Devices and Sensors Applicable to 5G System Implementations

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***Abstract*—This paper describes some of the device technologies currently in development at Analog Devices, focusing on key areas for future integration within the 5G ecosystem. Three distinct device technologies are examined that will enhance and enable system implementation and are for use in dedicated applications. The first is a state-of-the-art RF MEMs switch, the second, an Energy Harvester for IoT applications and the third, an RF SAW filter.**

Keywords—5G; IoT, RF MEMs; SAW; Energy Harvester

I. Introduction

With the advent of the Internet of Things (IoT) and the goal to enable the next generation mobile network, 5G, there have been advancements in both microelectronic circuits and device technologies to achieve this. This paper focuses on three device technologies and their components, ranging from RF/Microwave micro-electro-mechanical systems (MEMS) devices, to Energy harvesting for IoT sensors.

For this workshop paper on ADI developments, Section II will outline the RF MEMs switch device and the design requirements to achieve the desired RF focusing primarily on the device construction and the advancements in RF performance.

Section III will focus on the Energy Harvester for IoT applications. The Energy Harvester discussed is a Thermoelectric Energy Generator (TEG) device. Thermoelectric energy harvesters are devices that use small amounts of otherwise wasted energy (heat in this case) to generate usable electrical power. This power in turn is targeted towards industrial applications as part of a zero pin sensor initiative designed to generate enough power (~400μW) from a temperature drop of about 10°C to power a wireless sensor node. All of the power required by the sensor node is generated by mounting the node onto a heated surface (for example, pumps, motors, water heaters, pipes).

Section IV will investigate the RF Surface Acoustic Wave (SAW) filter developments [1]. These interdigital transducers (IDTs) will act as the RF passive MEMs filter targeting passive Wake-up applications.

II. RF MEMS Switch

A. Actice Open MEMs device

Presented at this workshop is a DC (0Hz) to over 26GHz (K-Band), ultra-long on lifetime single pole dual throw (SPDT) MEMS switch used with integrated driver circuitry. The switch exhibits 1dB of insertion loss and 23dB of off isolation at 26GHz.

The RF properties achievable by MEMS switch are very suitable for 5G as they are very linear devices, with low loss and high bandwidths that can deal with the power requirements. Key specifications which give ADI MEMS an advantage over other switching technologies for 5G are its Linearity with IIP3 of 69dBm and the power handling capability of >36dBm.

A three dimensional representation of the Active-Open MEMS Device [2] is shown in Fig. 1 along with corresponding SEM micrograph image of a fabricated device. Two gate electrodes are positioned at the back and front of the beam, which enable the beam to be closed and opened electrostatically by applying an appropriate voltage to the respective control electrode.

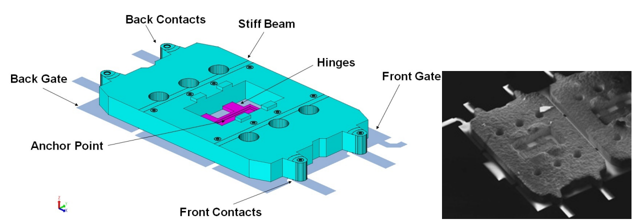

Fig. 1. Three dimensional model and SEM micrograph of the active open MEMS switch.

This MEMS switch die is constructed using a high resistivity silicon wafer, on which CMOS compatible interconnects including poly-silicon, aluminum, and tungsten are processed in a silicon-dioxide dielectric, to form the electrical interconnects to the switching device. The switch device is then micro-machined on top of this dielectric, using special non-stick contact metals and plated gold, which is subsequently released using a metal sacrificial layer. The switch device is then encapsulated in a silicon housing for protection, using wafer level seal glass capping. It represents an enhancement on the novel MEMS switch which has recently been commercialized, and was first reported at IMS 2015 [3]. The above flow was driven by both reliability, and compatibility with the wafer fabrication site.

B. RF Performance

Achieving an RF bandwidth of 26GHz in a plastic package, Fig. 2, required significant effort in minimizing wire bond inductance. The inductance of the wire bonds was reduced to ~300pH using multiple paralleled wire bonds, and configuring the package design to shorten the span of the wires as much as possible. A tuned matching capacitance was then created (~120fF) on the MEMS die which created a 50Ω match to the wire bond inductance, thus minimizing reflections and return loss. This matching capacitance value required is calculated using (1). The cut-off frequency of the LC resonator, created from the wire bonds and the matching capacitance at the bond pad, is calculated to be 26.48GHz, using (2).

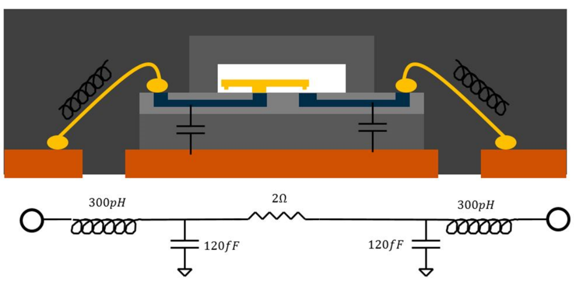

Fig. 2. Three dimensional model and SEM micrograph of the active open MEMS switch.

$$Z_0 = \sqrt{(L/C)} \quad (1)$$
$$F_{resonance} = 1/[2\pi\sqrt{(LC)}] \quad (2)$$

The isolation specification of the device is dominated by the input to output capacitance of the switch, which is made up of three primary components at the switch level; the capacitance from the tip to the drain contact, the capacitance from the beam to the drain region, and the capacitance from the source region to the drain through the substrate. Significant effort was made to minimize all these capacitances, with a level of less than 5fF being achieved.

Equation (3) can be used to calculate the resistive reactance (Xc) of a capacitor at a given frequency where f is the frequency of interest, and C is the off state capacitance of the switch. Equation (4) can be used to calculate the transmission coefficient (off-isolation) through the device dependent on the reactance [4], and the characteristic impedance of the system

$$X_C = 1/(2\pi fC) \quad (3)$$
$$S_{21} = -20\log_{10}(1+ X_C/2Z_0) \quad (4)$$

Fig. 3 shows a plot of expected off isolation versus frequency for various capacitances, representing the coupling capacitances through the switch. It can be seen that a capacitance of less than 4fF is required to generate an isolation of approximately 25dB at 26GHz.

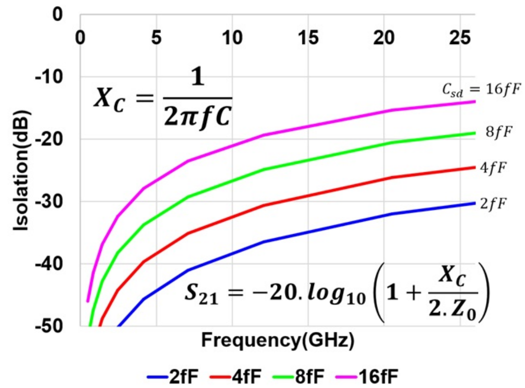

Fig. 3. Off isolation as a function of Csd (source to drain capacitance).

III. THERMOELECTRIC ENERGY GENERATOR

Thermoelectric energy harvesting devices enable self-powered systems for IoT applications bringing sensors to places previously thought impractical or inaccessible. They also reduce operating expense and maintenance cost of battery replacement. The device in focus here converts waste heat into electrical energy through the Seebeck effect, Fig. 4.

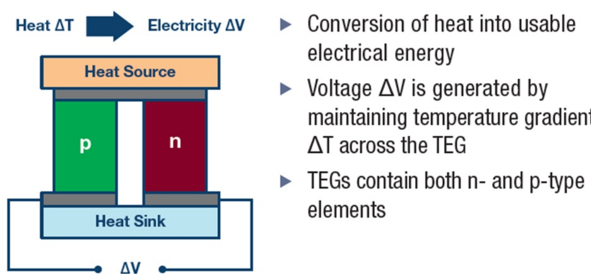

Fig. 4. Conversion of waste heat to energy using thermoelectric effect.

Analog devices chipscale thermoelectric energy harvesting devices have significant advantages compared to discrete devices

- Small device area (10mm2)
- Low-cost
- Microfabrication: Hundreds to thousands of TE legs
- High device thermal resistance: Optimize ΔT captured
- High output voltage: Maximize efficiency of power management

The current technology demonstrator combines low power sensors, power management and radio module with the thermoelectric energy harvesters for machine health monitoring. The system is mounted in a housing which combines the thermal contact to the heat source and the heat sink, Fig. 5.

A typical task sequence for IoT node using thermoelectric energy harvesting as a power source is shown in Fig.6. Power consumption can be optimised by component and also by data transmission rates and transmission modes.

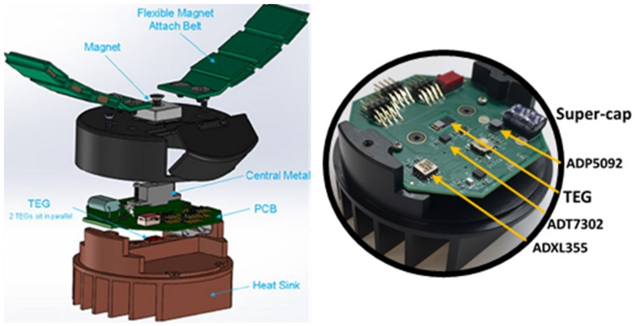

Fig. 5. Wireless sensor node demonstrator for machine health.

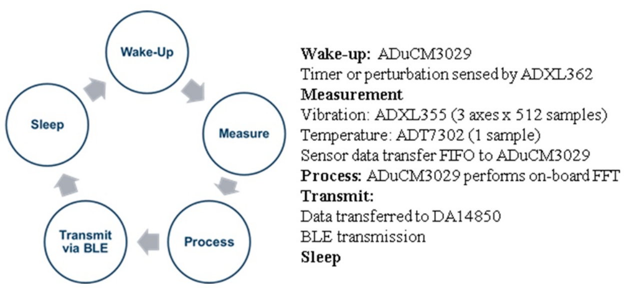

Fig. 6. Task sequence example for IoT node.

Energy harvesting is critical as an alternative power source for systems within the Internet of Things. Combining the use of waste heat, low power sensors and efficient power management solutions enables the proliferation of sensor nodes for IoT.

IV. RF SAW FILTER

The RF SAW filter investigated here is to target use in a Passive RF Wake-up system such as in Pacemaker telemetry in the healthcare industry. The wake-up system can also be integrated/co-packaged with wireless transceiver/sensors systems. The system concept will maximize the Pacemaker battery lifetime via the reduction in power consumption compared to a duty-cycle based wake-up system, Fig. 7.

The low power and RF performance are key differentiators while an RF Energy Harvester provides power to the receiver. The MEMS RF Filter being developed will set the Receiver's Selectivity. The product will require a highly selective passive filter with 1-2dB Insertion Loss and low temperature co-efficient. The RF SAW filter will therefore require High Q, low insertion loss resonators, which would be an advancement on RF MEMS filter technologies, similar to what was targeted and achieved as demonstrated in [5] shown in Fig. 8.

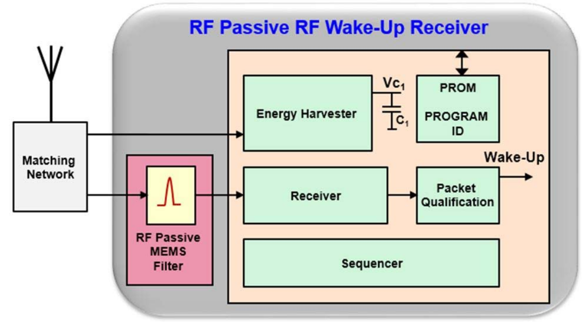

Fig. 7. RF Passice Wake-Up circuit Product Concept.

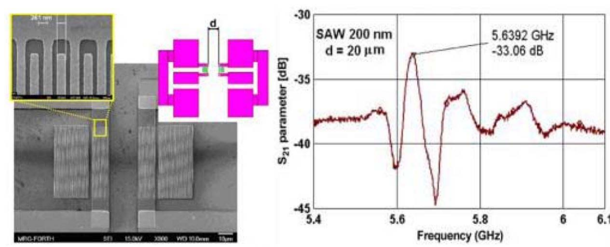

Fig. 8. SEM images and transmission response of a SAW filter, with 200 nm spacing (λ = 0.8 μm), and a 5.6 GHz resonance frequency [5]

CONCLUISION

This workshop paper outlines three device technologies in development for implementation into the 5G ecosystem and expansive Internet of Things. A RF MEMs switch design was discussed, with supporting measurement data, exhibiting excellent RF performance with only 1dB of insertion loss at 26GHz. A Thermoelectric Energy Harvester for IoT applications was introduced along with applications including machine health monitoring. Finally, RF SAW Filter designs and applications were introduced along with the challenges and limitations in present technologies.

REFERENCES

[1] Liu Bo et al ; "Surface acoustic wave devices for sensor applications", Journal of Semiconductors, vol. 37, issue 2, 2016.

[2] Carty E., Fitzgerald P., McDaid P., Stenson B, Goggin R.; "Development of a DC to K-band ultra long on-life RF MEMS switch with integrated driver circuitry," Microwave Conference, 2016. 46th European , 4-6 Oct. 2016.

[3] Goggin, R.; Fitzgerald, P.; Stenson, B.; Carty, E.; McDaid, P.; "Commercialization of a Reliable RF MEMS Switch with Integrated Driver Circuitry in a Miniature QFN Package for RF Instrumentation Applications," Microwave Symposium (IMS), IEEE MTT-S International, 17 - 22 May. 2015.

[4] Cory R.; Fryklund D.; "Solid State RF/Microwave Switch Technology: Part 2", Microwave Product Digest, pp 34, June 2009.

[5] A. Müller et al., "SAW devices manufactured on GaN/Si for frequencies beyond 5 GHz," IEEE Electron Device Lett., vol. 31, no. 12,pp. 1398–1400, Dec.2010.