A Low Power RF ID Transponder

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This is the Grand Prize winner in the design category of the 1993 RF Design Awards Contest. This entry exhibited both innovative use of RF technology and an elegant implementation of that technology. The author was awarded a NOISE COM model UFX-BER noise generator for bit error rate testing.

For some time railroad companies have been wrestling with the problem of tracking rail cars. This has traditionally required manual log entry of identification numbers displayed on the cars as they pass through the switching yard. Some years ago, an effort was undertaken to use an optically scanned ID system. Dirt and optical registration problems led to its demise, forcing railroad companies to revert to the manual system. RF engineers have come up with a solution, using transponders mounted on the side of the cars which are read by interrogating transceivers positioned along the track.

Design Considerations

A practical transponder design must include minimal maintenance, a rugged low profile and low cost. The most elusive of these has been low cost. Presented here is a design which meets these requirements along with a brief discussion on the current state-of-the-art in passive RF identification transponders. An important design constraint is that the transponder require little or no maintenance. Since no power is available from the rail car, the only conventional options are batteries or solar cells that maintain rechargeable batteries. The non-rechargeable batteries require periodic replacement, and the solar cell option would be both expensive and vulnerable to the environment. A passive design eliminates the need for batteries by rectifying energy from the interrogating RF field to power the circuitry. The harsh environment presented to an RF device mounted on the side of a rail car is a challenging problem. Minimum clearance requirements, dirt, weather, vibration and an extremely large chunk of ferro-magnetic material near the antenna have to be considered. Additionally, the unit should be encapsulated.. Microstrip patch antennas have come to the rescue. They afford a low profile and can be made with an ordinary double-sided printed circuit board. The patch antenna is on the top and a ground plane is on the bottom, thereby eliminating the effects of the steel mounting surface.

A Low Cost Transponder

An unusually simple method of converting the interrogating RF field into a data-modulated signal which can be transmitted back to the reader contributes to the low manufacturing cost of this transponder design. The circuit uses only one inexpensive microwave semiconductor (a diode) and allows all parts to be mounted on an FR-4 printed circuit board with the patch antennas (Figure 1). By contrast, other approaches use expensive microwave parts, including SAW devices, oscillators, mixers, filters and amplifiers. Designs involving more RF circuitry tend to be power hungry, requiring increased RF interrogation fields.

Figure 2 shows the block diagram of the low power transponder. A 915 MHz receive antenna powers the rectifier/frequency doubler/AM modulator. It provides a rectified DC source to the MCU which returns data to be AM modulated onto the doubled frequency. An 1830 MHz antenna transmits the modulated carrier.

A reader, incorporating an

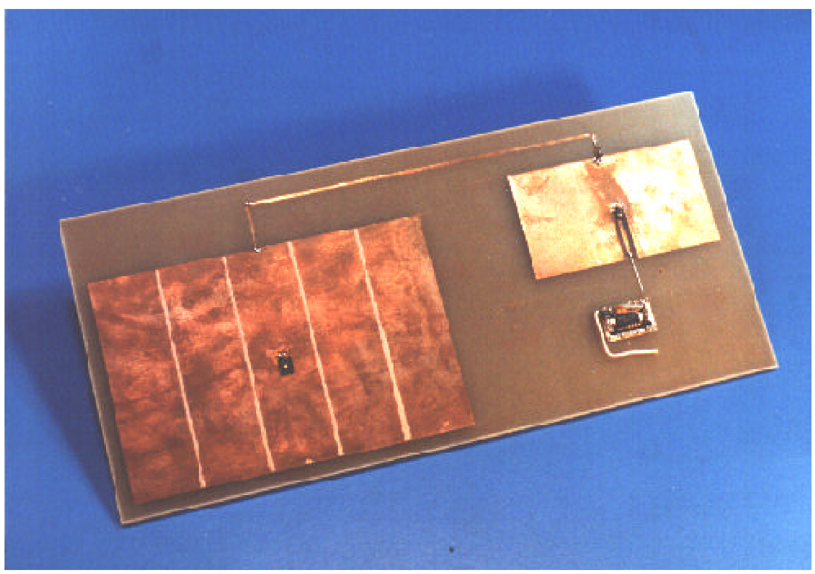

Figure 1. The complete transponder, with the 74AC00 test oscillator.

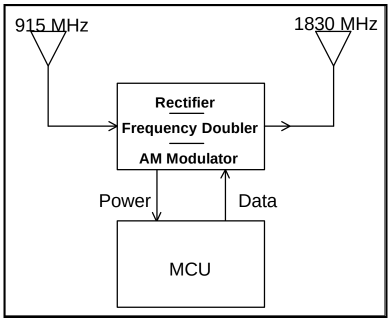

Figure 2. Block diagram of the passive transponder.

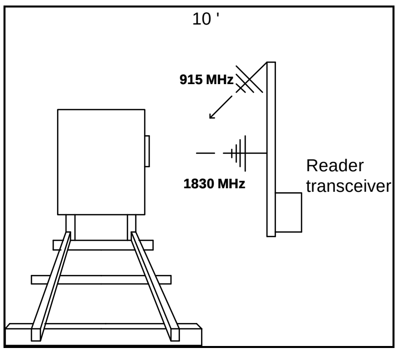

Figure 3. RF ID reader and transponder with rail car.

unmodulated 915 MHz interrogation transmitter with low (< -60 dBc) second harmonic distortion and an 1830 MHz AM receiver, is placed a relatively short distance away from where the transponder will pass (Figure 3). The amount of transmitted RF interrogation power needed to make the system function properly at a given distance can be estimated by equation 1:

$$P_r = P_t G_t G_r \lambda^2/(4\pi R)^2 \qquad (1)$$

Where P_r is the received power, and P_t is the transmitted power radiated by an antenna of gain G_t. G_r is the gain of the receive antenna, h is the free space wavelength and R is the distance between transmitters. G_t and G_r are the gains over an isotropic radiator. A sufficient second harmonic return path signal will occur for any combination of power gain and distance capable of energizing the MCU.

One watt of power transmitted with an antenna gain of 31.6 (16 dB) and received with an antenna gain of 2 (3 dB) allows the transponder to function from as far as 20 feet away. This suggests that just over 1 mW is adequate to energize the transponder.

The transponder's surprisingly low power requirement is due to its efficient means of rectification, frequency doubling and modulation. All of these functions are accomplished by a single microwave diode. A hybrid schematic in Figure 4 details the circuit. The 915 MHz patch antenna has two connections, a DC return path connected at the zero impedance point and a transmission line matched to the 120 ohm impedance at the edge of the antenna. The transmission line routes the signal to CR1 for rectification. A DC tap on the 1830 MHz antenna provides the power connection for the MCU. (See side bar on microstrip patch antennas.)

Careful placement of CR1 along the transmission line is crucial in creating the proper AC impedances for efficient frequency doubling. The 1830 MHz antenna becomes a 90 degree open stub at 915 MHz at the cathode of CR1, effectively giving the 915 MHz signal a low impedance trap to work against (Figure 5). Since the transmission line does not provide a similar low impedance on the anode side of CR1, a 90 degree open stub at 1830 MHz must be added.

Less than 100 uA are required to power the MCU (Figure 6). Consequently, little second harmonic is produced by CR1, leaving plenty of modulation headroom. Increased frequency multiplication occurs when the output port of the MCU goes low providing a path to ground for rectified current via the 1 kohm resistor, R1. Varying the value of R1 controls the modulation depth. CR2 and C2 work together to maintain sufficient voltage to the MCU while the voltage at C1 is being pulled down by the modulation action.

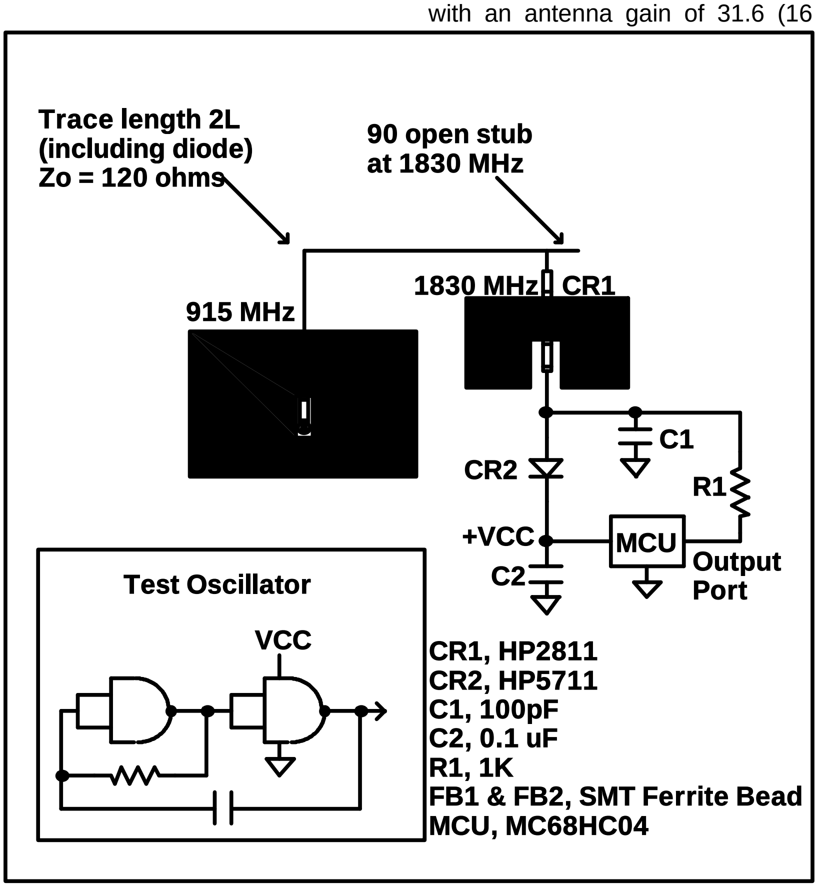

Figure 4. Hybrid schematic of transponder circuit.

Performance

As previously noted, the system can operate up to 20 feet away. However, performance is measured at the 10-foot separation required during normal operation. For test purposes, a spectrum analyzer functions as the receiver. A 74AC00 gate oscillator in Figure 4 is substituted for the MCU to simulate load and logic level conditions. The oscillator simplifies confirmation of the concept. Three kHz modulation is used for easy detection by the analyzer.

The transponder transmits data at 94 percent AM modulation. Measurements of the rectified voltage (2.7 VDC) and current (1.45 mA DC) give 3.9 mW total power which correlates nicely with the received power (5.3 mW) predicted by equation 1 at a distance of 10 feet.

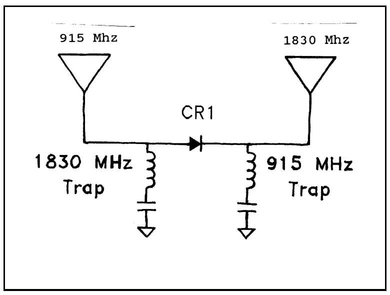

Figure 5. Equivalent AC circuit of transponder showing RF traps.

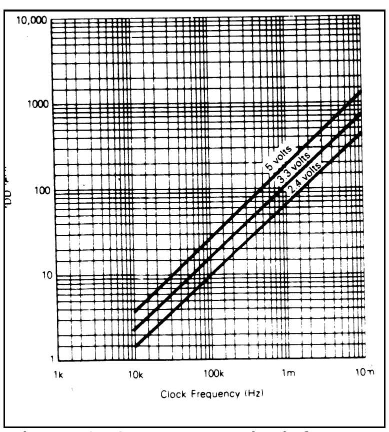

Figure 6. Current vs. clock frequency for a typical 68HC04 MCU.

Improvements

Inherent compatibility with spread spectrum is provided by this design since the returned signal frequency is derived directly from the interrogation signal. Frequency spreading is limited only by the bandwidth of the patch antennas. With the simple addition of a micro-power line receiver and the associated communications software, the transponder can be upgraded for two-way information applications. Size reduction can be accomplished by increasing operating frequency at the expense of costlier substrate material. Borrowing technology from missile and aircraft radar technology the transponder could be made a part of the "skin" of its host.

Summary

This paper has described the design, 'operation and application of a low-power RF identification transponder. The simple design is spectrum friendly, requiring minimal interrogation power and allows easy conversion to spread spectrum without modification to the transponder. Designed with one inexpensive microwave part on a single piece of FR-4 substrate, component and manufacturing costs are kept down, potentially opening up markets served exclusively by bar coding technology. Other uses include automatic tolling, inventory tracking and military vehicle security.

References

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2. Robert E. Munson, “Conformal Microstrip Antennas,” Microwave Journal, March 1988, pp. 91-109.
3. Alan Tam, “Principles of Microstrip Design,” RF Design, June 1988, pp. 29-34.

Our Design Contest Winner

Raymond Page is a design engineer for Wenzel Associates, a manufacturer of high performance crystal oscillators and frequency standards. Ray specializes in low noise designs for devices including oscillators, phase locked frequency sources, multipliers and dividers. In addition to having fun with electronics, he enjoys outdoor sports and music. He can be reached at Wenzel Associates. by equation 1 at a distance of 10 feet.

Appendix A: Rectangular Microstrip Patch Antenna

The rectangular patch antenna is essentially a resonant microstrip with an electrical length of 1/2 the wavelength of the frequency to be transmitted or received. Microstrip patch antennas work well for applications requiring a low profile, offering a height equal to the thickness of the printed circuit board from which they are made. PTFE substrates are normally used to minimize dielectric losses which affect the efficiency of patch antennas. However, FR-4 is a cost effective alternative for low power applications at frequencies below 2 GHz. Microstrip antennas come in all sizes and shapes. A rectangular patch is chosen for its simple geometry and linear polarization when fed from the center of an edge. The input impedance varies as a function of feed location. The edge of a 112 wavelength antenna has an input impedance of approximately 120 ohms which drops to zero ohms as the feed point is moved inboard to the center of the antenna. This allows easy impedance matching and provides a convenient means of DC tapping the antenna as seen in the transponder design. For simplicity, the dimensions of the microstrip patch antennas in Figure 9 are in terms of L, which is equal to 1/2 the electrical wavelength of the receive antenna (915 MHz). L can be determined by equation 2:

$$L = 0.49 \,(\lambda / \varepsilon_R) \qquad (2)$$

where λ is the free-space wavelength and ε_R is the relative permittivity of the printed circuit board. Bandwidth is determined by the substrate thickness and can be approximated for an SWR of less than 2 by equation 3:

$$BW = I28\ f^2\ t \qquad (3)$$

BW is in MHz, f is the operating frequency in GHz, and t is the substrate thickness in inches. Applying equations 1 and 2 to the transponder design using 0.125 inch FR-4 substrate material with an effective permittivity of 4.7 results in a value of 2.92 inches for L and a bandwidth of 13.4 MHz at 915 MHz.