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DIGITAL SYSTEM FOR DETECTION AND LOCATION OF MINERS TRAPPED IN HARD COALMINES – GLOP2

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Abstract

Paper deals with the new localizer GLOP2 designed for detection of the miners trapped in underground hard coal mines. The results of a field test conducted in coal mine BOBREK show that the presented localizer allows for efficient measurement of the distance between a trapped miner and the rescuer in the range of up to 15 m.

Keywords: hard coal mines, rescue systems, communication systems, trapped miner localizer.

1. Introduction

In underground hard coalmines particular conditions exist of propagation of radio waves. Walls of galleries in coalmines or dumps of rocky material deposited in the galleries after a crump attenuate radio signals in a significant way. Some of the used radio communication systems utilise repeaters or leaky feeders, which enables a considerable increase of the range of a communication system. However, such solutions can be easily damaged by falling fragments of rocks or by means of an explosion or fire, *etc*. An additional issue is electromagnetic interference that is caused mainly by operating electro-mechanic and electro-energy devices.

Communication systems used in hard coalmines are divided into two groups. Namely they are contact systems used in the conditions of normal operation of a coalmine and systems used during a rescue operation. The requirements for both groups of communication systems, therefore solutions used, differ significantly. This work concerns the structure of a new version of GLOP2 radio receiver and locator used in rescue operations in hard coal mines. The purpose of this receiver is to measure the distance between a rescuer and each of the trapped miners. Its practical tests carried out in a coalmine in Poland have confirmed the helpfulness of the offered solution.

The work is divided into four parts. The first part contains a short overview of widely used communication systems utilised in rescue operations conducted in underground hard coalmines. On this background, the GLON – GLOP system currently used in Poland has been described. The second part contains basic information on the newly developed GLOP2 locator. The third part presents the results of its tests carried out both in a laboratory and at the coalmine BOBREK at the depth of 723 m. The last part is a summary of the work and contains conclusions drawn from the carried out tests.

2. Rescue communication systems in coalmines

Existing communication systems currently used in rescue operations, due to the method of operation can be divided into three groups: Through-the-Wire (TTW) communication systems

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and two groups of wireless communication systems Trough-the-Air (TTA) and Trough-the-Earth (TTE) [9]. Below a short overview of used solutions is presented.

The seismic location system currently used by the US Mine Safety and Health Administration (MSHA) was developed in the 1970s. Although it cannot be treated as a system of communication, it enables locating a miner and informing him that his signal was detected. It receives seismic vibrations generated by a trapped miner and localizes their source. These vibrations are generated by hitting the rock.

The Personal Emergency Device (PED) manufactured by Mine Site Technologies (Australia) is a unidirectional TTE type communication system. It enables sending text information to a selected miner. The system works at the frequency of 400 Hz and utilises a set of antennas located both on the ground and under the ground. The message sent is displayed on a LCD display. Currently 18 PED systems are used in US mines and in about 140 mines in other countries. The basic drawback of this solution is the necessity of installation of an underground antenna that can easily be damaged by falling rocks or flames during a fire. Nevertheless, powering the antenna constitutes the risk of explosion or fire in mines endangered by methane.

TeleMag system by Transtek (US) is a bidirectional wireless TTE communication system that enables sending voice message as well as data between a ground station and devices located under the ground. It has been tested at the depth of 90 m. Design assumptions provide the possibility of sending a signal through a 300 m thick solid rock. It is not a portable system, though.

In literature [9] reports can also be found concerning currently carried out research and construction works on new solutions for communication systems used in underground hard coal mines. Examples of the new solutions are:

- Delta Electromagnetic (DeltaEM) Gradiometer Beacon Tracking System by Solar (USA). System consisting of a beacon transmitter and a DeltaEM wave gradiometer (receiver). The DeltaEM receiver is portable and is used on the surface to locate the transmitter. The beacon transmitter generates a 2000 kHz electromagnetic (EM) signal.
- Subterranean Wireless Electric Communication System (SWECS) by Kutta Consulting (USA) is the location system. It consists of a PDA-type device with a screen and keypad, a radio and an antenna (30 cm). The system can send voice communication through 240 m solid rock, and a digital photo through at least 1200 m of rock.
- Canary 2 by Vita Alert (Canada) is a two-way, TTE, voice and text messaging technology. It has the ability to penetrate the earth to depths of up to 300 m. The system consists of a mobile surface unit and several underground base units. Preliminary tests suggest the system can penetrate up to 120 m of overburden.
- CSIR Miningtek (South Africa) developed a trapped miner–locating device. During tests it provided detection and location of a trapped miner at the distance of more than 30 m through rock. It consists of a uniquely coded belt-wearable miner’s tag and a portable search unit.
- Institute for Advanced Physics, University of Innsbruck (Austria) developed a system which consists a beacon contained in a miner’s cap lamp, and a hand-held location receiver. The detection accuracy is about 50 cm. The information about the distance from the beacon to the receiver was not published.
- The research conducted by U.S. Nureau of Mines in the mid 70’s to the early 80’s concerned the communication systems incorporating the TTE transmission technology at frequencies between 600 Hz and 3000 Hz. The miner-carried part of the system was a belt-worn device with wire-loop antenna, a handheld receiver with loop antenna and surface antenna. The test data showed a 68% probability of detection of the miner’s beacon at a depth of 230 m.

Characteristic for Polish mines is their depth reaching from several hundred to over 1000 m. Therefore on-the-ground location systems cannot be used. Many mines are also endangered by methane, which imposes further limitations for the used electric devices.

The currently existing system of location of miners has been used in Polish hard coal mines since the 1980s. It was designed by Jan Łozak in cooperation with the Military Technical Academy (WAT) [4]. It bases on equipping each miner with a personal GLON transmitter, whereas rescuers are equipped with GLOP receivers. Compulsory use of such transmitters results from the regulations [8]. The frequency of each transmitter is precisely defined and related with the number of the personal cap lamp cover, which is standard equipment of each miner. The register of issued lamps and names of miners is held by the division manager.

GLON transmitters have a significant role in the system of protection and rescue operating in every deep mine. Signals from the transmitters received by a rescue team enable specification of the number of miners trapped in a broken-down gallery fragment and estimation of the distance to them, which contributes to increased effectiveness of a conducted rescue operation.

The transmitters operate within the frequency range from 4000 to 6000 Hz, divided into eight channels. In a given area of a mine where particularly high breakdown risk exists, the transmitter of each miner must operate on a separate channel [4].

The selection of frequencies was determined by the characteristics of signal propagation in a medium typical for breakdowns, containing not only fragments of rocks, but also large metal elements coming from broken lining, trams, tracks, pipelines, etc. Propagation of higher frequency electromagnetic waves, of hundreds of kHz, is limited in such environment.

The signal sent by GLON transmitters of individual miners is received by a GLOP receiver and locator which has to determine the current distance from the transmitter.

Currently used GLOP receivers have been manufactured in analogue technology. The operator or rescuer selects a specific channel and manually retunes the frequency of the receiver and the cooperating antenna to detect signals from individual transmitters. The strength of the received signal enables the determination of the distance between the rescuer and the missing miner. The use of direction-finding methods helps to determine the direction of the search.

According to the information in [2], the existing GLON-GLOP system is capable of detecting the presence and determining the distance between the rescuer and the trapped miner up to 25 m. The uncertainty of location of the trapped miner has been estimated at the level of +/− 13% by the designers of the device [1]. In the range of distances between 25 and 50 m the system is only capable of detecting the GLON transmitter signal. The test carried out by the authors at BOBREK mine have indicated that in fact even at shorter distances the currently used previous-generation receiver could not detect the presence of the GLON transmitter signal. The ranges of measurement and detection reached by GLOP and given in the literature depend particularly on the level of occurring electromagnetic interference as well as on their frequency spectrum, and also the frequency of the transmitter's signal.

The list of basic drawbacks of the currently used GLON-GLOP system should also include the necessity of compensation of system parameter changes resulting from the change of temperatures of operation. It is realised by calibrating the system before each operation. Furthermore, while working in the manual mode, the GLOP receiver requires precise tuning. The receiver weighs 3.3 kg and the cooperating antenna 1.2 kg. The result of distance measurement is read out from a analogue meter, while newer types of devices use 7-segment indicators to display the frequency and the distance. Consequently, using these receivers in extremely hard conditions of rescue operation requires high skills and much effort and the obtained result has a high level of uncertainty. Unquestionable advantages include: a compact and easy-to-carry structure, a portable transmitter powered with batteries which is the equipment of each miner.

The works carried out currently on the new design of the GLOP receiver are mainly directed towards simplification of operation. However it should be remembered that at present there are around 100 000 GLON transmitters functioning in Polish coalmines. Therefore any modifications to the GLOP receiver must provide its proper cooperation with the existing transmitters.

A similar system with maximum distance measuring range of 10 m is used by a German company Hamacher in the Ruhr [3]. That system was commercially offered in Russia as well. The literature, however, lacks information on the effectiveness of the location system employing radio locators used in certain German mines [5].

Many centres carry out research aiming at development of a digital locator for signals sent by personal miner transmitters. The basic features of the sought solution are simplicity of operation that would eliminate the necessity of strenuous tuning, a digital display presenting the count of detected transmitters and results of measurement of distance from each of those transmitters, a light and compact structure and battery-power.

Study [6] presents a locator designed by ELEKTROMETAL S.A. It is a digital device that enables measurement of distance from the transmitter and determination of the direction in which it is located in relation to the receiver. Furthermore it is possible to use the method of increments (which requires previous determination of the direction in which the transmitter is located) and the two point method for determining the location of the transmitter.

The basic algorithm of signal processing is the FFT analysis. In order to eliminate the impact of electromagnetic interference it is possible to carry out a multiple measurement and averaging of the frequency spectrum in time. However, according to the authors, such operation results in a significant increase of measurement time.

The range of effective detection depends on the level of electromagnetic interference. The total uncertainty of distance measurement in a space free of large metal objects has been estimated by the authors as 9%. It needs to be realized, though, that it is a result of a theoretical analysis, whereas in reality the uncertainty or distance measuring error strongly depends on the level and band of frequency of the occurring interference. Work [6] does not contain any results of experimental tests of the described locator.

This receiver is not attested in Poland with the certification issued by the Central Mining Rescue Station.

3. Description of the digital receiver GLOP2

The block diagram of the designed GLOP2 receiver, as well as its photograph is presented in Fig. 1.

The constructed receiver has been developed in analogue-digital technology. It is equipped with a PDA-type device and a LCD display. The whole device is powered from a 9 V battery.

A vital issue that needed solution was to work out the algorithm of measurement signals detection, characterized by high resistance to electromagnetic interference coming from different sources, particularly from electro-energy devices. This function is partly realized by the analogue system that processes the signal coming from the receiving antenna, and partly by the digital algorithm implemented in the PDA device.

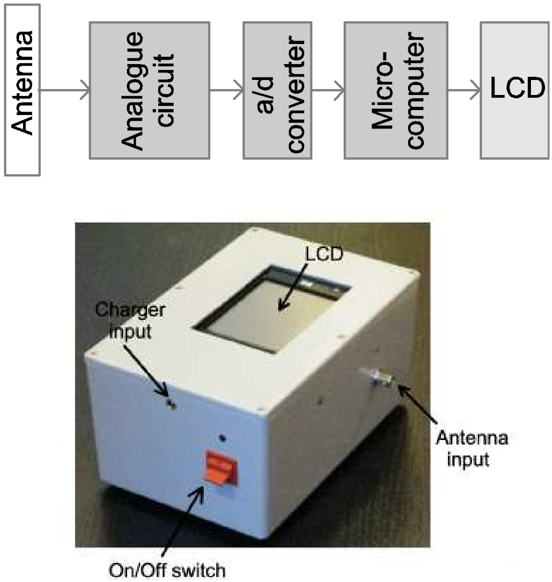

Fig. 1. Block diagram and photograph of GLOP2 locator.

The aim of the analogue system is above all proper amplification of the signal coming from the antenna and band filtration of that signal. Frequencies of mining transmitters are concentrated in selected bands, each of them with a width of 200 Hz. Therefore frequency characteristics of the analogue system should be similar to rectangular characteristics with the width of 200 Hz and the central frequency corresponding to the frequency of a selected band in which the locator operates. Because obtaining such characteristics in analogue technology is difficult, it has been decided that digital correction of actual characteristics of the analogue system would be better (Fig. 2).

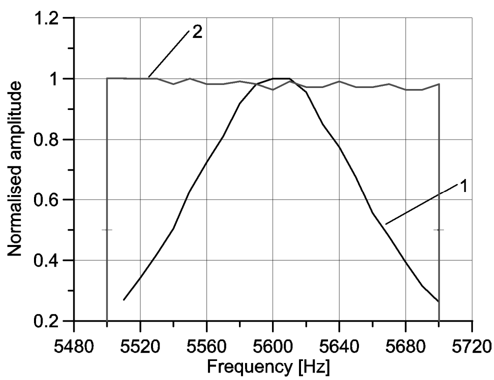

Fig. 2. Frequency characteristics of the course of analogue and digital signal processing within the frequency band 5500 Hz – 5700 Hz. 1 – actual characteristics, 2 – corrected characteristics.

Due to strong nonlinear relation between the electromagnetic field intensity and the distance to its source, the experimentally determined static characteristic of the constructed locator is nonlinear. The model describing this characteristic has been used in the designed locator to solve the inverse problem consisting in determination of the distance on the basis of measured spectral density of the signal received from GLON transmitter [7]. The error of distance estimation resulting from imperfection of the model does not exceed +/– 20 cm within a distance range up to 16 m (Fig. 3).

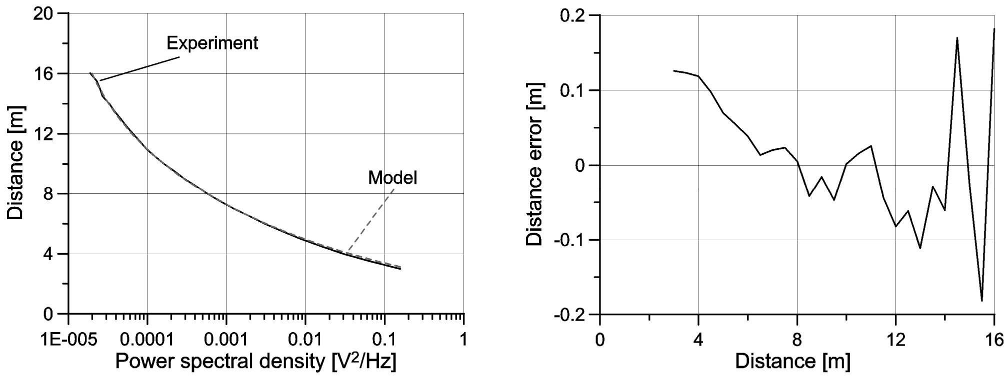

Fig. 3. Static characteristics of the locator: experimental, model and error of characteristics modelling.

The experimentally determined frequency resolution of the GLOP2 receiver, understood as the capacity of distinguishing two transmitters generating signals with similar frequencies, is approximately 15 Hz. Fig. 4 presents the result of functioning of the digital algorithm of estimation of spectral density of the signal received from a distance of 8 m and 16 m.

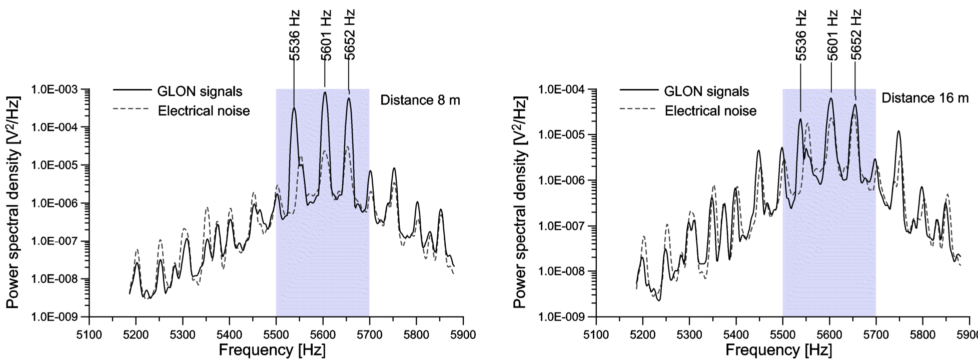

Fig. 4. The result of estimation of spectral density of the signal coming from three GLON transmitters with frequencies of 5536 Hz, 5601Hz and 5652 Hz, received from a distance of 8 m and 16 m.

4. Field tests

Experimental tests of the constructed GLOP2 receiver have been carried out both in a laboratory and in the hard coal mine BOBREK. The aim of both tests was to indicate errors in measuring the distance between the GLON transmitter and GLOP2 receiver.

Because of electromagnetic interference, harder conditions for measurement occurred during laboratory tests carried out on the ground. The experiments employed three GLON transmitters generating signals at different frequencies. The measurements have been carried out within the distance range between 3 m and 16 m. The obtained results are presented in Fig. 5.

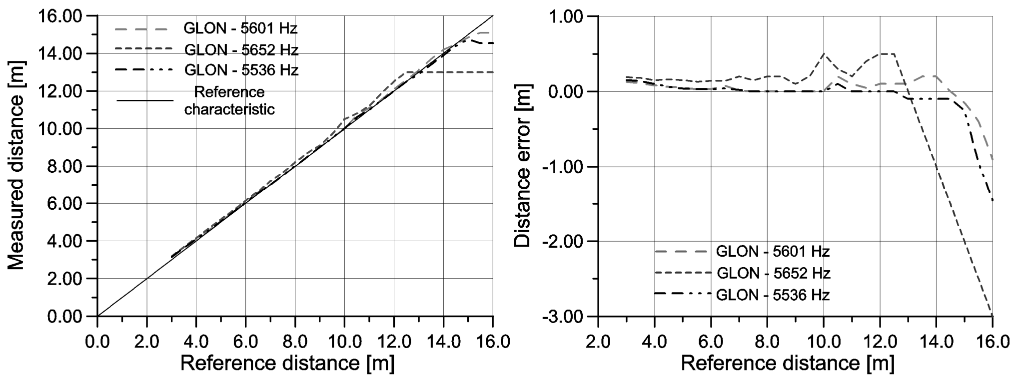

Fig. 5. Characteristics of errors of distance measurement with a GLOP2 locator – laboratory tests.

The signal of a GLON transmitter – 5652 Hz was in the band with particularly intensive electro-energy interference. In this case the distance estimation with an error not exceeding 1m is possible within the range up to 14 m. For the two other transmitters this range reaches 16 m.

The results of the laboratory tests have been confirmed by the experiments carried out at the coalmine BOBREK at the depth of 723 m. Tests were conducted along the out-of-use gallery. To avoid electromagnetic interferences all electrical devices at the gallery were switched off as it is done during a rescue operation. Additionally the tests encompassed the impact of the presence of large metal objects such as trams on the outcome of the distance measurement.

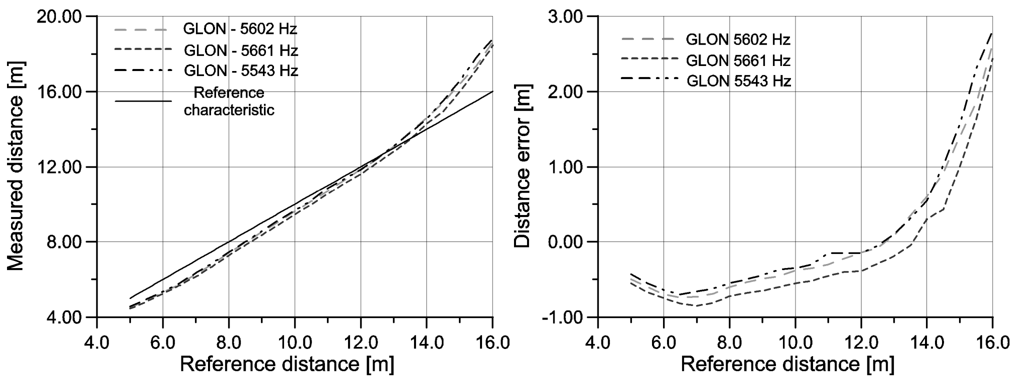

Fig. 6. Characteristics of errors of distance measurement with GLOP2 locator – tests at the coal mine BOBREK, depth 723 m.

Table 1 compiles the results of measurement of the distance from three simultaneously operating GLON transmitters placed in varied distances from the GLOP2 receiver. The obtained results are consistent with the characteristics presented in Fig. 6.

Table 1.Determination of errors of distance measurement in simultaneous operation of three GLON transmitters (BOBREK mine tests).

Transducer's frequency [Hz]		Reference distance [m]	Measured distance [m]	Distance error [m]
1	5604	8.0	7.40	-0.60
	5651	13.0	13.10	0.10
	5533	15.0	16.5	1.50
2	5604	15.0	16.2	1.20
	5651	15.0	16.4	1.40
	5533	15.0	16.36	1.36
3	5604	12.0	12.13	0.13
	5651	12.0	11.88	-0.12
	5533	8.0	7.48	-0.52
4	5604	12.0	12.14	0.14
	5651	10.0	9.50	-0.50
	5533	8.0	7.48	-0.52
5	5604	10.0	9.67	-0.33
	5651	10.0	9.50	-0.50
	5533	8.0	7.48	-0.52
6	5604	10.0	9.56	-0.44
	5651	6.0	5.57	-0.43
	5533	8.0	7.48	-0.52

A factor that has significant impact on the result of measurement of the distance between the locator and GLOP transmitter are large masses of metal located on the course of propagation of the EM signal, or in its close vicinity. Fig. 7 presents characteristics of errors obtained in a gallery along which trams were parked.

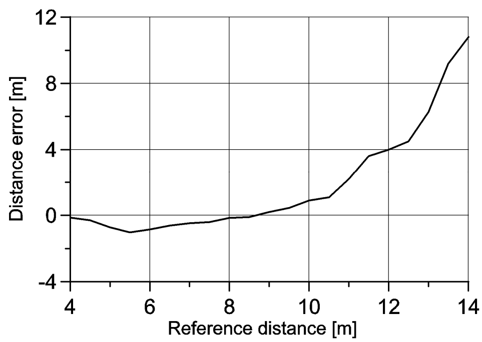

Fig. 7. Errors of distance measurement for three GLON transmitters obtained in measurements in the vicinity of large metal objects.

In these conditions the range of correct distance measurement (with an error not exceeding 1m) has been limited to 14 m.

5. Conclusions

The results of the carried out tests allow to draw the following conclusions:

- the constructed GLOP2 receiver enables location of the transmitter with an error not exceeding 1 m from a distance up to 15 m;
- the range of effective detection of a GLON transmitter is up to 30 m;

– simultaneous operation of several GLON transmitters, operating on similar frequencies; does not increase the error of distance measurement.

The developed device has been verified experimentally both in laboratory tests and also in measurements carried out at BOBREK mine. Due to the used efficient algorithms, the device operates in real time, which means that the operator can instantly watch the change of distance measurement result caused by movement of the operator or the searched miner. The total weight of a GLOP2 receiver is no more than 1 kg. The device is fully automatic. Actions of the operator or rescuer have been limited to switching the power on and reading from the LCD display the count of operating GLON transmitters and the distance between the rescuer and individual transmitters. Measurement results are presented on the LCD display clearly and accurately, which improves the comfort of work with the device.

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