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RESEARCH ARTICLE

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# Airborne direction finding method based on Doppler-phase measurement



**Abstract** A new direction finding (DF) method, in which the high-accuracy measuring can be realized only with single baseline, is presented used for airborne based on Doppler-phase measurement. The analysis discovers that the integer of wavelength in radial distance can be directly derived compositely, making use of the velocity vector equation and Doppler shift, as well as Doppler changing rate equation. From this, the integer difference of wavelength in path length difference of radial distance between two adjacent antenna elements can be obtained. As soon as the value less than a wavelength in path length difference is determined by phase difference measurement, the direction angle of target can be obtained. As compared with now existing interferometry first determining phase difference, this sort of direction finding method combining Doppler with phase difference first by determining path length difference does not have phase ambiguity nor require restricting base length. By simple mathematical identity transformation, we can prove that the equation derived in this paper is equivalent to an existing one from phase interferometry. The new method presented in this paper will certainly increase new developing force for the research and development of airborne single station direction finding system.

**Keywords** phase interferometer, direction finding, Doppler frequency, airborne single station location

## 1 Introduction

The phase interferometry is a direction finding (DF) method with better measurement accuracy. It is widely used for active and passive detection system [1–3]. However, for single baseline phase interferometry, there is a contradiction between the accuracy of direction finding and maximum unambiguity angle [4,5]. To solve this problem, the existing method is to utilize multibaseline system including the method combining long baselines with short ones [6–8] and algorithm resolving phase ambiguity with multibaseline [9,10].

In actual application, the method combining long baselines with short ones have two limitations [11,12]. In fact, corresponding baselines will also become extremely small since wavelength is very short for high-frequency signal. At this moment, not only must the antenna element be made very small, but also very high demand is put forward for antenna arrangement. It will bring about coupled between antennas and bring down antenna gain. At the same time, higher demand will be required for measurement accuracy of interferometer. For algorithm resolving phase ambiguity with multibaseline, the computing amount is heavy due to demanding multidimensional integer search [13,14].

The study shows that airborne single baseline interferometer will realize high-accuracy direction finding without phase ambiguity after combining with Doppler information. At the same time, the baseline length can be arbitrarily selected only from the standpoint of measurement principle. This paper presents the basic measurement principle and detailed analytic derivation method of Doppler-phase interference measurement.

## 2 Single baseline Doppler-phase difference DF principle

### 2.1 Existing DF expression

For contrasting, we first give the existing expression. Provided that incident wave is approximatively plane wave, the phase difference between two adjacent antennas takes the form

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$$2\pi N_0 + \phi = \frac{2\pi L}{\lambda}\sin\theta, \tag{1}$$

where $N_0$ is an integer, $\lambda$ is the wavelength, $L$ is the distance between two antennas, $\phi$ is the phase difference, and $\theta$ is the incidence angle of target signal.

### 2.2 Specific value of Doppler change ratio

Figure 1 shows the geometric relationship of single baseline direction-finding antenna array applying for flying vehicle based on Doppler shift-phase difference measurement. Provided that target is static or low speed, when flying vehicle is in uniform motion, the expressions of Doppler change ratio in two antenna elements are

$$\dot{f}_{d1} = \frac{v_{t1}^2}{\lambda r_1}, \tag{2}$$

$$\dot{f}_{d2} = \frac{v_{t2}^2}{\lambda r_2}, \tag{3}$$

where $r_i\,(i = 1,2)$ is the radial distance, and $v_{ti}$ is the tangential velocity.

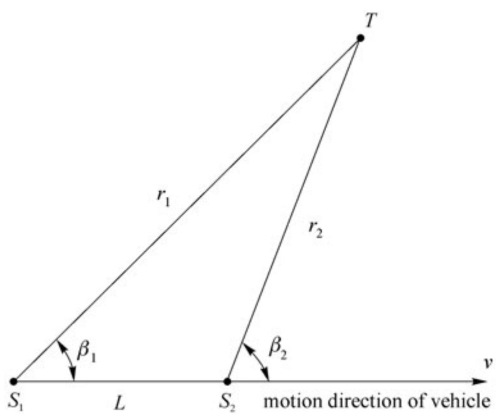


**Fig. 1** Geometric schematic for airborne DF with single baseline

The specific value of Eqs. (2) and (3) is

$$q = \frac{\dot{f}_{d2}}{\dot{f}_{d1}} = \frac{r_1}{r_2}\frac{v_{t2}^2}{v_{t1}^2}. \tag{4}$$

According to sine theorem, the specific value of radial distance corresponding with two antennas can be also obtained:

$$\frac{r_2}{r_1} = \frac{\sin\beta_1}{\sin\beta_2} = \frac{v\sin\beta_1}{v\sin\beta_2} = \frac{v_{t1}}{v_{t2}}. \tag{5}$$

It shows that the specific value of radial distance equals to the one of tangential velocity corresponding with two antennas when flying vehicle is uniform motion. Substituting Eq. (5) into Eq. (4) gives

$$q = \frac{v_{t2}^3}{v_{t1}^3}. \tag{6}$$

### 2.3 Integer value of radial distance

According to velocity resolution, the identical relation of velocity can be written as

$$v^2 = v_{r1}^2 + v_{t1}^2 = v_{r2}^2 + v_{t2}^2, \tag{7}$$

where $v_{ri}$ is the radial velocity.

After rearrangement, we have

$$v_{r1}^2 - v_{r2}^2 = v_{t2}^2 - v_{t1}^2. \tag{8}$$

Respectively substituting Doppler shift equation and Doppler change ratio as well as specific value into Eq. (8) gives

$$\lambda(f_{d1}^2 - f_{d2}^2) = r_1\dot{f}_{d1}(u-1), \tag{9}$$

$$\lambda(f_{d1}^2 - f_{d2}^2) = r_2\dot{f}_{d2}\left(1-\frac{1}{u}\right), \tag{10}$$

where $u = \sqrt[3]{q^2}$.

Thus, we can obtain integer values at about two radial distances:

$$N_1 = \text{int}\left[\frac{r_1}{\lambda}\right] = \text{int}\left[\frac{f_{d1}^2 - f_{d2}^2}{\dot{f}_{d1}(u-1)}\right], \tag{11}$$

$$N_2 = \text{int}\left[\frac{r_2}{\lambda}\right] = \text{int}\left[\frac{(f_{d1}^2 - f_{d2}^2)u}{\dot{f}_{d2}(u-1)}\right]. \tag{12}$$

### 2.4 DF equation based on Doppler shift-phase difference

Provided that the phase measured by descriminator is respectively $\phi_1$ and $\phi_2$ responding with two radial distances, radial distance can be represented by

$$r_1 = \lambda\left(N_1 + \frac{\phi_1}{2\pi}\right), \tag{13}$$

$$r_2 = \lambda\left(N_2 + \frac{\phi_2}{2\pi}\right). \tag{14}$$

Corresponding path difference is

$$\Delta r = \lambda\left(\Delta N + \frac{\Delta\phi}{2\pi}\right), \tag{15}$$

where $\Delta N = N_1 - N_2$ is the integer difference that has been determined by Doppler shift as well as changing rate, and $\Delta\phi = \phi_1 - \phi_2$ is the phase difference between two antennas that can be determined by phase difference measurement.

Due to sine theorem, target azimuth is

$$\sin\theta = \frac{\Delta r}{L} = \frac{\lambda}{L}\left(\Delta N + \frac{\Delta\phi}{2\pi}\right). \tag{16}$$

If $N_0 = \Delta N$ and $\phi = \Delta\phi$, then we can obtain the entire same result with existing phase interferometry Eq. (1). The different is that there is no phase ambiguity in Doppler shift-phase difference equation, wherein the measurement is perfectly independent of baseline length.

## 3 Conclusion

From the point of view of theory analysis, derived equation is only suitable to direction finding when flying vehicle is uniform motion because quoted Doppler changing ratio is only in uniform motion. However, this limitation may be solved by improving arithmetic step by step. At the same time, the uniform flight will be normal for practical aerial reconnaissance.

Since the integer value of radial distance can be first solved by use of Doppler information, there is no phase ambiguity in measurement and restriction for select of baseline based on the method presented in this paper. Hence, there is no contradiction for single baseline phase interferometry between the accuracy of direction finding and maximum unambiguity angle. This means that sense finding of high accuracy can be realized only by single baseline. This method has following advantages: 1) mounting demand is low; 2) detecting time is short; and 3) it is suitable for carrying out detection operation in a broadband.

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