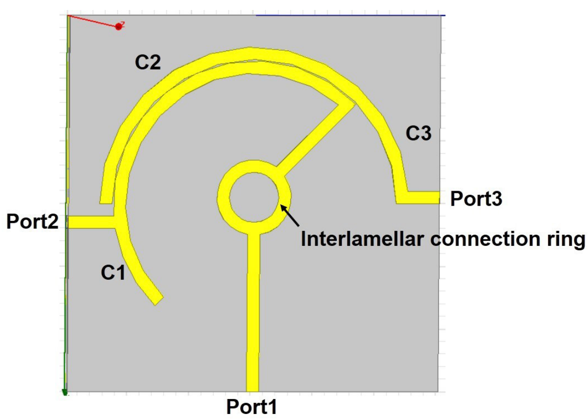

Figure 2: perspective model of frequency-tunable mechanical tuning coupler

The coupler includes baseplate for signal transmission and mobile plate for mechanical tuning. The inner metal ring is printed on mobile plate. By rotating the mobile plate, the coupling length C2 is changed leading to the tunability of frequency. The coupling signal is conducted to Port 3 by the coupled lines. The end of inner metal ring is open circuit. C1 will lead to the deterioration of reflection coefficient S11, so the ratio of C2/C1 shall be controlled. The mathematic relation of operating frequency can be written as Eq. 1 [19]

$$f_0 = \frac{c}{4\alpha L \varepsilon_r^{0.5}} \tag{1}$$

where f_0 is operating frequency, c is light speed, α is shape correction factor, L is arc length of coupled lines, ε_r is relative permittivity of dielectric material.

The structure of frequency-tunable mechanical tuning coupler is shown as Fig. 1. The substrate material is FR4 with a relative permittivity ε_r about 4.2-4.7 with a height h of 1 mm. The metal line is made by gold with a height of 35 μm. The total size of the coupler is 40 mm×30 mm. Fig. 3 is the structure of frequency-tunable mechanical tuning coupler.

The parameter r1, r2, s and w in Fig. 3 mean external radium of inner ring, external radium of outer ring, interval between coupled lines and width of metal line which equal to 11.45 mm, 12.5 mm, 0.05 mm, 1 mm respectively. The mobile plate is connected to a stepper micromotor, which drive the mobile plate rotating from the bottom. The micromotor has a small volumn of Φ3.4 mm ×10.75 mm, which can ensure the compactness of this component. Besides, stepper motor

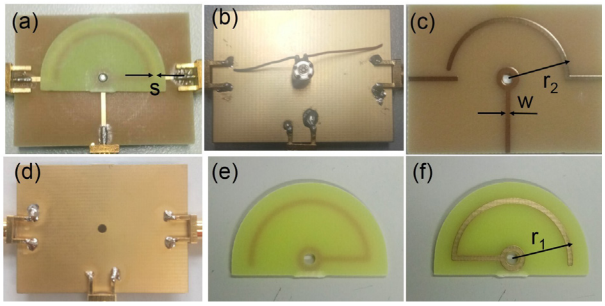

Figure 3: (a) top view of frequency-tunable mechanical tuning coupler (b) bottom view of frequency-tunable mechanical tuning coupler (c) top view of baseplate (d) bottom view of baseplate (e) top view of mobile plate (f) bottom view of mobile plate

means a motor driven by electric pulse signal. Each electric pulse signal will make the motor rotate for a certain degree, ensuring the controllability and stability of tuning. The operating frequency is determined by its rotation angle. The simulation and measurement result is shown in Fig. 4.

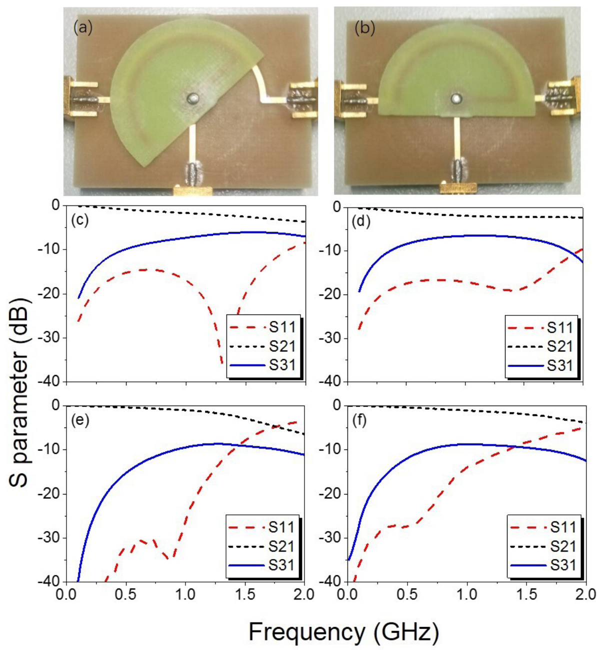

Figure 4: (a) (b) tunable coupler with a rotation angle about 135° and 180° (c) (d) simulation and (e) (f) measurement result of tunable coupler with a rotation angle about 135° and 180°

S31 in measurement is weaker than that in simulation for a distance. The metal line is set as perfect conductor in simulation, while real gold line has a weaker conductivity than perfect conductor. It causes some difference between simulation and measurement. The height of metal lines can be improved to reduce this difference. The tightness between two plates is another important factor.

The 1 dB-passband of Fig. 4(e) is from 0.97 GHz to 1.69 GHz with a coupling coefficient S31 around -8.66 dB at a center frequency of 1.27 GHz. While the 1 dB-passband of Fig. 4(f) is from 0.71 GHz to 1.58 GHz with a coupling coefficient S31 around -8.75 dB at a center frequency of 1.02 GHz. The transmission coefficient S21 of 135° deteriorates a bit than that of 180° in passband, but it is still in reasonable range.

3 Result and discussion

This coupler is based on quarter-wave resonance phenomenon, so the tuning range appears inapparently for the limited change of coupling length in lower frequency. In theory, the tuning range is 24.5% with the rotation angle tuned from 180° to 135°. So the tuning range can be more apparent in higher operating frequency. Table 1 shows the comparison with other works.

Table 1: Comparison of measurement result.

	Tuning range (GHz)	Coupling (dB)	NNC
This work	1.02-1.27 (24.5%)	-8.66	1
[5]	1.6-2.3 (36%)	-3~-4	4
[6]	6.7-7.1 (5.7%)	3~-6	4
[7]	1.3-1.9 (46%)	-3~-10	4

NNC means number of necessary tuning components.

As a passive component, the properties of current coupler is based on the structure of coupled line itself. Compared with active tunable couplers, current couplers cannot realize the tunability of S31 or signal amplification. However, the tuning of former works need to adjust their four tuning components (variable capacitors or RF switches) into respective certain value. While the tuning of this work relies on one micromotor, which has more flexibility of tuning.

The coupled lines of this coupler is semicircle-ring type, whose properties are similar to common linear coupled line coupler. So when this coupler is designed, classical equations of common linear coupled line coupler can be used as reference to choose parameters as shown in Eq. 2 and Eq. 3 [19]

$$Z_0^2 = \alpha_e Z_{0e} \alpha_o Z_{0o} \tag{2}$$

$$K = \frac{\alpha_e Z_{0e} - \alpha_o Z_{0o}}{\alpha_e Z_{0e} + \alpha_o Z_{0o}} \tag{3}$$

where Z0 is characteristic impedance of microstrip, αe is shape correction factor of even mode, αo is shape correction factor of odd mode, Z0e is even mode characteristic impedance and Z0o is odd mode characteristic impedance. The width of microstrip w determines Z0 mostly, the relation is shown as Eq. 4 approximately. w shall be calculated to make impedance matched [19].

$$Z_0 = \frac{60}{\sqrt{\varepsilon_r}} \log\left(\frac{8h}{w} + \frac{w}{4h}\right) \tag{4}$$

Besides, the interval between coupled lines s determine coupling degree K and S31. In general, a larger interval between coupled lines s gets a smaller S31. S31 goes from -8.6 dB to -12.4 dB when s goes from 0.05mm to 0.5mm in measurement of this study. Therefore, s shall be chosen according to desired S31. The height of metal lines can be improved to intensity the coupling degree *K* in some degree as well. The tunability of S31 can be realized if the tuning of *s* is achieved.

Some differences caused by shape difference can be adjusted by simulation software subsequently.

Port 1 and Port 2 are connected by the mobile plate. If the metal lines do not contact tightly, the signal will not transmit normally. The height of metal line can be thicked for strengthening tightness. Besides, the equivalent impedance of interlamellar connection ring shall be well designed and impedance matched in case of return loss. The interlamellar connection ring is better to be a small circle whose diameter is similar to the width of metal line. Besides, the ratio of C2/C1 and C2/C3 will influence the reflection coefficient S11, especially C2/C1. Namely, the C2 cannot be close to C1. If this ratio is too small, reflection coefficient S11 will improve largely and deteriorates transmission coefficient S21. So the rotation angle shall be controlled in reasonable range.

4 Conclusions

In this study, a frequency-tunable mechanical tuning coupler is proposed. By changing rotation angle of mobile plate, the coupling length of coupled line is changed leading to tunability of operating frequency. The operating frequency of this coupler can be tuned from 1.27 GHz to 1.02 GHz while the rotation angle is tuned from 180° to 135°, the tuning range is 24.5%.

5 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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