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Wireless Temperature Sensing using a Passive RFID Tag with Film Bulk Acoustic Resonator

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Abstract—**The lifetime of active RFID tag is limited by the equipped battery capacity. A passive RFID tag which gathers power via inductive coupling from RF power for temperature sensing was proposed to extend the lifetime of the tag. An oscillator with film bulk acoustic resonator (FBAR) lies at the heart of the tag. A four-layered FBAR with Al/AlN/SiN_X/Au composite structure was fabricated. The oscillation frequency of the oscillator varies with the temperature linearly. The temperature can be detected easily by measuring the shift of oscillation frequency. The measured phase noise of the oscillator is -75dBc/Hz at 10 kHz offset. A linear temperature sensitivity of -34.5 ppm/^{o}C in the temperature range from 10 and 80^{o}C at 2.48 GHz is achieved.**

Keywords-RFID; Temperature Sensing; FBAR; AlN

I. INTRODUCTION

Temperature sensing during a certain time is needed in scientific, medical and industrial applications. The network can be constructed with wired sensor nodes for power and data transmission. The cable and the maintenance costs dominate the system cost. In some dangerous environments, the temperature should be sensed wirelessly. This means that the energy needed for the temperature sensor has been provided by the equipped battery or the reader. The lifetime of active RFID tags is limited by the battery capacity. Passive RFID tags recover the inductive RF power for internal circuits' power consumptions. They have a long life and do not need maintenance. A passive RFID tag integrated a temperature sensor will fulfill the requirement.

Acoustic wave devices have been widely used in various commercial applications, among which surface acoustic wave devices (SAW) and FBAR devices are rapidly growing in personal communication. Sensing applications are also increasing because of higher sensitivity and reliability than others. Mass sensors, temperature sensors, gas sensors, chemical sensors, humidity sensors, pressure sensors and bio sensors utilizing acoustic wave devices have been reported. [1–6] Here, the focus is on the temperature sensing by using FBAR resonators.

II. ARCHITECTURE FOR RFID TAG

The block diagram of the proposed passive RFID tag is shown in Figure 1. The passive RFID tag consists of a LC tank, a RF-to-DC converter, a voltage regulator, a power oscillator with FBAR, and an UHF antenna.

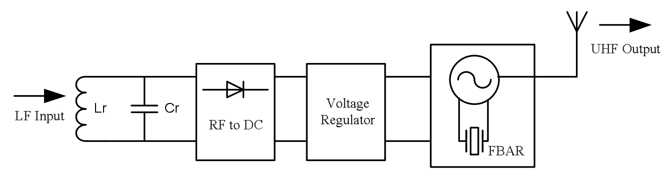

Figure1. Block diagram for the proposed RFID tag.

125 kHz is chosen as the frequency for powering the RFID tag. It is heavily used below 135 kHz because it is not reserved as an ISM frequency range. This frequency range allows reaching large ranges with low cost tags. Miniaturized tag formats can be achieved by use of ferrite coils in tags. Low absorption rate or high penetration depth in nonmetallic materials and water are available due to lower frequencies.

The voltage regulator stabilizes the DC power generated by RF-to-DC converter and supplies the power consumption of the oscillator with FBAR. The resonance frequency of FBAR will vary with the environment temperature. Using this resonator, an oscillator at 2.48GHz unlicensed ISM band was constructed for temperature sensing. The oscillator is design as a power oscillator structure to avoid the requirement of extra RF power amplifier. The resonance frequency of power oscillator is transmitted via the UHF antenna. We can easily sense the temperature variation with a frequency counter and the FBAR oscillator.

III. FRONT END CIRCUITS FOR RFID TAG

The RFID interrogator transfers the energy to the tag by sending a LF wave through the LC tank. Lr and Cr form the LC tank with resonance frequency f_0 and quality factor Q as:

$$f_0 = \frac{1}{2\pi\sqrt{Lr \cdot Cr}} \tag{1}$$

$$Q = \frac{R_L}{2\pi f_0 Lr} = 2\pi f_0 R_L Cr \qquad (2)$$

Where R_L is the equivalent load resistance of coil Lr. The voltage of coupled LF power at the input of the RF-to-DC circuit is proportional to the quality factor Q. Due to the large variation of the distance to the LC tank, the tag has to operate over more than three orders of magnitude of field strength. This means that the induced voltage at 125 kHz can reach several hundred volts. The inductance of Lr is about 4mH in this work and the quality factor is about 40 to insure the power supply of the tag. The capacitance of the resonance capacitor is about 330pF to keep the resonance frequency of LC tank is 125 kHz. Because of the high voltage at the end of LC tank, the resonance capacitor is constructed with Cu-FR4-Cu structure to avoid the high voltage breakdown of resonance capacitor. The thickness of Cu is 3oz and the thickness of FR4 is 0.2mm. The resonance is shown as Figure 2.

The RF-to-DC converter consists of a 4 diodes full-bridge rectifier and a storage capacitor. It generates a dc voltage from RF signal inductively coupling by the LC tank and charges up the large storage capacitor. The heart of the voltage regulator is the zener diode. Because the induced voltage is up to hundred volts, the voltage regulator is used to stabilize the DC voltage and avoid the electric overstress of the other circuits. The UHF antenna is shown in Figure 3. The antenna is developed with capacitor-plate structure. The central frequency of the antenna is about 2.5GHz.

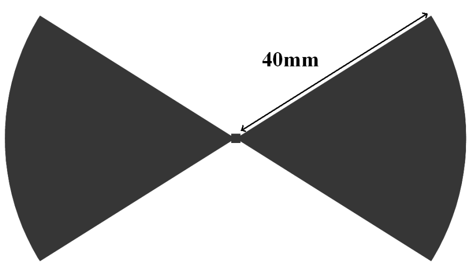

Figure 2. Layout Pattern for Resonance Capacitor

Figure 3. Layout Pattern for UHF antenna

IV. Film Bulk Acoustic Resonator

The FBAR device is an Al/AlN/SiN_X/Au structure with the top and bottom electrodes of aluminum and gold sandwiching a middle layer of oriented piezoelectric aluminum nitride. An air interface is used on both outer surfaces to provide high-Q reflectors at all frequency. When RF signals are applied near the mechanical resonant frequency the piezoelectric transducer excites the fundamental bulk compress wave traveling perpendicular to the films [7].

The picture of FBAR is shown in Figure 4. The size of the resonator is 70x70um. Figure 5 shows the device geometry for the FBAR.

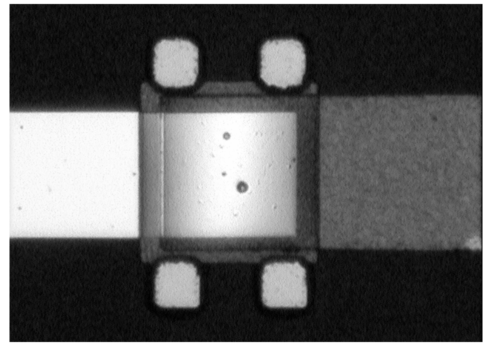

Figure 4. The die photo of the FBAR

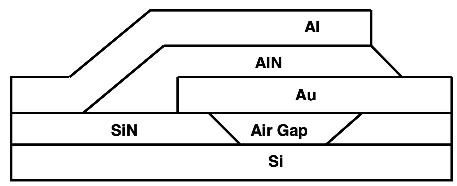

Figure 5. The configuration of FBAR

The Modified Butterworth VanDyke (MBVD) equivalent circuit model is shown in Figure 6. The typical values for the FBAR, to be described below, at 2.5GHz are; Lm = 143 nH, Cm = 29 fF, Rm = 1 Ohm, C0 = 2 pF, R0 = 1 Ohm and Rs = 1 Ohm.

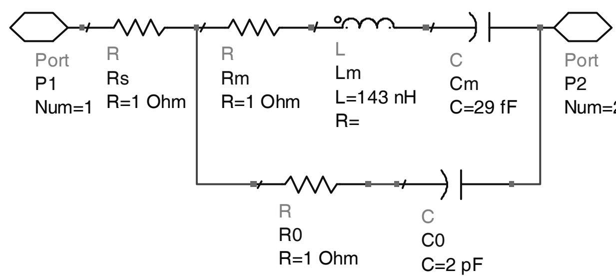

Figure 6. MBVD equivalent circuit model of the resonator

V. Oscillator with FBAR

With the success of FBAR, an oscillator was designed and fabricated. Its functional block is illustrated in Figure 7. The architecture with FBAR forms a feedback loop. It consists of a single loop amplifier, a Wilkinson power splitter, a phase adjusting, and a FBAR resonator. The HBT monolithic amplifier is selected as the loop amplifier because of low noise figure and high dynamic range. The P1dB is at +17dBm and the bandwidth is 4GHz. Its bandwidth was properly selected to prevent high 2^{nd} harmonics. The nominal gain of 17dB is much greater than that required to overcome the total loop losses to insure the stable oscillation. The magnitude of gain variation over temperature is approximately 0.005dB/°C and this feature can prevent the temperature variation of oscillator. The power divider and phase shift were made of lumped elements. The resonator acts as a short circuit with zero phase-shift at the desired frequency. The oscillation occurs as the closed loop gain satisfies Barkhausen's criteria. During design phase, the open loop gain is actually evaluated by breaking the loop at the appropriate plane with equal input and output impedance, such as line AB noted in Figure 7. The oscillation starts when the phase of S21 equal to zero and |S21|> 1, which in turn implies the equivalent resistance is negative. The Barkhausen's criteria are satisfied simultaneously. The linear simulation is performed by using Agilent Advance Design System (ADS) software. The linear simulation results are shown in Figure 8.

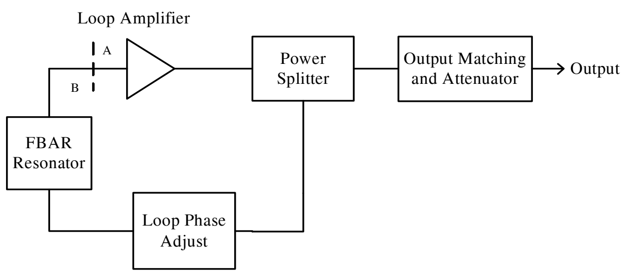

Figure 7. Block diagram of a feedback loop oscillator.

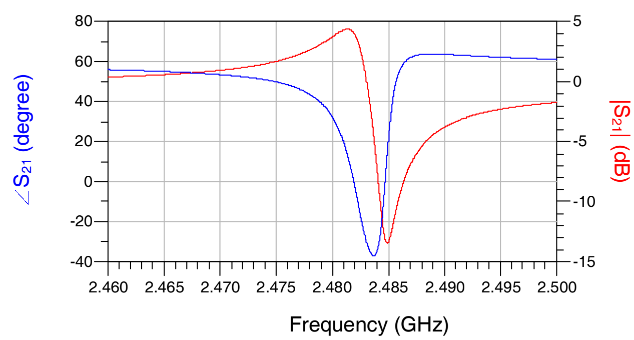

Figure 8. Linear Simulation Results using Agilent ADS

VI. MEASUREMENT RESULTS AND DISCUSSION

The harmonics oscillation spectrum was measured and shown in Figure 9. The 2nd harmonics is about -40dBc. This feature makes the fundamental frequency variation with temperature be detected by frequency counter easily. The oscillation frequency is slightly lower than the series resonance frequency *fp* because of the parasitic capacitance of package effect. The measured phase noise of the oscillator was shown in Figure 10. The phase noise of the oscillator is about -75dBc/Hz at 10kHz offset. The variation of fundamental frequency with temperature was also measured and shown in Figure 11. The temperature coefficient of oscillator is about -34.5ppm/°C and seems to be equal to that of FBAR. It implies that the effective tank of the oscillator is dominated by the FBAR resonator. This feature fulfill the requirement for temperature sensor.

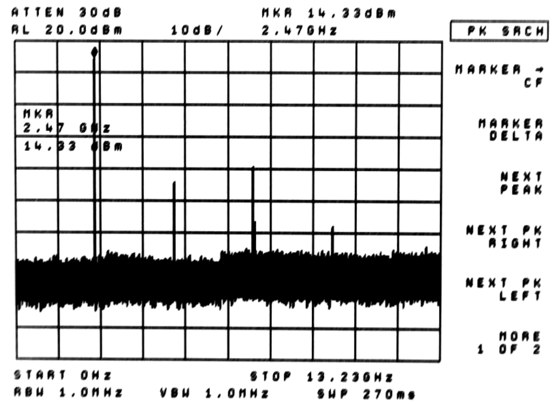

Figure 9. Harmonic Spectrum of the oscillator with FBAR.

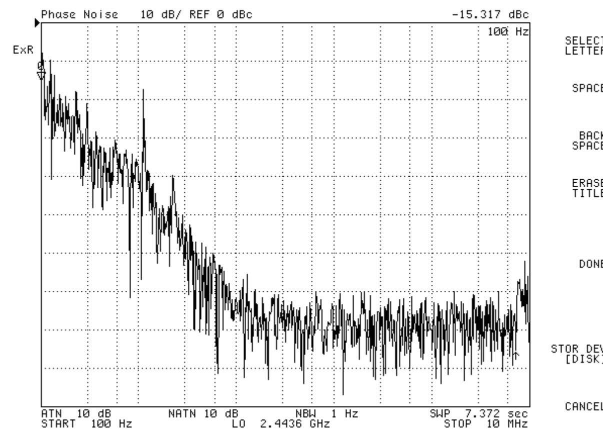

Figure 10. Measured Phase Noise of the Oscillator with FBAR

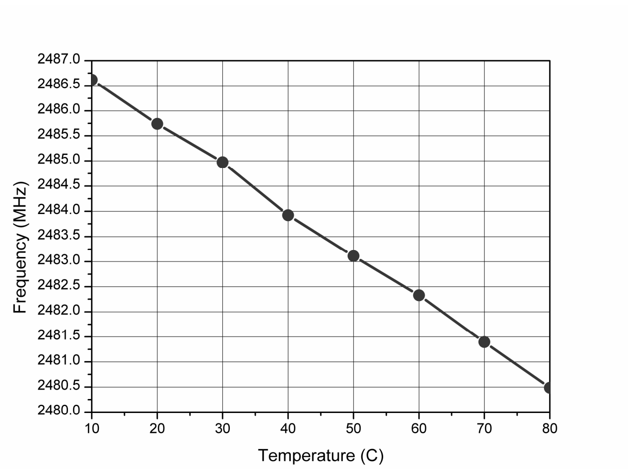

Figure 11. The Fundamental Oscillation Frequency Variation vs. Environment Temperature.

VII. CONCLUSION

An Al/AlN/SiN_X/Au film bulk acoustic resonator with membrane structure was applied in this passive RFID tag for temperature sensing. The RF to DC converter recovers the inductive RF energy to DC power. The voltage regulator stabilizes the DC power and supplies the power consumption of the oscillator with FBAR. The resonance frequency of FBAR will vary with the environment temperature. Using this resonator, an oscillator at 2.48GHz unlicensed ISM band was constructed. The oscillator is design as a power oscillator. In this structure, the RF power amplifier is not needed. The fabricated and characterized temperature sensor has a sensitivity of -34.5ppm/^{o}C in the temperature range from 10 to 80^{o}C. We can easily sense the temperature variation with a frequency counter and the FBAR oscillator.

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