Through Metal Communication for Using in Downhole Tool

Mostafa Koraei[1] and Magnus Hjustuen[2]

Abstract— **Hundreds of oil wells are being drilled each year and it is supposed to be in production for many years. Many downhole tools have been developed to give us more information about the condition of oil wells. A challenge in designing this kind of tools is that they should be survived at high temperature high pressure environment. Since they need to hove some kind of reliable sealing. For a specific tool it is required to be programmed after it has been sealed by EB welding. Because we only have some limited amount of energy inside it and the tool body is stainless steel 316, it is not affordable to use RF communication. Also the time of programming can be several months or years after its sealing process, so the electronic circuit should goes to sleep mode and have to be woke up by an external power. Because of the mentioned issues we decided to transmit power and data to the tool while programming.**

I. Challenges in communication with a sealed tool

The tool body is from stainless steel 316 that has relatively high conductivity and absorbs most of RF waves (more than 40 dB) that make it difficult to use high frequency communication bands like 900MHz, 2.4GHZ. A solution is to reduce the frequency to reduce the attenuation of the body. But downhole tools are designed to be used in different oil wells so one the first things that should be considered in their design is the OD of the tool. In our tool it is 16 mm, also the length of the electronic part of the tool must be kept limited to 25 cm. This small footprint limits us to use big antenna or coil for the communication. The tool is powered by some batteries that can provide maximum 4 mA, and the energy should be saved as much as possible to make it able to do its job after several months and years in the well. because of this power limit the micro-controller of the tool is also selected to be a low power MCU that its processing power is limited to 24 MIPS in practice. It means implementing complex real-time communication and protocol analysis algorithms on it is not possible. On the other hand to save the energy we have to keep MCU in the sleep mode, also if we use the RF communication we need an alive receiver all the time that needs power. So we need to wake up the tool by leveraging an external power and then start to send commands. Another issue is receiving the feedback of commands from the tool, again because of low energy source available in the tool, it should be considered in the design.

II. Physics has always a solution

We have studied different communication methods that were guess to be appropriate for this problem. Acoustic, magnetic and inductive communication where our candidates. Acoustic communication required some portion of inside energy to give the feedback to the outside programmer and also an internal alive receiver that we did not want to have it while the MCU is in sleep mode. Magnetic communication could be better by switching on and off a reed switch from outside of the tool but still for giving feedback we had energy limitation. Inductive communication was promising, we could transmit power to the tool and wake up the MCU and also by changing the frequency transmit data to it. In theory we can also do some switching inside the tool and by measuring the current feedback from the outside programmer and applying signal processing, recover the replied bits.

[1]Mostafa Koraei, Research Scientist at SINTEF, Norway
[2]Magnus Hjustuen, Project Leader at SINTEF, Norway

III. COMSOL MULTIPHYSICS AC/DC MODULES

All above theoretical advantages of inductive communication can be used if the correct core material, dimensions, coil turns are selected. The question is how we select number of turns in each coil and core material to not only can transmit enough power and data to the tool but also be able to have strong current feedback for the outside processing part to determine bits that are transmitted from inside the tool. We used COMSOL Multiphysics to explore the design space. Regarding to different possibilities for number of coils and OD of the core and its material, it is not practical to study different designs analytically. We used Magnetic Fields study[1] to understand what is happening for a sending power from outside of the tool to inside it. To do this we added stationary and frequency domain study by using following equations 1 and 2.

$\times H = J$
$B = \times A$
$J = \sigma E + \sigma v \times B + J_e (1)$

$\times H = J$
$B = \times A$
$J = \sigma E + j\omega D + \sigma v \times B + J_e$
$E = -j\omega A (2)$

We swept the frequency from 1 KHz to 50 KHz to find best the effect of frequencies on the induced voltage and current and at the same time find the sensitivity of the current feedback during different carrier frequencies. The goal was to define one frequency for power carrier and 5 different frequencies for data symbols as well as finding good determinable chopping frequencies for inside circuit.

We also added Electrical circuits from AC/DC module to study the induced voltage and current as well as required current and voltage at the out side coil. Figure1 illustrates a simple model of the simulated electrical circuit. The switch is being controlled by the MCU and other electronic parts of the tool that all of them are modeled as a resistor inside the tool. During chopping operation for signalling out the inside capacitor is responsible to keep the energy for electronic circuits.

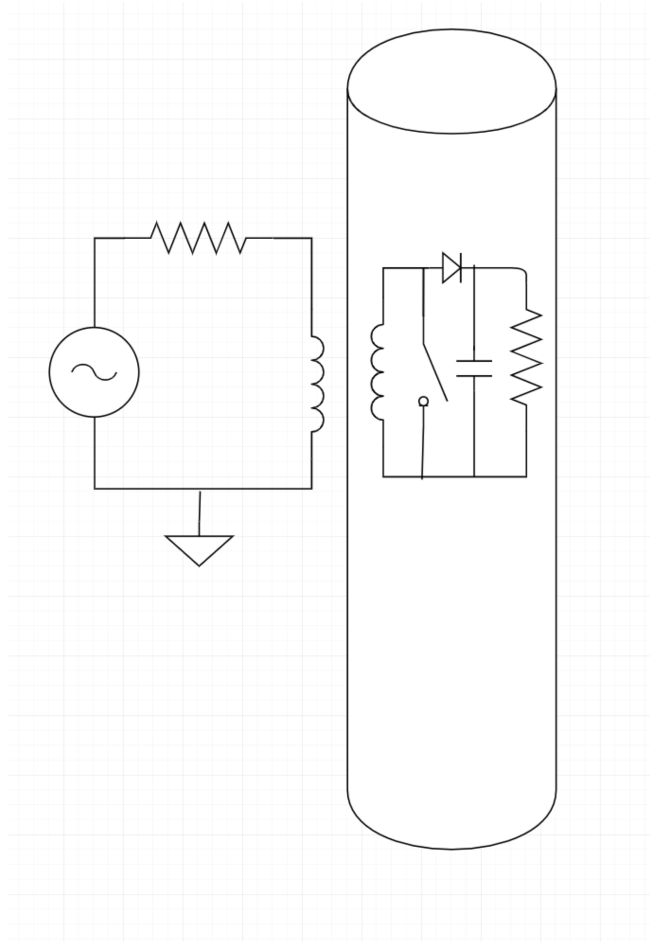

Fig. 1. Electrical Circuit of the Simulated Downhole Tool.

By using Electrical circuit physics we could study the effect of the inside chopper on the outside current frequency spectrum and use it to recover the data from current signal.

IV. GEOMETRY

The 3D model of the tool is shown in Figure2. It is the base model and one of nice features of the COMSOL is that we can define it parametric and then change the dimensions by changing parameters. The most critical parameter in our geometry was the core OD that had effect on defining the turns of the internal coil and also imposed the sensitivity of the current feedback. Sweeping on all of dimension parameters and applying different frequencies and time domain study for each one is a time consuming task.

Fortunately our model is axial symmetric and we could use another feature of the COMSOL

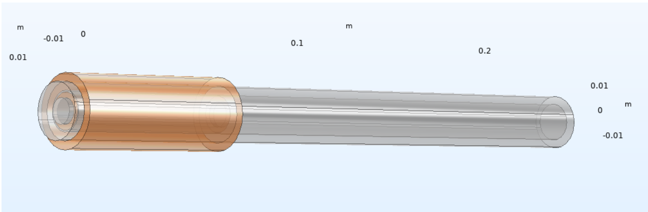

Fig. 2. 3D Model of the tool and communication part.

to solve this problem in an axial symmetric 2D model instead of a whole 3D model. It reduced the simulation time significantly and gave us the opportunity to study even more design space points. This 2D model is shown in Figure3

V. Numerical simulation and Experimental setup

One issue in the inductive communication design is that it should not have any effect on the other electronics part of the system, to be sure that we can keep our sensitive electronic circuits safe we decided to extend the core length. As Figure4 shows this little extension traps most of electromagnetic fields in itself and causes the inductive switching does not effect the electronics parts. After running the simulation found the semi optimum dimensions for coil and core and also we decided to use ferrite 78 as the material of the core. We made a setup to run our experimental tests and measurements and results were so close to our simulation results. Figures5 and 6 show our experimental setup that contains a stainless steel tube, two coils and one ferrite rod as the core of inside coil.

VI. Results and Conclusion

We found that semi optimum coil turns in our project are 350 turns for inside coil and 900 turns for the outside coil by considering the outside voltage not more than 1.5 volt and the current not more than 50 mA.

We managed to transmit power and data to the tool and reach 1 Kbps baud rate. Without using numerical simulation finding correct power and symbol frequencies was too difficult to be done in the lab by experiment. Also the results of axial symmetric geometry that we used in our simulation was not too different from experimental results,

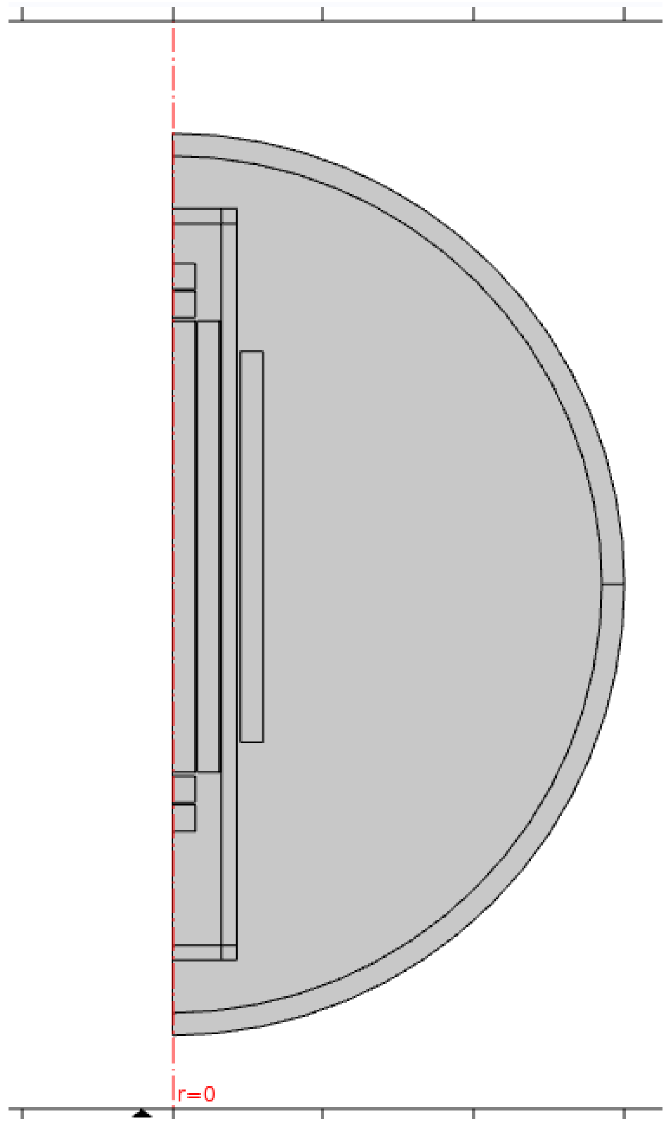

Fig. 3. Axial symmetric 2D Model of the tool and communication part.

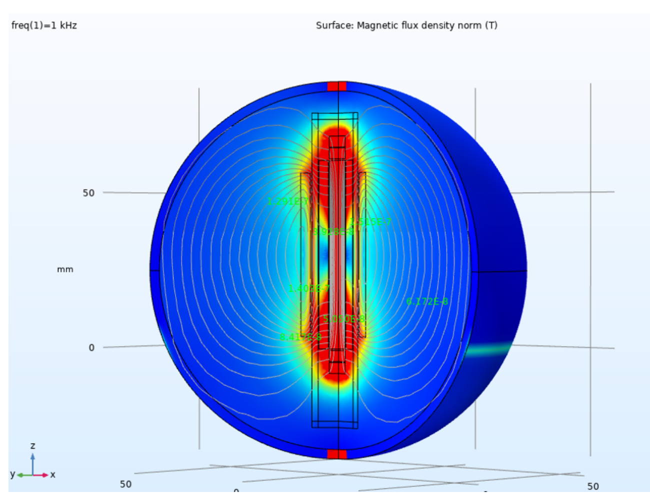

Fig. 4. Numerical simulation results.

Fig. 5. Experimental setup.

Fig. 6. Experimental setup with internal coil.

that means we have saved lots of time by bringing our model from 3D to 2D and using symmetricity.

VII. REFERENCES

[1] COMSOL Multiphysics Reference Guide