Sensors and Actuators A 201 (2013) 294–301

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

# Characterization of packaged inline-type radio frequency microelectromechanical systems power sensors

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ARTICLE INFO

*Article history:*
Received 3 February 2013
Received in revised form 4 July 2013
Accepted 22 July 2013
Available online 31 July 2013

*Keywords:*
Microelectromechanical systems (MEMS) membrane
Packaging
Phase noise
Response time
Temperature effect

ABSTRACT

This paper proposes the characterization of 8–10 GHz inline-type radio frequency microelectromechanical systems (RF MEMS) power sensors on the packaging-test-fixture for power self-detection systems in RF receivers and transmitters. The sensors are used to convert a certain percentage of the RF power coupled by a MEMS membrane into thermovoltages based on Seebeck effect. Two packaging methods are studied to evaluate the RF performance by the simulation and the measurement. The effects of the temperature from 5 °C to 75 °C on the packaged power sensors are quantified by the measurement of the output thermovoltages, which result in the 33.2% change in sensitivity at 10 GHz. After the packaging, rise and fall response times of <10 ms are obtained. In addition, measured mechanical resonance frequency ($f_{1st}$) of the MEMS membrane in the sensors is 78 kHz. Experiments show that the single-sideband phase noise of the packaged power sensors is as low as −122 dBc/Hz at the offset frequency $\Delta f$ = 500 kHz for an input RF signal of 100 mW and 9 GHz, and the sensors do not generate any significant phase noise in the interested RF range.



## 1. Introduction

Radio frequency microelectromechanical systems (RF MEMS) power sensors have the chance of becoming important elements in the next future communication systems. In order to embed into the systems, the low-loss packaging-test-fixture for the inline RF MEMS power sensors accomplished with the GaAs monolithic microwave integrated circuits (MMIC) technology has been reported, with good linearity and sensitivity [1]. Typically, the general principle to achieve inline RF MEMS power sensors is that a certain part of the transmitted RF power is extracted by some sensing agents and detected, e.g. an insertion power sensor [2], a capacitive power sensor [3], and coupling power sensors in our group [4], with the available RF signal during the power detection, but there is very little consideration of real applications. Currently, most of commercial power sensors are applied to microwave power meters as detection components like self-heating power sensors [5–7] and indirectly-heating power sensors [8–10], but they are termination devices compared with the inline sensors and the input RF signal is completely dissipated after the detection.

In our previous works, the basic inline coupling RF MEMS power sensors based on sensing a certain percentage of the incident RF power coupled by the MEMS membrane were reported in [4]. In order to obtain the good RF performance and the wideband frequency response, the coupling power sensors with the improved structures by modifying the gap size of the CPW line and adding the metal–insulator–metal (MIM) capacitors were proposed [11]. Following that, the open-circuital transmission lines were used to achieve the compensating capacitance instead of the MIM capacitor for minimizing the effect of the fabrication tolerance on the capacitance [12]. On this basis, the work [13] presented the detection and non-detection function of the inline power sensor by employing the shunt capacitive MEMS switches in the coupling branches. To study the effects of the MEMS membrane on the RF performance of the sensors and especially the phase characteristics of the input RF signals during the inline power detection, the microwave lumped model with the attenuation and phase mechanisms for the inline power sensors was described [14]. Finally, the packaging method of the inline power sensors has been developed [1].

The packaged inline RF MEMS power sensors can appear between the antenna and the low-noise amplifier (LNA) in a receiver system instead of a conventional automatic gain control through the DC output controlling an attenuated/amplified preprocessor for maintaining the output stability of the receiver front-end, with the expanded linear dynamic range and the increased anti-burnout level. To achieve the application, the differences of RF performance between the two packaging methods (mounted on the metal base and on the substrate of the microstrip lines) are analyzed by the simulation and the measurement. Because these power sensors are based on the principle of the power–heat–voltage conversion, the effects of the temperature administered from 5 °C to 75 °C on the power handling are discussed to show the sensitivities.

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http://dx.doi.org/10.1016/j.sna.2013.07.025

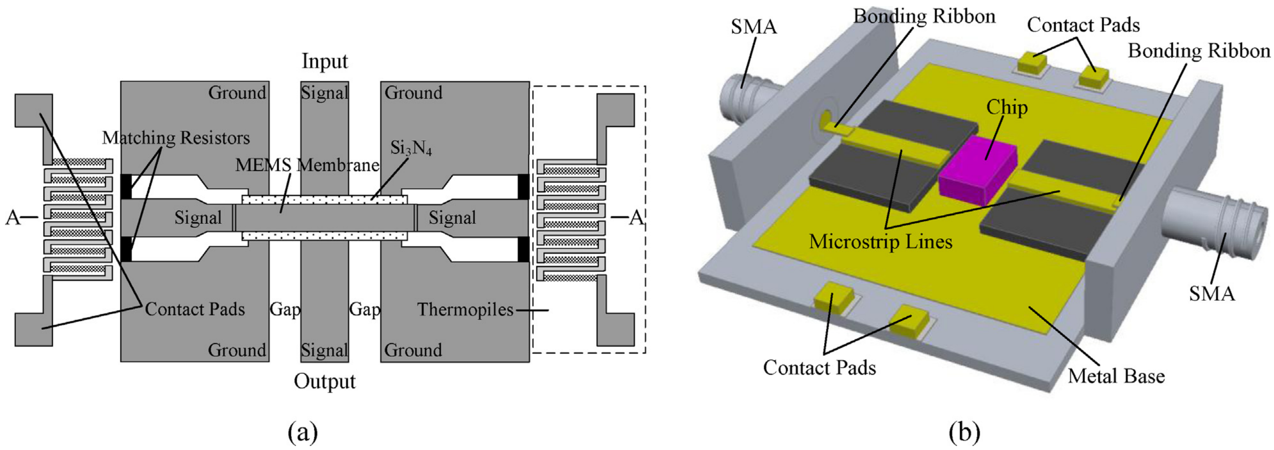


**Fig. 1.** Schematic views of (a) the inline RF MEMS power sensors and (b) the packaging-test-fixture.

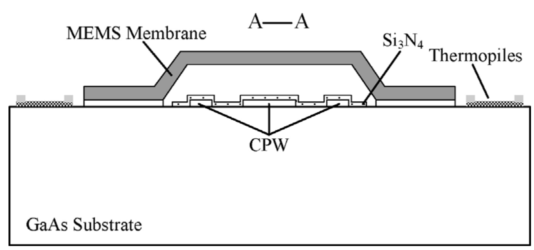


**Fig. 2.** Cross-sectional view of the on-chip power sensors along A–A direction.

In addition, these packaged power sensors suffer from ongoing challenges in terms of the effects of the response time and the phase noise on the entire receiver system. The phase noise in the packaged power sensors can degrade the receiver signal-to-noise ratio since these devices are located before the LNA. Recently, the modeling on RF MEMS switches has indicated that the MEMS membrane of the switches results in the phase noise [15,16]. This paper proposes an experimental study of the response time and phase noise to characterize the packaged inline RF MEMS power sensors.

## 2. Design and principle

Fig. 1 shows schematic views of the on-chip inline RF MEMS powers and the packaging-test-fixture. In Fig. 1(a), the principle of the power sensors consists of two steps [1,4,11–14]: (1) a certain percentage of the incident RF power is coupled from a CPW line where the RF signal is transmitted, into two inputs of the additional CPW lines by the MEMS membrane; (2) the coupled RF power is absorbed by the termination matching resistors at the end of the additional CPW and converted into heat and finally resulted in output thermovoltages by the thermopiles, based on Seebeck effect. It should be noted that this MEMS membrane is suspended above the CPW and its anchors are connected to the two additional CPW signal lines, as shown in Fig. 2. The RF MEMS power sensors were fabricated using the GaAs MMIC process. The thermopiles are composed of AuGeNi/Au and $n^+$ GaAs with a doping concentration of $1.0 \times 10^{18}\,cm^{-3}$. The spin-coated polyimide acts as the sacrificial layer of the MEMS membrane. The membrane is made of gold, with the thickness of 2 μm. The detailed fabrication of the on-chip power sensors has been reported in [11,17].

As shown in Fig. 1(b), in order to realize the application in real-life RF circuit systems, the 8–10 GHz packaging-test-fixture for inline RF MEMS power sensors is assembled by the transition of the power sensor, microstrip lines, and SMA. It mainly consists of five parts: a metal base, a chip area, two microstrip lines, two Sub-Miniature-A (SMA) connectors, and contact pads. The metal base is a supporting role of the test fixture. The chip area is used to place the RF MEMS power sensor. The microstrip lines are fabricated on the Rogers RT/Duroid 6002 substrate and responsible for transmitting the RF power inside or outside the power sensor, with impedance matching with the CPW-based ports in the power sensor. The SMA connectors are connected to the microstrip lines by bonding ribbons and keep the interconnecting with the outside world. The contact pads are used to output the thermovoltages of the power sensor. Despite rapid developments in chip scale packaging technology, bonding wires are still widely used because of their convenience and low cost. Therefore, the power sensor will be connected to the microstrip lines by gold bonding wires.

The fabrication steps of the packaged power sensors have been reported in [1]. In the fabrication, the ideal conductive adhesive layer is 50 μm in thickness and 0.0004 Ω cm in resistivity. Fig. 3

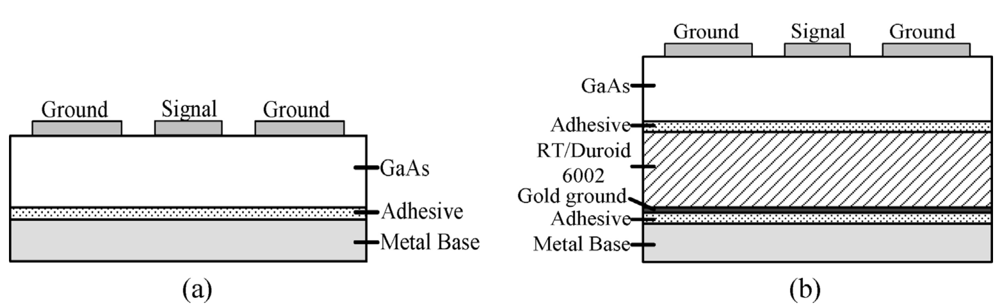


**Fig. 3.** Cross-sectional views of the power sensor mounted on (a) the metal base and (b) the substrate of the microstrip lines.