Suppression of Ambiguity of Phase Interferometer with Extended First Base

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***Abstract* – This paper discusses the design of an interferometric system with extended first base, that the role of a passive precision approach radar should perform. The topology of the interferometric system is designed. The method of detecting the angle of arrival of the signal is proposed. The main goal is to propose an algorithm for suppression of uncertainty of determination of angle of arrival. The system based on comparison of the results of determining the angle of signal arrival using the first and second bases is discussed. Based on this comparison, results obtain from third base are assigned. These results guarantee accurate and unambiguous determining the direction of signal arrival. Possibilities for further expansion are discussed**

***Keywords* – Phase Interferometry, Precision Approach radar, Radar,**

I. INTRODUCTION

In this paper the design of an interferometric system with extended first base is discussed. The design of this interferometric system is based on parameters defined in the paper Phase interferometry for approach radar [1]. The proposed system should match the parameters for a precision approach radar [2]. The main objective is to maintain the unambiguous determination of the direction of arrival within a sufficient range of detection angles. In the intended use for precision approach radar the field of view of this system ±35 °is sufficient. The prolongation of the first interferometer base is necessary to allow the construction of the antenna system of individual receivers, which must cover the desired sector to determine the position of the target. The system with a length of the first base 2*λ is described. This value allows maintaining unambiguous of determining the direction of signal arrival.

In addition, the design of an interferometric system with a detailed description of signal processing on individual receivers is described. The main emphasis is on evaluating the direction of signal arrival with the suppression of ambiguities.

For optimization of algorithm for suppression of ambiguity the simple model of receiving signal was used. In this model the continuous signal with defined signal to noise ratio is used. Based on expected parameters of receiving signal, the signal to noise ration 15 dB was chosen. AWGN noise was used.

II. PHASE INTERFEROMETER DESIGN

The phase interferometer [3,4,5] is used to determine the angle at which the plane wave falls on the plane fitted by the receivers. Two or more base interferometers are used to increase accuracy - see Fig. 1

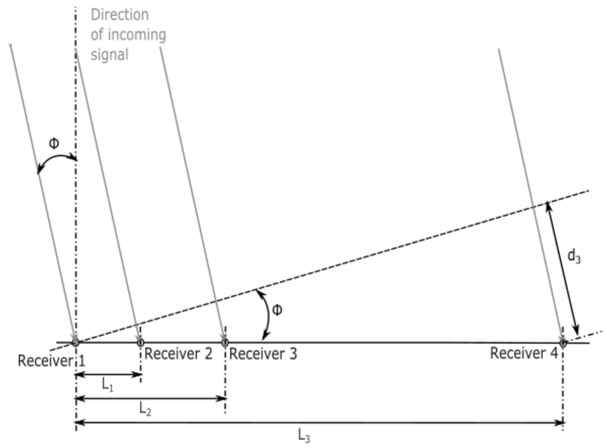

Figure 1. Phase interferometer with three bases (L_1, L_2, L_3)

Where:

Φ - The angle of arrival of the signal (ie the angle of plane wave impact on the plane of the antenna)

d_m - Extending the length of the beam path to the *m*-th antenna element

L_m - The length of the *m* base

The phase delay of the wave impinging on the *m* antenna element ψ_m can be calculated according to relation 1 .

$$\psi_m = 2\pi \frac{d_m}{\lambda} = 2\pi \frac{L_m \sin\Phi}{\lambda} \quad (1)$$

Where λ is the wavelength of the received signal.

The total voltage (complex signal envelope) received on the m-element is calculated according to the relation 2.

$$u_m = U \exp\left(-j\psi_m\right) + n_m; \quad (2)$$

Where *U* is the amplitude of the signal received on the *m*-th antenna element and n_m is the noise voltage (complex envelope) on the *m*-th antenna element.

The lengths of the individual bases to achieve the required accuracy of determining the angle of signal arrival (up to 0.3 °) and guaranteeing unambiguous determination of the angle of signal arrival in whole field of view (± 35 °) are L1 = 2λ, L2 = 4,8λ a L3 = 30λ.

The length of the first two bases will guarantee the unambiguous of determining the direction of signal arrival and the length of the third base L3 guarantees the accuracy of determining the direction of signal arrival. The wavelength of the considering signal with a carrier frequency of 1.09 GHz is 0.2752m. Therefore, the lengths of the individual interferometer bases are L1 = 0,5504m, L2 = 1,32096m a L3 = 8,256m. The length of the first base allows installation of the directional antennas of the first two receivers. The advantage of directional antennas is in suppression of targets which are located out of the field of view of intended system.

III. Calculating the Angle of Signal Arrival on Individual Bases

At first, we evaluate the phases of received signals on individual receivers. In the optimal case, we record phase samples for several periods of incoming signal with a sufficient sampling rate meeting the Shannon criterion. In digital form, phase samples are converted to unwrap format without rotation around 2π. It is advantageous for further processing. Subsequently, calculations of phase differences between individual receivers are performed. The mean value of the hundred samples of the phase differences on each interferometer basis is calculated. Thus determined the mean value of phase differences is then used as a phase shift constant $\Delta\Phi$ to calculate the direction of signal arrival on an individual basis.

To calculate the angle of signal arrival, use the following relation [6,7]:

$$AoA = \sin^{-1}\left(\frac{\lambda\left(\frac{\Delta\Phi}{2\pi}+I\right)}{L_m}\right) \qquad (3)$$

Where:

λ - The wavelength of the used signals

$\Delta\Phi$ - The phase difference between two signals on a given basis

I - An integer constant allowing shift by multiples of wavelengths and allowing eliminating the ambiguity of the measurement

This calculation is performed for all three bases and different values of constant I. For shorter bases (L1 and L2), a smaller number of replicas with a change of constant I is sufficient, for the longest base is necessary to use higher number of replicas with change of constant I. In our case for base L_1 the value of constant I -2, -1, 0, 1 are used, for base L2 the value -4, -3, … 3 are used and for longest base are used values from -25 till +25.

The following Figure 2 shows the results of determining the angle of arrival of the signal (for all three bases and all selected values of constant I). There is a large number of ambiguities in the specified values of angles of arrival. The darkest curves show the determining the direction of signal arrival by using the first shortest base, dark grey curves using a second base and the most densely represented curves show the determining the angle of arrival by the third longest base. The correct value of the direction of arrival of the signal can be seen on the diagonal of the graph (straight black line).

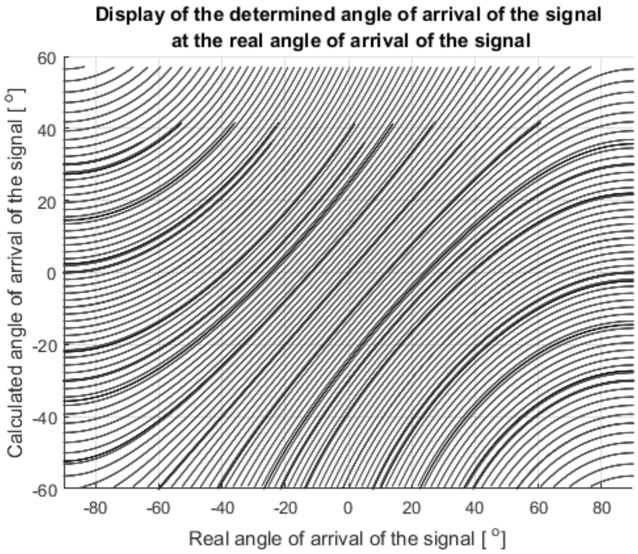

Figure 2. Determined angle of arival with use three bases (L_1, L_2, L_3) and different values of constnt I

IV. An Algorithm for Suppressing the Ambiguity of Determining the Direction of Signal Arrival

The purpose of this part of signal processing is to remove the ambiguities of determining the direction of arrival of the signal by comparing two adjacent bases L1 and L2 with appropriately selected constants I. The example of several waveforms determining the direction of signal arrival based on L1 and L2 bases with different constants I is in the following figure.

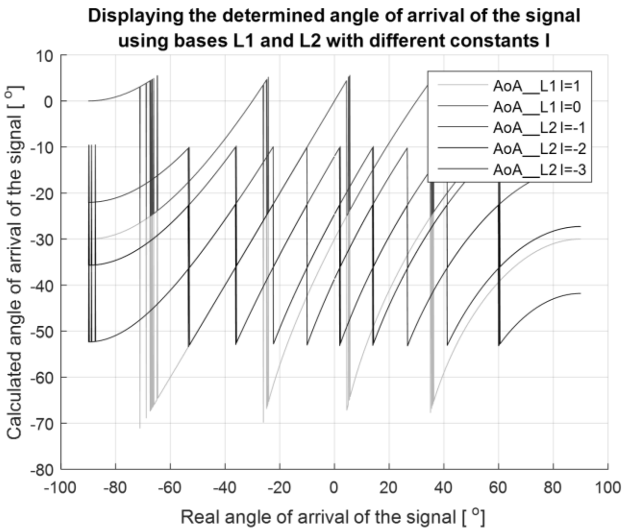

Figure 3. Detal of determined angles of arrival wit use bases L1 and L2 with few different valous of constant I

The algorithm of this part of the signal processing is shown in the flowchart in Figure 4. Individual parts of this algorithm will be described in more detail

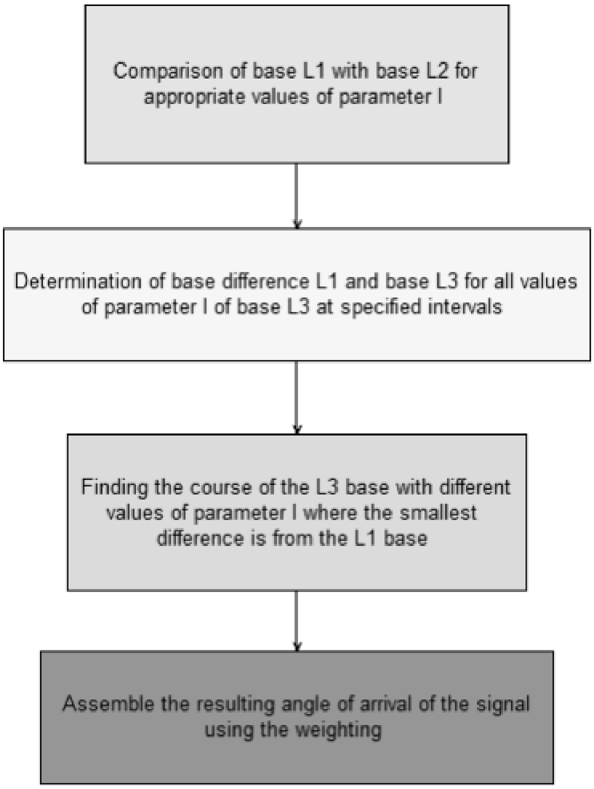

Figure 4. Algorithm for suppression of ambiguity

From Figure 3 it is obvious that determined angles of arrival based on L1 and L2 bases are similar only in small restricted areas. It is necessary to set the appropriate ratios of the first and second base lengths. The determined angles of arrivals based on L1 and L2 bases may only match in the area where they are identical with the real direction of signal arrival - sea Figure 5 in detil. In other areas, they must be different. The length of the first base L1 = 2*λ was fixed. It is due to the minimum antenna size requirements. The length of the second base L2 = 4.8*λ was chosen to meet the above conditions. The first block of this algorithm compares AoA (Angles of Arrival) determined on L1 and L2 bases with different values of constant I. If the difference is less than the defined constant K, calculate the difference AoA on the basis of L1 and the base L3 for all values of the constant I. In this case, the value of the constant K = 0.05 was chosen. This constant corresponds to the expected uncertainty in determining the direction of arrival of a signal.

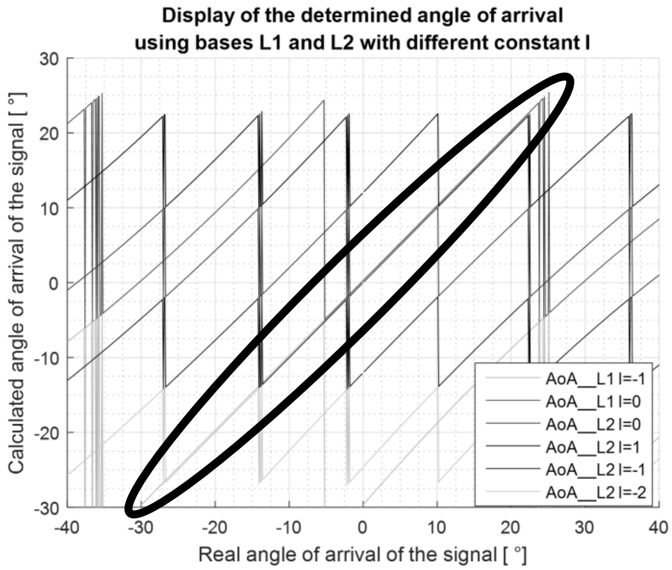

Figure 5. Detail of area wher the result from firs and secon bases are similar

The task of the third block of this algorithm is to find such a course of determination of angle of arrival with use L3 base (for all values of constant I) where is the smallest difference from the L1 base. This result is used for the final weighting of the resulting direction of signal arrival.

The last block of this algorithm from the appropriate selected parts of AoA assembles the resulting value of the determined signal arrival direction. Weighing is used here. The greatest accuracy of determining the direction of signal arrival using the longest L3 base which has a length of 30*λ is achieved. Therefore, the result obtained by this base is done 30 times. The result obtained from the shorter bases is add. The result is divided by the number 31. In this way, we obtain final weighted direction of signal arrival, which very accurately corresponds to the real direction of signal arrival. Primarily, this result is unambiguous at the required field of view ±35°. The resulting determination of the angle of arrival of the signal is shown in Figure 6

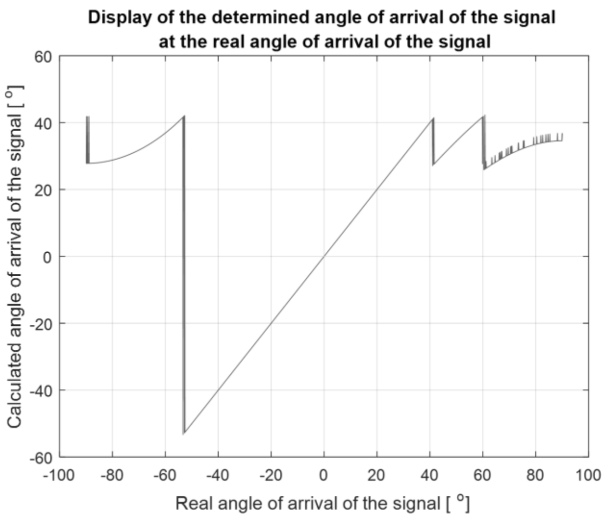

Figure 6. The resulting determined direction of arrival with unambiguous in fiel of view from -50° to +45°

If we subtract the evaluated direction of signal arrival from the real direction of signal arrival we will get the result in Figure 7. It is obvious that we will get very accurate results across the required field of view

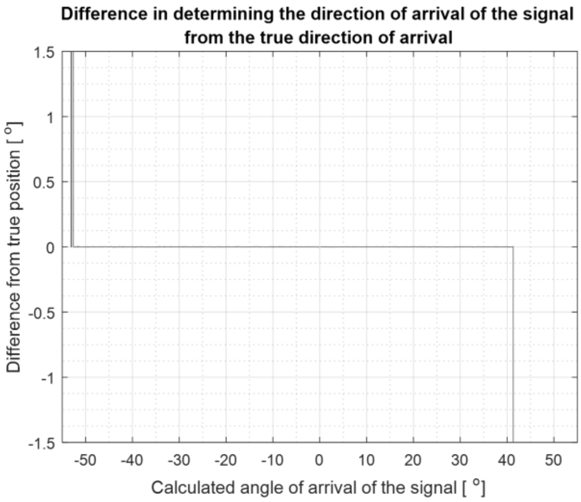

Figure 7. The difference of calculated direction of arrival from the real angle of arrival

V. Conclusion

This paper describes the design of phase interferometry system with extended first base. The length of the first base was set to 2λ. The key part is an algorithm to suppress the ambiguity of the evaluation of angle of arrival of signal.

From the presented results it is clear that the resulting range of unambiguous determination of the angle of signal arrival is in range from -50° to +45°. This range is absolutely sufficient for our application and well meets the required parameters. There is a possibility of further extension of the viewing angle but the algorithm for evaluation of the direction of signal arrival will be more complicated.

There is also the possibility of extending the first base in case of use an antenna system with higher directivity. This would lead to further increasing of complexity of an algorithm for evaluation of the direction of signal arrival. The directions of signal arrival on individual bases would have to be calculated with a larger range of constant I.

Acknowledgment

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