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Ku 波段 MEMS 微波功率耦合器设计

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摘要：针对现有的微波功率测量都基于热电偶和二极管等终端器件，功率信号在被检测后无法利用的问题，设计了一个基于微机电（MEMS）射频（RF）并联开关在 Ku 波段（12.4～18 GHz）应用的微波功率耦合器，包括等效电路、共面波导（CPW）匹配的设计和结构仿真。该耦合器是 MEMS 微波功率传感器的核心，它利用 MEMS 膜桥耦合 CPW 上的微波功率信号，大部分功率信号被检测后都能传至下级电路做进一步处理。为了减小反射损耗和获得宽频带响应，提出了两种优化方法，即凹槽调谐结构设计和补偿电容设计，经过优化设计后的 Ku 波段 MEMS 微波功率耦合器的回波损耗（S_{11}）和插入损耗（S_{21}）在中心频率 15.2 GHz 处分别达到了－42.90 dB 和－0.15 dB，显示出耦合器的高隔离度和低损耗。同时在 Ku 波段，上述参数同中心频率点处的偏差分别为±6.41 dB 和±0.04 dB，显示出其宽带特性。

关　键　词：微机电系统；微波功率耦合器；耦合系数；GaAs；Ku 波段
中图分类号：TN622　　**文献标识码**：A

Design of MEMS microwave power coupler based on GaAs for Ku-band

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Abstract：A novel MEMS microwave power coupler based on GaAs for Ku-band (12.4～18 GHz) is presented to improve the existing technology for measuring microwave power based on the termination devices，such as thermistors，thermocouples，and diodes，because the signals are not available after power detection by these devices. By the designed coupler，the microwave power is coupled with the Coplanar Waveguide(CPW) line，and most of the CPW signals can be transmitted to the next stage circuit for further processing. In order to reduce the reflection losses and to obtain broadband response of the power sensor，two kinds of optimal methods with a tuned structure and a compensating capacitor are proposed. Optimizations of the design with HFSS has demonstrated that the return loss (S_{11}) and insertion loss (S_{21}) at the central frequency of 15.2 GHz have reached －42.90 dB and －0.15 dB，respectively and the deviation of S_{11} and S_{21} compared with the central frequency have reached ±6.41 dB and ±0.04 dB in the Ku-band. These results show the microwave power coupler has advantages of high isolation，low loss and broadband characteristics.

Key words：MEMS；microwave power coupler；coupling coefficient；GaAs；Ku-band

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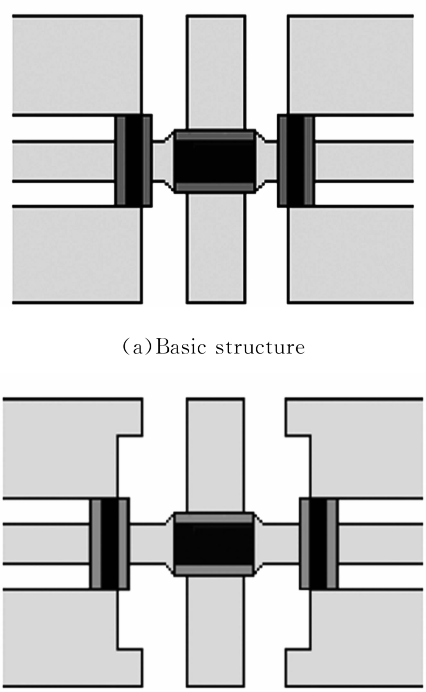
1 Introduction

The applications of modern personal communication systems and radar systems require the power sensors with low power consumption. Traditional measuring technologies for microwave powers are based on the termination devices such as thermistors, thermocouplers, and diodes, in which the measured signals are not available after power detection. Recently, to improve the measuring methods, three new design principles of the microwave power sensor are proposed. The first principle is realized by the movement detection of a suspended membrane over a Coplanar Waveguide(CPW) line through which the signal is transmitted [1]. The output of such a power sensor is related to the capacitance change, so it needs to read out by the electronics and its performance depends on the process seriously. The second principle utilizes the conversion of electricity into heat to result in a local temperature increase due to the ohmic losses of the center conductor of a CPW line[2]. The structure of this sensor is complex and not compatible with GaAs or Si process, and it has the trade-off between the microwave performance and the sensitivity. The third principle is that a small ratio of the microwave power which is transmitted in the CPW line is coupled by the MEMS membrane, and the coupled microwave power is converted to heat by the matched resistor and measured by the thermopile[3]. This power sensor has two independent steps: the coupled step and the measurement step, it leads to the microwave properties and the sensitivity of the sensor can be designed separately in convenience. But the reflection losses and the response of the structure need to be improved.

This paper focuses on the coupled step, and the improvement of the third principle is presented. By increasing the gap size of the CPW line directly before and after the capacitance so as to adjust the CPW characteristic impedance and by adding a compensating capacitor, the low reflection losses and the broadband response are obtained. This power sensor coupler has many advantages such as independent of signal waveforms, high dynamic ranges, small sizes, and low power consumption. The possible applications of such coupler include personal communication systems and radar systems.

2 Operation principle

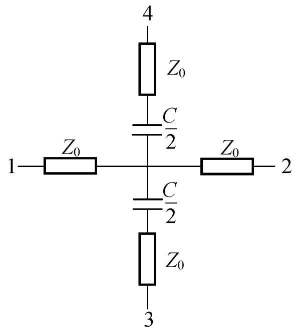
The microwave signal is transmitted by the CPW line. At a certain position, the gold MEMS membrane is suspended over the CPW line. The capacitor between the membrane and the center conductor of the CPW line couples a certain ratio of the microwave power which is transmitted in the CPW line. In order to obtain low reflection losses and the broadband response, the gap size of the CPW line is increased directly due to the capacitor, and a compensating capacitor is added[4]. Fig. 1 shows the improved structure of the



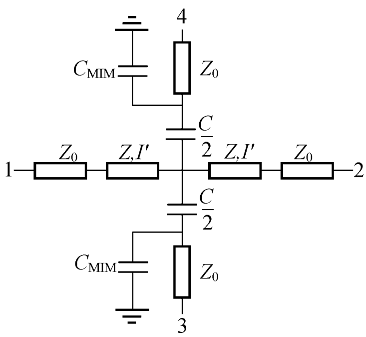
(a) Basic structure

(b) Improved structure

Fig. 1 Top view of the microwave power couplers microwave power coupler compared with the basic structure.



(a) Basic structure



(b) Improved structure

Fig. 2 Lumped element models of microwave power coupler

Fig. 2 shows the lumped element equivalent circuit models of the two above mentioned structures. C is the capacitor between the MEMS membrane and the center conductor of the CPW line, and C_{MIM} is the compensating capacitor[5-6].

$$C=\frac{\varepsilon_0 bw}{g_o+\frac{t_d}{\varepsilon_r}}+C_f, \tag{1}$$

$$C_{MIM}=\frac{\varepsilon_0\varepsilon_r b'w'}{t_d}, \tag{2}$$

Where, b is the width of the MEMS membrane, w is the width of the center conductor of the CPW line, b' is the width of the ground of the CPW line which is formed as the bottom plate of the compensating capacitor, w' is the width of the top plate of the compensating capacitor, g_0 is the membrane height, t_d is the thickness of the insulation layer, ε_0 and ε_r are the permittivity of free space and the permittivity of the dielectric layer, respectively. The matched impedance b can be calculated as

$$Z^3\omega C\tan^2(\beta l)-2Z^2\tan(\beta l)+ZZ_0^2\omega C+2Z_0^2\tan(\beta l)=0, \tag{3}$$

The S parameters of the basic structure of the microwave power coupler can be expressed as

$$S_{11}=-\frac{Z_0}{2Z_0-\mathrm{j}\frac{2}{\omega C}}, \tag{4}$$

$$S_{21}=-\frac{Z_0-\mathrm{j}\frac{2}{\omega C}}{2Z_0-\mathrm{j}\frac{2}{\omega C}}, \tag{5}$$

$$S_{31}=S_{41}=\frac{Z_0}{2Z_0-\mathrm{j}\frac{2}{\omega C}}. \tag{6}$$

3 Simulation and design

The microwave signal is transmitted by the CPW line, which is designed for matching a 50 Ω impedance. This design is simple and available, however, after adding a MEMS membrane, a capacitor between the membrane and the signal line of CPW is formed, which changes the matched 50 Ω-design, makes the transmission characters of the CPW worse[7].

In order to obtain a better microwave performance, two different ways of impedance compensation techniques are investigated:

(1) Reducing the width of the signal line;

(2) Modifying the width of the ground planes.

In both cases, the gap distance of the CPW, G (50 μm), is increased. As a result, lower capacitance and higher inductance are obtained in that region to compensate the extra capacitance added by the sensor.

For the first technique, although the reflection is lowered, the transmission loss increases when the signal line becomes too narrow (S=30 μm). This is a consequence of the higher resistance introduced into the line, since the dimensions of the metal line carrying the RF current have been considerably reduced.

For the second technique, when the ground planes become too narrow ($G'=250\ \mu m$), transmission loss does not further decrease due to the extra resistance introduced in the ground planes. Therefore, the results indicate that not only reflection but also transmission losses can be minimized with this impedance matching method. So we choose the second compensation technique.

We also consider the additional capacitor between the ground line of CPW and the MEMS membrane. The optical model is shown in Fig. 3.

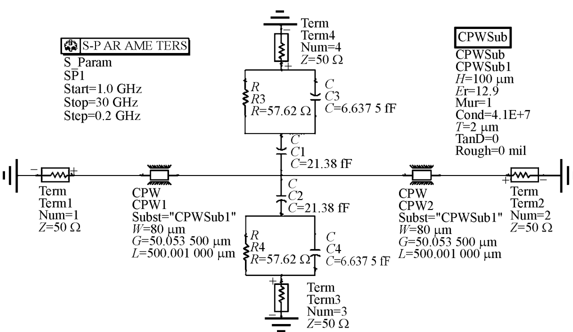


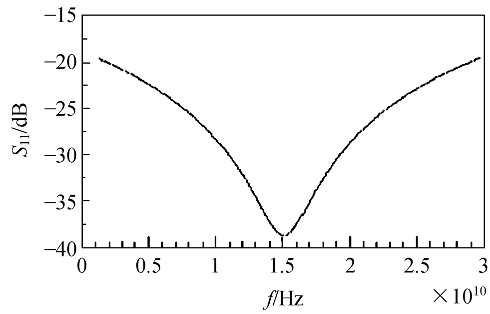
Fig. 3 Optical model of microwave power coupler

According to the formulas above, the improved structure can be designed. The geometry parameters in detail are demonstrated in Tab. 1.

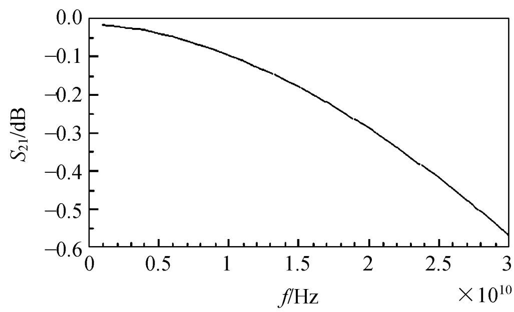
Tab. 1 Geometric dimension of the coupler

Geometric parameters(unit: μm)		
CPW	G	50
	S	80
	G	50
Concave	G'	74.63
	S	80
	G'	74.63
Membrane bridge	Length	160
	Width	90.41
	Height	2

Utilizing the Agilent's ADS software, the S-parameters curves can be calculated, as they are shown in Fig. 4. The actual structure is also presented in Ansoft's HFSS software, shown as Fig. 5, and the simulated HFSS results are shown in Tab. 2.



(a) Return loss



(b) Insertion loss

Fig. 4 Curves of S parameters

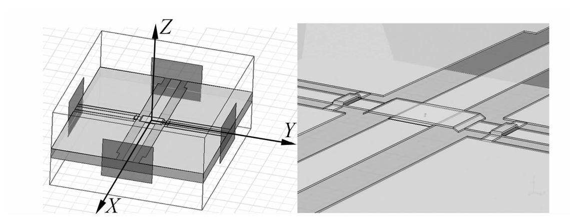


Fig. 5 Three dimensional model of coupler in HFSS

Tab. 2 Simulated S-parameter values

S-parameters	Simulated S-parameter values	
	Central frequency	Maximal deviation in Ku-band
S_{11}	−42.90 dB	±6.41 dB
S_{21}	−0.15 dB	±0.04 dB
S_{31}	−20.43 dB	±1.67 dB

Optimization of the design of the Ku-band MEMS microwave power coupler with HFSS has resulted in that the return loss (S_{11}) and insertion loss (S_{21}) at the central frequency of 15.4 GHz reach −42.90 dB and −0.15 dB, respectively. This shows a high isolation degree and low loss of the power coupler. At the same time, the deviation of S_{11} and S_{21} reach ±6.41 dB and ±0.04 dB, respectively, in the scope of the Ku-band as compared with the central frequency and this also shows its broadband characteristics.

4 Conclusions

This paper presents a detail discussion on the design of a MEMS microwave power coupler based on GaAs for Ku-band (12.4－18 GHz), including simulation, structure design and equivalent circuits. A novel MEMS membrane structure for coupling the microwave power is presented, by which the microwave power is coupled from the CPW line. With an inductively tuned structure and a compensated capacitor, the improved structure can obtain the lower reflection losses, better broadband response as compared with that of the basic structure, and can give the reflection losses and the insertion losses are －42.90 dB and －0.15 dB, respectively.

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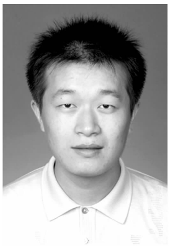

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