

A FOUR-PORT MICROWAVE PHASE DETECTOR AT S-BAND BASED ON MEMS POWER SENSORS

R. Elumalai¹ and Prof. K. Beulah Suganthi, M.E.,²

M.E, Applied Electronics

^{1,2}Thanthai Periyar Government Institute of Technology, Vellore 632 002.

Abstract - A four-port microwave phase detector based on MEMS power sensors at S-band (2–4GHz). Expanded power up to 4W at S-band proposed in this project. It consists of two power dividers, two power combiners, two phase shifters, and two MEMS power sensors. Four power dividers/combiners and two phase shifters compose a four-port junction to expand the phase detection range. A thermoelectric power sensor and a capacitive power sensor compose the MEMS power sensor for low and high power measurement. Two types of power sensors can improve the measurement range and enhance the overload capacity. This microwave phase detector is fabricated by GaAs monolithic microwave integrated circuit technology. Experiments show that its return loss is better than -4dB, and the isolation is better than -6.2 dB over S-band. Measured results of the phase shift fit well with the calculated results in an entire cycle of -180° ~ +180°. The phase detection sensitivities are 7.62 $\mu\text{V}/^\circ$ and 11.94 $\text{aF}/^\circ$, and the response times are 0.108 ms and less than 10 ms for the two types of sensors, respectively. The power expanded up to 4W for our previous works based on S-Band but now I can implement the dynamic range of phase detector can be expanded up to 4W based on S-band.

Index Terms— Micro electro mechanical systems (MEMS), monolithic microwave integrated circuit (MMIC), phase detection, power sensor, Directional Coupler, Network Analyzer.

1. INTRODUCTION

A microwave component, phase detector has been extensively employed in phase-locked loop, phase shift keying, and phase demodulators [1], [2]. In 1970s, Engen et al proposed a six-port technique to detect the microwave phase and amplitude by power measurement [3], [4]. Based on this principle many researches related to the design, analysis and measurement have been proposed in the literatures [5]–[10]. Such phase detectors based on RF MEMS technology have been proposed in our previous research [11], [12]. However, its phase detection range is only from 0° to 180°. To realize phase detection in an entire cycle of -180° to +180°, We have also design a four-port phase detector. Comparing to other phase detectors, this device has a simple structure and does not consume DC power due to apply MEMS power sensors [5]–[12].

This paper further completes the measurement and verification. The phase detection has been accomplished in entire -180° to +180°.

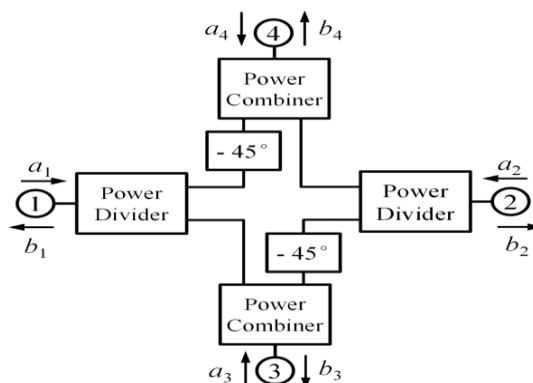


Figure. 1. Block diagram of the four-port junction.

Moreover, the frequency response, dynamic range, phase sensitivity and response time are analyzed and discussed in detail. In this design, the phase detector adopts a four-port junction to expand the phase detection range, and cascade two types of power sensors to improve the measurement range and dynamic range. In order to fabricate MEMS clamped-clamped beam and improve the thermal sensitivity of sensor, both the surface and bulk micromachining process are used in this paper. The fabrication of this phase detector is compatible with the GaAs MMIC technique.

II. PRINCIPLE

A. Four-Port Junction

A four-port junction comprises of two power dividers, two power combiners, and two 45° phase shifters. The incident and emergent wave of each port is marked as a_i and b_i ($i = 1, 2 \dots 4$). According to the relationship between incident wave a_i and emergent wave b_i can be expressed as

$$b_i = \sum_{j=1}^4 S_{ij} a_j, i = 1, 2, 3, 4 \quad (1)$$

$$a_k = \Gamma_k b_k, k=3, 4 \quad (2)$$

Where A_k and B_k are the complex constants, which depends only on the S-parameter S_{ij} and the reflection coefficient Γ_k . Therefore, both the amplitude and phase information of the incident wave a_1 and a_2 are contained in those equations (3).

$$\begin{bmatrix} b_3 \\ b_4 \end{bmatrix} = \begin{bmatrix} A_3 & B_3 \\ A_4 & B_4 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \quad (3)$$

In the ideal situation, the power divider and phase shifter are well matched of impedance, and the coefficients matrix of A_j and B_i are given as

$$\begin{bmatrix} A_3 & B_3 \\ A_4 & B_4 \end{bmatrix} = \begin{bmatrix} 1/2e^{j3\pi/4} & 1/2e^{j\pi} \\ 1/2e^{j\pi} & 1/2e^{j3\pi/4} \end{bmatrix} \quad (4)$$

The output powers to P3 and P4 are given as

$$\begin{aligned} P_i &= |b_i|^2 = (A_1 a_1 + B_1 a_2)(A_i^* a_i^* + B_i^* a_2^*) \\ &= |A_i|^2 |a_1|^2 + |B_i|^2 |a_2|^2 + 2 \operatorname{Re}\{A_i B_i^* a_1 a_2^*\} \end{aligned} \quad (5)$$

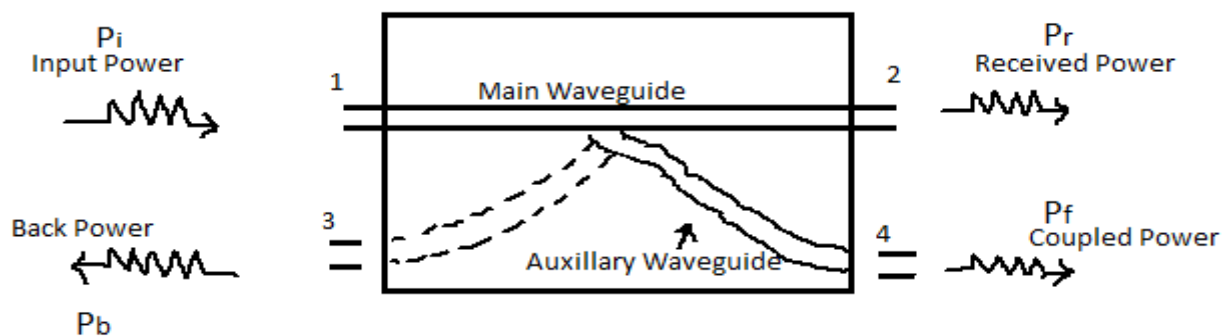


Fig.1.2. Directional Coupler Indicating Powers

The incident wave a_1 and a_2 are respectively taken to be as

$$a_1 = |a_1| e^{j(2\pi f + \phi_1)} \quad (6)$$

$$a_2 = |a_2| e^{j(2\pi f + \phi_2)} \quad (7)$$

Where f is the frequency of the incident wave, and the phase difference between a_1 and a_2 are marked as Δ

$$\Delta\phi = (\phi_2 - \phi_1) \quad (8)$$

Then, plugging the equation (4), (6)-(8) into (5) can be simplified as

$$P_3 = 1/4 (|a_1|^2 + |a_2|^2 + 2|a_1||a_2|\cos(\Delta\phi + \pi/4)) \quad (9)$$

$$P_4 = 1/4 (|a_1|^2 + |a_2|^2 + 2|a_1||a_2|\cos(\Delta\phi - \pi/4)) \quad (10)$$

After normalizing the equation (9) and (10), the ideal phase characteristic curve can be obtained

$$\cos(\Delta\phi + \pi/4) = \frac{2P_3 - (P_{3max} + P_{3min})}{P_{3max} - P_{3min}} \quad (11)$$

$$\cos(\Delta\varphi - \pi/4) = \frac{2P_4 - (P_{4max} + P_{4min})}{P_{4max} - P_{4min}} \quad (12)$$

B. MEMS Power Sensors

The MEMS power sensor consists of a capacitive power sensor and a thermoelectric power sensor. Two types of power sensors can improve the measurement range and enhance the overload capacity [17], [18]. In figure 3(a), a clamped-clamped beam is embed in the device as the actuator instead of cantilever beam. The reason for this design is that the former has a greater consistency than the latter during releasing process [19]. Through This cascading power sensor structure, the output power P3 and P4 can be converted to the change ΔC_i and DC output voltage V_i . The relationship can be expressed as

$$V_i = k_D P_i \quad (13)$$

$$\Delta C_i = k_C P_i \quad (14)$$

Where k_C and k_D are the sensitivities of the two power sensors, respectively. The ideal phase characteristic curve can be obtained.

$$\cos(\Delta\varphi \pm \pi/4) = \frac{2V_i - (V_{max} + V_{min})}{V_{max} - V_{min}} \quad (11)$$

$$\cos(\Delta\varphi \pm \pi/4) = \frac{2\Delta C_i - (\Delta C_{max} + \Delta C_{min})}{\Delta C_{max} - \Delta C_{min}} \quad (12)$$

Where V_{min} and V_{max} are the minimum and maximum values of test data V_i respectively; ΔC_{min} and ΔC_{max} are the minimum and maximum values of ΔC_i .

TABLE 1
RESPONSE TIME OF THE THERMOELECTRIC POWER SENSOR VERSUS DIFFERENT POWER LEVELS

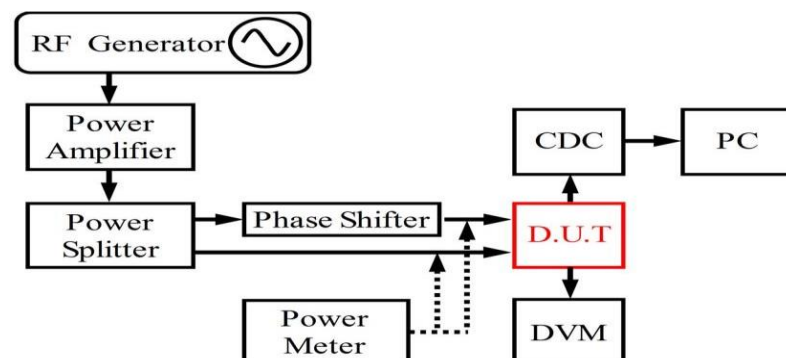
Power (W)	100	200	300	400	500
Time (us)	95	73	159	142	108

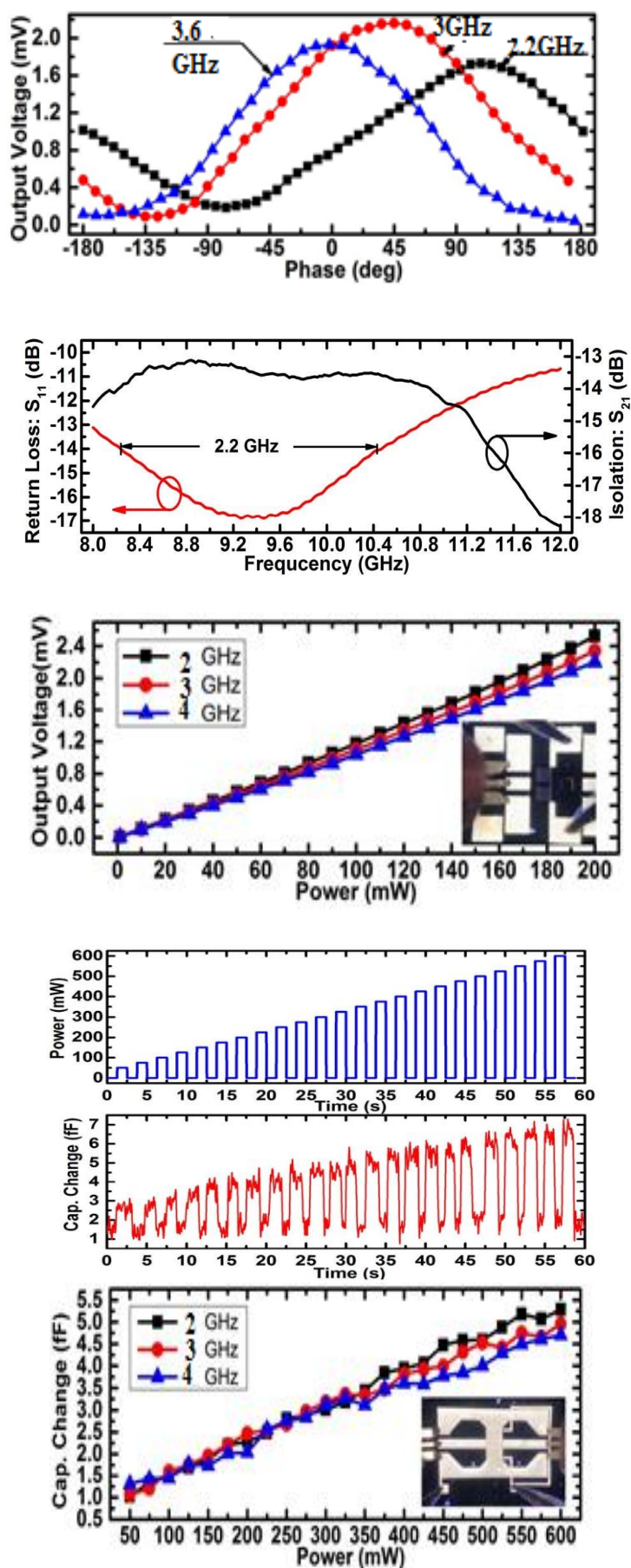
Power(w)	600	700	800	900	1000
Time (us)	91	166	98	125	183

TABLE 2

Size (mm ²)	Type	Waveband (GHz)	Phase range (degrees)
>650	SIW	12 – 16	-180~ +180
810	SIW	35 – 45	-180~ +180
645.2	MMIC	39 41	0 – 360
<225	MMIC	39 – 42	0 – 360
3283	PCB	1.2 – 2.8	-180~ +180
-	PCB	1.4– 2.95	-180~ +180
2.3	MEMS	02 – 3.1	0~180
2.38	MEMS	02 – 3.6	0~180
26.2(This work)	MEMS	02 – 04 (<-10db); 3.9 – 4.0 (<-14 db)	-180 ~+180

Measurement of MEMS sensor Unit:





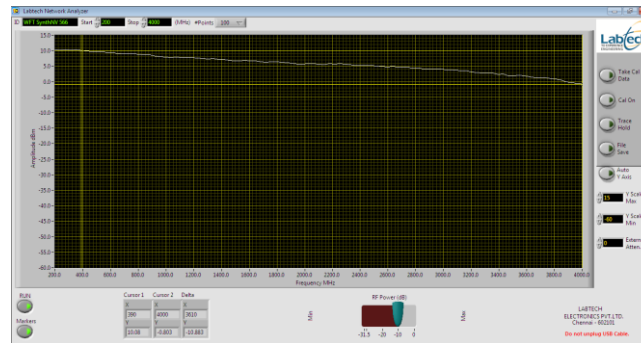


Figure. 3. Insertion loss

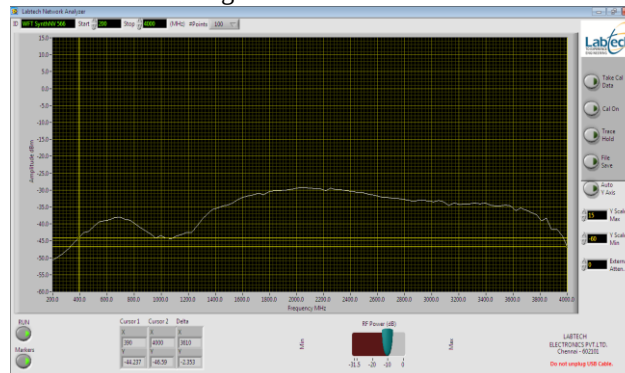


Figure. 5. Directivity

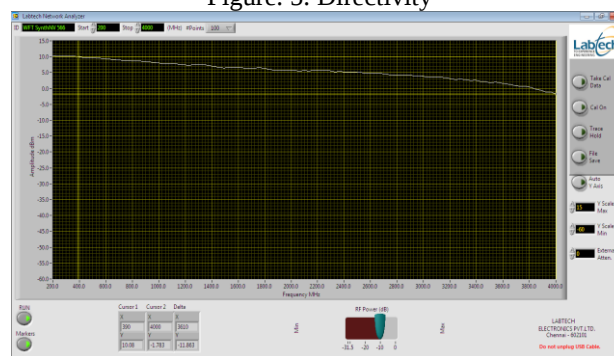


Figure. 4. Isolation

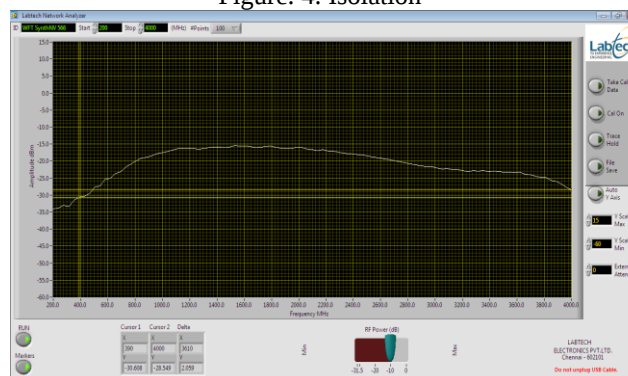


Figure. 6. Coupling

CONCLUSION

This paper proposes a four-port microwave phase detector at S-band, based on MEMS power sensors. It consists of four power divider/combiners, two phase shifters, two capacitive and two thermoelectric power sensors. Measured S-parameters indicate that the impedance of this device is well matched. Measured results of the phase shift fit well with the calculated results in one complete cycle, which proves the validity of four-port phase detector. Moreover, for the practical applications, the frequency response, dynamic range, phase sensitivity and response time are discussed and analyzed in detail. Experiments show that the response time of detector is in the order of milliseconds. By cascading

capacitive power sensors can effectively improve the overload capacity of system. This phase detector has potential applications in the radar systems and phase measuring equipment.

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