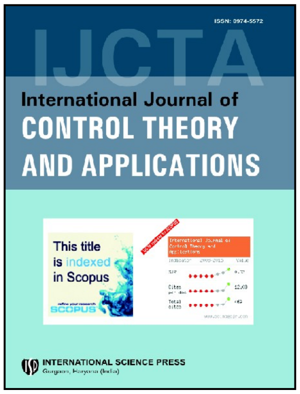

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Signal Processing in the Microwave Front-End Radiolink for Logging-While-Drilling through the Borehole Pipes

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Abstract: Logging-while-drilling (LWD) telemetry systems have been designed relying on cable-based equipment or advanced signal processing techniques applied to the electromagnetic channel through ground. The main disadvantage of such systems consists in the fact that measurements can be actually carried out only when the drilling operation is stopped. In this paper, X-band equipment for LWD telemetry along pipes regarded as dielectric waveguides is proposed. A hybrid-integrated power amplifier-transmitter for this purpose is described. This system represents a modern solution to geophysical applications where transitions from vertical to horizontal drilling are required. Drilling pipes provide a new communication channel for telemetry although the potential issues related to large attenuation in the soil and external disturbances are to be carefully assessed beforehand. In particular, great attention has to be put in such a way as to achieve an efficient excitation and reduced distortion of the radio signal propagating along the pipe. In the paper we put in details the simulated performances, transmitter design, and current-efficiently issues. The output power is up to 10–25 Wt in short-pulse mode, at central lobe of 9–10 GHz. This level of power is sufficient for the short boreholes. The proposed amplifier-transmitter is used to establish a new communication channel. It is link between surface and the drilling point. Some review explaining the great degree of interest in this topic is presented. Experimental measurement results are provided as well.

Keywords: Power Transmitter, Logging-While-Drilling, LWD, Borehole Waveguide, Microwave Pulse Generator.

1. INTRODUCTION

The gas and oil consumption in Europe increases, but deposits extremely decreased during the past years. Up to now in most cases the gas and oil resources to 2.5–3.0 km depth are already maintained. Moreover, the drilling process is very expensive. The problem can be resolved by the horizontal boreholes. Modern direction is drilling with large horizontal path. Efficiency of such technology has considerably increased. New technologies of horizontal drilling demand not only efficient drilling. It is also receiving the full notification on layers. It is the only way to receive of this information from the geophysical systems without cable (see Fig. 1). The existed cable systems have one disadvantage: the measurement of the layer properties entails stopping the drilling operation. On the other hand, the introduction of logging-while-drilling (LWD) systems allows receiving full information on the drilling process itself in real time and, at the end, makes it cheaper [1].

Smart drilling techniques use many channels for data transfer. A complete description of the available channels is provided in [2–3]. Common disadvantages of these channels pushed us to search for a new alternative one. In this study, a novel radio-frequency (RF) equipment with refined characteristics has been designed for telemetry application via drilling pipes regarded as an opportunistic communication channel in the microwave range useful to retrieve LWD parameters. As it can be easily inferred, high-performance receive/transmit devices are absolutely essential to the overall implementation optimization of the measurement information transmission and the communication channel. Up to now, the equipment for this goal was not design practically. All the same, hybrid modules on Gunn diodes or transmitters are found to be suitable for telemetry systems. As a matter of fact, such gadgets are reliable, rather cheap compare with the facilities needed to establish the electromagnetic channel as described in [4]. Thereby, the main novelty of the proposed investigation consist in the introduction of a pipe-based microwave channel and development of dedicated telemetry equipment for smart drilling applications.

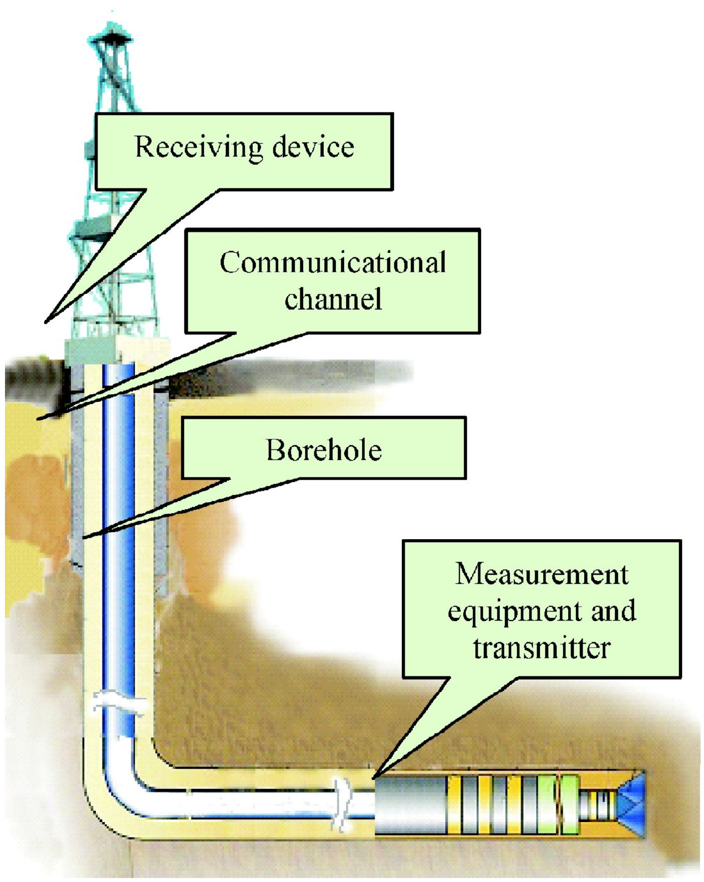

Figure 1: Composition of the telemetry transfer

2. DESIGN OF THE LWD TRANSMITTER

A hybrid microwave module with power level of 15–25 W has been developed for the LWD systems [5]. Photo of the generating device is presented in Fig. 2 together with the relevant package. Traditionally, Gunn diodes are used for noise generation. In this investigation such a diode is integrated in a rectangular waveguide for efficient excitation of a radiowave pulse. The module consists of first generator, amplifier, and waveguide chamber with Gunn diode (Fig. 3). The trigger is given by the positive polarity impulse signal with TTL amplitude from the geophysical equipment. The pulse signal level is afterwards increased through the amplifier stages VT1, VT3 by 15–20 V, 25 A and injected finally in the input terminals of the activator VD4 for the microwave impulse generation in the waveguide chamber. Frequency and duration of such signal define the characteristics of the microwave pulse. The pulse is radiated when the resonance condition of the waveguide chamber is met. We use 3A750 Gunn diodes with working impulse voltage near 30 V in the transmitter. A significant advantage provided by the control device is the absence of impulse falls due to the reduction of the amplifier output level caused by capacities. This ensures a good stability of the frequency relevant to the generated pulse. The bias of the 1st stage of the generator is stabilized by VD1, VD3, and VT2. An important problem regards the increase of the output impulse power in order to optimize the battery life. As a matter of fact, the generator spending power only when the pulse excitation occurs.

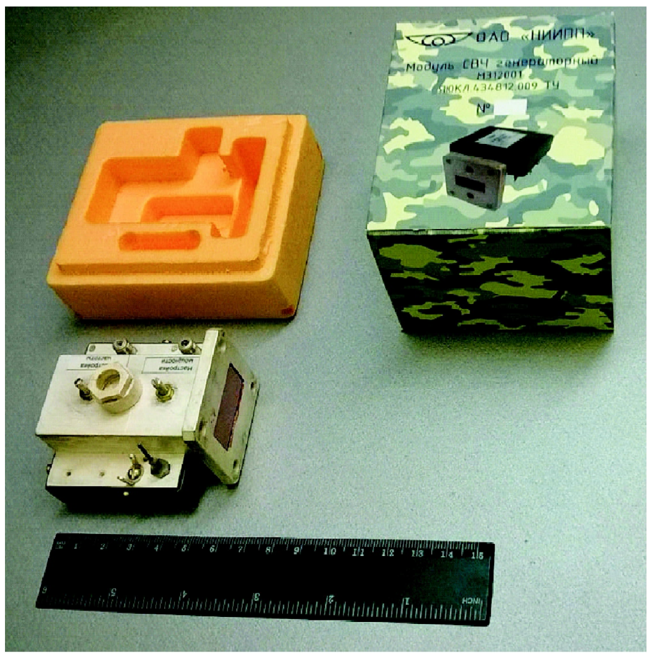

Figure 2: Transmitter with packing box

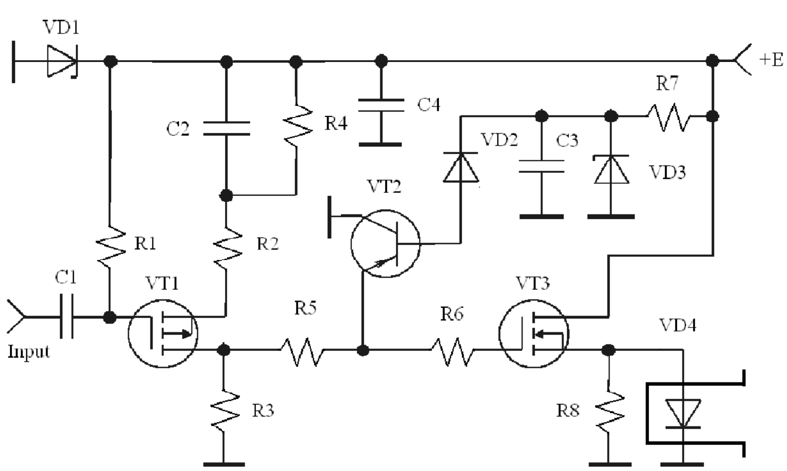

Figure 3: Diagram of the microwave generator

The last stage of the impulse generation gadget is designed with small output resistance for stable work. The limiter R3, R5, R6 provides stabilization of amplitude and duration of the output impulses. The Gunn diode VD4 is design with a tuning screw in the waveguide at a quarter wavelength distance from the edge of the rectangular waveguide (Fig. 4).

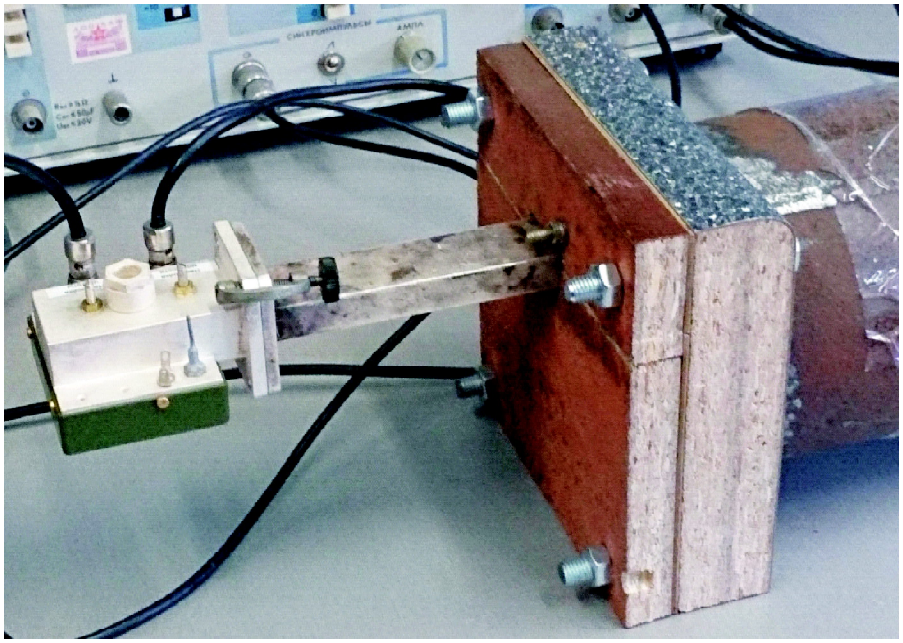

Figure 4: The experimental mock-up of transmitter

In this context, it is very important that the transmitter is designed in such a way that its dimensions do not outreach the internal diameters of the drilling pipes as the communication channel. Since the minimum diameter is 100 mm, the central frequency must be larger than 9 GHz. We use Gunn diode 3A750 working in frequency band 9–9.5 GHz.

3. EXPERIMENTAL RESEARCHES OF THE LWD TRANSMITTER

The experimental mock-up allows measuring of the central lobe frequency, the gain, output power, and output signal waveforms (Fig. 5).

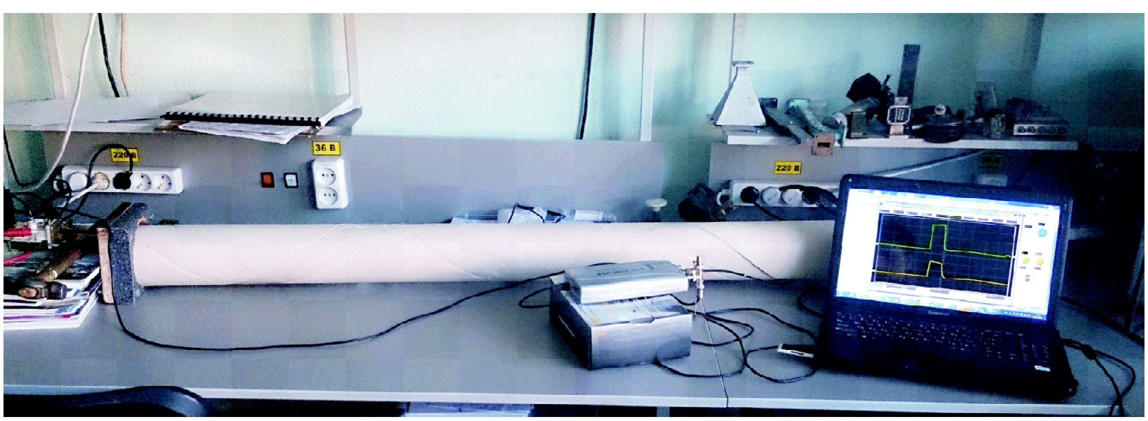

Figure 5: The experimental mock-up

First of all, the stability of the main characteristics of the module has been assessed. To this end, a number if telemetry of the output parameters of the transmitter have been performed by assuming a invariable duty ratio of the input impulse S=1000 and voltage U=90 V of the power supply. The bias current of the generator, the relevant power on output and central frequency have been evaluated as a function of amplitude and duration of the impulse from minimal operating values up to breakdown of the signal generation .

It has been found out that the majority significant parameters are power on the output with reduced bias level, small signal distortions, and level of reliability. The output power level evaluated as a function of the impulse amplitude and bias current features a load behavior (Fig. 6). Clearly, it is needful to raise of the impulse amplitude in order to increase the output power when the minimum current level is used.

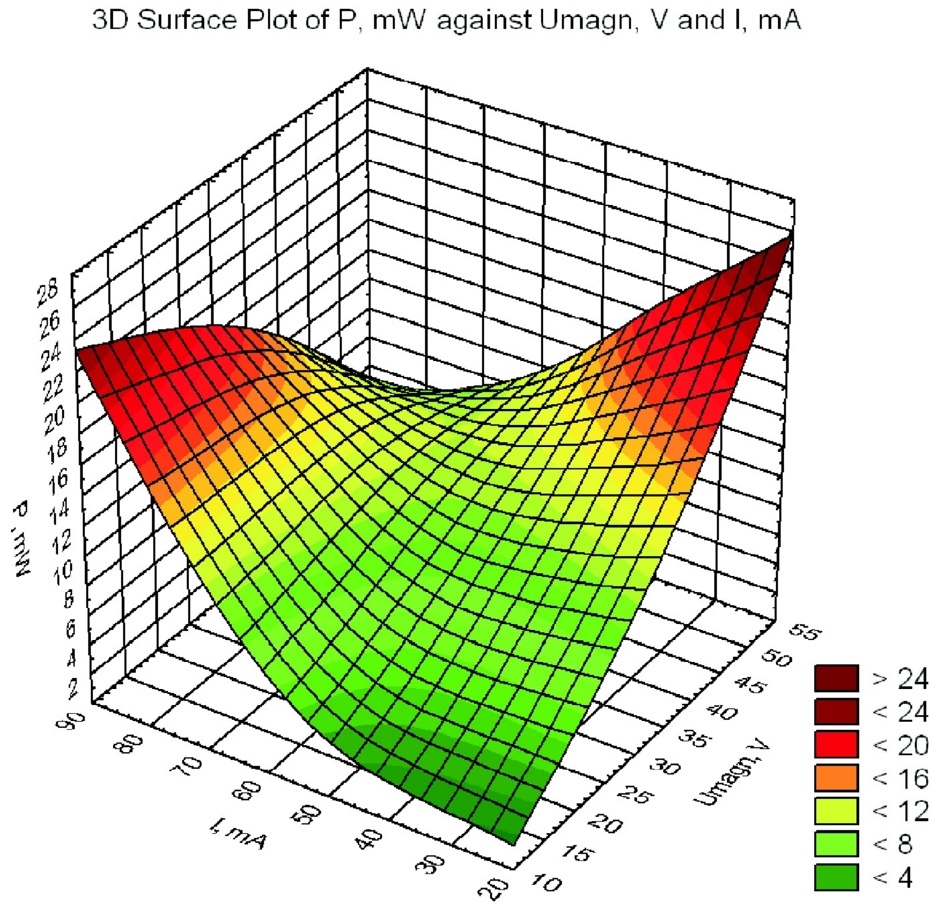

Figure 6: Dependences of the power on output from amplitude of input impulse U_{magn} and current I across generator

In Fig. 7 the output power $P=f\,(U_{amp}, T)$ evaluated as a function of amplitude of the impulse and duration is shown. There is a weak dependence on the duration and parabolic relation on the amplitude. The dependence has some region of power decreasing up to 10 W, which some changes at variation of impulse duration of generating near 100 ns.

The obtained graphs show that the radiated pulse power increases when the input pulse amplitude and duration become larger. The experimental measurements have shown that there is an optimal relation between output power, bias and current flowing through the transmitter.

4. ELECTROMAGNETIC PULSE IN CHANNEL WITH LWD TRANSMITTER – DETECTOR

We tested the diode detector integrated in a waveguide antenna for the retrieval radiowave pulses propagating along a pipe. The signal waveforms have been experimentally investigated. Fig. 8 show the typical behavior of the output and input signals of the measurement system. The telemetry data has been collected by using a 2m-long pipe filled up with water.

This system operates in evanescent mode below the cutoff frequency of the waveguiding section. In spite of this, we have experimentally verified that data transfer over long distances is still feasible under such conditions. The envelope graph of the radio impulse retrieved by the Fig. 8 depends on the waveform of bias pulse of the Gunn diode and dispersion characteristics of the media filling up the pipe (water, clay in real conditions).

The presence of water is responsible for the increase of the attenuation level. It has been found out that the attenuation strongly depends on the signal characteristics, and the electrical properties (and in particular the relative permittivity) of the filling media. The information regarding the attenuation has been collected experimentally. The adopted measurement procedure to this end consisted in the following: a metal pipe having 0.10 m diameter and 2 m length is closed on the signal generator on one end and the receiving detector on the other end. For mimicking a rel-life telemetry-based data transfer, the pipe is filled by water (Fig. 5).

The typical measurement results are shown in Fig. 9. It can be noticed that the higher the working frequency the larger the attenuation level along the filling media. A limpidity window for waves has been observed in frequency range 9–10 GHz.

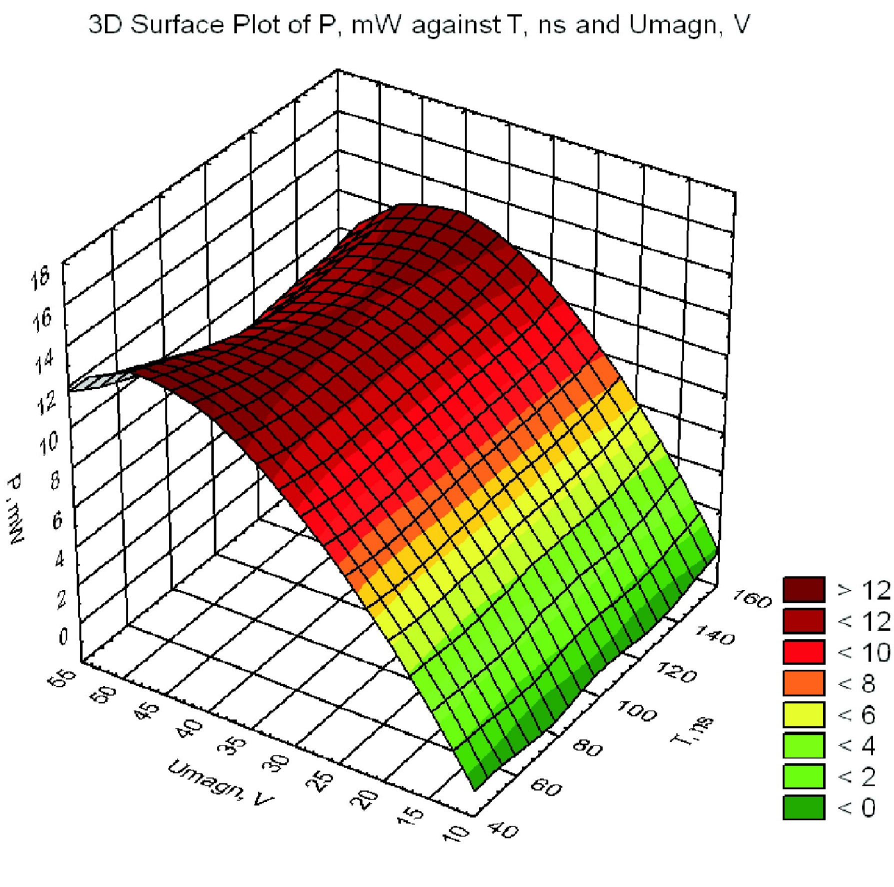

Figure 7: Relations of the output power vs amplitude of input impulse *Umagn* and pulse duration *T*

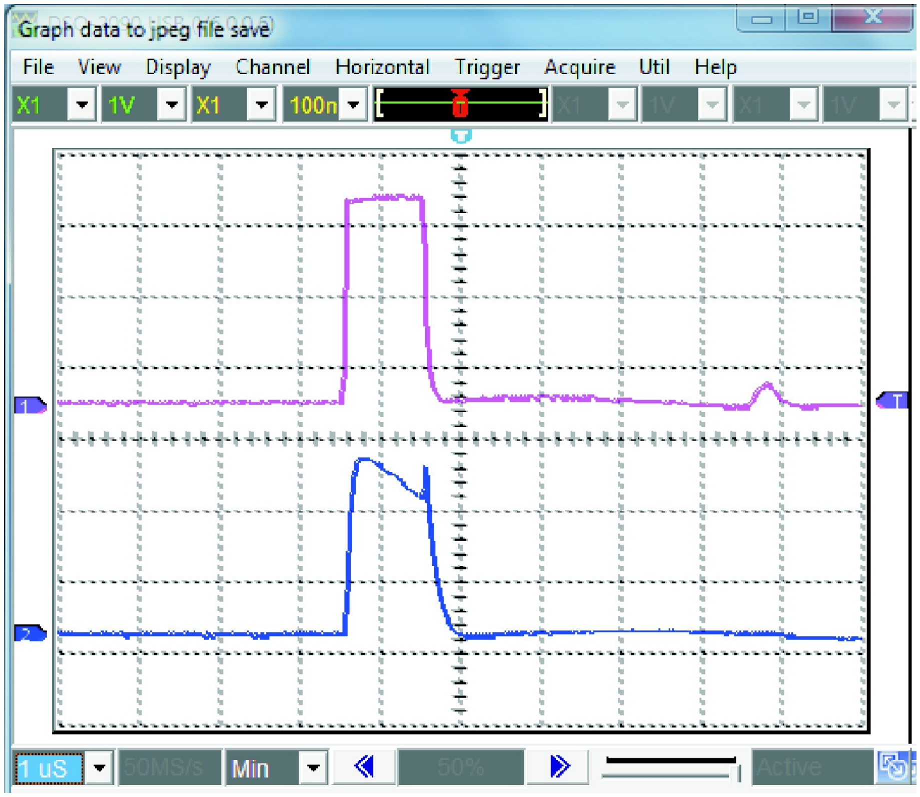

Figure 8: The input impulse of transmitter (1) and envelope graph of the detected signal (2) through the pipe in scale 1:100

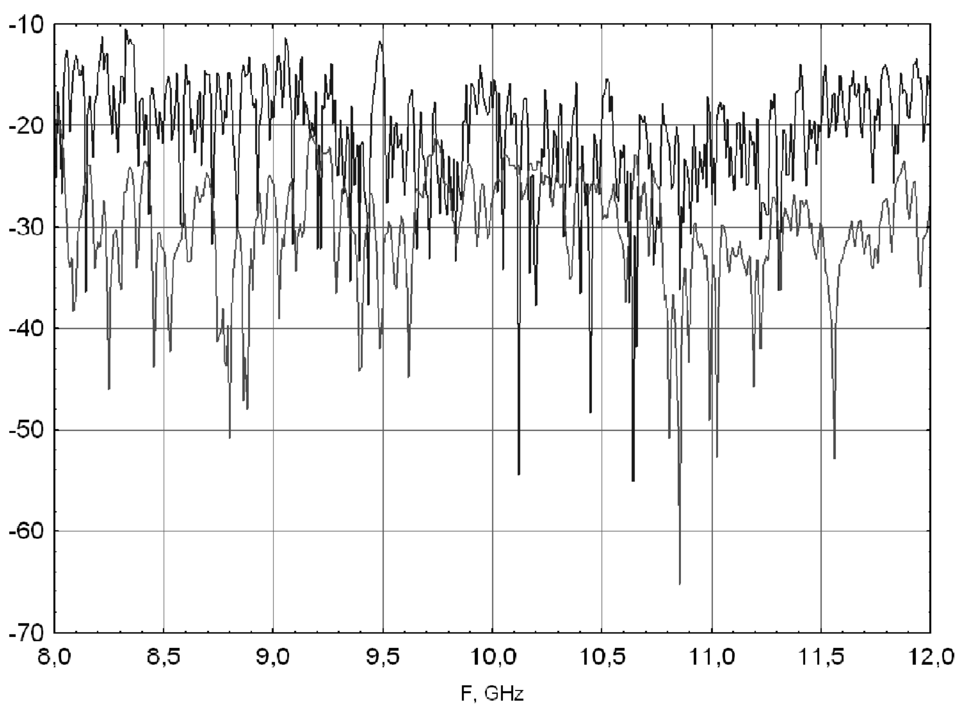

Figure 9: Signal attenuation vs frequency at propagation through the drilling pipe (blue curve – without water, red curve – with water)

5. SUMMARY

A dedicated transmit/receive module based on Gunn diode technology for LDW telemetry has been developed, and a detailed investigation of the relevant output power level has been carried out. In this way it has been found out that that increase of the excitation impulse voltage does not necessarily go to a corresponding growing of the power level of the module. Complex dependences have been observed between the central working frequency, and the current, duration, and amplitude of the excitation impulse. Based on the collected experimental data, the task regarding the power level of the generator might need to be addressed by switching to an alternative operational frequency framework.

The typical characteristics of the Gunn generator have been achieved [2] up to now:

- working frequency band: 9.3–9.5 GHz;
- amplitude of input impulse: 2.5–15 V;
- target impulse power: not less than 15 W;
- duty ratio of microwave pulse: not less 450;
- duration of start impulses: 0.05–1.5 us;
- maximum bias current: 30 mA;
- operating temperature: ±50 °C.

Such performance grade allows using such generating module both for MWD and LWD systems.

The experimental verification as well as the modeling of the radio channel are important in this research in order to analyze the effect of the clutter on the amplitude and distortion level of the radio signal propagating along a pipe. The direct injection of usual video pulses in the filling media is not feasible since the signal integrity would be severely affected. Furthermore, it has been found out that the signal-to-noise ratio strongly depends on the waveform of the signal propagating along the filling medium. Therefore, special pulse signals have to be used for data transfer in drilling pipes. This allows carried out investigations on data transfer via various media (including water) and to design an optimal measurement system based on the newly proposed pipe-based channel.

In our model the drilling pipes are filled up with dielectric composite materials, whose effective electrical properties can be determined by reflectometry techniques retrieving information from the radio signal reflected back to the antenna sensor used to establish the communication channel within the pipe.

ACKNOWLEDGMENT

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