Surface acoustic wave sensor interrogation using Goubau waves

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***Abstract*—Electromagnetic waves on single conductors (Goubau waves) are studied for the interrogation of wireless sensors. A demonstration of interrogation of a surface acoustic wave (SAW) sensor is presented, followed by the results of simulation of wave launchers on conductors of varying radius.**

I. INTRODUCTION

Circular conductors such as pipes are everywhere in the built environment. We consider here the use of these conductors to extend the range for the interrogation of wireless sensors. Here we specifically focus on surface acoustic wave (SAW) sensors which can be interrogated wirelessly but with a severely limited range. We consider large radius conductors that are likely to be of practical interest.

Waves guided propagating on the interior of hollow pipes and tubes are of course well known and have been studied for SAW sensor interrogation [1]. Goubau waves [2] propagating on the outside of a single conductor have been long known but are not widely used. In the following we demonstrate the use of Goubau waves for SAW sensor interrogation. We then discuss the development of wave launchers, with particular attention to conductors of large radius.

II. INTERROGATION OF A SAW SENSOR

Figure 1 shows the arrangement for a demonstration of interrogation using Goubau waves. A 0.0032 m radius brass conductor 1.83 m long has conical launchers at each end. One launcher is connected to a vector network analyzer and the other is connected to a surface acoustic wave device described below. There is no other electrical connection to the SAW device, eliminating the possibility of ground loops or any other confusing factor.

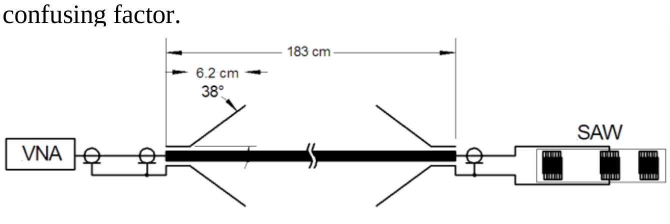
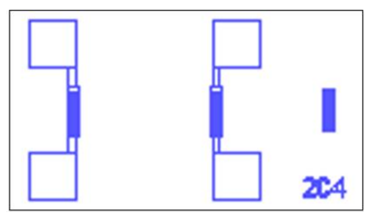


Fig. 1. Schematic of arrangement for demonstration of the use of Goubau waves for interrogation. Some experiments used additional copper shields.

The SAW device (Figure 2a) consists of three interdigitated transducers (IDTs) on a Y-Z $LiNbO_3$ substrate. The period of the interdigitated transducers is 8 µm leading to an operating frequency of about 435 MHz. The IDT in the center is used as an emitter and the two other IDTs spaced at 2.36 µm and 3.05 µm are open-circuited and operate as reflectors. When used as a sensor the emitting IDT is excited by a windows pulse with a center frequency of 435 MHz. Reflected pulses return to the emitter. The delay time changes according to strain, temperature, etc. changes in the SAW device and thus can be used for sensing. The direct connection to the emitter can be replaced with an RF link, allowing wireless interrogation.

(a)



(b)

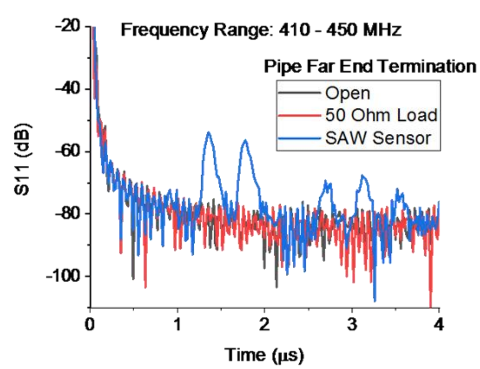


Fig. 2. (a) SAW sensor mask layout and (b) S parameter S11 magnitude transformed into the time domain.

Here we observe the SAW reflections by using a vector network analyzer to measure the scattering parameter S11 as a function of frequency. Transforming S11(w) into the time domain provides an equivalent way of observing the reflected pulses.

Figure 2(b) shows the transformed S11 using the experimental arrangement of Figure 1. We see the reflections from the two reflector IDTs (1.35 and 1.77 sec) along with multiple- bounce reflections (2.71, 3.12, and 3.54 sec). As expected, the reflections disappear when the SAW sensor is replaced with a resistive load.

In the following sections, we explore launchers for Goubau waves, with particular emphasis on designs suitable for large-radius conductors.

III. Conical Launcher

Conical launchers are commonly used for launching Goubau waves. [3,4] We have simulated a conical launcher operating at 450 MHz for Goubau waves using the finite elment simulation package Comsol 6.1. For simplicity the cone is fed by a section of air-insulated coaxial line with an impedance of 50 ohms. Simulation is performed in a 2 m radius domain 10 m long terminated in another identical conical launcher attached to a 50 ohm load.

Figure 3 shows the simulated S11 as a function of the angle and length of the cone. There is a sharp optimum in S11 although acceptably low S11 is obtained for a wide range of dimensions. A similar sharp optimum is obtained for larger conductor diameters.

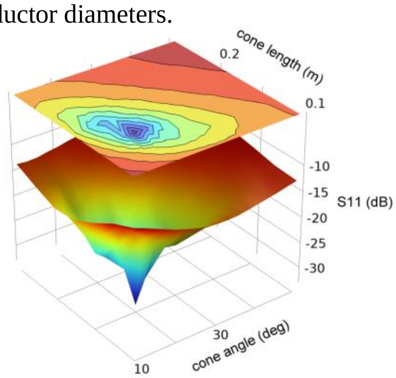


Fig. 3. Scattering parameter S11 for a cone launcher on a 0.0127 m radius conductor as a function of cone angle and cone length.

Figure 4 shows the radial component of the electric field in the simulated domain. Near the conductor we see Goubau wave with an approximately 1/*r* dependence of the electric field. In addition there is a spherical outgoing wave. Clearly this corresponds to energy propagation away from the conductor. As a result the power at the receiving conical transducer is reduced (S21 ~ -5 to -8 dB).

A pair of conical transducers would provide a very acceptable link loss for SAW interrogation. However the geometry of a conical launcher becomes impractical for large radius conductors. Problems with this launcher design include the impractically large radius of the coaxial feed and the difficulty of feeding the entire circumference of the cone with the same phase.

We are therefore exploring alternative launcher designs. An example is shown in Figure 5, where the launcher is a partical cone with a single feed point. A major challenge in launcher design, especially for large radius pipes, is maximizing the energy emitted as a Goubau wave relative to the energy lost in a spherical wave.

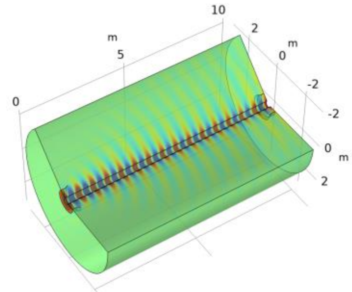


Fig. 4. Cone launcher at 450 MHz and a steel conductor of radius 0.152 m. Color represents the *r* component of the electric field in a 10 m long domain terminated in a scattering boundary condition.

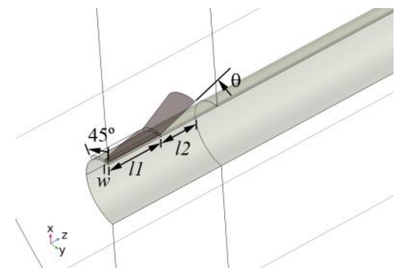


Fig. 5. Partial cone launcher.

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