Proposal of Anti-Radiation Missile Decoy Assisted by Microwave Photonics

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***Abstract* — This article proposes the concept of a decoy that could be used against anti-radiation missiles (ARMs). The bait signals are generated remotely and transmitted to the sacrificial antenna site over a fiber optic network. This network has the possibility to support broadband radar signals in the range of a few GHz. This study postulated a distance of 1 km in relation to its park of antennas, however, this distance may be greater. This analog fiber link was designed for radar signal transmission in the frequency range of 0.3 to 3 GHz. The theoretical results were compared with the experimental ones and it was observed that the behavior of the radar signal power gain in the studied range is straight, thus the signal does not present distortions. The system proposed in this study is promising as a distraction for ARMs.**

***Index Therms* — Decoy, electronic warfare, fiber-optic analog link, radar signals.**

I. INTRODUCTION

In recent years a very large spread of operators of the ARMs is observed, that is, missiles employing their guidance by signals of RF coming from radars [1]. This work intends to present a solution of low cost which allows the survival of vital sites of surveillance radar for a certain region. The concept of the use of this device of protection against anti-radiation missiles is based on techniques of transmission of RF signals developed by Microwave Photonics (MP). The linkage of the RF signals coming from the radar generation and reception station with the antenna site requires high RF bandwidth, low signal attenuation, immunity to electromagnetic interference and long operating distance. Microwave Photonics is very promising in meeting all these requirements [2]. Fiber optic RF signal links are widely known in the literature, but their use as a decoy is poorly studied. This study proposes the use of RF signal transmitted by fiber optic in order to take advantage of the good results obtained in previous studies presented by PM in RF signal transmission.

The system intends to use as bait a set of antennas and amplifiers as sacrificial elements to attract ARMs. The signals are generated by the radar to be protected in a sheltered location and far enough away not to be hit by shrapnel. A sample of the signal is transmitted by a fiber optic network that can branch out to distribute signals to the various sacrificial antennas. This procedure is intended to generate inaccuracy in the missile guidance system.

Using the MP, a link was proposed for transmission of signals from radar with a fiber optic channel with 1 km of fiber optics and which has an optical splitter to divide the signal to its bait antennas, as shown in Fig.1.

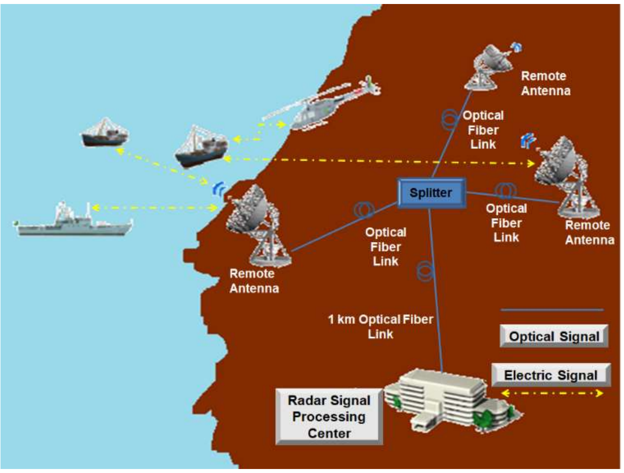

Fig. 1. Conceptual representation of the link of RF signals remotely transmitted from a localized radar (1 km) in relation to the antenna/amplifier sets [2].

As shown in Fig. 2, this link consists of a laser diode, impedance matching circuits, a Mach-Zehnder electro-optical intensity modulator, standard mono (SMF-28) fiber optic cables, optical splitter, p-i-n type of the photodetectors and RF amplifier units (AU).

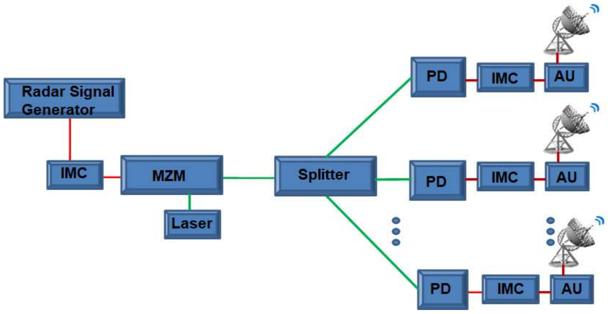

Fig. 2. Simplified schematic representation of an antenna system remotely located 1 km away from the radar generator. The green line means the link in the spectrum optical range and the red in the RF range. IMC - Impedance Matching Circuit, PD - Photodetector, AU - Amplifier Unit and MZM - Mach-Zehnder Modulator.

Observing the elements of the optical network proposed in Fig. 2, one can see the use of an optical splitter without optical amplification.

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II. THEORETICAL ANALYSIS OF THE ANALOGUE LINK TO THE OPTICAL FIBRE

The signal distribution system based on the fiber optic network must be reliable to the signal generated by the radar to be protected. This fidelity depends on the linearity of the network to transmit the RF signal in order to deceive the missile seeker. The link has non-linear optical elements that have linear operating ranges. For this link, the Mach-Zehnder modulator (MMZ) and the optical fiber are used within its limits of linear operation.

The MMZ has an optical response a quadratic sine, to avoid its non-linearity, a bias voltage was used at the modulator's quadrature point and a modulation index equal to 0.10.

The threshold of the Stimulated Brillouin Scatter (SBS) is defined as the necessary power pass from spontaneous to stimulated condition. This threshold is calculated by:

$$P_{SBS} = 21 b_p A_e / (g_B L_e), \tag{1}$$

where g_B is the maximum Brillouin gain in the steady state, L_e is the effective length given by (2) and A_e is the effective area of the optical fiber. This ratio can be extended to multichannel systems, where each channel interacts with the fiber independent of other channels. In Fig. 3 the variation of the power threshold is showed to avoid the spreading effect of Brillouin.

The b_p factor corresponds to the polarizations related to the pumping and probe laser, as well as the polarization properties of the fiber. In a fiber that maintains the polarization with identical states of polarization of the pumping laser and probe, $b_p = 1$. In a conventional fiber that does not maintain the polarization, $b_p = 2$, which will be considered in this study. The effective length of optical fiber is:

$$L_e = \frac{1 - e^{-\alpha L}}{\alpha}, \tag{2}$$

where α is the fiber loss coefficient [dB/Km] and L is the fiber length.

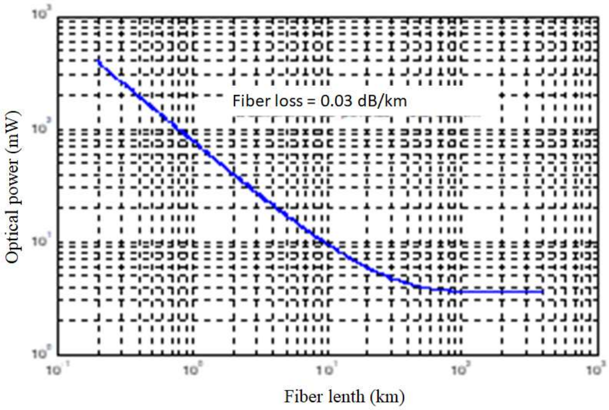

Fig. 3. Representation of the power threshold in an optical fiber to avoid the Brillouin scattering phenomenon.

The peak gain coefficient of SBS in single mode fibers is more than two orders of magnitude ($g_B = 4 \times 10^{-9}$ cm / W) higher than the gain coefficient for SRS. To ensure that the SRS effect does not occur it is sufficient to limit the input power to avoid the SBS effect. The SRS effect has its threshold above the SBS.

The optical fiber depends on the energy level of the optical signal, and the length of the link to be linear. For the purpose of this work, as the length of the link is 1 km and optical power available is 40 mW, there is a very large margin for the increase of optical power in order to improve the power gain of the RF signal because of P_{SBS} is around to 70 mW for 1 km of the length [3]-[7].

In view of these considerations and among the various figures of merit available for the verification of the quality of the link, it was made use of the analysis of the electrical power gain in (dB) that takes into account all these phenomena.

To determine the behavior of the RF power gain in the link, it is necessary to use the expression of the RF Power Gain [3] calculated with the help of the Graf addition theorem given by:

$$G = \frac{4 \eta_D^2 {\alpha_g}^2 (P_o^{In})^2}{P_{RF} Z_L} J_1^2 \left(2 m_i \, cos \left(\frac{1}{2} \theta_d \omega_{rf}^2 \right) \right) \tag{3}$$

The responsiveness of the photodetector is represented by η_D; α_g is the representation of all optical losses, such as insertion losses; P_o^{In} is the representation of the optical input power; P_{RF} is the strength of the RF signal at the system input; J_1 is the representation of the Bessel function of first-order species one; m_i is the RF modulation index in the MZM; θ_d is the first−order coefficient of dispersion determined at the angular frequency of the optical carrier, ω_o; ω_{rf} is the angular frequency of the RF signal and Z_L is the impedance of the load. This expression has been deduced using the Graf addition theorem that does not approximate the series of Bessel functions that model the operation of the MZM according to the modulation index.

III. EXPERIMENTAL ANALYSIS OF THE ANALOG LINK TO THE OPTICAL FIBER

The link was implemented by commercial components. A DFB laser operating at 1553.33 nm, MZM with half-wave voltage, Vπ = 4.1 V @ 1GHz, a splitter with two outputs, 1 km of optical fiber Corning Glass (SMF-28) dispersion of 17 ps/nm.km, two photodetectors for wavelengths from 900 to 1650 nm (RF output band >5 GHz) and RF amplifiers (band up to 3 GHz, gain min. 33 dB) were used. These components were assembled according to Fig. 4.

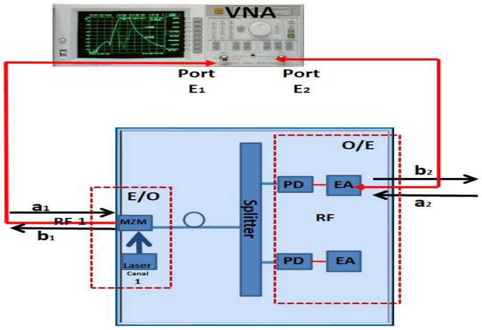

Fig. 4. Diagram representing the characterization of the analog fiber optic link as an RF system by a network analyzer.

First, all the components of this system were modeled and characterized experimentally in order to have knowledge of the values involved in each parameter of the link. It should be noted that the values of the parameters of the optical components used in the calculation of the theoretical value of the RF gain were the same as those observed in the experimental.

After this characterization, in order to measure the power gain of the RF signal of the link, one of the input RF cables of the system to be characterized was connected to port one of the network analyzer. The photodetectors were connected to their respective amplifiers. The output cables of the amplifiers were connected one by one to the RF port two of the network analyzer. With this procedure, parameter S21 of the RF scattering matrix can be calculated from the fiber optic link. The RF gain of the system was determined from the voltage values at the output of the RF amplifier for parameter S21 of each channel discounting the loss represented by the measured result of parameter S21 of the RF cables. Fig. 5 shows the comparison of the measured signals for one of the RF outputs overlapping the values calculated by the small signal method and by the exact method applying Graf's theorem. It should be noted that the results measured in each RF output were almost identical in view of the balance of the splitter of almost 50% in each output port.

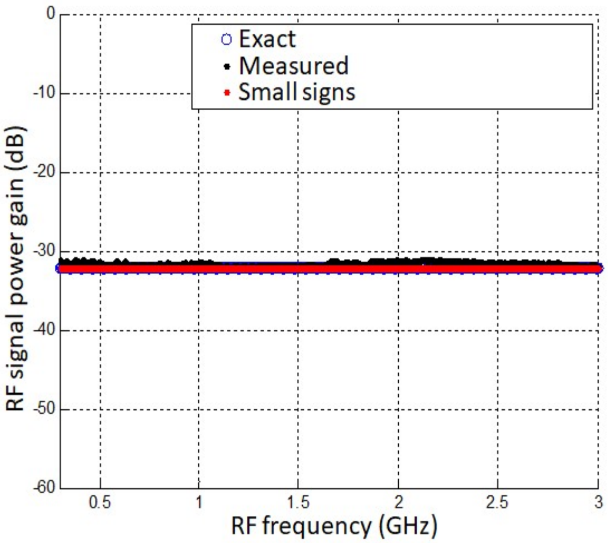

Fig. 5. Comparative graph of the measured result with the modulation index = 0.1 in relation to that calculated by the small signal method and by the exact method applying Graf's theorem.

Observing Fig. 5, the overlap of the values obtained in order to compare the calculated results with the measured values shows a very small difference. The measured values are -32 dB with a variation of approximately 0.5 dB in relation to the calculated results. The optical power was settled at 40 mW.

In Fig. 6 it was obtained the behavior of a pulsed signal at output of the link with RF amplification, centered at the frequency of 1 GHz, in the output of one of the RF ports. The RF signals were generated with a power of -4.68 dBm (equivalent to the modulation index equal to 0.1).

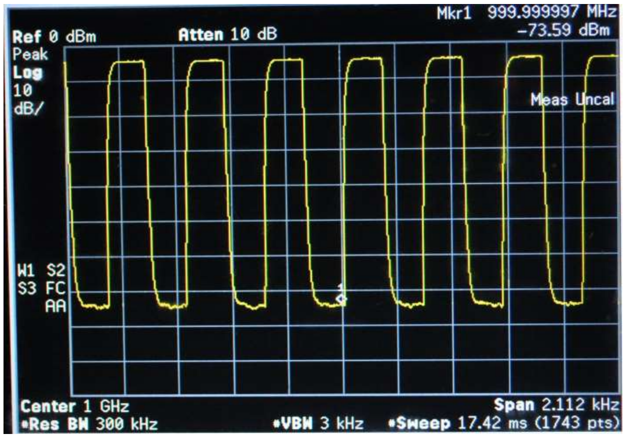

Fig. 6. Measurement obtained from the Agilent E4407B spectrum analyzer. The pulse of the RF signal referring to a pulsed signal centered at 1 GHz can be observed with the zero-span feature.

Analyzing (3), the RF gain depends on the power of the optical carrier and does not consider SBS effect. However, the optical signal strength should not be increased indefinitely. As shown above, when it comes to the transmission of an optical carrier on a fiber optic, the increase in optical power should be limited to avoid the stimulated scattering of Brillouin and Raman, taking into accounts the length of the link and optical power according to (1). As the length of the link is 1 km and optical power is 40 mW [3], there is a large margin for the increase of optical power to improve the power gain of the RF signal. The gain in the experiment could not be increased because the laser available for this experiment was limited in power and high losses. The SBS effect was not perceived because the match of theoretical e measured gain.

IV. CONCLUSION

Linearity may limit the linkage gain to the fiber optics of the RF signal. Observing the results, it can be seen, due to the length of the link of 1 km, that the dispersion and non-linear phenomena of the fiber did not influence the transmission of the RF signals. The RF power gain for this fiber optic link was approximately flat around to -32 dB for the frequency range of 0.3 to 3 GHz. This flat gain shows that this link allows large bandwidth of the RF signal. The results for the calculation method applying the Graf Addition Theorem and the results for the approximation for small signals were approximately coincident, considering that, with the modulation index (m_i) close to 0.10, there is no energy transfer from the fundamental component to the harmonics. It should be noted that if it was necessary to observe the behavior of the RF signals for the case of the larger modulations index, it could be evaluated with this expression developed based on the Graf addition theorem. With this mathematical expression, it became possible to accurately predict the behavior of the power gain of the RF signal. The experiment confirmed theoretical predictions, where the link is approximately linear thanks to the respect of the limits of optical power. This linearity allows the signal fidelity for this application. With these results, in this initial study, the possibility of using fiber optic linkage of RF signals to confuse a seeker of an anti-radiation missile in this frequency range may make this system possible as a distraction.

REFERENCES

[1] J. W. Rim and I.S. Koh, "Survivability Simulation of Airborne Platform with Expendable Active Decoy Countering RF Missile.", *IEEE Trans. On Aerosp. and Electron. Syst*., 2019, pp. 1-1, doi: 10.1109/TAES.2019.2913722.

[2] O. L. Coutinho, Almeida, V. R. e Oliveira, J. E. B. "Uso de Redes de Comunicações Ópticas para Transmissão e Distribuição de Emissores Radar", presented at XIII Simpósio de Aplicações Operacionais em Áreas de Defesa (SIGE), Brazil, São Paulo, São José dos Campos, 2011.

[3] A. P. Gonçalves, "Estudo experimental de enlace analógico a fibra óptica empregando WDM e sinal de RF multi-espectral". M.S. Thesis, Dept. Electron. Eng., Instituto Tecnológico de Aeronáutica, São Paulo, Brazil, 2014.

[4] W. D. Jemison and A. C. Paolella, "Introduction to Analog Fiber-Optic Links", in *RF and Microwave Handbook*, 2nd Ed, CRC Press, 2008

[5] B. H. Kolner and D. W. Dolfi, "Intermodulation distortion and compression in an integrated electrooptic modulator", Applied Optics, Vol. 26, No. 17, Sep. 1987

[6] S. K. Korotky and T. R. Halemane, "Distortion Characteristics of Optical Directional Coupler Modulators", in *IEEE Tran. on Microw. Theory and Techn,* vol. 38, nº. 5, Mai. 1990.

[7] S. P. Singh and N. Singh, "Nonlinear effects in optical fibers: origin, management and applications ", Progress in Electromagnetics Research, PIER 73, 249–275, 2007.