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The Path Similarity Method for Phase Measurements Disambiguation

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***Abstract*—We introduce the technique for phase measurements disambiguation based on the paths similarity identification. To obtain these paths, we use phase and amplitude measurements. By simulation, the performance of the presented approach is established. Its application for the phase measurements disambiguation is demonstrated by the example of the phase correlative direction finder for which the amplitude correlative direction finding mode is activated without any hardware changes.**

Keywords-phase measurements; multiposition direction-finder; disambiguation elimination

I. INTRODUCTION

Multiposition phase direction finders (PDFs) are applied for precise determining the angular coordinates of radio spacecrafts (RSC) [1, 2]. However, a problem of phase measurements (PM) disambiguation is still actual in this case. As a rule, it can be solved by installing one or more shorter midbases (intermediate scale), together with the "virtual" bases, into the PDF, in addition to the instrumentation base providing the required precision of measurements (precision scale) [3]. In [4], for the PM disambiguation, both optimal and quasi-optimal algorithms are introduced using the measurements carried out at all of the bases in order to determine the integer of the phase difference periods at each base.

Besides the optimal algorithms for the PM disambiguation, the heuristic algorithms are widely used, such as the algorithm of sequential PM disambiguation from one base to another [3-5], etc. The special feature of the sequential PM disambiguation method is determination of the total number of the phase difference periods at i-th base in terms of the measurement results at $(i-1)$-th and i-th bases only. Every one of the algorithms mentioned above provides the disambiguation within a certain interval of the angular domains – that is the unambiguity interval. The size of such interval depends upon the PDF antenna arrangement and diameter as well as on the radio source wavelength. These algorithms also require the target designation, if the radio source is beyond this interval. Below, we will demonstrate the technique allowing overcoming the specified disadvantages.

II. THE PROBLEM DEFINITION

The application of the directional follow-up antennas in the PDF allows significant simplification of the requirements to the range of the PM unambiguity interval that is now selected according to the applied antenna beamwidth for the specified range of angular measurements. The optimal use of the directional antennas in the PDF is made possible, if the signal detection zone size (by amplitude) matches the range of the unambiguous PM interval.

The selection of the antenna parameters (mirror diameter, beamwidth) is based on the requirements to the sensitivity and the spatial discrimination. In their turn, the PDF antenna field parameters are selected according to the specified accuracy and the need to provide the PM unambiguity, within the main beam at least. Under the fixed antennas arrangement, the "angular sizes" of the unambiguous PM interval for each of the bases depend on the object position on the upper hemisphere. These sizes are minimum when observing the objects located at the directions perpendicular to PDF base. For double-range PDF, they are defined from the relation:

$$\gamma_u = \lambda q / B_{PS}\,, \qquad (1)$$

where γ_u is the sector size by the angle of the unambiguous PM; λ is the received signal wavelength; q and p are the scale contingency coefficients; $p/q = B_{IS}/B_{PS}$ is the transition coefficient; B_{PS} is the PM precision scale baseline distance; B_{PS} is the PM intermediate scale baseline distance.

By the criterion of the signal detection within the main beam width under the –3 dB level, the condition for the self-contained unambiguous angular measurements using the double-range PDF with the directional antennas has the form of

$$B_{PS} \le q d_A\,, \qquad (2)$$

where d_A is the PDF antenna diameter.

The condition (2) implies that the object is located within the pattern center. While detecting the object outside the specified borders, the anomalous errors may take place due to the limited range of the unambiguous PM interval. Therefore, for the correct PDF operation, we should significantly decrease the risk of producing the anomalous measurement results.

III. The Amplitude Correlative Direction Finding

In order to expand an area of reliable and precise angular measurements over the whole upper hemisphere, we suggest the amplitude emitter location method in addition to the phase method.

As the PDF equipment contains some identical directional antennas, within their patterns it is possible to locate the object by the emitted signal amplitude by means of the antennas diversification, i.e. practically without the additional hardware installation. In Fig. 1, we can see the pattern layout for five PDF antennas A1-A5 within the "tangent" plane while the object amplitude direction finding is going on.

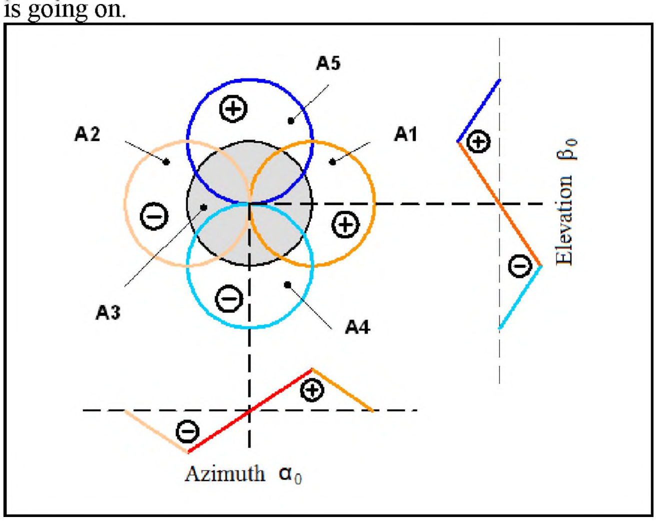
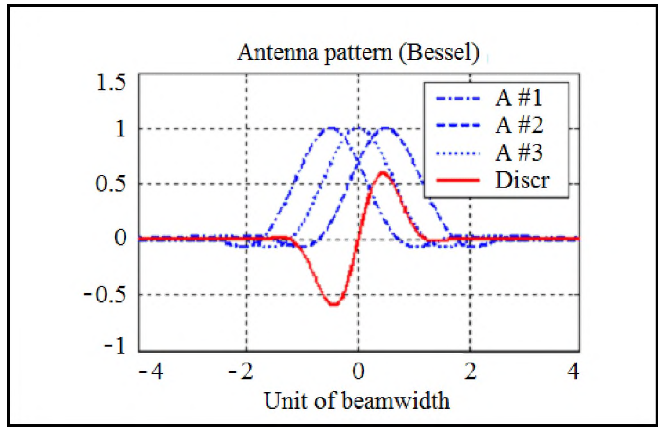
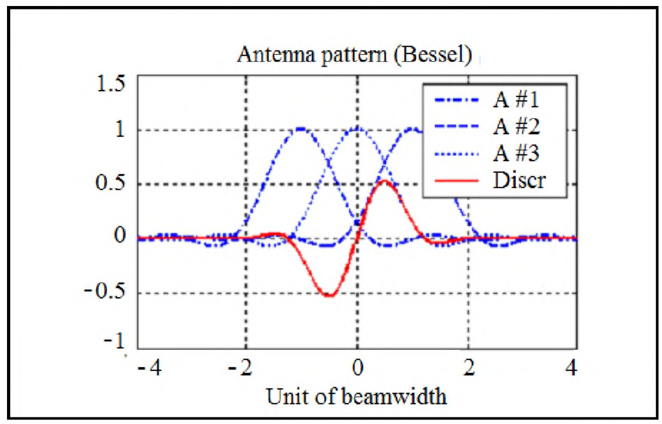


Figure 1. The pattern layout for five PDF antennas within the "tangent" plane under the object amplitude location



a



b.

Figure 2. The direction finding characteristics of the five-antenna ACF: a) 0.5 pattern shift of A1, A2 (A4, A5); b) 1.0 pattern shift of A1, A2, (A4, A5)

If the radio source signal modulation format is unknown, then, for the implementation of the amplitude direction finder with the diversity of aerials, it is reasonable to apply the cross-correlation reception. We will name such angular coordinate measurer as the amplitude correlative direction finder (ACF). It should be noted that the amplitude measurements are carried out simultaneously with the phase measurements, and through the common reception channels. The direction finding characteristics in the ACF mode are presented in Fig. 2.

While carrying out the session of the angular coordinates measurements by the PDF with the directional follow-up antennas, the disambiguation, as a rule, is implemented only once – at the beginning of the session [2-4]. Further auto-tracking is made in terms of the phase information (in phase correlative finding mode). The PM disambiguation error is demonstrated as the gradual increase of the RSC phase auto-tracking error, while the object is in fact gradually leaving the antenna patterns until the moment of the auto-tracking loss.

The presence of the ACF mode allows controlling the process of phase automatic tracking. At the interval of significant errors that is comparable with the interval of uniqueness, it is necessary to repeat the disambiguation procedure at the base with the most appropriate conditions for that. The more so as the probability of a correct disambiguation at one base is higher than that for another base, except in the case when the direction cosines to each of the bases under measurement are equal.

If the decision on repeated disambiguation is made in the absence of a priori information on the RSC trajectory, then the use of the amplitude direction finder data as targeting parameters for the phase direction finder does not provide the accuracy required. This makes the disambiguation error correction during the phase tracking process impossible.

IV. The Amplitude Correlative Direction Finding

Let us consider the operation of a phase direction finder in the mode of automatic tracking by the amplitude information (ACF mode) with the simultaneous recording of all phase information. We presuppose that the PDF measuring bases are located along the X- an Z-axes of the right-handed coordinate system where the X-axis is directed to the north and the Z-axis is directed along the local vertical.

For the disambiguation during the post-session processing, we suggest to use the "path similarity" method. It means that in a given interval of the possible values of an integer number of phase cycles for the selected points that are optimal for each of the measuring bases we choose the values under which the RSC path measured by the amplitude method is similar (parallel) to the path calculated based on the complete phase information. Under the path in this case we mean the time sequence of values that the azimuth and the elevation of the RSC take.

Phase measurements using the suggested approach to the disambiguation include the following operations.

1. Tracking of the RSC by the phase direction finder in the ACF mode and storing the samples array of the RSC angular coordinates (azimuth α and elevation β) based on the results of the amplitude direction finding.

2. Synchronously storing the arrays of the phase samples Φ_{PSx} and Φ_{PSz} of the phase direction finder and the angular coordinates α and β of the amplitude correlative direction finder at the accurate X and Z bases.

3. At the end of the session, the samples Φ_{PSx} and Φ_{PSz} obtained during the measurement (session) are rectified. The initial arrays of the phase samples Φ_{PSx} and Φ_{PSz} are in fact the "sawtooth" sequences of the measurement results of the received RSC signals phase shifts. At the same time, each measurement that actually is a fractional part of the total difference of the phase shift must be between 0 and 2π. Thus, data rectifying procedure recovers the continuity of the arrays of the phase samples Φ_{PSx} and Φ_{PSz}.

4. The smoothed samples $\overline{\Phi}_{PSx}$, $\overline{\Phi}_{PSz}$ and $\overline{\alpha}$, $\overline{\beta}$ are formed for the rectified samples of the phase $\widetilde{\Phi}_{PSx}$, $\widetilde{\Phi}_{PSz}$ and the angular coordinates α, β.

5. Determining the minimum RSC elevation β_0 in the array $\overline{\beta}$, as well as the azimuth α_0 corresponding to it.

6. Estimating the integers of the phase cycles N_{PSx}, N_{PSz} for the appropriate phase samples $\overline{\Phi}_{PSx}$, $\overline{\Phi}_{PSz}$ by means of the angular coordinates α_0, β_0 that have been obtained in the ACF mode at the same time point.

Estimating the integers of the phase cycles N_{PSx}, N_{PSz} carried out by the recalculation of the angular coordinates in the phase of the orthogonal bases of the PDF antenna field:

$$N_{PSx} = \{B_{PSx} K_x / \lambda\}, \qquad N_{PSz} = \{B_{PSz} K_z / \lambda\}, \qquad (3)$$

where $K_x = \cos\alpha_x = \cos\beta_0 \cos\alpha_0$ is the X-axis direction cosine; $K_y = \cos\alpha_z = \cos\beta_0 \sin\alpha_0$ is the Z-axis direction cosine; $\{\}$ is the operation of taking an integer.

7. Recovering the arrays of the phase samples Φ'_{PSx}, Φ'_{PSz} of the signal allowing for the integer of the computed phase cycles N_{PSx}, N_{PSz}:

$$\Phi'_{PSx} = N_{PSx} + [\overline{\Phi}_{PSx}], \quad \Phi'_{PSz} = N_{PSz} + [\overline{\Phi}_{PSz}]. \qquad (4)$$

Here $[\overline{\Phi}_{PSx}]$, $[\overline{\Phi}_{PSz}]$ are the fractional parts of the arrays of the smoothed X-axis and Z-axis phase samples.

8. Recalculating the recovered arrays of the phase samples Φ'_{PSx}, Φ'_{PSz} in the array of the values of the azimuth α' and the elevation β'.

9. Calculating the residuals $dEl = \beta' - \overline{\beta}$, $dAz = \alpha' - \overline{\alpha}$ that are between the calculated values α', β' and the smoothed results of the measurements of the angular coordinates $\overline{\alpha}$, $\overline{\beta}$.

10. Repeating the operations 6-9 by changing the values of N_{PSx}, N_{PSz} in both directions by the values defined for the point α_0, β_0 within the interval specified by the expected error of the angular coordinates measurement in the ACF mode.

11. From the resulting arrays of the residuals dEl, dAz, we select a pair of N_{PSx}, N_{PSz} values under which the deviation of the residuals is the constant value for the whole measuring session. This pair of N_{PSx}, N_{PSz} values will correspond to the correct disambiguation of the PM for each of the bases.

We tested the efficiency of the disambiguation using the path similarity method by means of simulation in MATLAB [6], the results are shown in Fig. 3.

The simulation was carried out with the following parameters of the RSC orbit:

– The altitude of the circular orbit is 800 km;
– The height culmination is 55 degrees;
– The azimuth culmination is 225 degrees.

The minimum elevation of the RSC is equal to 10 degrees; the frequency of the radio source is 4 GHz. The disambiguation of the PM is conducted through the base $B_{PS} = 50$ m.

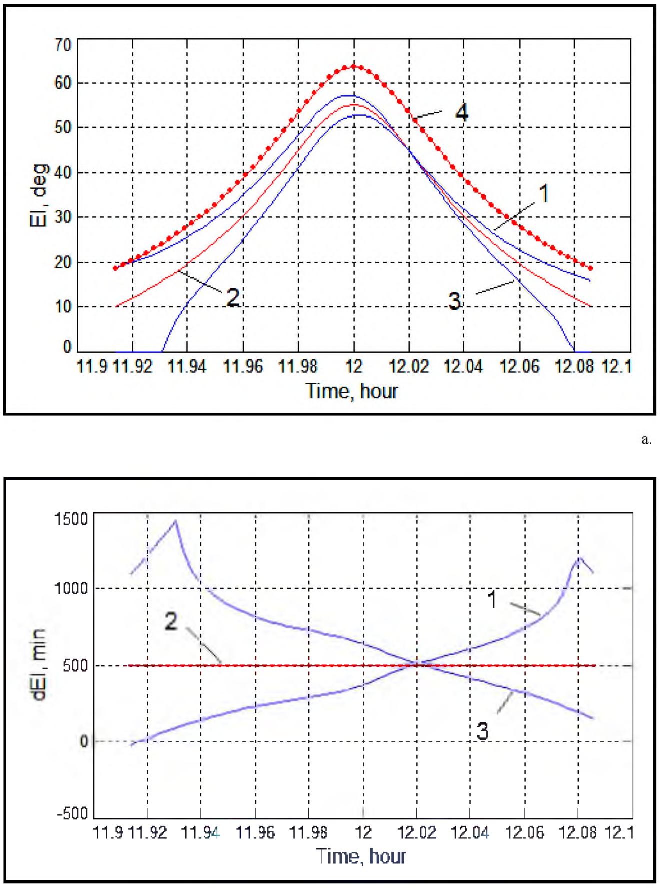


Figure 3. The results of measurements of the elevation of the correlation-amplitude direction finder (a) and of the residual by the elevation between the correlation amplitude direction finder measurements and the correlation phase direction finder results (b)

In Fig. 3a, we have the following designations. Curves 1, 3 are the RSC paths (elevation) according to the results of the PM measurements (disambiguation error is ±50 phase cycles). Curve 2 is the RSC path according to the results of the PM measurements (disambiguation error is 0 phase cycles). Curve 4 is the RSC path according to the results of the amplitude measurements in the presence of the direction finding errors.

In Fig. 3b, curves 1, 3 are the residuals by the elevation between the amplitude (Fig. 3a, curve 4) and phase (Fig. 3a, curves 1, 3) measurements, while curve 2 is the residual under the correct disambiguation.

The following conclusion can be drawn from the results of the simulation. The integer of the phase cycles fitting the array of the rectified values of the phase samples during the observation allows reduction to the constant value of the residual between the results of the angular coordinates measurements in the modes both of the correlation-amplitude direction finder and the correlation-phase direction finder. The largest residuals are observed under low elevation, and then the disambiguation of the phase measurements is recommended.

V. Conclusion

Complex use of both amplitude and phase direction finding in multi-position direction finder allows new approaches to the problem of the disambiguation of the phase measurements based on the similarity of the paths received under the simultaneous phase and amplitude direction finding.

The path similarity method is applicable for the direction finding of the objects, the directions to which vary with respect to the directions of the bases by the value providing the optimal points of the disambiguation for the both measurement bases of the phase direction finder.

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