Simulation and Processing Methods for the Guiding Signal of an Opt -Electronic System for a Homing Missile with a Modulator Disk, Faults Modelling

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Abstract**—** In this paper we are proposing to present a technique of simulation for the formation of the digital signal generated with a modulator disk and also to describe the methods of processing the signal in order to obtain radial information. In the same time we will analyze different techniques for filtering the signal in order to damp the noise. For doing so, we will use band filtering techniques as well as more advanced techniques such as those based on the Fourier transformation. Finally, we will analyze the influence of these filters in which concerns the dependence of the radial information in comparison with noise/signal, and will model the two possible faults in optoelectronic system.

Keywords**—** fault, filtering, Fourier transformation, homing missile, modulator disk.

I. INTRODUCTION

The field of analyzing and processing methods for signals has been the focus of a number of investigations for many years. The objective of these investigations is to improve the algorithms required for data processing, as well as to develop new algorithms starting from real life problems, as shown in papers [5], [6],[7],[8].

As shown in paper [4] transducers and in particular the sensors that equip an aircraft can be digital or analogous. Analogous sensors are characterized by the fact that at output the variation is continuous and follows the input shape. Because most signals are continuous, most sensors used in technical applications are analogous. When perturbations are involved, or when data must be transmitted at a distance, processed or stored, analogous sensors are no longer satisfactory. In this case digital sensors are preferred. Such an example is represented by the opto system of the seeker in the case of homing missiles. In this case, the digital sensor is represented by the modulator disk which transforms the optical image in to a signal which is modulated in amplitude. This signal contains dual information: an information related to the phase of the signal, which represents the angular position of the target related the missile, and an amplitude information, which indicates the radial position of the target. By transforming the two polar coordinates in to rectangular coordinates we obtain the required signal for accomplishing the guidance command.

II. METHOD FOR GENERATING THE MODULATED SIGNAL

For an opt-electronic system in figure 1 it is represented the path of the signal which comes from the target, traverses the fairing (1) is deflected be the magnet - mirror (6), is again reflected by the lens-mirror (2), focalize by lens (3), quantified and coded by the modulator disk (4) and finally transformed into electric signal by the photoelectric cell (5).

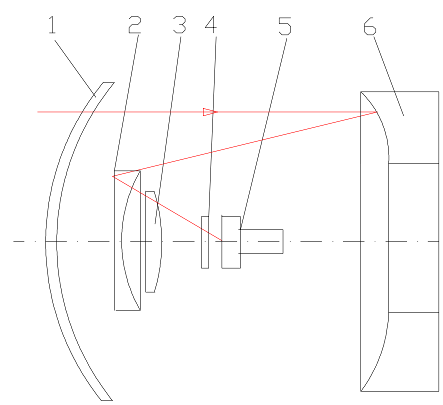

Figure 1: Optical scheme of the coordinator

In figure 2 it is presented a model for the regular modulator disk, which contains two zones, a zone with a spiral drawing which is responsible for the portion with the oscillator signal and a zone with circular drawings, which is responsible for the constant signal, as one can see from figure 4.

Figure 2: Modulator disk

The switching point from one zone to another is used for obtaining phase information and the mediated amplitude is used for obtaining radial information (the spot distance from the disk center). It is obvious that the shape of the drawing differs from one type of seeker to the other in respect to the type missile which uses it.

For describing the functioning of the opt system it is required a mathematical model which should describe the shape of the signal with the help of the modulator disk and afterwards to develop techniques for processing it. The model of the modulator disk can be constructed in a classical manner, thru analytical calculus formulas or thru numerical methods as shown in paper [3]. In contrast to [3], in our paper it will be obtained thru a graphical construction integrated in the model. The method is based on the processing of the image obtained by overlapping a light circular spot over the modulator disk drawing.

For achieving the model we built the negative image of the disk which later on was saved as a bitmap file (figure 3).

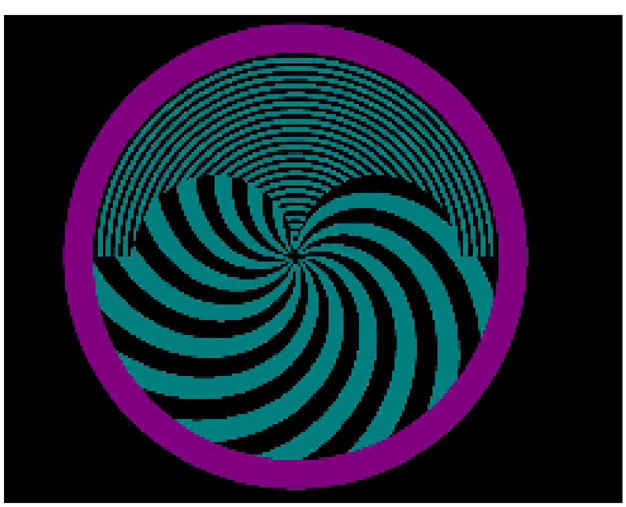

Figure 3: Negative image of the modulator disk

Separated from it, a circular white spot was generated which was loaded in a memory buffer as a retained segment. After deleting the screen the negative image of the disk from figure.3 was loaded, and afterwards thru the positioning of the circular spot in different points the number of white pixels was determined, which represent the dimension of the spot that is crossing the transparent area. The dimension of the spot from the transparent area was scaled to the total dimension of the spot and by doing so, a dimensionless signal was obtained. For obtaining the functioning signal of the system it was presumed that the spot executes a circular movement of a given radius. If this radius is considered scaled to the radius of the modulator disk, then we can operate with it as if it were a dimensionless size.

III. Detection and filtering methods of the guidance signal, the elimination of the uncontrolled noise.

The raw signal obtained has been processed thru 2 different methods, which are analyzed further on in order to find a way to reduce the white noise which affects the useful signal provided be the photoelectric cell. If we consider the normalized signal to the total dimension of the spot, then its values can be determined thru the relation:

$$I_i = \frac{n_i}{n_{\max}} \tag{1}$$

where n_i represents the number of white pixels (pixels of the spot positioned on the transparent area of the disk) in the angular position i of the spot, and $n_{\max}$ is the maximum number of pixels for the spot. If we consider that the frequency of rotation for the disk is $f = 80\,Hz$ the time corresponding to the swept angle can be calculated as:

$$t_i = \frac{\alpha_i}{2\pi f} \tag{2}$$

where the angle swept by the disk is given by:

$$\alpha_i = 2\pi i / N\,;\ i = 1..N \tag{3}$$

where N represents the number of angular positions in which we do the assessment.

Observation: For applying the rapid Fourier transformation it is necessary that *N* represents a power of 2. For this application we used *N=512*.

To the useful signal I obtained thru the calculus model described in (figure 4) we added the centered white noise ε_1 on the average value of the signal with constant amplitude.

$$X_i = I_i + \varepsilon_1 \tag{4}$$

We obtained the signal from figure 5 which is close to the real signal, obtained thru several measurements.

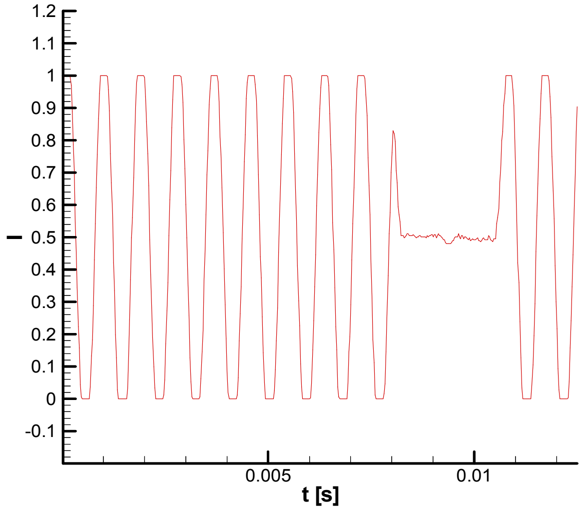

Figure 4: Diagram of the base signal

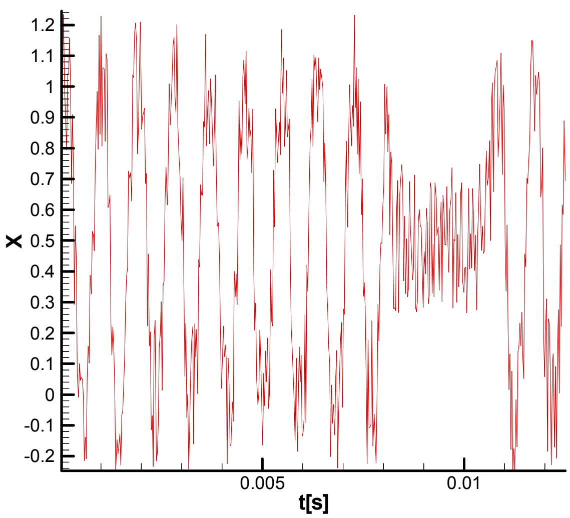

Figure 5: Diagram of the signal with noise

The first method analyzed is the one presented on the majority of guidance systems and consists in a semi-detection

The semi-detection is given thru the relation:

$$Z_i = \begin{cases} X_i - 0.5 \; for \; X_i - 0.5 > 0 \\ 0 \quad for \;\; X_i - 0.5 \le 0 \end{cases} \tag{5}$$

relation that cancels the negative values of the signal X_i

The results obtained are presented in figure 6.

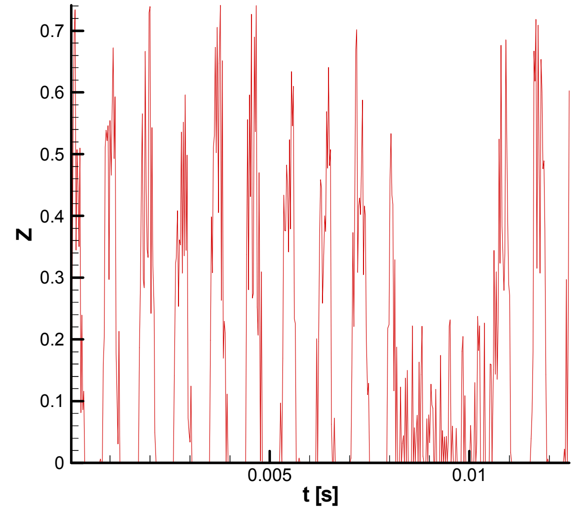

Figure 6: Signal with noise after the semi-detection

The filtering of the signal from figure 6 is done with the relation:

$$U_i = U_{i-1}\left(1 - \frac{\Delta t_i}{\tau}\right) + Z_{i-1}\frac{\Delta t_i}{\tau} \tag{6}$$

which represents a „going down" filter, the results obtained being shown in figure 7

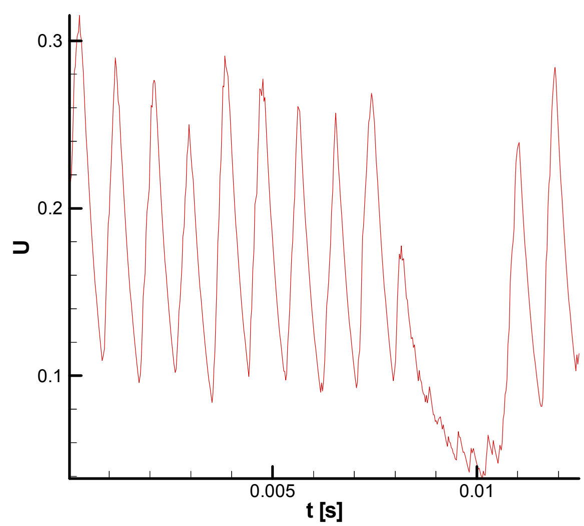

Figure 7: Signal wrapper after semi-detection and filtering

Further on we are proposing a detection method which is based on the correlation of two different signals. For this method we are generating an additional signal I_i to which we add the noise ε_2 different from the first noise, which in a practical way can be done thru a new measurement:

$$Y_i = I_i + \varepsilon_2 \tag{7}$$

Then, we do the product of the two signals:

$$Z_i = (X_i - 05)(Y_i - 0.5) \tag{8}$$

obtaining a new signal that is presented in figure 8.

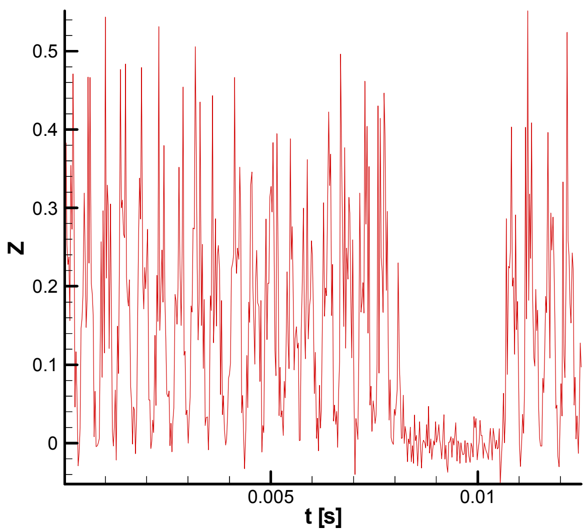

Figure 8: Diagram of the correlated signal

Afterwards, we apply the Fourier transformation, which allows for the selection of the fundamental harmonic and several high order harmonics, so, the realization of a filter with the desired width, which will not have a delay

For determining the Fourier transformation we used the fast subroutine DG01AD from library [2], which uses an algorithm described in paper [1]

So, if we have the complex numbers series

$$Z_i = X_i + jY_i \tag{9}$$

where $j = \sqrt{-1}$

the discrete Fourier transformation is obtain with the relation:

$$F_k = \sum_{i=1}^{N} Z_i e^{-j\frac{2\pi(k-1)(i-1)}{N}} \tag{10}$$

the result being presented in figure 9:

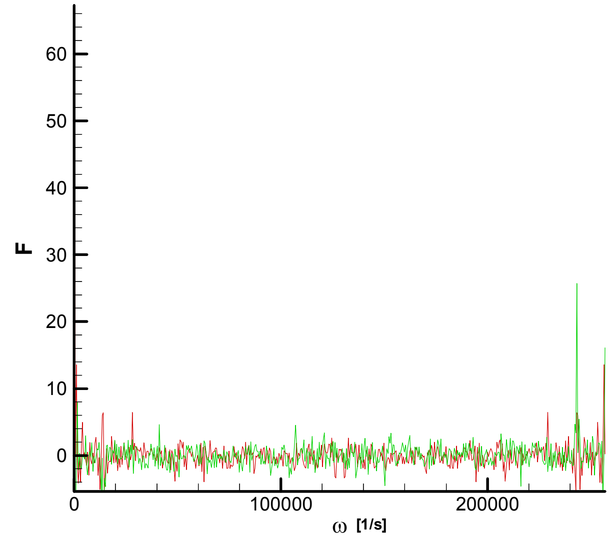

Figure 9: Fourier transformation of the correlated signal (red - X real part ; green – Y imaginary part)

If we consider the Fourier transformation of the form:

$$F_k = X_k + jY_k \tag{11}$$

The frequencies filter can be obtained with the relations:

$$X_k = X_k\left(e^{-\tau\omega_k} + e^{-\tau(\omega_N - \omega_k)}\right); \quad Y_k = Y_k\left(e^{-\tau\omega_k} + e^{-\tau(\omega_N - \omega_k)}\right) \quad , k = 1 \ldots N \tag{12}$$

the result being shown in figure 10.

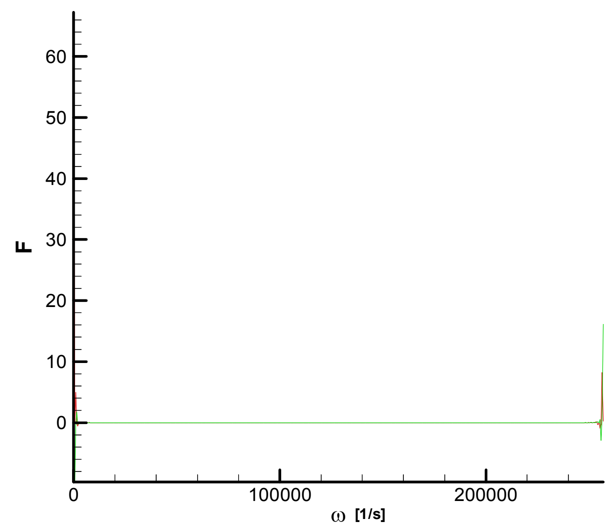

Figure 10: Fourier transformation in frequency domain (red – X real part; green – Y imaginary part)

After filtering, thru the reverse Fourier transformation:

$$U_i = \sum_{k=1}^{N} F_k e^{j\frac{2\pi(k-1)(i-1)}{N}} \tag{13}$$

we obtained the rapper of the useful signal, that is presented in figure 11.

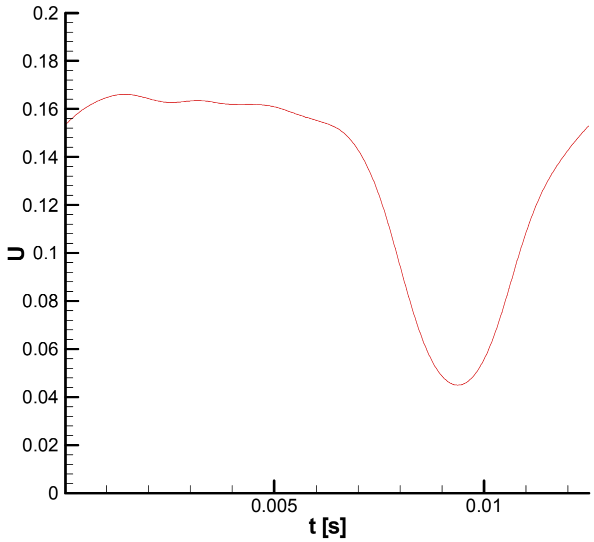

Figure 11: Wrapper of the useful signal

Based on this diagram, by integrating, we determined a magnitude which is proportional with the signal amplitude, that gives us information regarding the position of the spot along the radius of the modulator disk.

For the wrappers of the previously presented signal (figure 7 and 11) we can determine the integral U , also called the effective value of the signal, at different fractions of the values for noise/signal with the formula:

$$S = \sum_{i=2}^{N} \left(\left(U_i + U_{i-1} \right) \frac{(t_i - t_{i-1})}{2} \right) \tag{14}$$

Results are shown in figure 12.

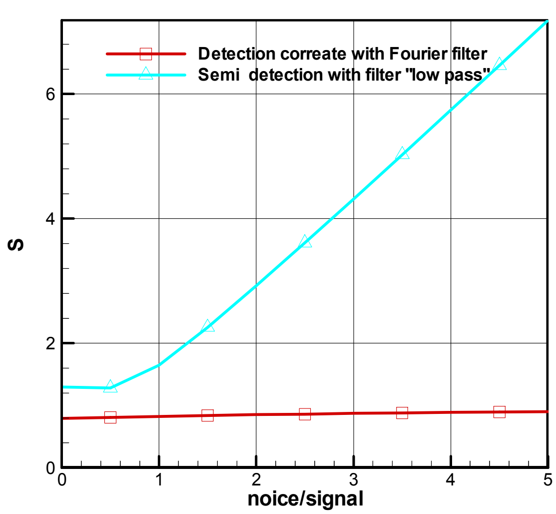

Figure 12: Effective value for the signal depending on the noise/signal fraction

IV. Faults Modelling

For interpreting the experimental results two types of defects were modeled, the results being presented in figure 13 and figure 14. Therefore, in figure 13 we present the case in which the surface of the spot which reaches the modulator disk has a different light intensity, depending on the angle under which the careen is being crossed (optical aberration). This case corresponds to an opacity / transparency that varies along the careen. We can then observe that the signal obtained has an asymmetric shape. The second case analyzed is the one presented in Figure 14, which corresponds to the situation in which the spinning of the spot on the disk takes place on a different rotation axis than the axis of the disk. As it can be seen from the graphic, we obtain a translation of the signal diagram, while maintaining the symmetry.

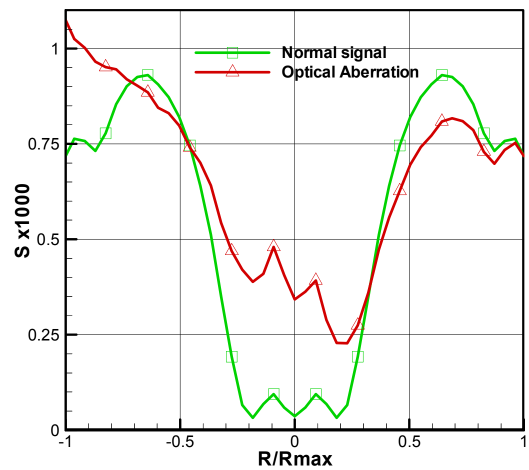

Figure 13: Opt-electronic system with aberration

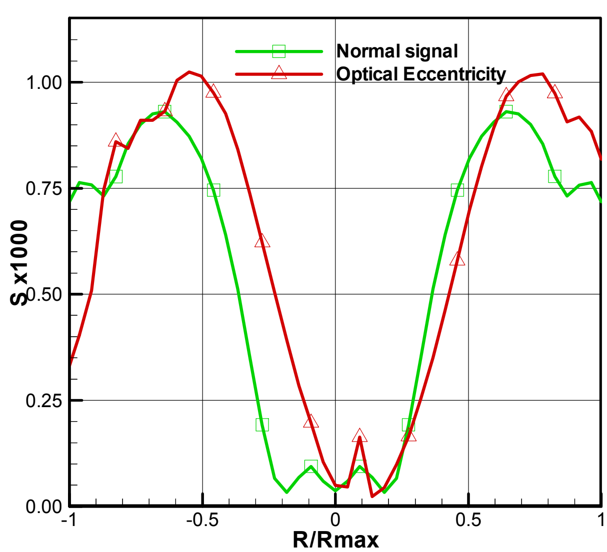

Figure 14: Opt-electronic system with eccentricity

V. CONCLUSION

By analyzing the results we can observe that the second processing method, based on the correlation of two signals in addition to a Fourier filtering, assures the elimination of the uncorrelated noise centered in zero, which at the end may lead to the increase the tracking range of the opt - electronic system analyzed. Also, we succeeded to build the models associated to two types of possible faults that help the interpretation of experimental results obtained on the opt - electronic system of the homing missiles.

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