INTEGRATED ANTENNA SYSTEM FOR WIRELESS RFID TAG IN MONITORING OIL DRILL PIPE

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(Invited Paper)

Abstract

This paper reports a new integrated antenna system for a 5.8 GHz Radio Frequency Identification (RFID) tag proposed for predicting the pipe's lifetime and to provide inventory control. The tag requires a minimal incident power density of 13.5 mW/cm^2 to establish a link and transmit 64-bit coded information to the interrogating reader.

I. Introduction

RFID systems are used for identifying and tracking objects, but its benefit to the oil industry has not been fully explored [1]. Most RFID systems consist of a reader and a tag. The reader transmits power to the tag which then sends a coded signal back to the reader. For oil drill pipe monitoring, this coded signal contains information about the drill pipe being used including the drill pipe identification, size and previous usage [2]. Better inventory and usage control will enable the pipes to be used for longer periods of time resulting in huge cost savings for oil drilling companies.

The reader interrogates the tag whenever the tag leaves the "down hole" environment and rises above the earth's surface. The "down hole" environment consists of temperatures that can reach 230°C and outside pressures normal to the tag's surface that can exceed 20,000 pounds per square inch. At these high storage temperatures batteries often fail. An alternative for powering the tag's electronics is to use rectifying circuits that convert microwave energy into DC energy [3]. This rectification is achieved when microwave energy is incident upon a Schottky detector diode. The rectified or DC portion of the energy is then used to power the electronics that create the "passive" tag's unique identification [4].

The system being proposed is a passive system operating at 5.8 GHz. This ISM band frequency is chosen because the tag must fit in a cylinder ¾ in. tall and 1 in. in diameter. This size restriction is due to the rotational stresses on the oil drill pipe. If too large a tag is used, the structural integrity of the pipe's high-grade steel is compromised which could lead to the pipe twisting into multiple pieces.

II. Operational Theory and Component Design

The tag's placement in the tool joint of the drill pipe and the interior of the tag are presented in Figure 1. The tag is recessed 19 mm (~0.75 in.) into the tool joint of

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the drill pipe. A 5 mm (~0.25 in.) thick Teflon cover is then placed over the tag in order to protect the tag from the "down-hole" environment. The circular patch located behind the Teflon couples RF power in and out of the tag. The patch has two ports that are orthogonally spaced [5] on its surface 4.5 mm away from the patch's center. The patch is linearly polarized with one port being H-plane polarized and the other E-plane polarized. These orthogonal ports are also isolated and thus can perform receive and transmit functions simultaneously.

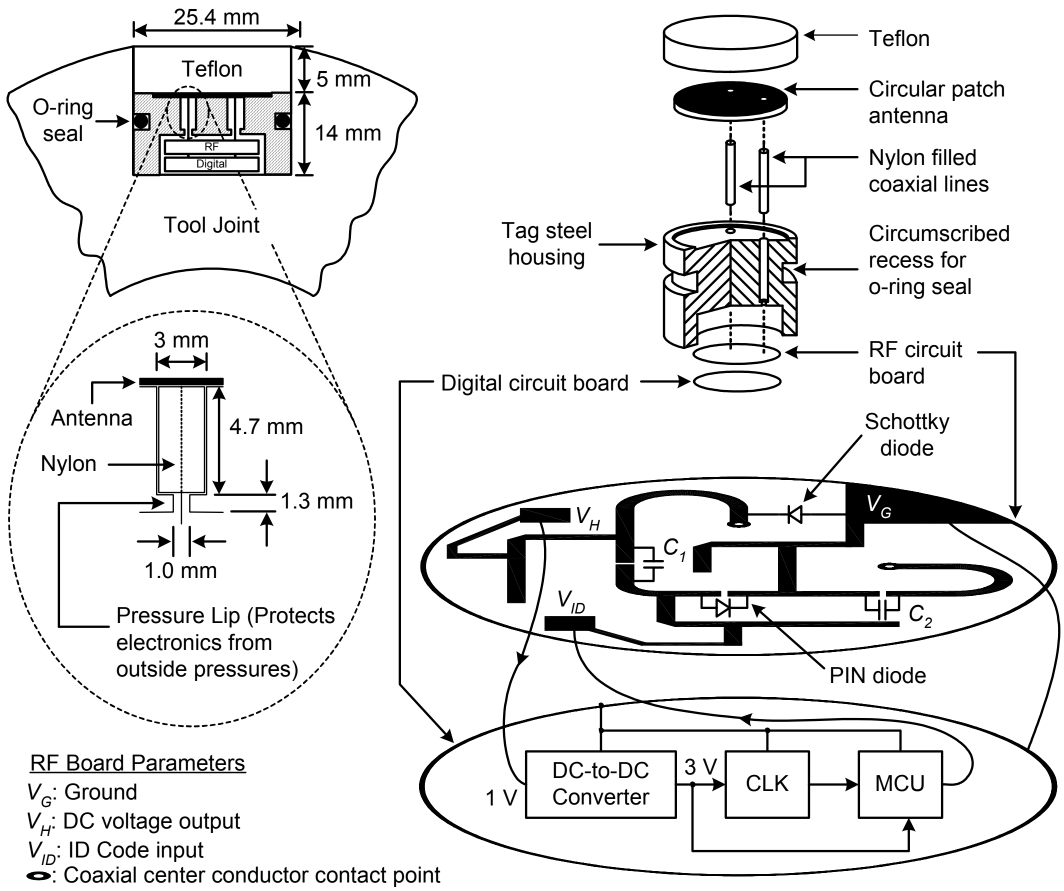

Fig. 1. Tag recess and 3-D structure view.

The patch is connected to the RF circuitry by two Nylon-filled coaxial lines. These coaxial lines have a cross-sectional area of 7.1 mm^2. Assuming the 20,000 psi exterior pressure is uninhibited by the Teflon or the antenna, 220 lbs of pressure will be applied to each of the Nylon coaxial lines. The Nylon maintains its rigidity at this pressure so as to not change the electromagnetic properties of the coaxial lines. The short lip section between the Nylon coaxial lines and the diodes keeps the pressure on the tag's Teflon surface from reaching the RF and digital circuit boards.

After the 5.8 GHz energy is collected by the patch antenna, it flows down the coaxial line leading to the Metellics MSS30-142-E20 Schottky rectifying diode.

This diode then converts a portion of the microwave energy into a DC power consisting of voltage V_H. The remaining power is distributed at 5.8 GHz and its higher order harmonic frequencies. This rectification is responsible for making the tag passive since it generates the DC power that operates all of the "on-board" electronics. A 1 to 3 V DC-to-DC converter is then used to step up the rectified DC voltage in order to lower the Schottky's rectification requirement which ultimately lowers the transmit power necessary to turn-on the tag's electronics. The converter's 3 V output drives both the 16 MHz clock oscillator and the Motorola MC68HC908JK3-CDW microcontroller. The microcontroller produces a 64-bit ID unique to the tag and is programmed to repeat the code until it shuts down due to a lack of turn-on voltage. This repeating 64-bit ID sequence of 1's (3 V) and 0's (0 V) is used to modulate the 5.8 GHz energy remaining from the Schottky diode mixing process. This 5.8 GHz energy travels through the low loss capacitor C_1 and couples to a MA/COM 4P804-129 PIN diode. When V_{ID} = 3 V, this PIN diode shorts and allows the 5.8 GHz energy to pass through it. Conversely, in the case where V_{ID} = 0 V, the PIN open-circuits to reflect the 5.8 GHz energy back to the Schottky diode where it remixes and creates more DC power. The modulated signal then travels through another low-loss capacitor C_2 to reach the connection to the coaxial line. The coaxial line is connected to the patch antenna where the microwave energy radiates back to the reader. Both low-loss capacitors are required to separate the three voltage levels, i.e. ground, high, and the ID code. At the locations of these three voltage levels are three $\lambda/4$ wavelength stubs that are used as RF chokes to isolate the microwave energy from the digital circuitry.

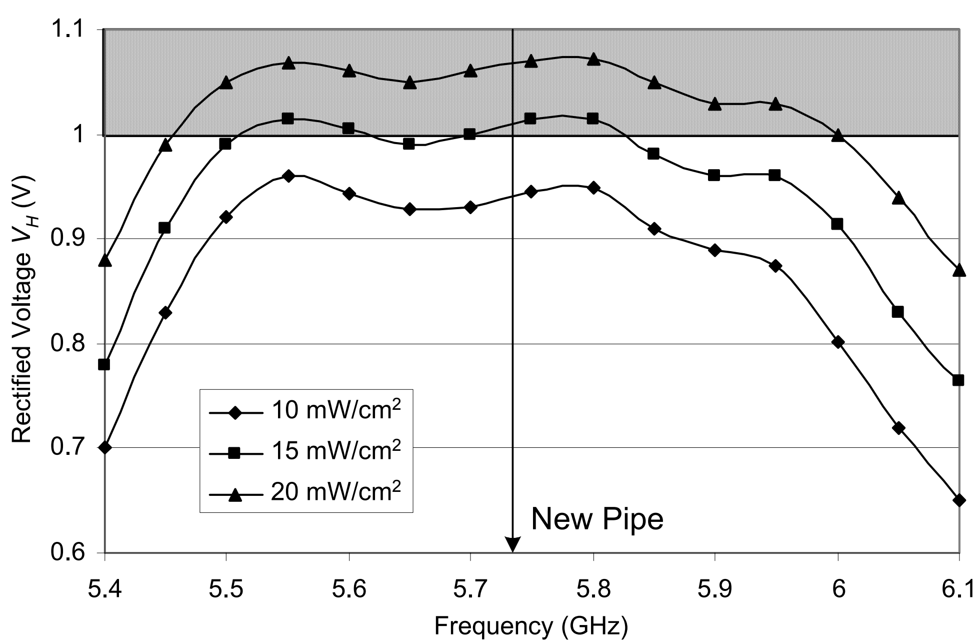

Fig 2. Measured rectified voltage V_H versus frequency for different linearly polarized power densities incident upon the tag's Teflon surface.

III. Measured Data for RFID Tag

A horn is used to transmit the amplified signal to the tag which is recessed into a cross-sectional slice of drill pipe. The tag's return signal is received by another horn rotated 90° with respect to the transmitting horn. This incoming signal is then detected by the reader with the use of a Schottky detector diode and displayed on an oscilloscope.

Figure 2 presents the rectified voltage V_H versus frequency for different linearly polarized power densities incident upon the tag's 5 mm thick Teflon surface. The shaded area of Figure 2 reveals the voltage region $V_H > 1$V required for the tag's electronics to produce the 64-bit identification code.

IV. Conclusions

This new tag has the potential of greatly reducing the operating costs of oil drilling and exploration. It is designed to operate without a battery and can withstand large pressures. The tag is small in size and has a very high data rate to communicate multiple reads between the tag and reader.

Acknowledgements

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