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ELECTROMAGNETIC MWD/LWD - WHERE AND WHY?

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Key-words: Measurement While Drilling (MWD), Elektromagnetics (EM), Historic development of EM and EM MWD, Attenuation, Skin effect.

Application of electromagnetics as a mean of data transfer from bottom hole assembly to the surface during deep well drilling is described. Particularly, it is convenient when drilling with foam, aerated mud or air drilling in underbalance condition. Historic development of electromagnetics (EM) and of EM Measurement While Drilling (EM MWD) is elaborated briefly. Accentuated is the problem of attenuation of EM waves propagating through the rocks.

Ključne riječi: Telemetrija (MWD), Elektromagnetizam (EM), Povijesni razvitak EM i EM MWD, Slabljenje, Skin efekt.

Opisana je uporaba elektromagnetizma kao načina prijenosa pokazatelja od alatki na dnu bušotina do površine. To je posebno povoljno kod bušenja uz uporabu pjene, aerizirane isplake ili ispuhavanja pri bušenju u uvjetima podtlaka. Sažeto je prikazan povijesni razvitak elektromagnetizma i elektromagnetske telemetrije. Naglašen je problem slabljenja elektromagnetskih valova pri prolazu kroz stijene.

Introduction

With existing geological knowledge and up top now applied technology proven oil reserve in Croatia was about 115 million tons. More than 80% of that was produced already and the rest of about 25 million tons may be produced in a few coming years. We may be sure that there should be at least 10% of proven reserve or another recoverable 11.5 million tons as by-passed oil because of conning of water and/or gas or of oil traps left behind in pay reservoirs. This oil may be produced by horizontal or ER (extended-reach) re-entries from existing vertical or slanted wells or from new, well situated horizontal or ER wells.

Drilling of horizontal and ER wells has become a reality since development of adequate PDM (**p**ositive **d**isplacement **m**otor), computerized process control and MWD (**m**easurement **w**hile **d**rilling). That has happened during the last 20 years. The most applied MWD system is that using mud pulses for signal transfers from the BHA (**b**ottom **h**ole **a**ssembly) through a continuous liquid column to the surface, where signals brought by these pulses are elaborated and data shown in analog or digital form (S t e i n e r and B o š k o v S t e i n e r, 1994).

If there is no continuous liquid column, as it is the case when foam or air used as circulation media, mud pulses are not a reliable media for signal transfer. In case of development of low pressure oil and/or gas reservoirs or in searching of by-passed oil in depleted reservoirs, when underbalanced drilling is the most efficient way for enabling efficient recovery of the reservoir, it is advisable to apply foam as circulating media or even to apply air drilling. It is often the case that horizontal or ER wells are the best solutions to enable high recovery of hydrocarbon fluids from such reservoirs or the only efficient solution for that. Drilling of such wells is practically impossible without an MWD system. If there mud pulse MWD can't be applied the only solution is sending data through an electrical system (S o u l i e r and L e m a i t r e, 1993).

In early stage of MWD development cable has been used for signal transfer. It was not practical to pull out and build in the cable at each lengthening of drill string. Having a window in a pipe below the rotary table was a solution to avoid pull out and build in the cable. But if drill pipe has to be rotated, the cable has often been ruined in the annulus.

A solution to apply wireless electric power for signal transfer in a wellbore has been developed since 1980. That year ***Geoscience Electronics Corporation*** (GEC) in Westlake Village, California, US has started a develop of a MWD system based on an electromagnetic circuit where one coductor was the drill string and the other was ground surrounding the borehole. First application of it was in River-Crossing Drilling. Following successful control of a short and shallow well, the system has been adapted and applied for large-diameter oilfield drilling. Than it was used in Australia for drilling through a gassy coalbed. Sponsored by the US DOE (**U**nited **S**tate **D**epartment **o**f **E**nergy) GEC has developed and tested successfully an EM MWD system for horizontal air drilling in coal reservoirs and in oilfields. Recently GEC has developed a system, having a relay between the transmitter in the BHA and the receiver at the surface which is giving reliable data from a depth of about 6000 m (x x x 1993, r e v.. 1994).

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Geoservices in Le Blanc-Mesnil in France has started its research with EM MWD two years later, in 1982. Its first telemetry (MWD) system was applied for in real-time pressure and temperature measurement in a DST (drill stem testing) operation. In 1987, Geoservices has started to apply EM MWD for well control of horizontal and slanted wells till depths of 2000 to 3000 m. Recently, after a relay was built into its system too, well may be controlled till a depth of about 7000 m (M a g l i o n e et al., 1994).

According to available information these two companies have made the greatest progress in introduction of EM MWD till now. A number of other service companies in the US are announcing their EM MWD service and there are data in literature showing that Japan and Russia are applying own EM MWD systems.

Where Electromagnetics is Applied?

In the 6th century BC the Greek philosopher *Tales* from Milet has observed and described electrostatic forces created by rubbing amber which attracts then surrounding objects.

In 1800 *Alessandro Volta* has discovered the first source of electricity, a battery composed of elements denominated after *Luigi Galvani.*

In 1819 *Hans Christian Oersted* has discovered an interaction of a magnetic needle and a conductor (wire) through which electric current is flowing.

In 1820 *Andrè-Marie Ampére* has established that electrical currents are mutually influenced by forces whose he has mathematically defined as:

$$B=\frac{\mu_o \times I}{2\pi \times r}$$

where are:

B= magnetic induction, magnetic field, T

μ_O= magnetic constant in vacuum, permeability,

$4\pi \times 10^7\ N \times s^2/C^2$

I=current in the wire, A

r=radial distance of the magnet from the wire, m

At the same time *Jean-Baptiste Biot* and *Felix Savart* have defined the so called Biot-Savart law of the magnetic force produced by a system of stationary current, I which is governing this phenomena:

$$B=\frac{\mu_o \cdot I}{2\pi}\oint_s \frac{ds \cdot r_o}{r^2}$$

where are:

ds=conductor length, m

r_O=radius of rotation, m

In 1826 *George Simeon Ohm* has defined that current force in a conductor (wire) which doesn't content any electromotor force is proportional to the potential difference on its ends. That is called the Ohm's law.

In 1831 *Michael Farraday* has discovered that change of magnetic field is inducing an electromotor force in a coil (spiral wire).

In 1841 *James Prescot Joule* has defined a law which connects current flow through a conductor with the heat developed in it.

In 1847 *Gustav Robert Kirchhoff* has defined two laws: the first one describing continuity of electrical current, and the second one which is mathematically identical with the law that potential difference between whichever two points has the same value on all paths between them.

In 1855 *James Clerk Maxwell* has described mathematically Farraday's developments as:

$$e=\frac{d}{dt}\int_s B_n dS$$

where are:

e = induced electromotor force in the contour

$\int_s B_n dS$ =t otal magnetic flux embodied in that contour

With a number of other equations Maxwell has contributed a lot to discovery of numerous electromagnetic phenomena which have been introduced in contemporary technology and solving of everydays life problems (Tehnička enciklopedija, 1967).

Recently these applications are:

Table 1. Frequencies and wavelengths (in air) of various electromagnetic waves

	f(Hz)	λ in air (m)
gamma-ray	10^{18}-10^{22}	10^{-10}-10^{-14}
X-ray	10^{17}-10^{21}	10^{-8}-10^{-13}
ultraviolet (UV)	10^{15}-10^{17}	10^{-7}-10^{-9}
light	10^{14}-10^{15}	10^{-6}-10^{-7}
infrared (IR)-heat	10^{11}-10^{14}	10^{-3}-10^{-6}
microwaves	10^{8}-10^{11}	10^{0}-10^{-3}
radio	10^{6}	10^{2}-10^{3}
TV and radio	10^{4}-10^{9}	10^{-1}-10^{5}
Induction log	10^{6}-10^{7}	10^{1}-10^{2}
EM MWD	10^{0}	10^{8}

As you can see on the Fig. 1 a relation does exist between f and λ in the air. That relation is:

$$\lambda = c \times f$$

where is: $c=3 \times 10^8$ m/s and that is the velocity of light through air (B u e c h e, 1980).

Through the ground velocity of light is lower and so the wave length of the electrical current. At the same frequency wave length is lower through loose sediments filled with fresh water than through elder, consolidated rocks, particularly through those containing brine or evaporite.

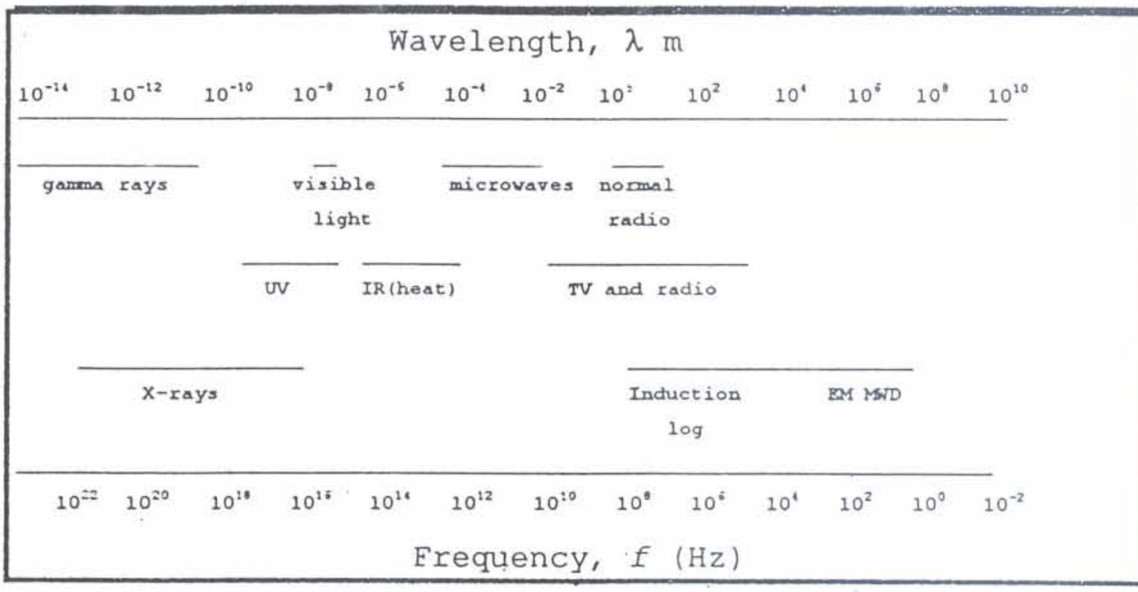

Fig. 1. Position of various electromagnetic waves (Source: B u e c h e, 1980, Supplement: Steiner, 1996)

Electrical current traveling along the drill string and through ground has substantial losses of energy which causes attenuation. According to literature (Hayt Jr., DeGauque and Grudzinski etc.) there is a skin effect when electrical current is traveling along conductors and its depth can be calculated by equation:

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

where are:
δ=skin depth, m
f=frequency, Hz
μ=permeability, H/m
σ=conductivity, S/m (or: mho/m)

These authors (B u e c h e, 1980 and H a y t, 1981) are showing a relation:

$$\alpha = \frac{1}{\delta}$$

where is:
α=attenuation, dB/km.

Consequently:

α : : f, μ,σ;

$$\alpha :: \frac{1}{R}$$

where is:
R= resistivity, ohm.m

Application of Electromagnetics for MWD

Three types of EM borehole comunication methods are available (R u b i n and H a r r i s o n, 1990). As it is shown on Table 2, that are:

Table 2. Electromagnetic Borehole Communications Methods and Techniques

TECHNIQUE	METHOD	COMMENTS
	HARD-WIRED	
COAXIAL DRILL PIPE		
STORED WIRE		EXPENSIVE UNRELIABLE
SINGLE WIRE FIXED (WIRELINE)		WIRELINE LOGISTICS
MULTI-CONDUCTOR WIRELINE		AND EXPENSE
	THROUGH - THE - EARTH	
VERTICAL MAGNETIC (SOLENOIDAL)		VERY HIGHLY ATTENUATING
VERTICAL ELECTRIC (DIPOLE)		IMPOSSIBLE IN PRESENCE OF DRILL-STRING
	DRILL - STRING/EARTH (TRANSVERSE E & H)	
TOROIDAL COUPLED		STRUCTURALLY WEAK, POOR MATCH
DIRECT COUPLED		GEC MATCHED-FEED-POINT

Source: R u b i n & H a r r i s o n (1990)

Hard-Wired methods

Specially manufactured coaxial pipe joints or a stored-wire system are necessary. Handling is

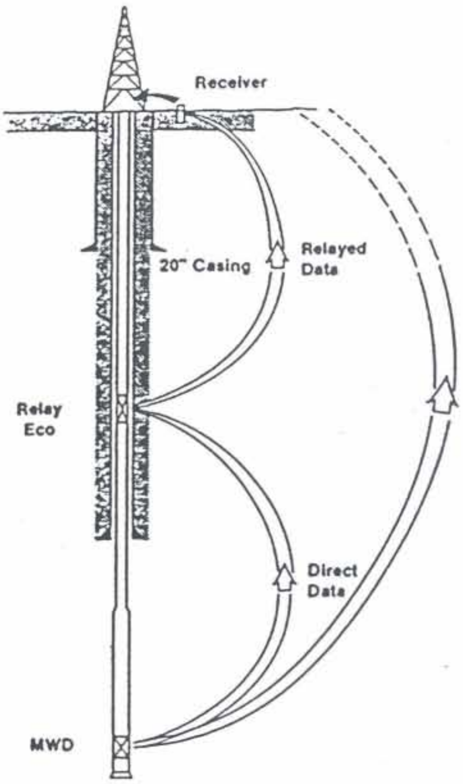

Fig. 2. Double stage transmission (relay transmission) -synoptic (Source: Soulier and Lemaitre, 1993)

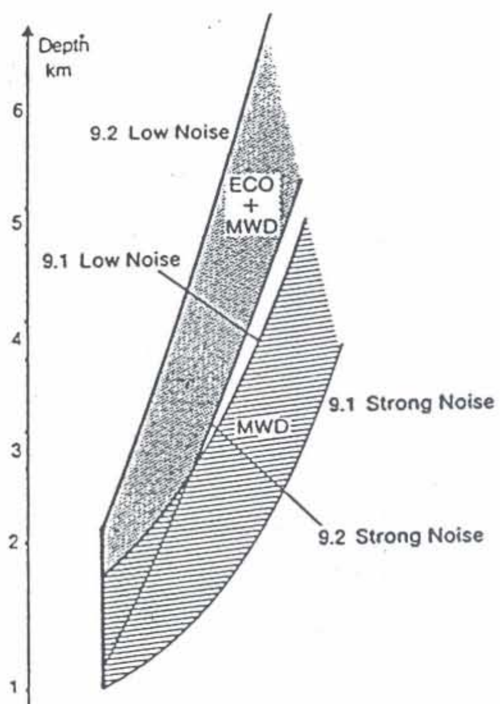

Fig. 3. Single and double stage transmission expected propagation distances (Source: Soulier and Lemaitre, 1993)

complex and time consuming. Only the Single Wire Fixed System has a limited commercial use.

Through-the Earth methods

Only the Vertical Magnetic (VM) Method is an EM Trough-the-Earth method. The other one, namely Vertical Electric Method, in case that it is applied in borehole condition, becomes the Drill-String/Earth Method in the presence of casing and/or a drill- string. For the VM Method or the Solenoidal Method relatively high frequencies have to be used for successful propagation through conductive earth. Therefore, attenuation may be so high that this technique is unacceptable for practical borehole scenarios.

Drill-String/Earth Communication (D-S /EC) method

This method utilizes the drill-string (or any electrical conductor such as casing or tubing) as one conductor and the earth as the other "conductor". By that way attenuation is lower, particularly because ultra-low frequencies, from one Hertz to about 20 Hertz are applied. The attenuation rate is increasing with depth and with higher earth's conductivity. In younger, poorly consolidated sediments containing brine, attenuation rate is high and reliable EM signals can be achieved from depths up to 2000 m, in some cases up to 3000 m. In consolidated rocks those depths are up to 50% higher. By implementation of a relay at about half of the length of the drill-string *(S o u l i e r and L e m a i t r e, 1993, and xxx, 1994) the measurement and recording of data can be realized from about double of those lengths, from 5000 m to 7000 m depth (Figs. 2 and 3). The only condition for placement of the relay is that it has to be in the openhole section of the well and not inside a casing. When a relay is placed inside the cased hole, its transmission efficiency is noticeably reduced, by 30 to 40 dB compared to open-hole transmissions.

There are three techniques applied in realization of the D-S/EC method: solenoidal coupled, toroidal coupled and direct coupled (Fig. 4). Solenoidal and toroidal transducers have their weaknesses: they are large, costly and inherently weak. They cannot efficiently match realistic loads at ultra-low frequencies. On the other side, direct coupling uses a short insulated gap and the part of the pipe where the gap is situated is strong as the rest of pipe or can be even stronger than it. The design is less expensive than any practical toroid design.

Practical Application of the EM MWD

In conditions similar to our Pannonian basin structures, in the Italian Po valley Trécaté field, a well was drilled through uncompacted quaternary and tertiary formations (M a g l i o n e et al., 1994). These formations are very unfavorable for EM

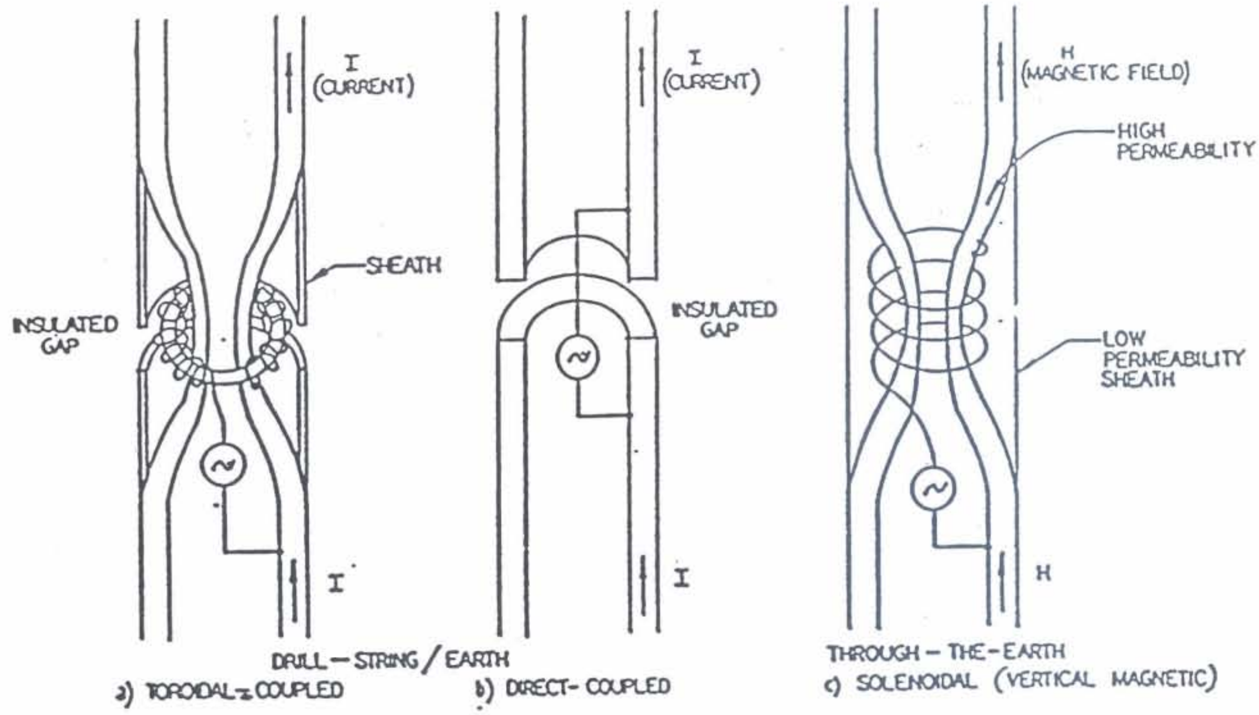

Fig. 4. Electromagnetic methods/techniques-Means of coupling energy (Source: Rubin and Harrison, 1990)

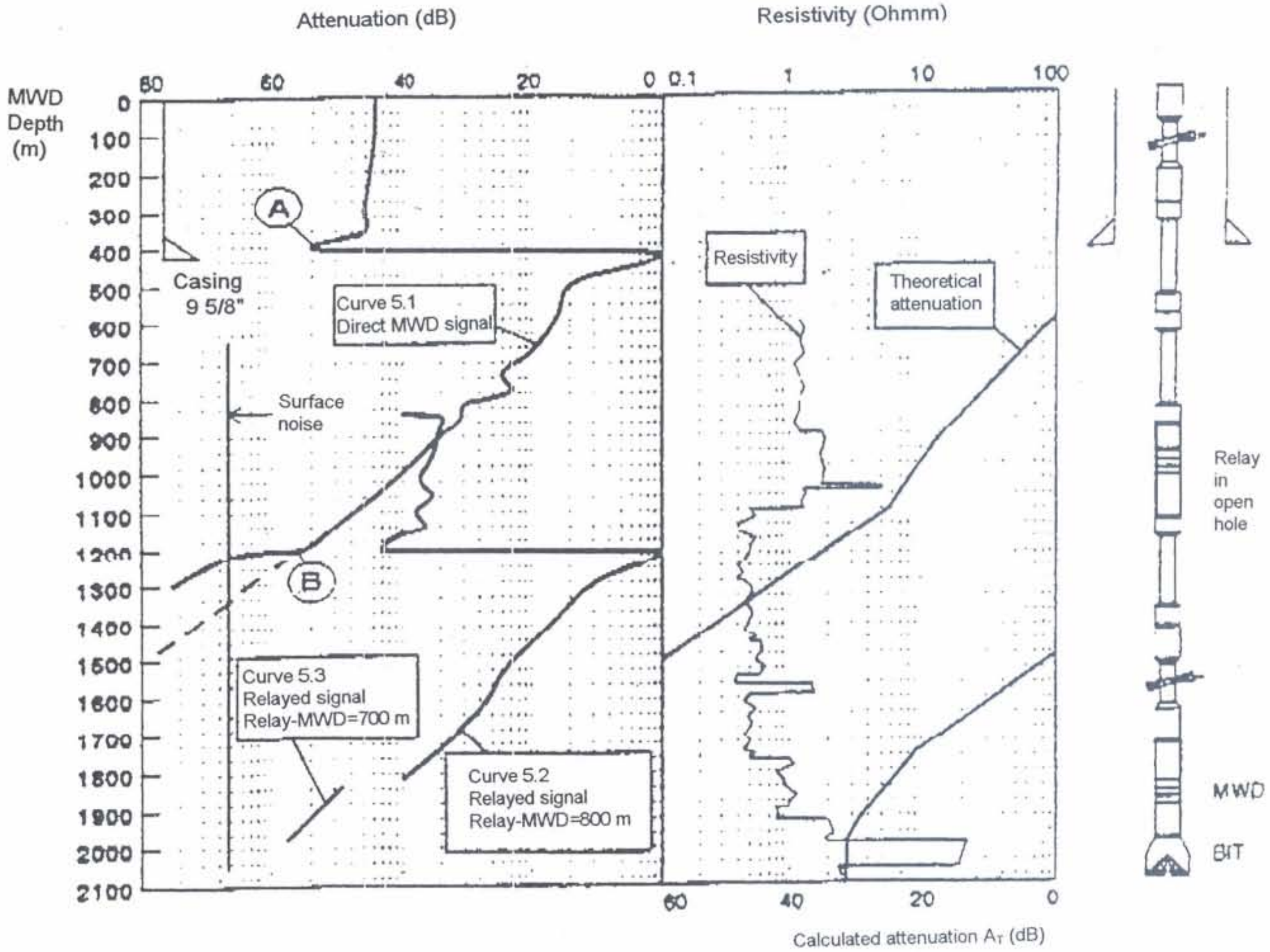

Fig. 5. Trécaté C well, 8 1/2" drilling phase, MWD and relay transmission results (Source: Maglione et al., 1994)

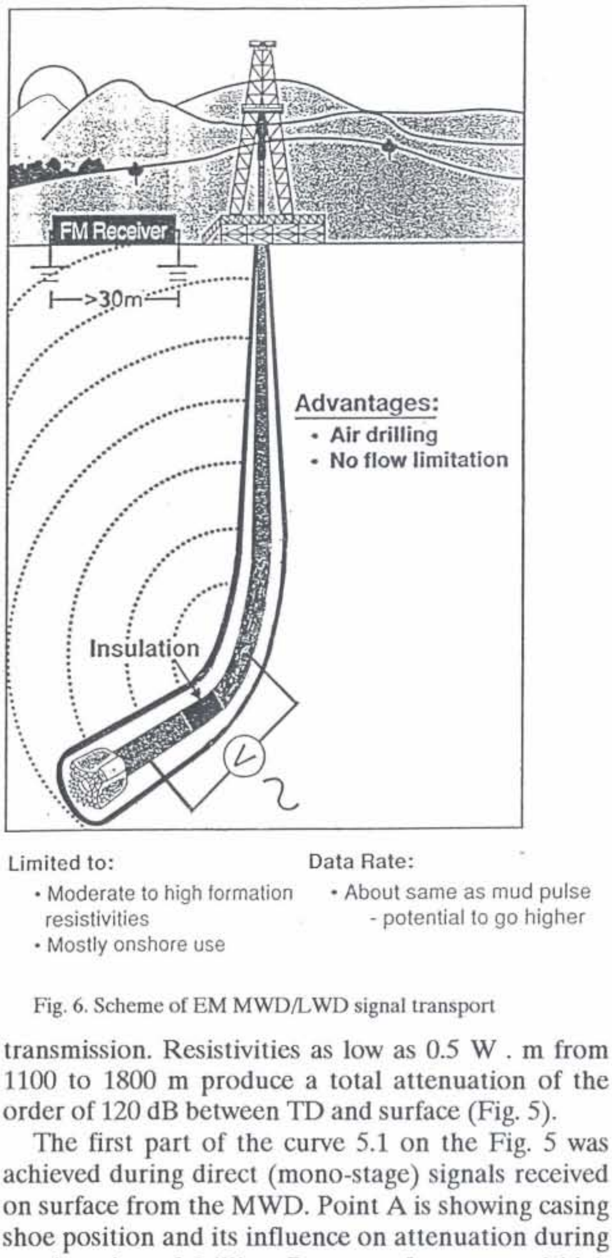

Fig. 6. Scheme of EM MWD/LWD signal transport

transmission. Resistivities as low as 0.5 W . m from 1100 to 1800 m produce a total attenuation of the order of 120 dB between TD and surface (Fig. 5).

The first part of the curve 5.1 on the Fig. 5 was achieved during direct (mono-stage) signals received on surface from the MWD. Point A is showing casing shoe position and its influence on attenuation during continuation of drilling. Because of unexpected high surface noise coming from a refinery adjacent to the wellsite, attenuation of the EM MWD system has reached that level. A relay was placed 800 m above the BHA and attenuation has dropped to the level shown on the curve 5.2. Curve 5.3 was plotted after a change of bit (run pipe), when the relay was situated 100 m closer to the BHA.

Since power of signals was over the limit of 20 dB, even in this geologically unfavorable circumstances the MWD signals have been used successfully.

Conclusions

In spite of later start of development, comparing with mud pulse MWD, the EM MWD is penetrating into practical application and has shown certain advantages already. With EM MWD we may have all the readings which we usually have from mud pulse MWD (azimuth, dip-angle, tool face angle, weight on bit, torque, temperature, pressure) and two important LWD readings (gamma-ray and resistivity). It is question of time when other appropriate LWD readings will be developed for EM MWD/LWD (Fig. 6).

EM MWD does not need mud circulation for signal transfer and it can be used during break of circulation and when there is not a homogeneous liquid column in the drill-string.

EM MWD system can be applied in two directions: from BHA to the surface and backward, from the surface to BHA (S o u l i e r and L e m a i t r e, (1993). At the moment there exist no part of the BHA whose function can be controlled by electromagnetic signals. But such tools may be developed in the future.

Signals from the surface to the bottom of the hole may be applied for opening and closing valves of the DST equipment, for activating and deactivating of inflatable packers, for control of gas lift valves and numerous activities in workover and production.

As a conclusion it may be stated that from the technical standpoint EM MWD has defitinely a good future in the petroleum industry. Its shortcoming is a usually high price for rent (in the US c/a $ 4500.- per hour, comparing with c/a $ 3500.- per hour for the mud-pulse MWD). May be that will be lower if it will have a broader appliance in the future.

We have seriously to consider appliance of this system in aim to get experience and may be apply it in domestic and foreign service jobs.

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