Wireless, remotely powered telemetry in 0.25μm CMOS

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Abstract — **This new architecture for wireless power and data telemetry recovers power and system clock from a weak incident RF signal. An efficient RF-DC converter rectifies and multiplies the received signal generating a practical DC voltage, far higher than the incident RF signal amplitude, increasing the range between the base station and the transponder. An injection locked LC oscillator recovers a system clock from the incident signal. Super-harmonic or sub-harmonic locking facilitates the separation of the incident and telemetry frequency without the need for a PLL. Experimental data from a 900MHz transponder and a remotely powered 2.3GHz wireless temperature sensor are presented. Both prototypes implemented in 0.25μm CMOS occupy less that 1mm^2.**

Index Terms — **Continuous wave modulation, injection locked oscillator, low-power oscillators, power telemetry, RFID transponder, temperature sensor.**

I. INTRODUCTION

Wireless, batteryless, systems and sensors have application in biomedical systems [1], smart card readers [2], RFID, and environmental monitoring. Wireless transmission of power eliminates the battery, making the system far smaller, more reliable and lower cost. We describe new techniques for fully integrated, efficient, remotely powered telemetry. Two fully integrated prototypes, implemented in 0.25μm CMOS are presented.

The key contributions of this work include techniques for more efficient extraction of power and recovery of reference clock from the incident RF signal. The use of higher RF frequencies (i.e. GHz rather than 10s of MHz) for both power transmission and telemetry, allows antenna size to be reduced – in most systems the antenna dominates the overall size. Power consumption is minimized through power management and through the use of power efficient biasing, clock generation, modulation circuitry and class AB output power amplifier.

A block diagram of a conventional telemetry system is given in Fig. 1. Both the system clock and system power are extracted from the incident RF signal. The system clock is modulated and fed to the power amplifier to be transmitted [3].

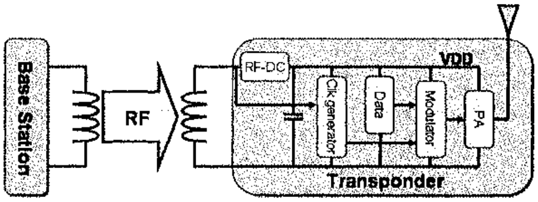


Fig.1. The Block diagram of conventional active telemetry

A full-wave or a half-wave rectifier usually performs the RF to DC conversion. However, with this approach the amplitude of the received signal must be large enough to overcome the junction voltage of the diodes in the rectifier. Since the maximum power transmitted from a base station cannot exceed FCC regulations, the separation between the base station and the transponder is limited (often millimeters).

In most implementations, a Schmitt trigger circuit [4] recovers a system clock from the incident signal. Frequency multiplication and division methods, such as the use of a PLL, are employed to separate the output carrier frequency from the incident RF frequency. These circuits are complex and consume additional power. In practice, the power consumption of the Schmitt trigger limits the maximum frequency to 10s of MHz. Furthermore, Schmitt trigger based clock recovery is prone to phase noise and jitter, especially for low amplitude incident signals, limiting range.

We propose a new RF-DC conversion method, which generates a useful DC voltage even with very small incident signal amplitude. It is composed of a series of clockless voltage multipliers and can operate under very low input signal levels. Furthermore, we propose a new clock recovery technique, based on an injection locked LC oscillator. Very low power, low phase noise and phase jitter clock recovery is achieved even with very small input signal amplitudes.

Two prototype systems based on these building blocks are described. A remotely powered wireless temperature sensor transmits temperature information through FM modulation of a 2.3GHz carrier. A remotely powered transponder relays 8 bit information by continuous wave modulation of a 900MHz injection locked carrier.

II. OVERVIEW OF THE SYSTEM

A block diagram of the proposed system is given in Fig. 2. An RF-DC converter generates a DC voltage much higher than the peak amplitude of the incident RF signal and stores the energy on a large storage capacitor.

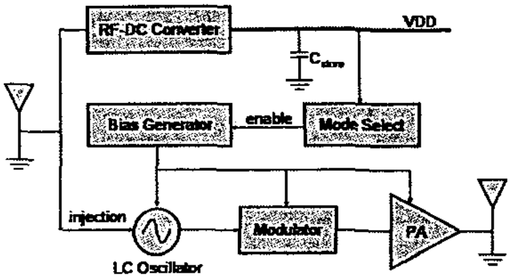


Fig.2. The block diagram of the proposed architecture

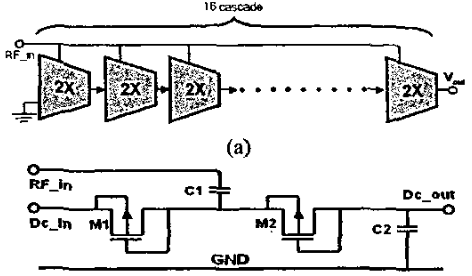
A mode-selector circuit detects when the capacitor voltage exceeds a threshold, powering up the bias circuitry. The full system continues to operate until the capacitor voltage drops below a lower threshold. At this point the telemetry circuit is powered down, allowing the capacitor to recharge. Given a sufficiently high received power level, the telemetry circuit can operate continuously.

Unlike more conventional RF powered systems, this telemetry IC accumulates energy in standby mode, increasing the range from base and reducing required base transmission power. A key feature of this approach is that there is no on-chip supply regulation. This saves power and chip area. Simple regulators such as source followers are inefficient and also rely on a relatively accurate reference voltage from a zener or bandgap reference. Instead, by tolerating large swings in supply voltage we can efficiently discharge and utilize the power stored on the capacitor.

An on-chip LC oscillator generates the system clock by injection locking. The LC oscillator locks onto an integer multiple (or fraction) of the incident RF signal. A fully integrated low power modulator and a power amplifier (PA) are used to modulate the transmit data.

A. RF-DC Converter

A Dickson [4] multiplier circuit with multiple stages is used to generate a DC voltage higher than the peak signal amplitude at the receiving port. A block diagram and the schematic details of one stage are given in Fig. 3. We chose a Dickson multiplier over a clocked voltage doubler circuit, since the latter needs a fast clock and consumes clock power during switching. We use zero V_T transistors as diodes in order to minimize the voltage drop. The minimum voltage swing required for operation is only $100mV_{peak}$. With a $150mV_{peak}$ input signal, a conversion efficiency of more than 80% is achieved. A cascade of 16 stages is used to generate and store 2.5V on the storage capacitor to power the system.



(a)

(b)

Fig.3. (a) Block diagram, (b) detail of the voltage multiplier

B. System Clock Generation

Conventionally, Schmitt triggers have been used to extract a system clock from the incident radiation. However, these can be very power hungry at high frequencies and are prone to jitter. As an alternative, we employ injection locking [5] of an LC oscillator to the incident RF signal. Injection locking is far more efficient and delivers a recovered clock with very low phase noise and phase jitter. Injection locking also makes it possible to efficiently generate a clock signal that is an integer multiple (or integer fraction) of the RF power signal frequency without the complexity, area and power consumption of a PLL. This allows the received and transmitted signal frequencies to be separated with no extra power dissipation.

The low power LC oscillator, as shown in Fig. 4, lies at the heart of the injection locking scheme. For low voltage operation, the oscillator uses only NMOS cross couple devices (M1, M2).

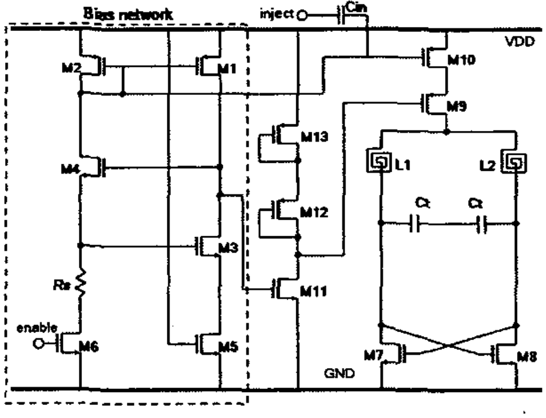


Fig.4. Schematics of the LC-oscillator and the bias network

The oscillator is operated in current limited mode [6] to minimize power dissipation. To minimize power consumption, we achieve maximum effective tank resistance, by maximizing inductance. The received RF carrier is capacitively coupled to the tail of the oscillator to achieve injection locking. With this technique, the 900MHz circuit successfully locks to 450MHz (sub-harmonic), 900MHz, and 1.8GHz (super-harmonic) inputs.

The bias circuit (also in Fig. 4) is designed to minimize the supply sensitivity of the oscillator. For a free running oscillator (no injection lock) the measured oscillation frequency varies by 70 KHz over a supply voltage variation from 1.5V to 2.5V, giving an oscillation frequency supply sensitivity of only 70ppm/V. An enable signal is generated by the mode-selector discussed in the next subsection.

C. Mode Selector

The mode selector circuit, as shown in Fig. 5, decides whether the device is in standby mode (i.e. charging) or operating normally. In the standby mode, the system waits for the capacitor to charge and dissipates very little current. The time required to charge the capacitor depends on the power received. During this phase it is essential that the current dissipation low. In the standby mode, the system dissipates only 5μA.

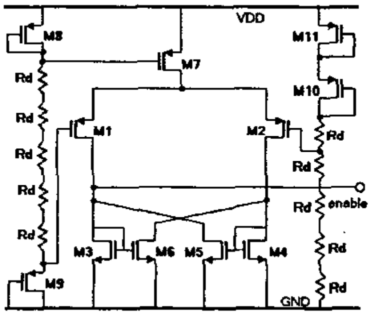


Fig.5. Schematic of the mode-selector

The system is enabled by the mode-selector circuit when the voltage stored on the storage capacitor exceeds 2.5V. When enabled, the system draws current from the capacitor, discharging it. The system is again put back in the standby mode, dissipating very little current when the voltage on the storage capacitor drops below 1.5V.

III. PROTOTYPES

A 900 MHz long range data telemetry device and a 2.3GHz wireless temperature sensor are designed using the circuit blocks mentioned. Both systems are fabricated in TSMC 0.25μm CMOS process through the MEP program. The die micro-photograph showing both systems is given in Fig. 6.

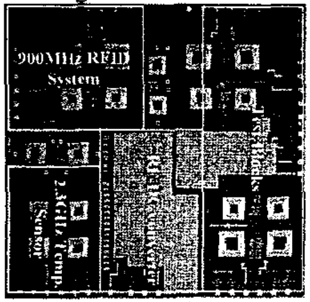


Fig.6. Die microphotograph

A. 900 MHz Wireless Data Telemetry Device

A long range, low power RFID transponder is designed using the techniques described above. Fig. 2 is a block diagram of this system. The 900 MHz LC oscillator locks onto the first sub-harmonic signal at 450 MHz. The locking range was measured to be 20 MHz with 150mV$_{peak}$ input signal amplitude (Fig. 7).

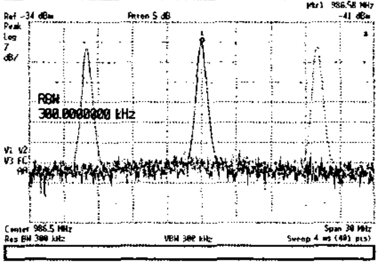


Fig.7. 900 MHz oscillator locked at 3 extremes

When locked to the sub-harmonic, the phase noise of the system is measured as -102dBc/Hz at 100kHz offset achieving a figure of merit (FOM) [7] of 185dBc/Hz.

The functionality of the voltage sensor is verified by sweeping the VDD line from 0V to 2.6V, as shown in Fig. 8. Both devices employ the same RF-DC converters and mode-selectors.

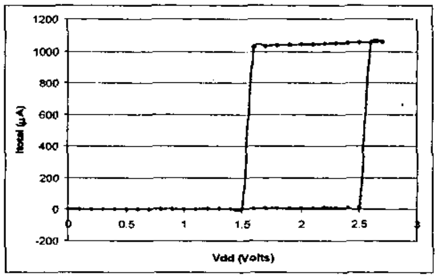
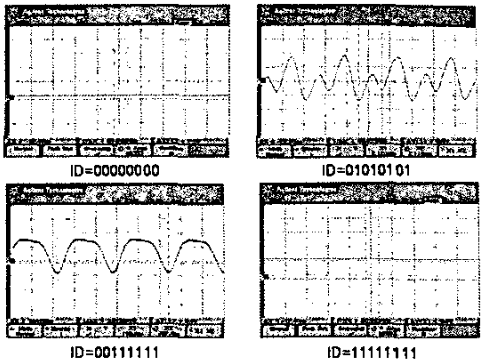


Fig.8. Test results of the mode-selector

The device was tested by transmitting an externally programmed, 8 bit ID word on a continuous wave modulated 900MHz carrier. The received demodulated data for four different words is given in Fig. 9.


ID=00000000 ID=01010101

ID=00111111 ID=11111111

Fig.9. Demodulated output for four ID inputs

B. 2.3GHz Wireless Temperature Sensor

A low power long range wireless temperature sensor, as shown in Fig. 9, transmitting data at 2.3GHz is built using the same RF-DC conversion technique. A block diagram of the system is given in Fig. 10.

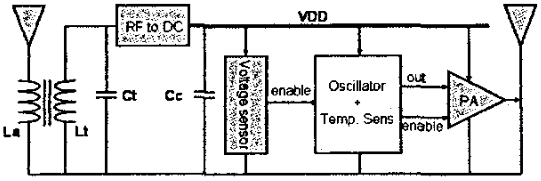


Fig.10. Block diagram of the 2.3GHz temperature sensor

The temperature data is transmitted as a shift in the output frequency of a free running LC oscillator. The tank capacitance is modulated with varactors, whose control voltage is connected to a PTAT voltage source. The measured temperature sensitivity is 126ppm/°C with a linearity of 0.983, as shown in Fig. 11.

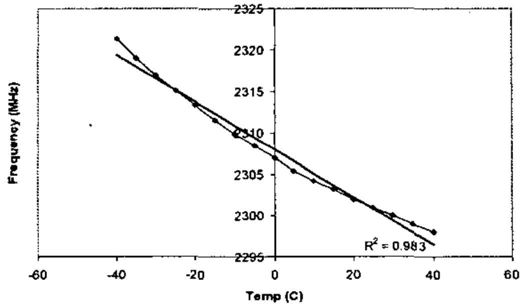


Fig.11. Temperature sweep results

IV. CONCLUSION

We present a new architecture to convert incident RF signal to DC efficiently to increase the operational range of a wireless transponder. A very low power clock extraction technique based on injection locking is used to generate low phase noise system clock. Two prototypes were built and tested to verify the functionality of the architecture. Table 1 gives a summary of the two systems.

Table 1. Summary of the two prototypes

	RFID Transponder	**Temp. Sensor**
Size	1.1mm^2	0.9mm^2
Frequency	900 MHz	2300 MHz
Modulation	Continuous Wave	Freq. Shift
Power (active)	1.1mA	1.1mA
Power (standby)	5μA	5μA
FOM	182dBc/Hz	171dBC/Hz

ACKNOWLEDGEMENT

The authors acknowledge the assistance of Prof. Ranjit Gharpurey, Ivan Bogue, Sunghyun Park, and Robert Gordenker. This work was supported primarily by the Engineering Research Centers program of the National Science Foundation under NSF Award Number EEC-9986866.

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