Microprocessor-based information system for control of exploitation in bottom-to-head channel on the basis of noise-like signals

A A Shakirov\textsuperscript{1,2}

\textsuperscript{1}Ufa State Petroleum Technological University, Branch of the University in the City of Oktyabrsky, 54a, Devonskaya St., Oktyabrsky, Republic of Bashkortostan, 452607, Russian Federation
\textsuperscript{2}Public joint-stock company Research and Development enterprise Research and Design Institute of Well Logging, 1, Gorkiy St., Oktyabrsky, Republic of Bashkortostan, 452614, Russian Federation

E-mail: albert551@yandex.ru

Abstract. The work demonstrates the results of noise-like (spread-spectrum) signal application in oil industry. A functional practical scheme of information support in bottom-to-head communication channel is presented. Some of spread-spectrum signal noise resistance issues are described.

1. Introduction

When a hydrocarbon deposit enters the later phase of development, reduced basic cost of the product becomes an urgent issue. Rejecting the traditional information support of oil extraction both reduces the basic cost and opens new technological opportunities in the sphere. The measurements when the well is equipped with submersible pumps can be made easily, because the information signals are transmitted to the surface through the pump power supply cable. More than 70\% of wells are equipped with underground extraction equipment with ground drives. The information about exploitation parameters of the wells can be received directly or indirectly, which has appreciable drawbacks. It can also be made by suspending the well and submerging research instruments between the casing and production strings, which has no positive effect on oil extraction profitability. The situation gets worse when the well is operated by dual completion.

This paper considers application of a wireless telemetry system on the basis of a communication channel using ground currents (electromagnetic communication channel) [1–5].

2. Equipment and methods

The ASI\textsuperscript{M} hardware-software complex realizing the described system was implemented following the “Technical manual on geophysical studies and operation of wireline equipment in oil and gas wells” (RD 153-39.0-072-01).

3. Analysis of electromagnetic communication channel and its applications in development of hydrocarbon deposit
This technology assumes that the initially narrow-band (in terms of the spectrum) desired signal during the transmission transforms such that its spectrum significantly widens as compared to the initial state. This means, the signal spectrum is somewhat spread along the frequency range. Together with the signal spectrum widening, the redistribution of the spectral energy density of the signal occurs; the signal energy is also spread along the spectrum. As a result, the maximum power of the transformed signal becomes considerably lower than the power of the initial signal. In addition, the level of the desired signal can virtually reach that of the natural noise. As a result, the signal becomes undecipherable, it blends with the natural noise. It is the change of the spectral energy density of the signal, which is the main concept of the spread-spectrum signal [5].

After potential coding, the information bits—logical zeros and ones—are transmitted as square voltage pulses. A square pulse with duration $T$ has the spectrum with the width inversely proportional to the pulse duration. In this regard, the lower the duration of an information bit, the wider spectrum such signal takes. The sequences of chips embedded into information bits are referred to as noise-like codes (PN-sequences), which emphasizes the fact that the resulting signal becomes noise-like, and its is hardly distinguishable from the natural noise. It becomes clear, how to widen the signal spectrum and make it indistinguishable from the natural noise. One can simply use a random chip sequence. However, the question of how one should receive such signal remains unanswered. If it becomes noise-like, then isolating the information signal from it is a non-trivial task, if not impossible. It turns out that it is possible by selecting right sequence of chips. The sequences of chips used to widen the signal spectrum should satisfy a definite requirements of autocorrelation. In mathematics, the term autocorrelation means the degree of function similarity to itself at different moments of time. If the sequence of chips selected for which the autocorrelation function will have a clear peak only for a single moment of time, then such information signal can be distinguished against the noise. To do so, the received signal in the receiver is multiplied by the sequence of chips, i.e. the autocorrelation function of the signal is calculated. As a result, the signal again becomes narrow-band. Then it is filtered in a narrow band equal to double transmission rate. Any noise getting into initial spread-spectrum after multiplication by the sequence of chips, conversely, becomes spread and cut by filters, while the information band receives only the part of the noise having appreciably lower power than the noise on the receiver input (Fig. 1).

Barker codes, among the known pseudo-random sequences, have the best noise-like properties, which conditions their wide application. There are different Barker codes in terms of duration: 3, 4, 5, 7, 11 and 13 chips. For instance, let us consider the situation when into a single information bit corresponding to logical 1, an 11-chip sequence of zeros and ones is embedded: 10110111000. The logical zero in this case can correspond to the inverted sequence of chips, i.e. 01001000111. To transmit the signal, the information sequence of bits in the transmitter is combined modulo 2 (mod 2) with 11-chip Barker code using XOR operator (Fig. 2) [6, 7].

**Figure 1.** Technology of spectrum widening allows transmitting data with the level of natural noise.
Figure 2. Spread-spectrum signal formation on the basis of 11-chip Barker sequence

Discrete alternative of autocorrelation functions in terms of considered signal is as follows:

\[ K_u(n) = \sum_{j=-\infty}^{\infty} U_j U_{j-n}, \]

where \( n \) is a positive or negative integer or zero; \( U_j, U_{j-n} \) are discrete signals.

For zero offset, the autocorrelation function turns into discrete signal energy [7]:

\[ K_u(0) = \sum_{j=-\infty}^{\infty} U_j^2 = E_u. \]

To illustrate the above, let us calculate the discrete function of autocorrelation of 11-position signal \( U=\{1,1,1,-1,-1,1,1,-1,-1,1\} \) (Barker signal). The autocorrelation function is

\[ K_u(11)=\{11,0,-1,0,-1,0,0,1,0,-1\}. \]

The autocorrelation function is plotted in Fig. 3.

Evidently from Fig. 3, there is a clear peak only for a single sequence of discrete signal of for a single moment of time. Depending on the noise environment, the peak amplitude will decrease, but will be distinguishable against the noise.

Figure 3. Autocorrelation function plots.

All the operations with transmitted and received signals are made in software. The resident software of the downhole equipment and ground transceiver are implemented using Atmel microprocessors [8].

Fig. 4 illustrates a dual completion technology with two sucker-rod pumping units with information system implemented using two wireless telemetry systems generating time spaced signals. A strong point of this dual completion technology is the capability of simultaneous extraction from two different reservoirs.
Figure 4. Dual completion technology with wireless telemetry system and two sucker-rod pumping units: 1) oil-well tubing, 2) sucker-rod pumping unit with ASIM main unit, 3) filter, 4) pay zone, 5) and 7) lower electrode, 6) connecting separating cable, 8) AGRU, 9) PC, 10) antenna communication line, 11) packer.

Figure 5 depicts dual completion technology with two screw pumps with information provision by wireless telemetry system. Upper oil-bearing and lower water-bearing beds are separated by the packer. The hydrocarbons extracted from the oil bed are separated, while the reservoir water is pumped into the lower water-bearing bed. A strong point of this dual completion technology is in higher productivity of watered beds.
Figure 5. Dual completion technology with wireless telemetry system and two screw pumps: 1) oil-well tubing, 2) screw pump, 3) filter, 4) water bed, 5) main ASIM unit, 6) connecting separating cable, 7) lower electrode, 8) AGRU, 9) PC, 10) antenna communication line, 11) ground drive, 12) oil bearing bed.

4. Conclusions
The majority of deposits in Russia enter the late development phase. One of the ways to preserve the profitability is the information provision of oil well exploitation using wireless telemetry system. To accomplish this task, the prototypes of the advanced direct monitoring system of hydrocarbon reservoir were developed: basic downhole instruments, repeaters and software for interaction of information and telemetry systems. In addition, the organizational and technological measures are performed to promote and improve solutions laid in the base of the system [9, 10–12].

5. Acknowledgements
The paper uses results of research works at oil and gas extracting facilities of Tatarstan and Bashkortostan.
References

[1] Baker Hughes 2014 E-MTrak Electromagnetic Telemetry, available at: http://www.bakerhughes.com/products-and-services/drilling/drilling-services/measurement-while-drilling/e-mtrak-electromagnetic-telemetry

[2] Farahani S 2011 ZigBee Wireless Networks and Transceivers (Newnes: Oxford, UK)

[3] Gao, Finley D, Gardener W, Robbins C, Linyaev E and Moore J L 2006 Acoustic telemetry delivers more real-time downhole data in underbalanced drilling operations SPE/IADC Drilling Conf.

[4] Jurkov A S, Cloutier J, Pecht E and Mintchev M P 2011 Experimental feasibility of the in drilling alignment method for inertial navigation in measurement-while-drilling IEEE Trans. Instrum. Meas. 60(3) 1080–90

[5] Márton L Szanyi, Casper S Hemmingsen, Wei Yan, Jens H Walther and Stefan L Glimberg 2018 Near-wellbore modeling of a horizontal well with Computational Fluid Dynamics J. Petrol. Sci. Eng. 160(1) 119–128

[6] Kozikhin R A, Daminov A M, Fattakhov I G, Kuleshova L S and Gabbasov A Kh 2018 Identifying the efficiency factors on the basis of evaluation of acidizing of carbonate reservoirs IOP C. Ser.: Earth Env. 194(6) 062013

[7] Akhmetov R T, Mukhametshin V V and Andreev A V 2017 A quantitative assessment method of the productive formation wettability indicator according to the data of geophysical surveys SPE Russian Petroleum Technology Conf. (Moscow: Society of Petroleum Engineers, 16-18 October 2017) p 12

[8] Mukhametshin V V 2018 Rationale for trends in increasing oil reserves depletion in Western Siberia cretaceous deposits based on targets identification Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering 329(5) 117–124

[9] Fattakhov I G, Kadyrov R R, Nabiullin I D, Sakhibgaraev R R and Fokin A N 2015 Using artificial neural networks for analyzing efficiency of advanced recovery methods Biosciences biotechnology research Asia 12(2) pp 1893-1902

[10] Akhmetov R T and Mukhametshin V V 2018 Estimation of displacement coefficient with due account for hydrophobization of reservoir using geophysical data of wells IOP C. Ser: Earth Env. 194(6) 062001

[11] Yakupov R F, Gimazov A A, Mukhametshin V Sh and Makaev R I 2018 Analytical method for estimating efficiency of oil recovery technology in case of bottom water-drive reservoir, verified on the hydrodynamic model Oil Industry [in Russian – Neftyanoye Khozyaystvo] 6 66-69

[12] Goryunova M V and Yantsevich V V 2018 Determining the location of restriction in formation pressure management systems pipelines with wavelet analysis IOP C. Ser.: Earth Env. 194(2) 082015