Bearing Accuracy Improvement of the Amplitude Comparison Direction Finding Equipment by Analyzing the Error

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Abstract: Direction finder, an important component of electronic warfare system, is a device that detects electromagnetic waves radiated from target radar and measures its angle of arrival. Compared to the phase-comparison method, the amplitude-comparison method has simpler system, and it’s easy to miniaturize; however, relatively, its direction finding is less accurate, and it has various factors that occur errors. This paper suggests improving for the DF accuracy of the amplitude-comparison DF method base on analysis of error type and cause. Also, this paper proves the usefulness of the result through the test that we suggest for the polarization error that has the greatest effect on the amplitude-comparison method’s DF accuracy.

Keywords: DF, direction finding; electronic warfare; bearing accuracy; Amplitude-Comparison.

1. Introduction

DF(Direction Finding) system is a component of EW (Electronic Warfare) that is a main element of modern battlefield environment, and it’s a device that measures the electromagnetic waves’ angle of arrival radiated from target radar. Measured bearing information has been used to determine transmission direction to raise jamming effect for EA(Electronic Attack) or used as Pre-processing data to raise signal analysis efficiency in multi-threat environment. Therefore, the main purpose of direction finders is to measure radiation source’s bearing accuracy fast and accurately, and many methods for realizing the purpose of direction finders have been suggested and developed [1]. DF system have been developed in various forms depending on the system’s demand environments, and DF’s error types and causes becomes complicated by its formats and fields. As DF method, commonly the phase-comparison DF that uses electromagnetic waves’ time difference and the amplitude-comparison DF have been used [2]. In the case of the phase-comparison DF, it has higher DF accuracy, but its format is complicate. On the other hands, the amplitude-comparison DF has lower DF accuracy, but its format is simple, so it’s easy to miniaturize. Therefore, the improvement of the amplitude-comparison DF’s DF accuracy is demanded to maximize its advantages; the low cost and the miniaturization. For that, this paper analyzes the various causes of error of the device and suggests the DF system that fixes the errors and improves its DF accuracy. For this process, the paper analyzes the various causes of errors that occur in operating environment of SD system. We proved that the amplitude-comparison DF’s DF accuracy has been improved by 60% through the improved algorism suggested in the paper, and we expect that the device size can be reduced below a half size of a device that has the same performance. Expected errors of the DF system occur depending on the source radiating strong signals, the electromagnetic waves’ radiant environment, the device’s radiant environment, the device format, and the operator, and this paper suggests the algorism that improves the major errors that have the greatest effects from those causes.

2. DF system and error

In modern warfare, EW means all the military activity related with the use of electromagnetic waves and consists of ES(Electronic Warfare Support), EA, and EP (Electronic Protect). Among them, the object of ES is to immediately detect target signal in a war, and ES’s activities include detecting and monitoring radiated electromagnetic wave energy, producing information through direction finding and identification process, and providing the information of target for EA. The general form of the amplitude-comparison DF method used for ES is the same as the figure 1. [3][4]. In the way the picture shows, the device detects target signals through Dual Polarization Omni Antenna. Because it’s a device that measures the electromagnetic wave’s angle of arrival in free space, signal amplitude reaching a receiving antenna can be changed by various factors, and it results DF accuracy errors.

The first factor of the error is the position of radiation source and signal receiver. DF accuracy errors occur depending on the height of transmission and receiving antenna and the conditions of the ground or the sea when radiation source is in a minimum distance. If the distance between a radiation source and an antenna is longer than certain distance, the error’s effect will be decreased, so it will have minor effect on the device. Another error is occurred in the channel between the radiation source’s transmission antenna and the DF system’s receiving antenna. It occurs in the forms of scatter, refraction, reflection, and re-radiation. Among them, Scatter Error is occurred by scattering of transmitted electromagnetic waves in the ionosphere of the earth. It’s a phenomenon that transmitted electromagnetic waves return by the ionosphere’s characteristic, and it can...
be divided by long and short scatter. Refraction Error occurs when the electromagnetic waves move between the materials that have different dielectric constant from each other. Also, it can be occurred by dielectric constant between the atmosphere and the seawater when the radiation source or the DF device is near the coastlines, and it occurs variously depending on frequency. On the other hands, Reflection Error is occurred by various reflectors such as an island in between the electromagnetic waves. The distortion of signals because of the arrival time differences of the direct wave and the reflected wave decreases DF accuracy. Lastly, Re-radiation Error is occurred when the used signals cause resonance with metals and results the re-radiation of the electromagnetic waves. It also decreases the DF accuracy by the distortion of polarization.

The amplitude-comparison DF places directional antennas as the figure 2. and detects the direction by using the amplitude differences between the antennas depending on the electromagnet waves’ angle of arrival like the figure 3. [5]. The attendant error upon the measurement is Polarization Error. It is occurred because of a receiving antenna’s axial ratio and the characteristic of radome, and it decreases the DF accuracy because it changes the receiving antenna beam pattern because of the unconformity of the radiated electromagnet waves’ between the receiving device’s polarization Characteristic.

Also, Site Error is occurred because of the direction finder’s installation place, and it has various effects depending on the surrounding environment and the installation type. Instrument Error that occurred by the DF device’s installation environment and installation condition needs to be realized based on the repetitive simulation for the purpose of decreasing the errors by tuning and adjustment considering the propagation characteristic of the electromagnet waves.

3. The DF system’s error analysis

When the same signals are inputted in different time because of Path Error, and it causes the phase difference of the electromagnet waves, the signal amplitude is differentiated as the following “equation (1)”. 

\[ A_{\text{sum}} = A_0 + A_1 = \sqrt{A_0^2 + A_1^2 + 2A_0A_1\cos(\theta_0 - \theta_1)} \] (1)

In the case of the reflected wave in the figure 4. below, such as the direct wave arrives earlier, and the reflected wave’s arrival is delayed as much as the distance of two waves. After the direct wave (T0) arrives, there is no distortion until the arrival time (ΔT) of the delayed wave (T1), but after the delayed wave arrives, the signal distortion begins to happen.

![Figure 2. The amplitude-comparison DF device’s antenna configuration.](image)

Also, Site Error is occurred because of the direction finder’s installation place, and it has various effects depending on the surrounding environment and the installation type. Instrument Error that occurred by the DF device’s installation environment and installation condition needs to be realized based on the repetitive simulation for the purpose of decreasing the errors by tuning and adjustment considering the propagation characteristic of the electromagnet waves.

4. Improvement plan DF error

4.1. Long term error improvement plan

If measuring signal amplitude for direction finding is completed in 100ns after direct wave arrives, the indirect wave of which arrival time difference (Δt) is longer than 100ns can get out from the error’s effects. Therefore, the measurement time for the signal amplitude in the DF system design should be short as much as possible.

4.2. Short term error improvement plan

For the short term error minimization that happens in various environments such as re-radiation, reflection, and instrument, the device’s structure design should be optimized. Another way is to secure the height of DF device using vessel’s mast as the figure 5. and to secure delayed wave’s incidence angle by installing DF device the outside of a vessel using arms. In that way, the short term error can be minimized.
4.3. Polarization error improvement plan

In the paper, a DF system using 6 receivable spiral antennas of dual polarization was installed as the figure 6 for the improvement of DF accuracy and receiving sensitivity. As a result of the test, the DF accuracy as the table 2 was measured. When the measurement data is the number of n, the DF accuracy is measured by the following “equation (2) and (3)”[6].

\[
\text{Error}_{\text{RMS}} = \sqrt{\frac{\sum_{n=1}^{n}(Error)^2}{n}} \quad (2)
\]

\[
\text{RMS} = \sqrt{\mu^2 + \sigma^2} \quad (3)
\]

\(\mu\) = the mean of the data points

\(\sigma\) = the standard deviation

The figure 7. shows the configuration of testing device for the error improvement. The experimental condition is the same as the table 2. The measured values of vertical polarization and horizontal polarization from the test was 3.428 ° RMS and 3.477 ° RMS, and synthetically the error causes about 3.423 ° RMS difference.

<table>
<thead>
<tr>
<th>Table 2. Experiment condition</th>
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<tbody>
<tr>
<td><strong>Division</strong></td>
</tr>
<tr>
<td>Polarization</td>
</tr>
<tr>
<td>Frequency</td>
</tr>
<tr>
<td>Bearing</td>
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<tr>
<td>Total</td>
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Also, the variation of the DF error depending on the frequency and the bearing from the text is given in the figure 8 and figure 9.

Polarization error, a critical element among the causes of the amplitude-comparison DF’s errors, is commonly occurred by spiral antenna’s axial ratio and radome’s permeation characteristic. For decreasing the cause of error, the antenna beam pattern change by Polarization can be used like the figure 10. and figure 11.[7].

In other words, it’s to synthesize vertical/horizontal data as from the measured the amplitude differences between two antennas for DF system and to use linearized characteristics. Through this method, it is possible to avoid structural complexity without measuring receiving polarization. To improve the fixed error that happens in receiving electromagnet waves, linearized vertical/horizontal data should be applied based on measured polarization of receiving electromagnet waves, then the device can get relatively revised bearing.
A common way for DF accuracy improvement was to install DF devices’ receivers for each polarization. However, this way makes the device size big, and it costs a lot. To improve that, this paper suggests the way that satisfies the DF accuracy improvement and the miniaturization of the device applying the method measuring the electromagnet waves’ polarization through the Omni-directional receiver’s mono channel.

For the experiment, configure the device as the figure 14, and improve the polarization error through the bearing operation depending on measured polarization. As a result of virtual figuration of polarization measurement circuit through M&S, the DF accuracy improved 3.423 ° to 1.383 ° as the figure 15 and 16 and the table 3. show.

### Table 3. Improve device experiment result

<table>
<thead>
<tr>
<th>Division</th>
<th>Result value</th>
<th>Note</th>
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<tbody>
<tr>
<td>Vertical polarization</td>
<td>0.9885 ° RMS</td>
<td></td>
</tr>
<tr>
<td>Horizontal polarization</td>
<td>1.6872 ° RMS</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.3827 ° RMS</td>
<td></td>
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</tbody>
</table>

### 6. Conclusions

The DF system that has polarization measurement function was verified through M&S using the data from dual polarization receiving method. As a result of that, the paper checked that the DF accuracy had been improved. The weight of additional components for the polarization measurement is expected lighter than 4 Kg, so it is expected that the use of the device is possible.

It is expected that the miniaturized electronic warfare equipment of which the DF accuracy is improved by the amplitude-comparison DF method will be developed, then it can substitute many expensive middle/full sized the amplitude-comparison DF devices.

### 7. Acknowledgement

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### References

Figure 1. A format of the amplitude-comparison DF device for ES.

Figure 3. The amplitude-comparison DF device’s operation principal.
Figure 7. Configuration of testing device.

Figure 13. Existing polarization measurement method.
Figure 14. Improved polarization measurement method.

Figure 15. Improved device test result (vertical polarization).
Figure 16. Improved device test result (Horizontal polarization).