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Optimizing data transmission in communication systems which use magnetic couplings

Communication systems which make use of magnetic couplings are systems in which the transformation of signals is conducted through induction elements. These elements transfer and receive energy from the transportation unit. A good example of such a solution is a shaft communication and signal system which sends a transmission signal through ferromagnetic couplers by means of head ropes or balancing ropes. This type of communication has, undoubtedly, some advantages, such as high reliability and uncomplicated exploitation. Yet, there are some limitations related to the employed bandwidth. The article discusses important issues related to shaft communication and presents methods which allow to make maximum use of available transmission channels.

key words: optimizing data transmission, magnetic couplings, propagation of electromagnetic waves, signal propagation in a shaft, mining communication system.

1. INTRODUCTION

In a deep mine infrastructure there are communication systems which make use of magnetic coupling for signal propagation. They are used mostly in shafts where the propagation of electromagnetic waves is hampered due to the following factors [2]:

- size of the shaft, which is usually a cylinder with the diameter of about 9 m and length up to 2,000 m,
- concrete supporting structure with steel reinforcements which encloses the whole space of the shaft; sometimes the structure is made solely of metal elements,
- abundance of metal elements in the shaft, such as shaft guides, skips, power and signal cables,
- climate conditions, particularly high humidity, salinity and a high temperature gradient.

Due to the above reasons, the initial user requirements for such communication systems focused chiefly on providing proper reliability of operation. The systems were to transmit a phonic signal along with a small amount of discrete information and control signals [1]. As shaft communication became a commonly used solution, the requirements for the systems changed because the users, once their basic requirements were fulfilled, began to notice wider possibilities of the systems. The main demand was to use the existing transmission channel to transfer data from other devices. In order to fulfill these requirements, first it was necessary to check whether the currently used system can fulfill the new requirements. If not, it was necessary to develop a new data transmission platform.

2. COMMUNICATION BY MEANS OF RADIO PROPAGATION

Proper operations of a transmission system which works in a mine shaft can be secured by different technical means [1]. In practice, there are two methods employed: radio propagation or magnetic coupling with the transmission path. In the case of radio propagation and with respect to work frequency, the systems have big connection capacity. However, in terms of the working environment, it is necessary to consider and assess the influence of the following phenomena on the capacity: electromagnetic wave diffraction and multipath propagation. These phenomena occur when there are obstacles on the wave propagation path. According to the Huygens-Fresnel principle, a wave which finds an obstacle gets diffracted and generates secondary waves. As a result of that there is interference in the propagated wave [3]. In the cross section of a wave emitted from the transmitter to the receiver it is possible to distinguish zones in which the propagation paths of wavefront points differ by as little as nλ/2 from the direct propagation path. They are called Fresnel zones. Spatial Fresnel zones have a shape of concentric ellipses whose focal points are the points where antennae are placed. As the biggest volume of energy is transmitted in the first zone [4], in order to achieve stable transmission, it is important to make sure that there are no objects within this space. The radius of this space can be calculated by means of the following dependency:

$$R = \frac{1}{2}\sqrt{\lambda r} = 8{,}66\sqrt{\frac{r[m]}{f[MHz]}} \qquad (1),$$

where:
r – distance between antennae,
f – frequency of the signal.

Figure 1 features a proper distribution of radio antennae on the surface.

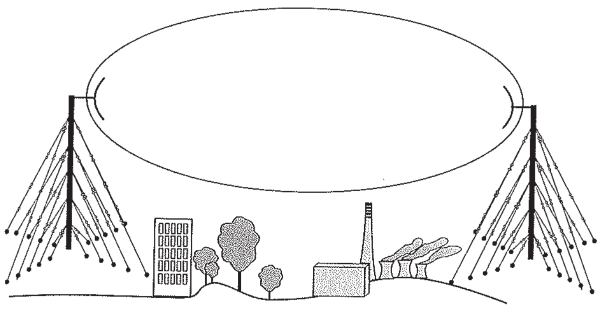

Fig. 1 Spatial Fresnel zones

As we can see, all objects which can impact the emitted wave are located beyond the zone. However, in the case when there is a whole surface which interferes into the first zone, to determine whether it causes reflexion of the wave or its dispersion, we need the Rayleigh criterion expressed by the following dependency:

$$h < \frac{\lambda}{8 sin\gamma} \qquad (2),$$

where:
h – height of the obstacle,
λ – wave length,
γ – angle of wave incidence onto the surface.

As far as real conditions of radio waves propagation in a shaft are concerned, due to the above mentioned limitations it is not possible to fulfill the demand of the free first Fresnel zone, as it is shown in Fig. 2.

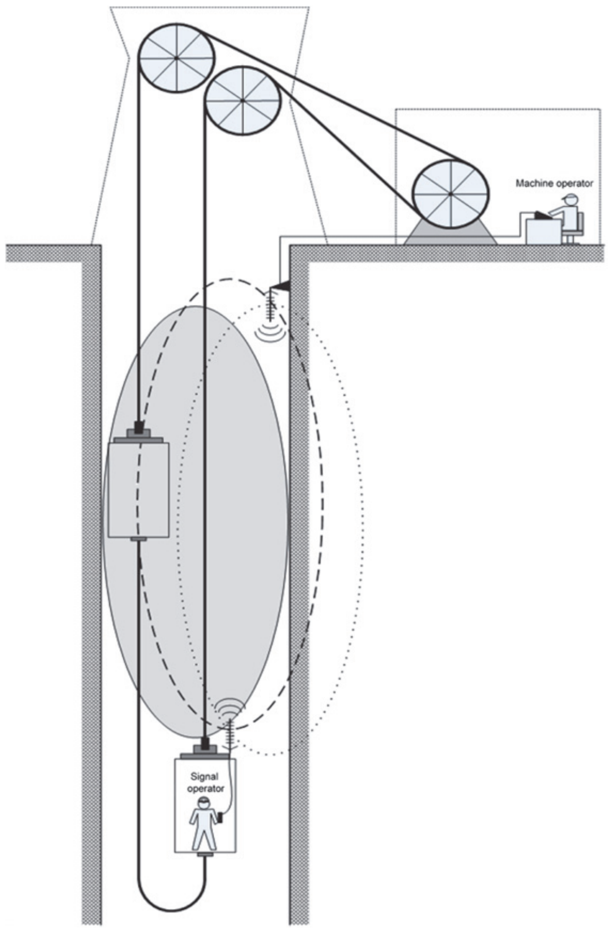

Fig. 2 Distribution of Fresnel zones in a mine shaft

The grey field illustrates how the antennae of devices should be distributed in the shaft, i.e. in its central part. This is not possible because head ropes of the skip are placed there. What is more, it is not possible to place the antennae in one line at the left or right side of the shaft, as the skip moves in the shaft which results in having different zones for particular antennae – this was marked in the figure by two ellipses. The radius of the first Fresnel zone was estimated for extreme frequency values of devices which work in the shaft and with the use of the dependency (1). Thus at the assumption that the shaft is 1,000 m deep, the radius is 43 m for the frequency of 40 MHz and 5 m for the frequency of 2.5 GHz. Taking into account geometrical dimensions of the shaft, the border frequency which allows signal propagation with theoretical capacity is 750 MHz. The walls of the shaft fulfill the Rayleigh criterion for the reflective surface at the height of the obstacles not bigger than 12 m for 40 MHz and 2 m for 2.5 GHz. As such obstacles cannot be found in shafts, it can be acknowledged that the whole surface of the walls does not disperse the waves. These estimations are proper if we assume that the space inside the shaft is empty. In the next step it is necessary to consider that there are some objects in the shaft, i.e. we have to estimate the impact of the multi-path phenomenon on the propagation conditions. This phenomenon is illustrated in Fig. 3.

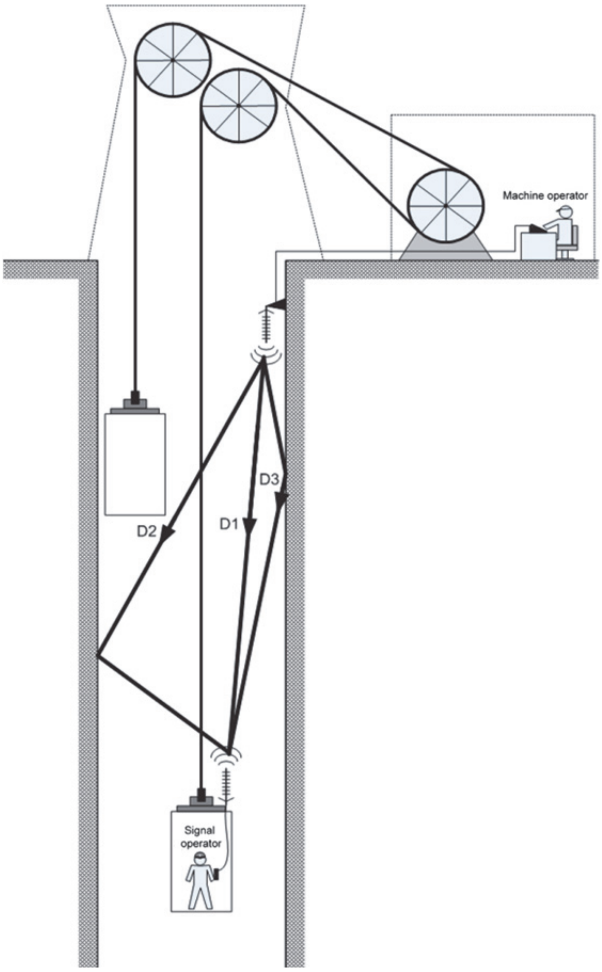

Fig. 3 Multi-path phenomenon in a mine shaft

The simplest case on the surface is two-path propagation: direct propagation between antennae and indirect propagation reflected from the ground. For such a case the power of the transmitter, needed to provide proper transmission, can be estimated in two ways. The first method is to calculate the power supplied to the transmitter for the distance d from the transmission antenna, with respect to the reference signal which is located at the distance d_0. This is done with the use of the following dependency:

$$P_R(d) = P(d_0)(\frac{d_0}{d})^2 \tag{3}$$

The reference signal has to be measured in the far field of the antenna, determined by the so called Fraunhofer distance:

$$d_0 = d_f = \frac{2r_{max}^2}{\lambda} \tag{4}$$

where:
r_{max} – maximum physical linear dimension of the antenna,
λ – wave length.

In practice, the Fraunhofer distance for the frequency 40 MHz is set at 10 m, and for the frequency 2.5 GHz – at about 1 m.

The second method is to measure the electrical field amperage at the distance d from the transmission antenna, based on the following formula:

$$E = \frac{3{,}94\sqrt{P_T G}}{r^2 \lambda} H_1 H_2 \tag{5}$$

where:
P_T – power of the transmitter,
G – transmission antenna power gain,
H_1 and H_2 – heights of transmission and receiving antenna respectively.

In the case of a mine shaft the situation is more complicated, as we have to deal not with one but at least with two reflective surfaces, as it is shown in Fig. 3. When the multi-path phenomenon occurs, the received power is inversely proportional to the value of distance raised to the power of four. For the shaft, due to the multi-path phenomenon, the power received at a given distance from the transmission antenna is determined by means of the following dependency:

$$P_R(d) = P(d_0)(\frac{d_0}{d})^\gamma \tag{6}$$

where the coefficient γ is in the range from 2 to 5.5 and depends on many environment variables.

This means that the value, in practice, will be different for each shaft. Thus it is difficult to predict the signal behaviour based on the experiences from already exploited installations. Dispersion is another negative phenomenon that impacts the channel capacity. When a radio wave propagates between the transmission antenna and the receiving antenna along different paths, the difference between propagation times causes dispersion, i.e. dispersion of the radio signal in time. If this difference is comparable with the duration of a single symbol in the radio signal, inter symbol interference (ISI) occurs, which deteriorates the bit error rate of the signal.

3. COMMUNICATION BY MEANS OF MAGNETIC COUPLING WITH THE TRANSMISSION PATH

Communication by means of magnetic coupling with the transmission path is conducted as duplex transmission with Frequency Division Duplex (FDD). This means that there are separate paths for transmission and receiving. However, such a solution does not provide full capacity of the transmission channels. Figure 4 features a scheme of a transmission and receiving station. One transmission channel is responsible for the transfer of digital data, control signals and phonic signals – so there is competition to get access to the channel. As, due to the employed frequency band, it is not possible to extend the capacity of the channel, the only way to increase the volume of the transferred data is to optimize the access to the channel for particular functional blocks.

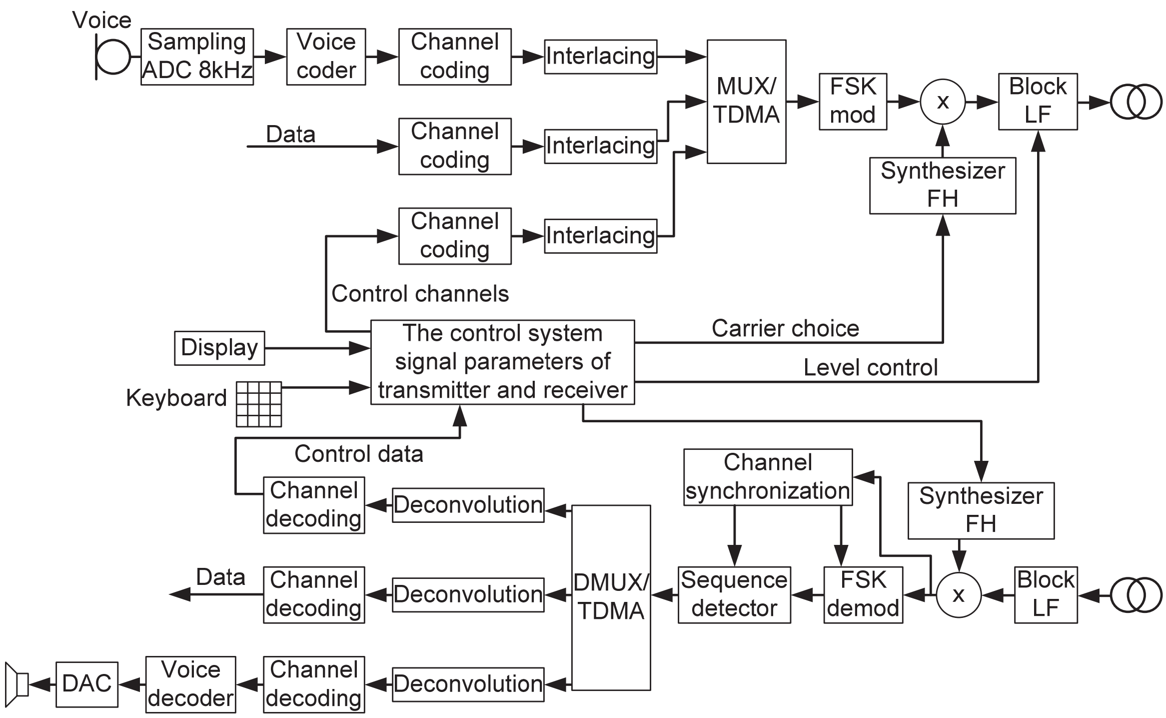

Fig. 4 Diagram of a transmission-receiving station

This demand was fulfilled by implementing in the control program of the ECHO/AS apparatus an algorithm that enables to change access priority to the channel in the ECHO/AK apparatus, depending on the current needs of the user. Figure 5 presents a diagram of the ECHO-P system for monitoring the tension of head ropes of skips. The system allows to perform simultaneously the following: conversations between the people in the skip and the machine operator, transmitting control signals, including one-beat signals, transmitting the state of bi-stable sensors installed in the skip, and transmitting signals from four current loops 4-20 mA.

During a daily exploitation all information that can be transmitted by the system at different moments of time has changing priorities. Therefore after a priority access change algorithm in the access of the transmission channel is implemented, the user can decide what kind of data are most needed at the moment. The method of controlling data transmission can be seen in Fig. 6.

The screen of the application for data registration and system control is a multi-window screen with the function of quick language change. Particular windows feature data downloaded from the system, i.e. current state of tension in particular ropes, historical diagram of tensions, state of particular buttons on the apparatus and their historical diagram. The control of data transmission is possible from the menu Transmission. When the option Normal Transmission is selected, the system operates based on time and events, i.e. the data are sent when a button is pushed or a state of the sensor changes, and collectively once a minute. When the option Quick Transmission is selected, the system sends data from the sensors and the data are averaged for a given period of time. Because, in practice, it is not possible to conduct two operations simultaneously, for example, to make the shaft revision and to measure the work dynamics of the ropes, the implemented mechanism satisfies the expectations of the users.

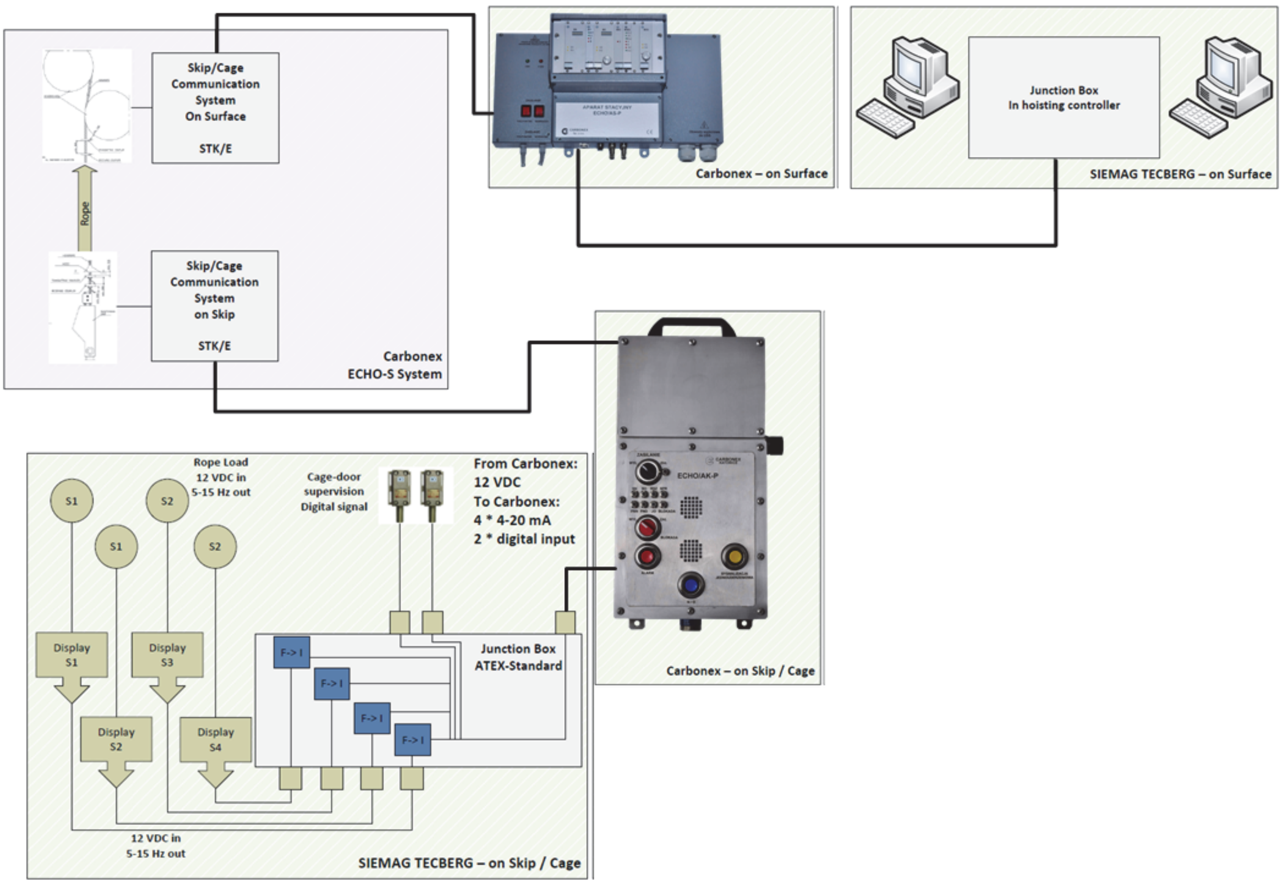

Fig. 5 Diagram of the ECHO-P system for measuring the tension of head ropes

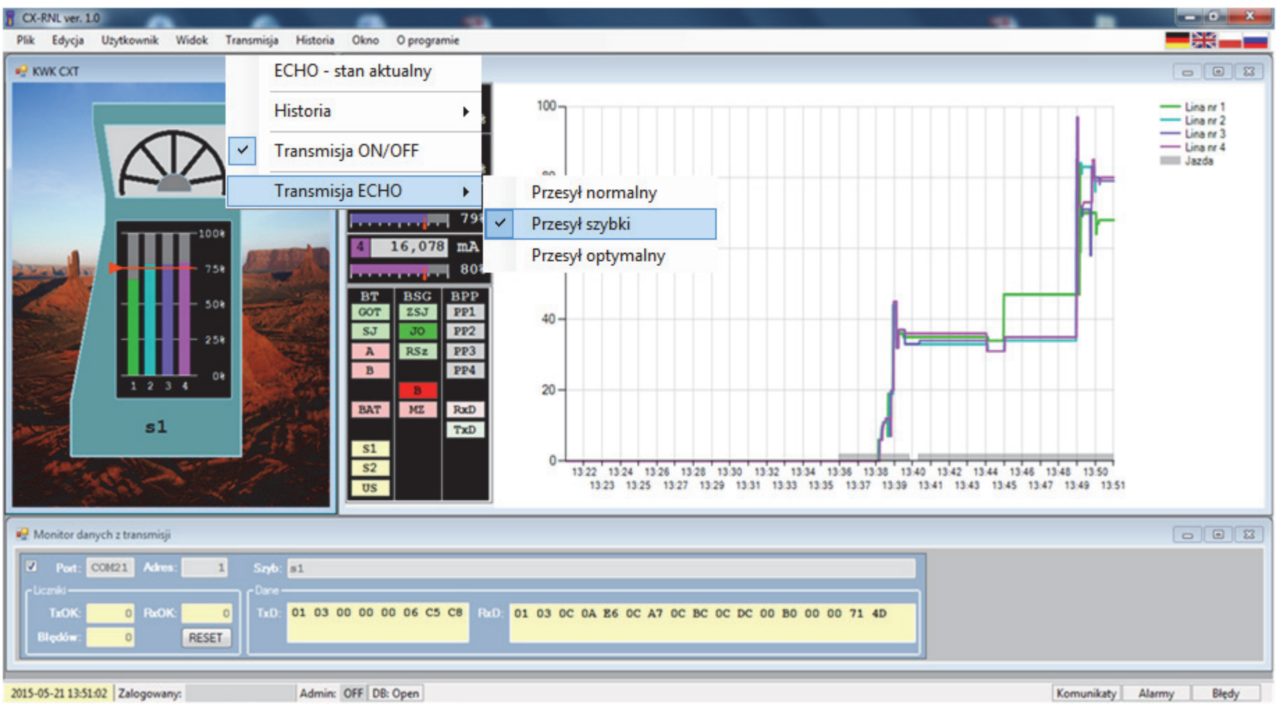

Fig. 6 Controlling data transmission in the ECHO system

4. CONCLUSIONS

So far the systems of wireless communication in shafts have specified quite undemanding requirements as far as the capacity of the transmission channel is concerned. This resulted from technical capabilities and the needs voiced by the users. With the increasing demand to transmit data with the use of such transmission, it was necessary to launch work on bigger capacity of the transmission channel. In practice, this can be done by radio transmitters, however this method is related to many phenomena which diminish the quality of transmission or transmitters which make use of magnetic coupling with the transmission path. In the latter case, proper selection of transmission type and access algorithm to the transmission channel allow to secure data transmission at an acceptable level in the system with small communication capacity.

References

1. Giel R., Jackiewicz T.: Propagacja fal elektromagnetycznych w górniczych wyciągach szybowych (Propagation of electromagnetic waves in mining shafts). Mechanizacja i Automatyzacja Górnictwa 7(473), 2010.
2. Jackiewicz T., Wiśniewski G.: Wpływ doboru parametrów filtrów LF na propagację sygnału w szybie kopalnianym (Impact of parameters selection of LF filters on the signal propagation in a shaft). Mechanizacja i Automatyzacja Górnictwa 6(520), 2014.
3. Szóstka J.: Fale i anteny (Waves and anten nas). Wydawnictwa Komunikacji i Łączności, Warszawa 2006.
4. Wesołowski K.: Systemy radiokomunikacji ruchomej (Mobile radiocommunication systems). Wydawnictwa Komunikacji i Łączności, Warszawa 2003.

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