Design of a Microstrip Patch Antenna for Microwave Sensing of Petroleum Production Lines

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***Abstract*— In this paper, the design of a microstrip patch antenna for microwave sensing of sand production in petroleum pipelines is presented. Two antennas are designed in order to cover the entire sensing regime (gas to liquid including large percentages of brine) common to petroleum production lines. The antennas are designed to operate at ~5GHz. The antenna intended for sensing with low-loss fluids (gas or oil) is capable of ~4% bandwidth ($|S_{11}|$<-10 dB), and the antenna intended for sensing with high loss fluids (brine) is capable of ~7% bandwidth.**

Keywords*— *Microstrip patch antenna; microwave sensing; petroleum production monitoring, sand production.

I. Introduction

Produced fluids from petroleum wells often contain a number of materials including brine (salt water), hydrocarbons (oil and natural gas) and sand (as a result of formation failure). Sand production is a serious problem in the petroleum industry and can cause rapid erosion in production system equipment and subsequent production downtime and additional replacement expenses. Therefore, it is important to be able to detect the onset of sand production so that mitigation techniques may be implemented. In addition, the ratios of produced gas, hydrocarbons, and brine change over time, leading to a diverse range of potential sensing scenarios.

Various sensing techniques have been considered for detecting the presence of sand in produced fluids including electrical resistance probes, acoustic sensors, fiber optic sensors, electromagnetic-based sensors, etc. Among these methods, microwave methods have shown success for flow measurements in the petroleum industry but with limited applications. In [1], it was shown that the microwave resonator perturbation technique can be applied as a fluid sensor, but requires complex system integrity and has not been tested for high permittivity materials (such as brine). Two coaxial probes (operating at high and low frequencies) [2] and a wideband coaxial probe [3] to determine the ratio of materials inside the pipeline were also utilized. However, coaxial probes have a very low efficiency and are not good radiators. Microwave sensing of sand production by utilizing an X-band open ended waveguide [4] also showed promise, but such probes are difficult to integrate into pipelines due to the waveguide dimensions. As such, this paper considers the design of two microstrip patch antennas capable of sensing over a wide range of production fluids. Also, operating frequency of ~5 GHz to achieve sufficient sensitivity to sand particles and avoid high transmission loss in water is considered.

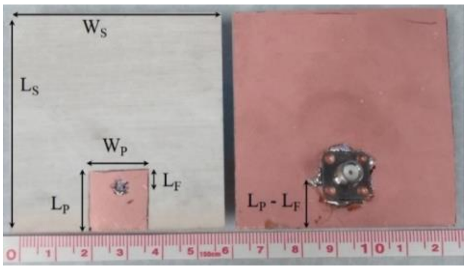

Fig. 1. Microstrip antenna design: front view (left), and back view (right), W_S = 60 mm, L_S = 60 mm, W_P = 16 mm, L_P = 16 mm, L_F = 4.8 mm (for Antenna 1), L_F = 1.6 mm (for Antenna 2) .

II. Antenna Design and Discussion

As mentioned, the pipeline contents can vary significantly over time (gas to brine). In Table I, typical values for the dielectric properties of these materials are shown in order to illustrate this wide and diverse range.

Table I - Constituent dielectric properties.

Material	Gas	Oil	Brine	Water
ε_r	1-j0	2.2-j0.1	50-j40	70-j10

From a dielectric properties point-of-view, this changing environment leads to a wide range of effective dielectric properties of the produced fluid. As such, the antenna(s) of a microwave sensing system must be designed in such a way as to be able to operate efficiently under these diverse operating conditions. To this end, a microstrip patch antenna is considered as the antenna of choice for this sensing need. These antennas are light weight, compact in size, not costly to fabricate and can be made conformal with other geometries and structures (such as a pipeline). Therefore, two different microstrip patch antennas (with a center frequency of ~5 GHz) are designed in order to operate in this diverse environment.

Generally, conventional microstrip patch antennas are designed to radiate in air. However, a change in the material (such as oil or brine, with dielectric properties differing from air) in front of the antenna affects the magnitude of the electric and magnetic fields of antenna which alters the input impedance of the antenna. Therefore, since the range of dielectric properties of the pipeline constituents is quite diverse (see Table 1), initially two different patch antennas were designed; one to for use with low permittivity materials (gas), and one for high permittivity materials (brine/water). To this end, the feed location (for a coaxial feed) must be altered as a function of the material in front of the antenna. The optimum dimensions for Antenna 1 (for gas) and Antenna 2 (for brine/water) for an operating frequency of ~5 GHz ($|S_{11}|$<-10 dB) were determined through full wave electromagnetic simulation using CST microwave studio, and are provided in Fig. 1.

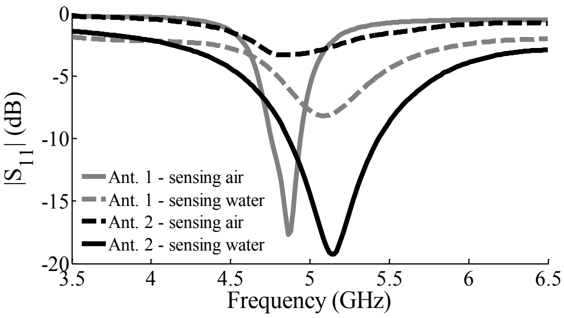

Fig. 2. Measured $|S_{11}|$ of the two antennas.

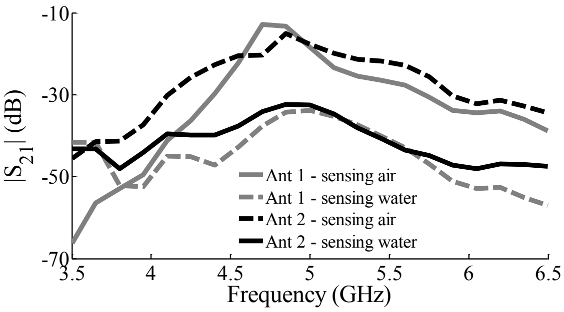

Fig. 3. Measured $|S_{21}|$ of the two antennas.

To test the antenna performance, a plastic box (50 mm^3) was utilized (thickness of 1 mm) to hold water. Measurements were also conducted utilizing an empty box (mimicking a box filled with natural gas). Reflection (S_{11}, shown in Fig. 2) and transmission (S_{21}, shown in Fig. 3) measurements were performed using a calibrated Antritsu MS4644A Vector Network Analyzer. Both antennas were utilized for measurements with both materials in order to illustrate the improved performance offered by each design.

As shown, the antenna designed for air (Ant. 1 in Fig. 2) when used with the empty box has ~4% bandwidth ($|S_{11}|$<-10 dB) at 4.9 GHz. However, when this antenna is used with the box holding water, the resonant frequency shifts to 5.1 GHz with $|S_{11}|$ > -10 dB (indicating poor antenna matching). Also, the antenna designed for water (Ant. 2 in Fig. 2) when used with water has ~7% bandwidth at 5.1 GHz. However, when this antenna is used with the empty box (air), the resonant frequency shifts down to 4.9 GHz and suffers a significant reduction in $|S_{11}|$ with no bandwidth ($|S_{11}|$ > -10 dB).

In order to see the transmission ($|S_{21}|$) performance of each antenna, the antennas were placed on opposite sides of the box, facing each other (50 mm apart), with the results shown in Fig. 3. From the results, it is seen that when the material between to antennas is air, the antenna designed for air shows ~5 dB stronger transmission than antenna designed for water. Also, it is seen that when the material between the antennas is water, the antenna designed for water shows ~2 dB stronger transmission than the antenna designed for air. The apparently reduction in performance of the antenna designed for water (as compared to that of the antenna designed for air) is attributed to the additional signal loss resulting from the water (a high loss material).

III. Conclusion

In this paper, the design of a microstrip patch antenna for microwave sensing of sand production in petroleum pipelines is presented. Two antennas are designed to operate at ~5GHz in order to cover the entire sensing regime (gas to liquid including large percentages of brine). The antenna intended for sensing with low-loss fluids (gas or oil) is capable of ~4% bandwidth ($|S_{11}|$<-10 dB), and the antenna intended for sensing with high loss fluids (brine) is capable of ~7% bandwidth. Future work will include a study on the performance of these antennas for other possible materials (with dielectric properties in between air and water) in a petroleum production pipeline (i.e., combinations of brine, gas, and oil). Advanced measurements utilizing these antennas, incorporated into a flow loop and conforming to a pipeline, will also be conducted.

IV. References

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