Wireless data transfer in salt rock

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Abstract

The measurement of processes up to the point of long-time monitoring of abandoned mines or mine parts is a need in salt mining and final waste disposal. Recent available measurement technology is often based on data transfer via cable connections and a power supply by an underground available power network. This is in contradiction to the commonly aspired fluidic pressure tightness of sealing or to the integrity of flow barriers as well as to the technical effort to keep the monitored mine excavations open.

In the scope of a research and development project subsidised by the German Federal Ministry of Economy and Technology (BMWi) a concept for wireless data transfer using radio propagation through mainly dry salt rock was developed by IBeWa-Ingenieurpartnerschaft (IBeWa). Successful tests were performed at different reference sites. Recent tests in a drift sealing at the Morsleben repository for radioactive waste (ERAM) are kindly supported by the German Federal Office for Radiation Protection (BfS). The measuring concept allows the wireless transfer of data from different physical parameters in dry salt rock up to several hundred metres distance. The patent-protected radio sensors were extended time tested and reached in the recent configuration about 10 million measurements and about 760000 data transfers. Depending on the measuring problem (e.g. frequency of measurement) actually a measurement time up to several decades seems to be possible.

1. Motivation

Electromagnetic waves are in use for many decades in order to explore geological structures of saliniferous formations (e.g. ground radar) and became state of the scientific and technical knowledge. However, data transfer through rocks based on propagation of electromagnetic waves seems to open many applications in mining. Data transfer based on propagation of electromagnetic waves is defined by the electromagnetic properties of the rock, its pore space and the contained fluids.

Monitoring in salt mining is a fundamental basis for excavation planning, optimising of production and long-term, post-abandoned monitoring. That is reason for the importance of installation of measurement technology under the condition of surface and underground mining. However, monitoring of fluidic tight sealed spaces is in contradiction to cable based data transfer because of potential leakage along the cable connection. In this situation, wireless data transfer exhibits an excellent alternative for ambitious monitoring concepts.

Against this background, a concept for the wireless data transfer from fluidic tight sealed mine working to an underground based as well as a surface based data acquisition (DAQ) was developed and successfully tested in the scope of the R&D-project *"Zerstörungsfreie in situ-Permeabilitätsmessung / non-destructive in situ permeability determination"* [1].

2. Basic information

The demands on wireless data transfer is defined by the measuring task and hence are according to experience very broad. This is because of variety of possible input-signals of sensors, their wattage, the measurement and transfer frequency, the variability of measurement and transfer frequency as well as the need of external control and possibly embedding of scoping-control processes. For a better understanding, the complete measurement and transfer circle can be divided into:

- the transfer of control parameters (programming of sensors),
- the actual acquisition of the indicated value (physical or chemical parameters, e.g. pressure, stress, temperature, humidity, concentration),
- the transmission of digital coded data and
- the receiving and recording of sent data (including modulation processing and logging).

There is no need to explain the different measure technologies for the broad variety of sensors to measure different parameters. Generally, these are documented in detail.

Wireless data transfer is focused on the monitoring of processes in inaccessible cavities and was developed for long periods. This is the reason for an appropriate and careful assortment of sensor technique to achieve the measuring tasks. Especially, the knowledge of time-dependent change of the measuring signal (long-time stability) and of the influence on the thermodynamic boundary conditions, e.g. compensation of temperature, alteration of batteries), have to be considered. These circumstances have to be already integrated into the preparation of the measurement and transfer concept.

The result of the measurement is an analogue signal which is transferred into a digital data structure having a 16 bit resolution by an analogue digital converter. This data is transferred in short pulses within the frequency band 433 MHz (ISM-band). The ISM-band covers the frequencies from 433.05 MHz to 434.79 MHz. The application of ISM-frequency bands is globally regulated by the articles 5138 and 5150 of the VO-Funk. The ISM-band at 433 MHz is approved as SRD for region 1 (inter alia Europe, Africa, Russia, parts of Asia) for industrial, scientific, medical and private use. The approval and use is representatively focussed on superficial application. Based on limited range, disturbances or interferences with other transfer processes is less relevant or completely irrelevant for applications in mines as defined by the VO-Funk. However, frequencies in the range of 410 MHz to 470 MHz (mine voice and alarm radio) or of 433 MHz to 470 MHz (mine remote active radio) can be used in mines referring to the general allocation for usage in mines (mine radio communication) [5]. To avoid radio technological interactions the applied radio parameters have to be site-related coordinated with the mine authorities (person responsible for mine radio).
For transmission process of wireless data transfer the sensor uses normally a bar flagpole antenna with aligned dimensions. The radio propagation is defined by the geoelectric properties of the rocks. Within a rock consisting of the gain skeleton (minerals / crystals) and the filled

pore spaces (fluid, e.g. gas and/or liquid) the propagation is the result of the dielectric conductivity of the particular components as well as of the polarisation and reflection effects between these components. The range of data transfer is dependant on the frequency, the transmission power, radiant emittance characteristic of the antenna (antenna gain), the dielectric constant (absolute permittivity or dielectric conductivity of rocks), the resulting, site and rock specific attenuation factor as well as the information band width (bit/s). The mentioned dependencies, their relevance and site-relevant determination will be discussed again in conjunction with the test measurements in chapter 4. Because of the definition of the transmission frequency within the ISM-band and the limitation of the electric transmission power with the purpose of minimising the power consumption an improvement of the transfer process is primarily possible by the enhancement of the antenna gain of the transmitting and receiving aerial.

Relating to the geoelectric properties of rocks it can generally be assumed that the propagation of radio waves reduces with increasing electric conductivity or with other words with increasing liquid content in the pore space. Therefore, good conditions for radio propagation is found in compact, dry rock salt having water contents in the magnitude of ≤ 0.02 Ma% [2] and attenuation constants in the order of 0,7-2.4 dB/m (e.g. rock salt from the Südharz-Kalirevier) [4]. There is further data of attenuation constants available for a variety of salt rocks. The experience from recent applications has revealed that the measurement of site-related transfer conditions in advance allows a detailed planning and dimensioning of the measurement and transfer facilities.

The data receiving from the on different channels sending sensors occurs in dependence on the site and receiving conditions either by a bar flagpole or beam antenna. A microprocessor controlled receiving unit allows the bi-directional communication with the wireless sensor. The transmitting and receiving process is organised in a way to avoid any data loss. In case of no contact between the transmitting and the receiving unit an intermediate storage will be performed in persistent data storage. This enables the system to carry out self-sustaining measurements (monitoring) even without permanent contact between sensor and receiving unit. The read-out may take place at a later moment.

After a recorded receive of data a serial RS485 bus system transfers the data to a logger. In this way several radio sensors can simultaneously be controlled and read-out by one receiver unit. Data can be read-out from logger via USB or WLAN interface.

3. Hardware

Figure 1 shows the recently tested wireless sensors. The different types demonstrate on one hand the opportunity and on the other hand the necessity of the essential constructive adjustment of the sensor body to the measuring task and the conditions governing location. The size of wireless sensors is mainly affected by the required power supply (battery power) which depends on the power consumption of measuring sensor units and the frequency of transmission.
Due to the previous application of the wireless sensors in borehole having a diameter of 70 mm the sensor antenna was designed as a bar flagpole antenna. However, the design of a beam antenna is also principal possible depending on the available space and the possibility of positioning of the receiving unit.

The electronic interior of the wireless sensor basically consists of the following components: measuring sensor unit, micro controller, high grade transformer, amplifier and storage units, radio module, and power supply unit.

The sensor and antenna bodies are designed accordingly to the measuring task non-corrosive, pressure-resistant and watertight. Up to this stage high grade stainless steel and pressure-resistant synthetics were used for bodies of sensors and antenna units.

In the scope of the research and development project the developed wireless sensors as well as the wireless data transfer through dry salt rock are proprietary by patent law.

4. Tests and application

The sensors depicted in Figure 1 were used for functionality and range tests in various lithologies under different installation conditions. Beside tests in various salt rock formations tests were also performed in soil and rock formations having higher water contents.

A selection of results is shown in Table 1. The attenuation influence of moisture in pore spaces is clearly demonstrated by this data. The water content of the Freibergian gneiss and in the natural soil attenuate as expected the range of radio propagation down to a few meters or decimetres. On the other side ranges up to 200 m are proved for rock salt having low water contents in the order of ≤ 0.02 Ma.-% [2] and in carnallite rock. Recently, the coupling with a newly method of wireless data transfer through wet rock is tested in order to overcome these limitations of radio based data transfer through rocks.

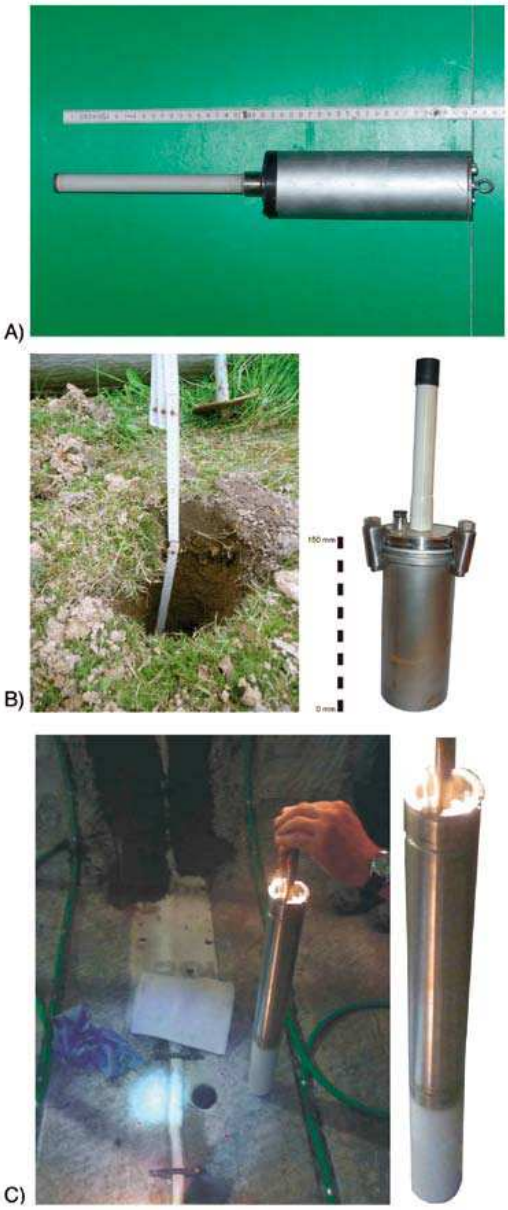

Figure 1 Different design of tested radio sensors

Table 1 Results of range tests within different lithologies

Lithology	Locality	Results
Rock salt, Werra-Member (Na1)	Mine Merkers	distances up to 200 m
Potash salt, Staßfurt-Member (K2)	Mine Teutschenthal	distances up to 100 m
Argillaceous, detritus rich soil	City of Freiberg	distances up to 15 m
Freibergian gneiss (PR3F)	Mine Reiche Zeche, Freiberg	distances up to 3 m

Based on the test of functionality three wireless sensors are applied in a sealing dam consisting of hydraulic hardening material which is explained more detailed in [3] for monitoring of process parameters in the scope of a construction test. Figure 2 shows schematically the alignment of the wireless sensors in the contours of the test location. To avoid negative influences of temperature increase during the hardening of dam material on the durability of the used lithium batteries and to optimise the antenna position wireless sensors were installed in boreholes radial to the construction site.

One of the sensors is exemplary shown in Figure 1C right before installation. All sensors are directly hydraulic connected to the contact area between building material and ground.

The sensors are continuously measuring and transferring process parameters of the construction test and of special tightness tests using gas and liquids since their installation in November 2010. The position of sensors in reference to the construction is depicted in Figure 2. Sensor 20 and 21 are installed in the floor level whereas the sensor 22 is situated in the S-face of the drift.

The frequency of measurement was repeatedly changed between 1 Hz and 1.2E-5 Hz during this period. The measurements were switched off and restarted. Figure 3 gives a summary of logged data.

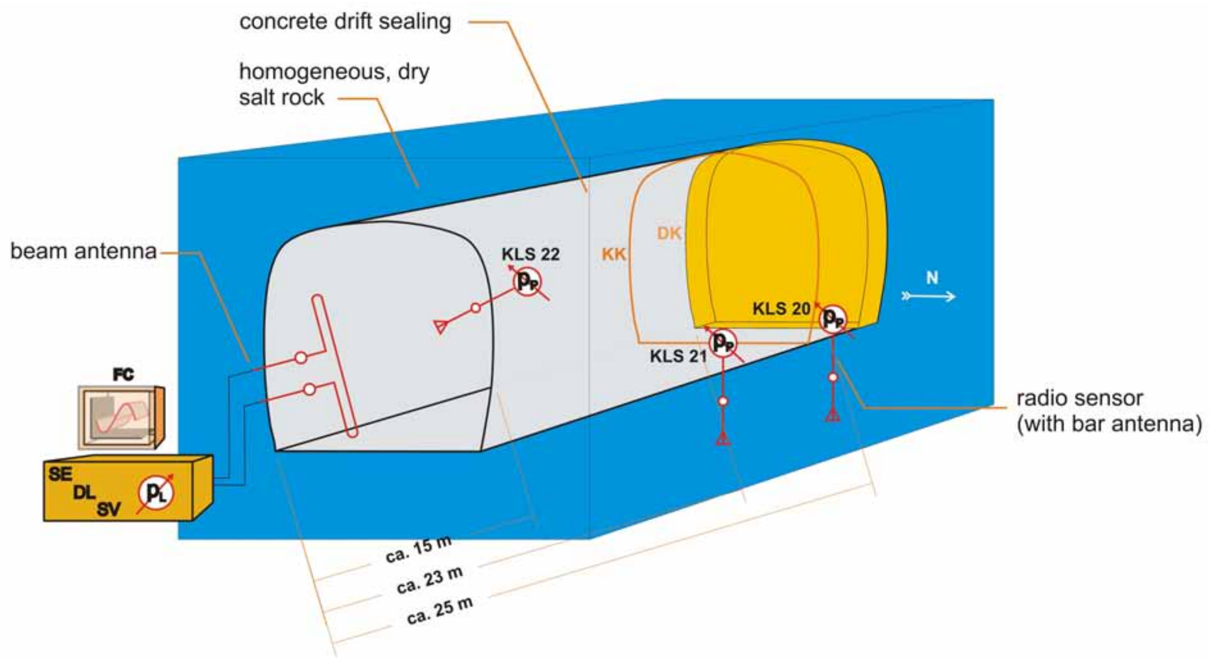

Figure 2 Position of radio sensors within the concrete drift sealing

An actual power consumption of about 10 Wh was detected of the period of ca. 700 d (almost 2 a). This results in recent, relative power consumptions of ca. 8 % (KLS21 und KLS22) and ca. 12 % (KLS20) at specific battery capacities of the KLS[1]. Based on this data it is possible to assume a theoretically continuation of measurements for further ca. 18 a (KLS21 and KLS22) or ca. 11 a (KLS20) at the same frequency of measurement. Alteration processes of

[1] KLS - wireless sensor

batteries caused by frequent and large temperature fluctuation can be excluded as far as possible based on the conditions governing location. However, the long-term behaviour of the used battery packs can not be finally evaluated based on the recent experiences.

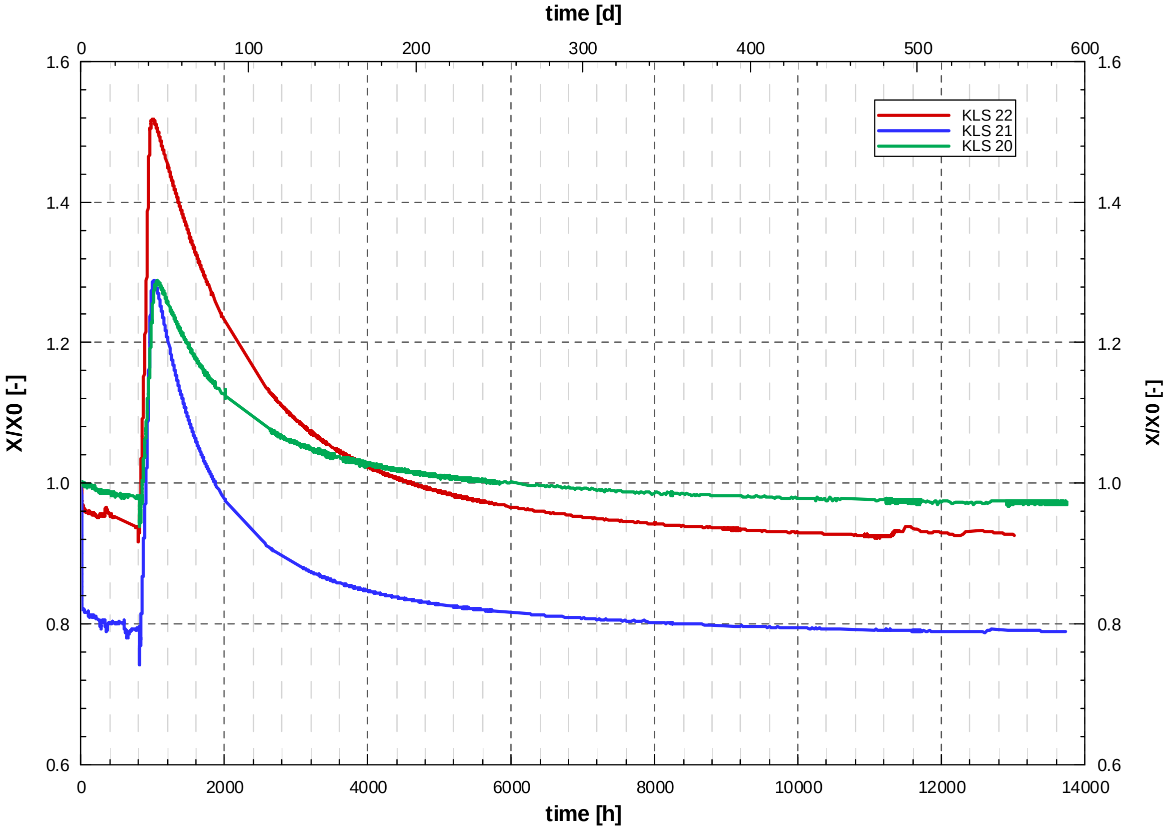

Figure 3 Normalised load curve of a parameter measured by the radio sensors

In order to evaluate the attenuation by the construction material and the surrounding rocks limiting the radio propagation measurements of field strength/ emission power were performed for the single sensors and the transmission equivalents were determined. As example Figure 4 shows the results of the measurements of field strength/ emission power for KLS20.

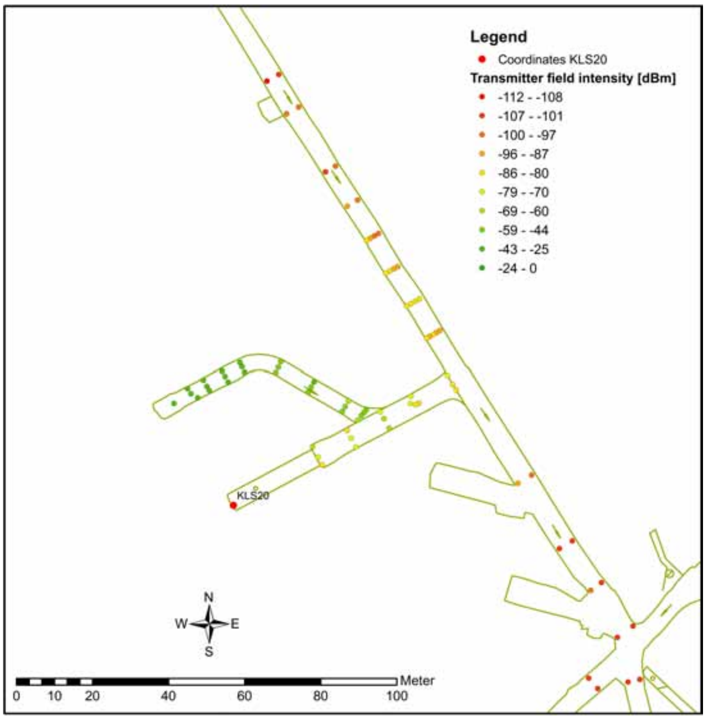

Figure 4 Measurement of transmitter field intensity for sensor KLS20 at the test site

The measurements were performed at different stages of construction. Comparison of the time-dependant results reveals an influence of the moisture distribution as well as orientation of the transmitting antenna in reference to the wet construction material on the transmission equivalent. This data subsequently enables to evaluate the radio propagation at the site, to determine the rock specific attenuation constants and to make conclusions for the positioning of the receiving antenna. Assuming a homogeneous geological situation the attenuation is mainly influenced by construction material.

The preparatory performance of appropriate power measurements gives the opportunity of optimising and dimensioning of sensor position as well as of configuration of necessary transmitting antenna and power.

5. Efficiency options and vision

The recently reached functionality and the power spectrum of the wireless data transfer system can be summarized as following:

- bi-directional communication between the sensor and the receiver unit including control of measurement and transfer frequency,
- operative connection to a variety of sensor types having different output signals, e.g. voltage, amperage, resistance, to realise individual measuring tasks, e.g. monitoring of mine air (moisture, temperature, CO_2 content), monitoring of convergence and other rock mechanical parameters, monitoring of fluid pressure, humidity of materials, saturation and capillary pressure,
- range of data transfer is lithology and geology dependent (ranges of about 200 m are actually reachable),
- extension of ranges are possible (e.g. by application of radio transponders),

- period of application depends on the conditions governing location, amount of measured parameters, power consumption of necessary sensors as well as on the measure and transfer frequency,
- embedding of data into an online database by GSM modem and continuously visualization is principal possible,
- coupling with other concept of wireless data transfer makes the system to a powerful monitoring tool.

The actual experiences based on tests and application of wireless sensors have shown an individual modification of the applied sensor technique and radio communication units to the conditions governing location and the measuring task is essential of an optimal use. This requires a concept planning, dimensioning, potentially test measurements at the site of usage as well as a technical co-ordination. A wireless data transfer over a long time excuses this effort of preparation.

Eventually, a vision of wireless data transfer in salt rock is a monitoring of open and particularly closed mines and repositories without any cable connection. In the case of closed mines and repositories, this means a long-lasting wireless data transfer from ground sites to the surface through dry and wet rocks.

6. Summary

Monitoring of inaccessible or badly accessible mine parts in salt mining represents a great challenge because of installation and measurement technical difficulties. Data transfer via cable connection is often in contradiction to the aspired fluidic tightness of technical and geological barriers. For this reason a concept of wireless data transfer within salt formations was developed and successfully tested for three wireless sensors over a duration of recently ca. 700 d (almost 2 a).

The data communication concept is based on the usage of the ISM frequency band for bi-directional communication between individual configurable, wireless sensors and a combined receiver and data acquisition (DAQ) unit. Depending on the measuring problem and the conditions governing location, the data communication concept can be individually modified as well as dimensioned based on site-related measurements.

Tests at different sites and in different lithologies revealed ranges up to 200 m. The experience from test measurements shows the need of individual modification in order to accommodate the measuring problem and the conditions governing location. This is mainly because of the process variety and consequently the sensor technology that has to been chosen as well as the geoelectric properties of different lithologies.

Recently, a combined system of the presented radio transmission of monitoring data and a data transfer through wet ground is subject of intensively research. The vision of a wireless monitoring of closed sites is the fundamental of this effort.

7. Acknowledgments

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Abbreviations

BfS - German Federal Ministry of Economy and Technology
BMWi - German Federal Office for Radiation Protection
DAQ - data acquisition
DK - pressure chamber
ERAM - Morsleben repository for radioactive waste
IBeWa - IBeWa Consulting Freiberg
GSM - Global System for Mobile Communications
ISM - industrial, scientific and medical band
K2 - potash seam “Staßfurt”
KK - control chamber
KLS - wireless sensor
Na1 - rock salt, Werra-Member
PR3F - Freibergian gneiss
SRD - short range devices

USB - universal serial bus
VO - enforcement order
WLAN - wireless local area network