Optical communication system investigation with application for VLF solar flares monitoring system

Tsvetan Valkovski[1], Ivaylo Nachev[2] and Peter Z. Petkov[2]

Abstract – **In this research focuses on investigating an optical communication channel in a system for monitoring solar flares system using a technique for VLF signal level monitoring. Optical communication has the potential to offer high data rates, long transmission distances without loses, and immunity to electromagnetic interference, making it a promising technology for use in systems of the proposed type.**

Keywords – **D-region, ionosphere, VLF, solar flare, radio astronomy, SID, optical communications, fiber, optics, SMF.**

I. INTRODUCTION

In recent years, the importance of solar flares monitoring has become increasingly critical due to the potential environmental and health hazards associated with such events. To resolve these cases, various methods have been proposed for detecting and monitoring different kinds of solar activity, including techniques for solar flares (representing sudden ionosphere disturbances (SID)) detection based on very low frequency (VLF) signal level monitoring [1].

Some monitoring systems for solar flare detection utilize very low frequency (VLF) transmitters to detect and measure changes in the Earth's ionosphere. VLF signals can penetrate through the ionosphere and be transmitted long distances, making them an effective means of monitoring ionospheric disturbances resulting from solar flares. Through the measurement of VLF signal changes, can be studied ionospheric properties, enabling a better understanding of the dynamics of solar flares and their impact on Earth's environment. Thus, VLF transmitters are a crucial component of solar flare monitoring systems, playing a critical role in advancing our knowledge of these phenomena [2, 3].

Solar flares are classified based on their peak flux, measured in watts per square meter (W/m2), into A, B, C, M, or X classes. Each class is then divided further on a logarithmic scale from 1 to 9, such as B1 to B9 and C1 to C9. An X2 flare is twice as strong as an X1 flare and four times more powerful than an M5 flare. The X-class category extends beyond X9, allowing solar flares to be classified as Super X-class when they reach X10 or greater [4, 5].

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One of the disadvantages of the VLF system for SID monitoring is using of conventional transmission lines between the receiving device and the antenna - mainly signal cables or coaxial feeder lines are used, characterized by path losses and susceptible to electromagnetic interference. To reduce the losses in the transmission line between the antenna and receiver and increase the reliability of data transmission this study focuses on the optical communication channel investigation of a solar flare monitoring system using the VLF method. Optical communication has the potential to offer the following advantages to systems from described type [6, 7]:

- High Data Rates: Optical communication allows for much higher data rates compared to traditional cable communication, allowing for faster and more accurate transmission of data;

- Long Transmission Distances: Optical communication can transmit data over much longer distances than traditional cable communication, reducing the need for additional signal boosters or repeaters;

- Immunity to Electromagnetic Interference: Optical communication is not affected by electromagnetic interference, making it a more reliable and secure method of data transmission in environments with high levels of electromagnetic interference. This advantage allows the installation of a VLF SID system in an urban environment where the electromagnetic field is "polluted" and there is a huge presence of interference;

- Low Signal Attenuation: Optical communication experiences much less signal attenuation than traditional cable communication, resulting in better signal quality and reliability;

- Reduced Cable Weight and Size: Optical cables are typically smaller and lighter than traditional copper cables, reducing the weight and size of the solar frame monitoring system and making it easier to install and maintain;

Overall, these advantages make optical communication an attractive option for use in VLF-based solar frame monitoring systems, offering faster, more reliable, and more efficient data transmission over long distances with minimal signal attenuation and interference. Also by increasing the efficiency of the system, it will be possible to increase the ability to detect lower solar flare cases.

In this research focuses on investigating an optical communication channel in a system for monitoring solar flares system using a technique for VLF signal level monitoring. Optical communication has the potential to offer high data rates, long transmission distances without loses, and immunity to electromagnetic interference, making it a promising technology for use in systems of the proposed type. Theoretical analysis and practical experimentation to evaluate the performance of an optical communication channel in a VLF solar flares monitoring system are presented.

II. THEORETICAL PART

In the previous point that was mentioned, the specifics of VLF radio wave propagation are suitable for monitoring the change in the character of the ionosphere during solar takeoff. The researched experimental setup is at a frequency of 26.7 kHz - the frequency at which it works Bafa Turkey VLF transmitter (37° 24'43 "N 27°19'25 "E). The optical communication system will be part of an SID monitoring station positioned on the territory of Sofia, Bulgaria. Which system, in turn, will sit for solar eclipses on the way of the radio route Sofia Bulgaria - Bafa Turkey.

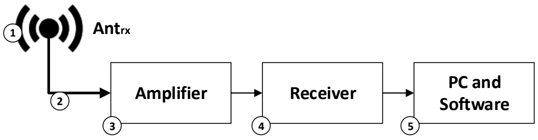

Fig.1. VLF system for SID monitoring block diagram.

Figure 1 presented block diagram of VLF system for SID monitoring block diagram and their main elements – (1) the system sensor – VLF loop antenna, (2) the transmission line, (3) amplifier, (4) receiver – here can be used different devices - spectrum analyzer, software defined radio, audio card, etc., their advantages and disadvantages could be subject to further research and (5) a computer with software for recording, processing and presenting the data received by the receiver in real time. The main subject of the present investigation is the transmission line (viz., (2), refer Fig. 1). Using an optical transmission line, block diagram figure 1 segment (2) will consist of two optical converters and an optical cable.

In fixed communication systems, optical fibers are the main medium for long-distance propagation. It is also the practical environment in which the best value for money is currently achieved. As an example, we will point to the lines under the Atlantic Ocean and more specifically the Hibernia Atlantic line connecting the USA, Canada, Ireland and England. The total length of the laid cables is 13,200 km.

The route between Southport and Halifax - Canada is about 5443km. The speed at which the data is transmitted is 160GBps, which is expected to increase to 1920 GBps. The delay is of the order of 54ms (RoundTrip Delay). In comparison, the alternative satellite connection has a delay of about 250ms.

The main indicators of fiber-optic communication systems are the information throughput (the maximum amount of information that can be transmitted per unit of time through a given physical section of the line) and the error rate - BER (see topic 1). It is these indicators that will serve us for comparison and will be useful in the considered designs.

For the practical design of SM fiber systems at a distance of several tens of kilometers and an information throughput of several GBps, it turns out that energy losses are of crucial importance. In general, they can be divided into localized and distributed. Localized losses are in detachable joints - connectors, non-detachable joints, power dividers, transitional devices, etc.

III. EXPECTED RESULTS AND FUTURE WORK

An initial part of our study is the selection of the components that make up the system, the assembly of a test laboratory environment and initial experimental results of the operation of such a system with the transmission of information over optical fibers. The experimental setup is presented in Fig. 2.

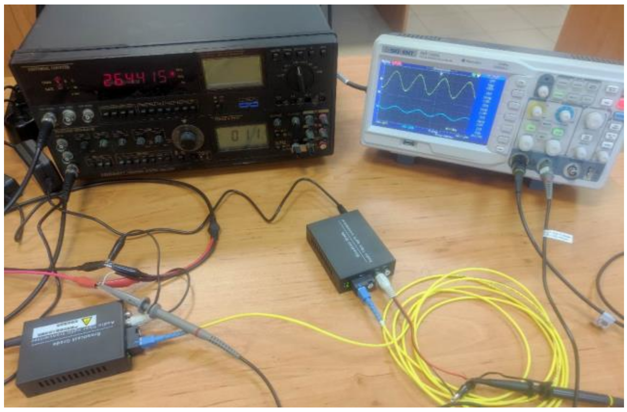

Fig.2. Experimental laboratory enviroment

For the signal source we use a function generator part of the Voltcraft Universal System MS-9150. As an additional frequency meter, we use the one built into the same device in order to further check the results. Transmission of the electrical signals is over unbalanced copper fibers with RCA connectors, which are connected to the 2Ch RCA Audio to Fiber Optic Digital Audio Converter Stereo Audio Over Fiber Optic Extender Converter for Broadcast System with parameters shown on table 1

TABLE 1
PARAMETERS OF THE OPTICAL CONVERTERS

Max input/output voltage	3.0Vp-p
Frequency Response	10 Hz~29kHz @±3dB
SNR	> 70dB
Connector	RCA
Input Power Requirements	DC 5V@2A
Operating Temperature:	-40°C ~ +85°C
Wavelength	1310nm
Optical Power Budget	18dB
Max Transmission Distance	25km
Fiber Mode	SM

The reading of the experimental results was carried out using a Siglent SDS 1052DL oscilloscope.

In fig. 3 is the preamplified input and output signal at a frequency of 26.7 kHz and the input signal without external influencing factors.

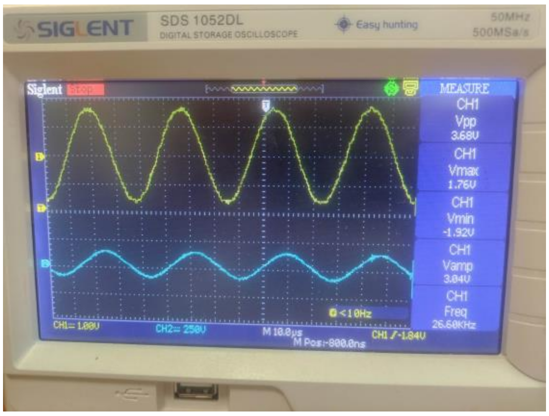

Fig.3. Input and output signal at a frequency of 26.7 kHz

Fig. 4 shows the input and output signal at a frequency of 26.7 kHz and an input signal with external influencing factors such as EMFI/RFI interference.

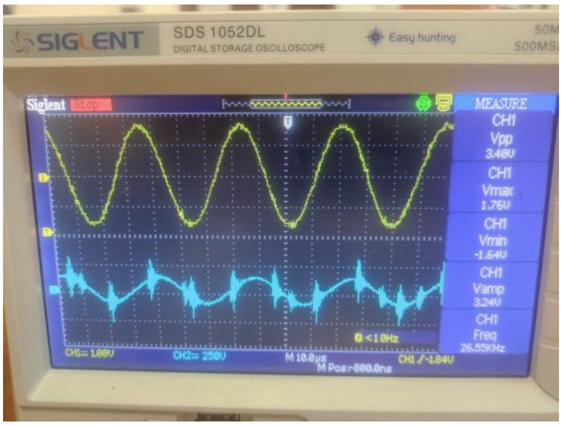

Fig.4. Input and output signal at a frequency of 26.7 kHz

As can be seen from the visual presentation of the oscillograms, even with EMFI/RFI interference, they do not affect the output signal after the optical communication channel. This is an important prerequisite for the application of optical fibers as a communication channel offering not only high transmission speed and channel security, but also prevention of various types of interference that are present in copper cables and radio communication links.

The optical fibers used are single-mode type G.652, and for the experiment the length of the cord is 2 meters.

The first experiment we conducted was at a frequency of 26.7 kHz as a constant value for the experiment. We changed the gain of the input signal from 0.9 volts to 4 volts in order to observe the change of the output signal after the optical converters, since they are equipped with a filter group and an optical signal amplifier. As seen in fig. 5 when increasing the input voltage above 3 volts, the optical converters reach a moment of "saturation" and then the output signal at the output of the optical converter reaches 4.5 volts. It can also be seen from the graph that we have a fairly linear increase in gain in terms of input voltage to output voltage.

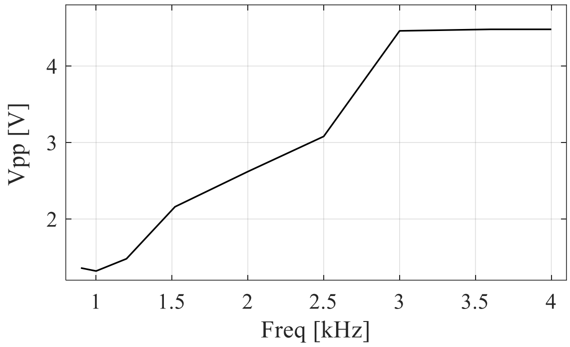

Fig.5. Graphic representation of the original experiment. Input vs output voltage

The second experiment we conducted was with a constant input voltage in the first case 1 volt, in the second 2 volts. We varied the frequency in the range of 10 to 30 kHz in 2 kHz steps and observed the output voltage. As can be seen in Fig. 6, with an input voltage of 2 volts, the output signal has good linearity from 15 to 30 kHz, while with an input voltage of 1 volt, we have "dips" in the range of 22 - 24 kHz. But even with the lower voltage of 1 volt, it can be seen that for the operating frequency we are interested in, 26.7 kHz, we have a good performance with it as well.

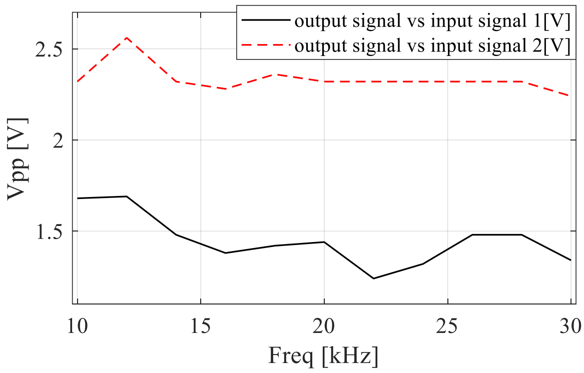

Fig.6. Graphic representation of the original experiment. Frequency vs output voltage

The presented experiments provide a prerequisite for applicability and possibilities for optimizing the system, as through the optical link channel it is possible to transmit the signal up to 25 km with losses along the channel of only 8 dB losses along the link channel. For transmissions over short distances of less than 1 km, losses along the optical link channel will be negligible below 0.32 dB.

Using mathematical models of solar flares captured by VLF technology [10], we can generate plausible solar activity data in Matlab using a priori data from already captured solar (for example data from different super SID station), and set up the specialization of different transmission lines – table 2, in the communication toolboxes of matlab, we can show the expected improvement of the data recorded by kind of VLF SID monitoring system - figure 7. Figure 7 conceptually shows the main components of a graph representing a solar flare captured by the VLF method.

TABLE 2
CHARACTERISTICS OF DIFFERENT TRANSMISSION LINES

Type transmission line	Characteristics and length losses in dB
Signal cable	Length = 100m Attenuation [dB/100m] ≈ 30 [dB]; Losses in connectors ≈ 1[dB] per connector;
Coaxial cable type RG58	Length = 100m; Attenuation [dB/100m] ≈ 30[dB]; Losses in connectors ≈ 1 [dB] per connector;
Optical cable	Length = 100m; Attenuation [dB/1km] ≈ 0.32[dB]; Losses in connectors ≈ 0.5[dB] per connector;

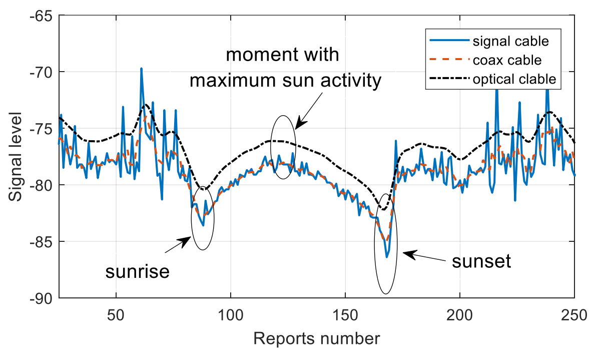

Fig.7. Simulation prediction of signal levels VLF system for SID monitoring with different transmission lines

A potential future improvement would be to install monitoring stations at various geographical locations, allowing for the collection of data along the path of the electromagnetic wave released by the transmitter.

IV. CONCLUSION

The presented experiment demonstrates that an optical communication channel can effectively transmit data from the VLF SID monitoring system over long distances with minimal signal attenuation and interference. However, the system's performance is subject to environmental conditions such as atmospheric disturbances, and the use of optical communication may require additional power consumption and specialized equipment. The statements made in the article have been confirmed by theoretical analysis and real research on an optical communication system.

Overall, this research contributes to the development of more efficient and reliable radiation monitoring systems and highlights the potential of optical communication as a viable option for use in VLF-based monitoring systems.

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