Capacitive rf power sensor based on MEMS technology

Luis J. Fernández, Eelke Visser, Javier Sesé, Remco Wiegerink, Henri Jansen, Jaap Flokstra and Miko Elwenspoek

MESA+ Research Institute, University of Twente, P.O. Box 217, 7500AE, Enschede,
The Netherlands, l.j.fernandez@el.utwente.nl

ABSTRACT

We present the theory, design, fabrication, and measurements of a novel power sensor for rf signals, based on capacitive detection. The novelty of this sensor is that it measures the force that is exerted by the rf signal on a grounded movable electrode. In this case a "through" sensor is realized, which means that the signal is available during the power detection.

1. INTRODUCTION

The existing technology for power detection for radio frequency (rf) signals is based on thermistors, thermocouples and diodes. These are terminating devices, i.e. the signal is dissipated during the power measurement. A completely different philosophy to realize power detection has been recently proposed, in a way that the signal is available during the measurement [1-3]. The power measurement is based on the movement detection of a grounded membrane suspended above a planar transmission line where the signal is traveling. This movement is measured capacitively. The first part of this paper explains the operation principle of the sensor. Then, the design and fabrication is shown. Finally the experiments on first prototypes are presented and compared to theory.

2. OPERATION PRINCIPLE

An rf signal that is transported on a transmission line with characteristic impedance Z_0 has a power level that is given by V^2_{rms}/Z_0, where V_{rms} is the rms voltage of the rf signal. When a capacitor is connected in parallel with the transmission line, an electrical force will appear between the capacitor plates: $F=C\,(V\cos\omega t)^2/(2d)$ where C is the capacitance and d is the distance between the capacitor plates. One of the plates is movable supported with spring constant k. For frequencies of the signal that are much higher than the resonance frequency of the movable plate, the plate is only sensitive to the rms value of the force, that is proportional to the power level: $F=CV^2_{rms}/(2d)$. Therefore, the power level can be deduced by detecting the movement of the plate. In practice the movement is detected as a capacitance change between a measuring electrode and the movable plate.

The addition of the capacitor will change the impedance of the transmission line and hence reflection losses are introduced. The reflection parameter is given by $S_{11}=10\cdot\log(|\Gamma|^2)$ where $\Gamma=(Z-Z_0)/(Z+Z_0)$ and $Z=Z_0 \,//\, 1/j\omega C$. The transmission parameter, $|T|^2=1-|\Gamma|^2$, assuming no conduction and dielectric losses, is given by $S_{12}=10\cdot\log(|T|^2)$. The minimum power that can be detected is primarily limited by the measuring electronics and ultimately by the thermo-mechanical noise of the membrane.

3. DESIGN AND FABRICATION

Figs. 1 and 2 show schematic drawings of a prototype of the power sensor.

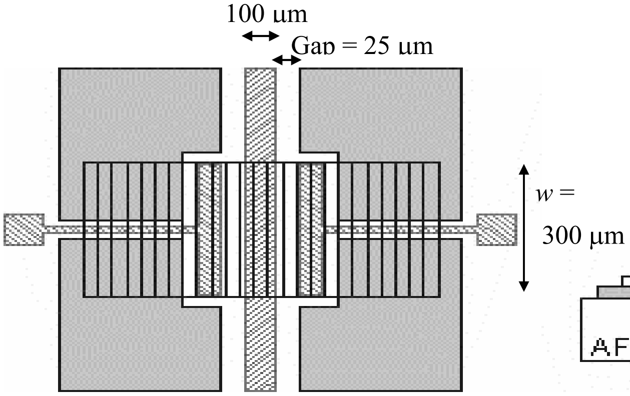

Fig. 1: Drawing of the sensor (top view).

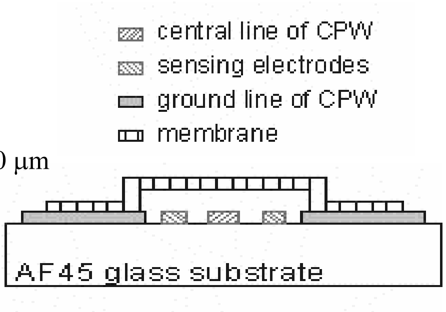

Fig. 2: Drawing of the sensor (cross section).

The rf signal is transported by a Coplanar Waveguide (CPW). At a certain position, an aluminum membrane is suspended above the central line of the CPW and connected to the ground planes, resulting in a grounded moving plate. In this way, a capacitor is created. Then, a force appears as mentioned in the previous section, and the membrane deflects. The deflection is measured by sensing the changes in capacitance between the membrane and the measuring electrodes placed next to the central line of the CPW. The width, *w*, was chosen to be 300 µm for all membranes. Three different lengths (*L*=200, 1800 and 3600 µm) were designed in order to test the response for different capacitance values.

The fabrication was done by aluminum surface micromachining. An AF45 glass substrate was used because of the low losses (≈0,001 dB/mm) for rf signals (ε_r=6.2, tanδ=$9 \cdot 10^{-4}$ at 1 MHz). The CPW lines were designed to have 50 Ω characteristic impedance. The CPW and measuring electrodes were fabricated by sputtering of a 3 µm thick aluminum layer. The membrane was made by sputtering of a 1 µm thick aluminum layer (h) and the gap was determined by 1.8 µm of photoresist. SEM pictures of the devices are presented in Figs. 3 and 4.

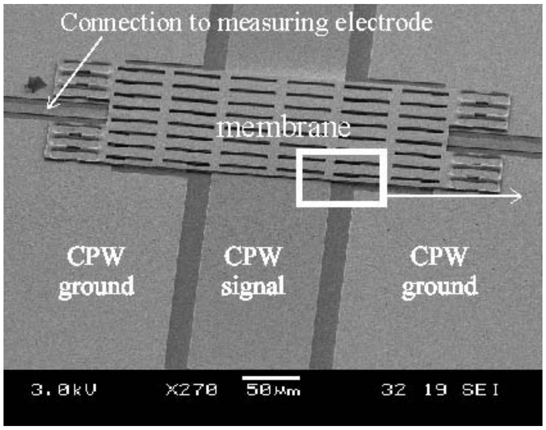

Fig. 3: SEM picture of the sensor (top view).

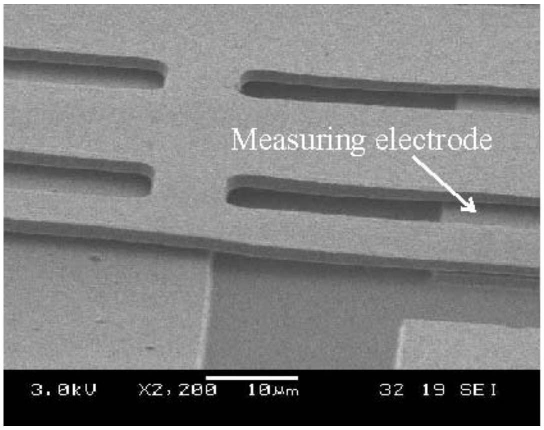

Fig. 4: SEM picture of the sensor (close-up).

4. EXPERIMENTS

The rf characterization consisted of the measurement of S-parameters with an HP 8510C Vector Network Analyzer and using a Cascade Microtech 9000 probe station.

Figure 5 shows reflection losses from a CPW with different membrane dimensions.

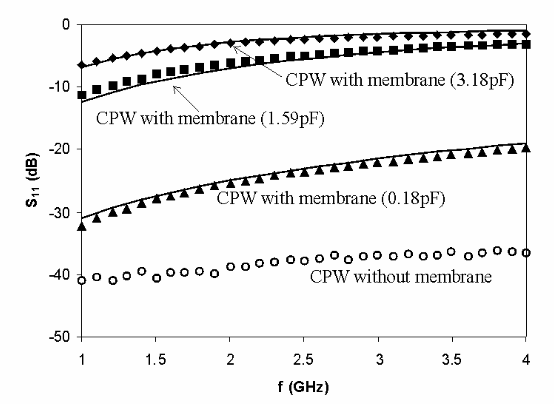

Fig. 5: S_{11} parameter measurements (symbols) and comparison with theory (lines).

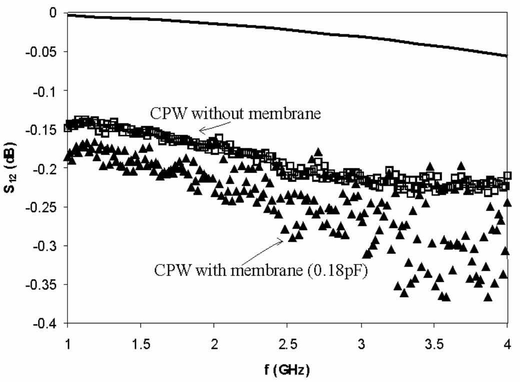

Fig. 6: S_{12} parameter measurements (symbols) and comparison with theory (line).

It shows good agreement between theory and experiments. For the theory, the change in characteristic impedance due to the added capacitance is considered without fitting parameters. Fig. 6 shows that the transmission losses are slightly higher than predicted. On the other hand, the difference between S_{12} for the sensor and for a bare CPW is much smaller. This indicates that the transmission losses due to the CPW itself are more important than the reflection losses from the membrane. In fact, the transmission losses are in good agreement with the CPW losses presented in [4]. Since the length of the CPW is 6 mm (more than needed for the sensor), better results could be achieved by using shorter transmission lines.

The first movement measurements were done by applying a dc voltage, V_{dc}, between the central line of the CPW and ground. Fig. 7 shows a measured quadratic relationship between the increase of C and V_{dc}. The electrical force is proportional to V_{dc}^2 and gives a linear displacement of the membrane. When we apply rf signals we are controlling the power, and a linear relation between capacitance change and rf power is then expected. This is confirmed by the measurements in Fig. 8. From this graph we can deduce the sensitivity factor of the hf power measurement: $dC/dW = 0.45$ fF/mW.

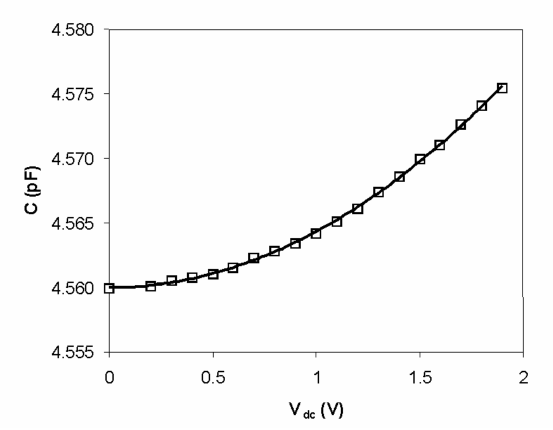

Fig. 7: Variation of capacitance between the measuring electrode and the membrane with applied dc voltage. The line is a quadratic fit.

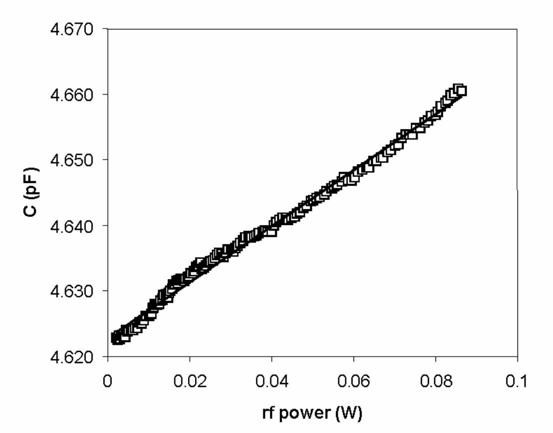

Fig. 8: Variation of capacitance between the measuring electrode and the membrane with applied rf power at 2.5 GHz.

5. CONCLUSIONS

We have presented a new capacitive rf power sensor based on MEMS technology. The sensor is based on a force detection that is proportional to the power and it does not dissipate the power of the signal, this being a main advantage compared to the existing technology for rf power sensors. Theory has been presented and compared to hf measurements. The first experiments are presented as a proof of the operation principle.

6. ACKNOWLEDGEMENTS

This work is part of the IST-2000-28261 EMMA programme of the European Commission. We wish to thank Tauno Vähä-Heikkilä, Jukka Kyynäräinen, Aarne Oja, Jussi Varis, Heikki Seppä and Anu Kärkkäinen from VTT for useful discussions.

7. REFERENCES

[1] Seppä H., Kyynäräinen J., Oja A.: “Microelectromechanical systems in electrical metrology”, IEEE Trans. Instrum. and Meas., Vol. 50 Issue: 2, pp 440-444, 2001.

[2] Tauno Vähä-Heikkilä, Jukka Kyynäräinen, Aarne Oja, Jussi Varis, and Heikki Seppä, “Capacitive MEMS power sensor”, MEMS WAVE Workshop, Crete, 2002.

[3] L.Fernández, J.Sesé, J.Flokstra, R. Wiegerink, "Capacitive MEMS application for high frequency power sensor", Micromechanics Europe, Sinaia, Rumania, October 6th-8th.

[4] H. Jansen, S. Pamidighantan, W. de Raedt, G. Beccarini, O. Dimonaco, D. Baert and H. Tilmans, “Micromachined devices for space telecom applications”, pp. 87-94, 3^{rd} round table on Micro/Nano-Technologies for Space, ESTEC, Noordwijk, The Netherlands, May 15-17, 2000.