# 통신대역신호 방향탐지 장치 Test-bed 개발 및 성능 분석

## Design and Performance Analysis of Direction Finding System Test-bed for Communication-band Signals

최 준 호* 박 영 미* 양 종 원* 나 선 필* 박 철 순*
Choi, Jun-Ho Park, Young-Mi Jong-Won Yang Nah Sun-Phil Park, Cheol-Sun

ABSTRACT

A direction finding system test-bed(DFSTB) at the electronic warfare communication-band is presented to efficiently evaluate and optimize the performance of the direction finding system through the indoor test setup. This test-bed gives a significant benefit to the designers of the direction finding system because it allows flexible test and design trade-off in the system design cycle. The system description and implementation of test-bed architecture, and the experiment results of direction finding accuracy according to modulation schemes are presented.

주요기술용어(주제어) : Direction Finding System Test-Bed(DFSTB), Direction Finding(DF), Electronic Warfare (EW), Antenna Array Simulator Unit(AASU), Electronic Support(ES)

## 1. Introduction

Direction finding(DF) of the electronic warfare (EW) communication-band is ever increasing in importance because the derived information can give the number, type, strength and location of the enemy units, and also give useful data for jamming the communication network[1]. To develop the such kind of the system, one should investigate the constraints and characteristics of the DF system such as bearing accuracy effects according to DF algorithm, antenna array configuration, modulation scheme, interference signal, and tolerance and noise in the receiver. These characteristics are analyzed using simulation and theoretical analysis or open field test. But they have limitations like nonideal signal model or complex and expensive experimental set up at the operational test environment.

A test-bed proposed in this paper has been designed to evaluate the system design concept and DF accuracy systematically. Appling to versatile, an antenna array simulator unit(AASU) is implemented by using the wideband variable attenuator, phase shifter and fast sweep local oscillator to adjust phase and amplitude as a function of signal direction at wide frequency range. The advantage of AASU can give the test

† 2007년 3월 8일 접수~2007년 6월 15일 게재승인
* 국방과학연구소(ADD)
주저자 이메일 : junhochoi@add.re.kr

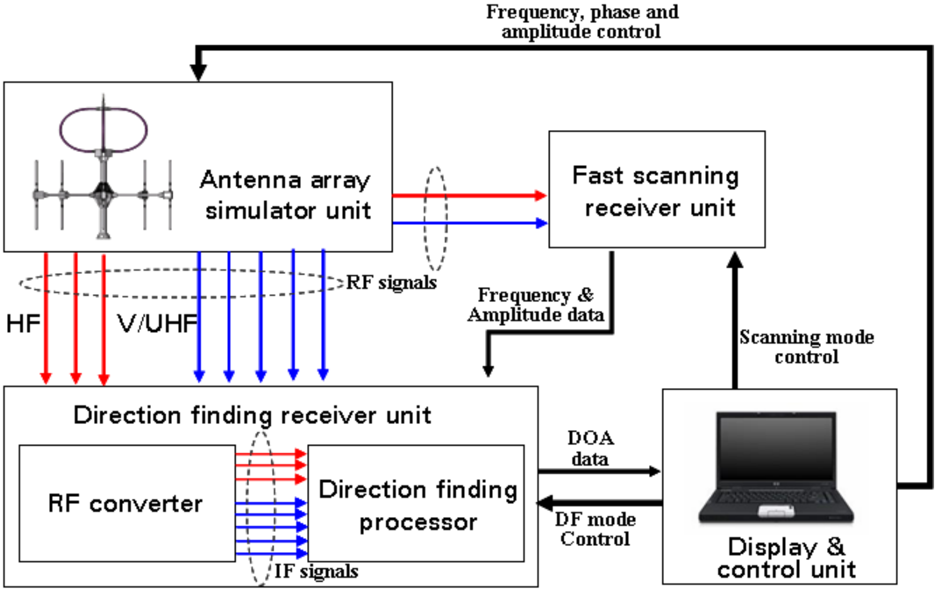
flexibility of DF accuracy according to the different number and spacing of antenna array and various modulation methods. To test frequency hopped signal spectrum, a fast scanning digital receiver is also implemented. It plays a role in fast searching the frequency and magnitude of injected unknown signals and also provides the searching data to DF receiver.

## 2. DF algorithms for mobile ES

DF is to estimate the direction of an emitter by measuring and evaluating one or multiple signals which are received by the multiple receivers. DF techniques generally used on the electronic support(ES) system for mobile applications are the Watson-watt technique using crossed-loop antenna at HF-band[2], and interferometer technique[3], correlation vector DF technique(CVDF)[4] using the antenna array at V/UHF-band. The first technique measures the amplitude of the RF signals through the antennas and then calculate the differences of the amplitude between two crossed-loop antennas. They are converted to the direction of the incident signal. The second technique measures the relative phase differences of the same incoming signal by placing the antenna at different positions. The third technique is based on a comparison of the measured complex voltage vectors between the antenna elements of the DF antenna system with those obtained for the same antenna system at all possible directions of incidence. The comparison is made by correlating the two data sets. Using different comparison data sets for different wave directions, the bearing is obtained from the data set for which the correlation is at a maximum.

## 3. Design and configuration of DFSTB

As shown in Fig. 1, the DFSTB is composed of antenna array simulator unit(AASU), fast



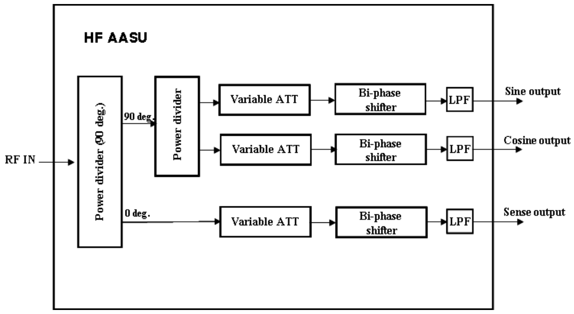

[Fig. 1] Configuration of DFSTB

scanning receiver unit(FSRU), direction finding receiver unit(DFRU) and display/control unit. The AASU emulates the crossed-loop antenna and five electrically short vertical dipoles placed in an equilateral circle using the variable phase shifter, variable attenuator and signal generator to adjust phase and amplitude as a function of signal direction at wide frequency range. The FSRU and DFRU play a role in fast searching the frequency from the unknown signals and estimating direction of arrival(DOA) respectively. The display/control unit provides as the operator interface.

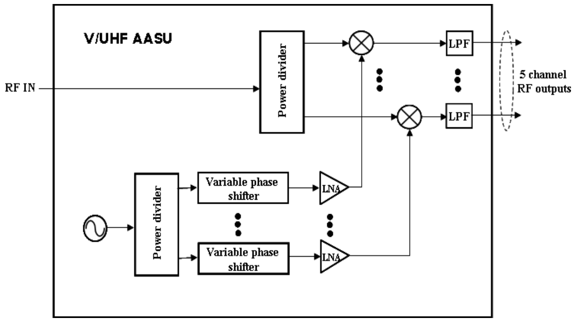
### A. Antenna array simulator unit(AASU)[5]

The AASU is composed of two parts : HF AASU and V/UHF AASU as shown in Fig. 2. The former part plays a role in emulating the crossed-loop antenna. Because the bearing information is obtained from the ratio of the amplitudes of the orthogonal figure-eight patterns as shown in Fig. 3, it generates sine, cosine and sense signals using the bi-phase shifter and variable attenuator. The sense signal is used to resolve the ambiguity. The RF input signals are firstly converted two signals with phase difference of 90 deg. to generate sine- and cosine-shaped directional characteristic and then secondly adjusted the amplitude of signals according to the wave angle by using the variable attenuator to provide as the function of signal direction at HF-band.

The latter part emulates five element antennas with equal spacing circular array to represent the expected phase differences between the antenna elements for the direction of incidence signals as shown in Fig. 4. Because the DOA is estimated by relative phase differences of the same coming RF signals by setting up the antennas at different positions, to generate the five antenna signals, the one RF input signal is divided into five channels and then they are mixed by LO signals of which the phase is each adjusted by the variable phase shifter corresponding to the incident angle. This AASU can handle several types of modulation

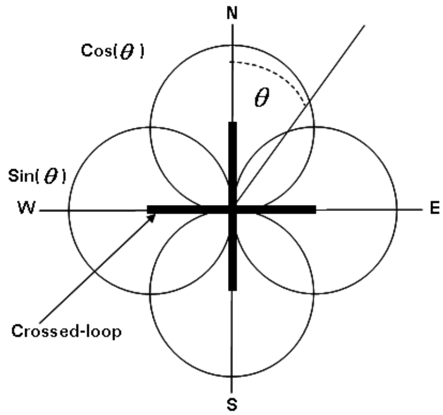



(a) Configuration of HF AASU

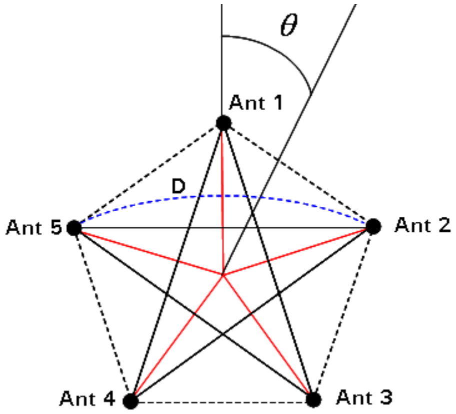



(b) Configuration of V/UHF AASU

[Fig. 2] Architecture of AASU




[Fig. 3] Antenna configuration of crossed-loop antenna

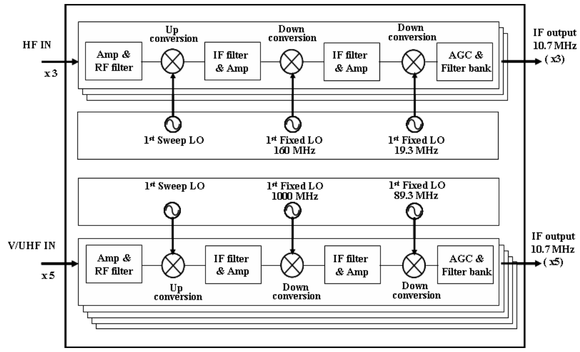



[Fig. 4] Antenna configuration of 5 elements circular array

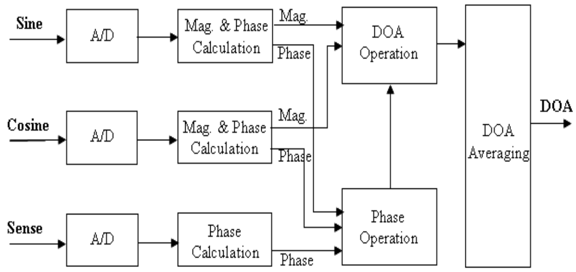
and the manifold of antenna array up to five antenna element, and especially emulate frequency hopped signal using the DDS-based PLL which has fast lock time of below 50 usec.

### B. Direction finding receiver unit(DFRU)

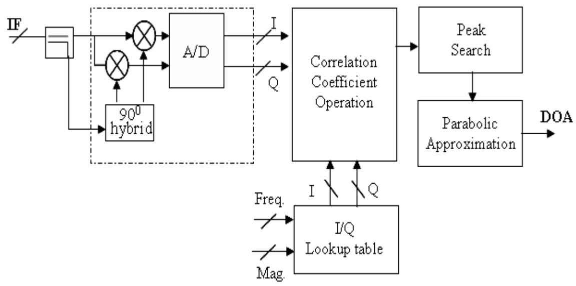
The DFRU consists of three HF receivers, five V/UHF receivers and DF processors. In the receiver parts corresponding to each elements, the received signals are amplified, filtered, and down-converted to an intermediate frequency of 10.7 MHz. To improve the dynamic range and selectivity, three IF conversion is employed as shown in Fig. 5. These IF outputs are sampled simultaneously by high speed A/D converters and then analyzed in the DF processors. The local oscillators(LO) are coherently split between the receivers to keep the equal phase and amplitude in all receiver sections. The DDS-based PLL is used as sweeping LO to improve tuning speed and resolution. This technique allows for a high probability of intercept and accurate DOA estimation of short duration signals. The automatic gain control(AGC) circuit and filter banks are inserted to automatically drive the received signal power and to improve the




[Fig. 5] Configuration of DF receivers




(a) DOA computation of Watson-watt processor




(b) DOA computation of CVDF processor

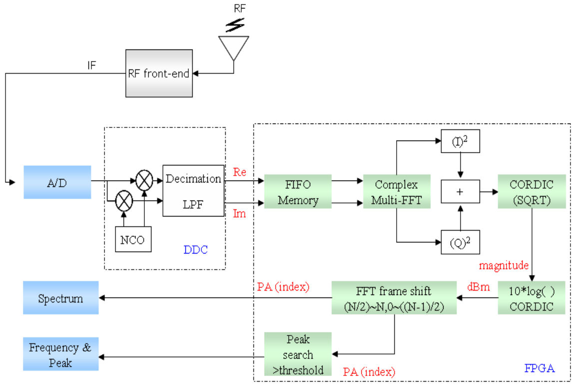
[Fig. 6] Configuration of DF processor

sensitivity according to the modulation methods such as CW, AM and FM respectively. The DF processor contains the Watson-watt and CVDF processor. Fig. 6 shows the DOA computation process respectively. The Watson-watt processor calculates DOA from the ratio of the sine- and cosine signal and resolves the ambiguity from the phase relationship of the sense signal.

An averaging technique allows a reduction of random error to give accurate DOA. The CVDF processor is based on the ability to learn the response of the DF antenna array to received signals over all angles and frequencies. For each antenna element output, an IF is converted to complex I/Q signals using Zero-IF concept. Although this technique provides some shortcoming[6], it gives short processing time. A complex signal describes the amplitude and phase of that element. The measured complex voltage vectors are correlated with those contained lookup table to search the maximum point of the complex correlation coefficient. The parabolic approximation is used to efficiently deduce the location of the maximum from the correlation values at the discrete points[4].

### C. Fast monitoring receiver unit(FMRU)[7]

The FMRU is designed as digital-IF receiver to provide the information of frequency and magnitude of the incident unknown signals with the DFRU. This type of the digital receiver provides improved performance such as the capability of multiple simultaneous signal processing with good frequency accuracy, high single- and two-tone spurious free dynamic range for detecting a weak signal in the presence of an adjacent strong signal. Fig. 7 shows the operation diagram of the digital-IF FFT receiver architecture. An unknown modulated signal is received by RF front-end where it is filtered, amplified, and down converted to IF signal of 10.7 MHz. This signal is sampled by a high speed A/D converter with sampling rate of 85.6 MHz and then fed to digital down converter(DDC) to perform a dramatic reduction of the signal bandwidth from 85.6 MHz down to 10.625 MHz. The sampling rate has also reduced 10.625 MHz by decimation lowpass filter. The complex output of the DDC allows to fast

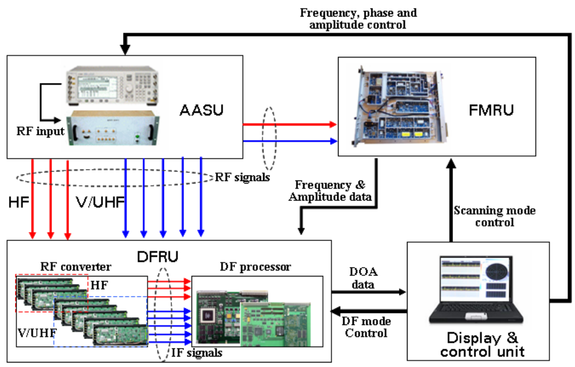



[Fig. 7] Architecture of digital-IF FFT receiver

compute a complex FFT power spectrum centered at 0 Hz. After the time-frequency conversion in the complex FFT, CORDIC and peak search algorithm are carried out to calculate magnitude and search the peak of the signals respectively. The frequency and magnitude is provided with DFRU through RS-422 cable.

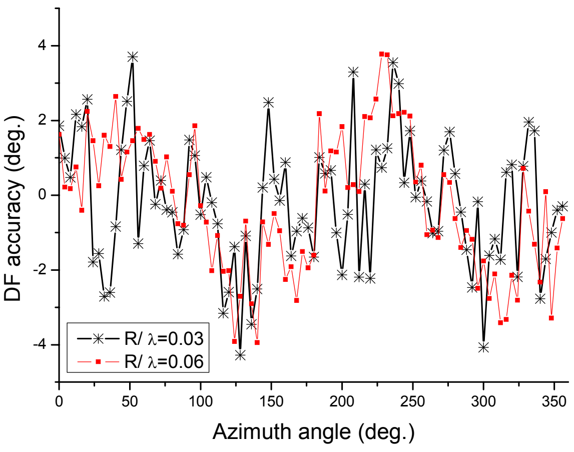
## 4. Measurement and evaluation

DF accuracy depends on several factors such as DF algorithms, antenna array types, modulation schemes, instrumental errors, and environmental errors. To measure the DF accuracy, the test-bed is configured as shown in Fig. 8.



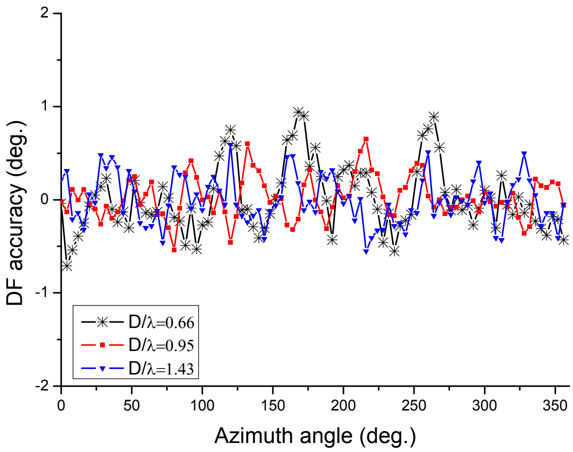

[Fig. 8] Test-bed configuration for DF accuracy test

In this test, the environmental errors like site error, interference error, and propagation error are not considered owing to indoor test procedures. Prior to the proper DF operation, in order to ensure equal amplitude and phase of most multi receivers, a reference calibration signal is injected to the receiver sections using the AASU as a test generator. The IF outputs of the receiver sections are processed digitally. These phase and amplitude variations according to the frequencies are calculated and recorded as correction tables to compensate the gain- and phase mismatch errors. In the DF process, the measured values are corrected by the stored correction tables before the DOA is calculated. Fig. 9 shows the DF accuracy of the Watson-watt DF algorithm over azimuth angle when the closed-loop antenna is configured with ratio of $R/\lambda \le 0.2$ at HF band to reduce the spacing errors. R is radius of the closed-loop antenna and $\lambda$ is wave length. This antenna output is emulated by the HF AASU. The CVDF algorithm is emulated by V/UHF AASU with antenna configuration of five antenna circular array with maximum ratio of $D/\lambda \le 2.5$ at V/UHF to increase accuracy and reduce ambiguity errors. Fig. 10 shows the DF accuracy of CVDF algorithm for the ratio of $D/\lambda$.

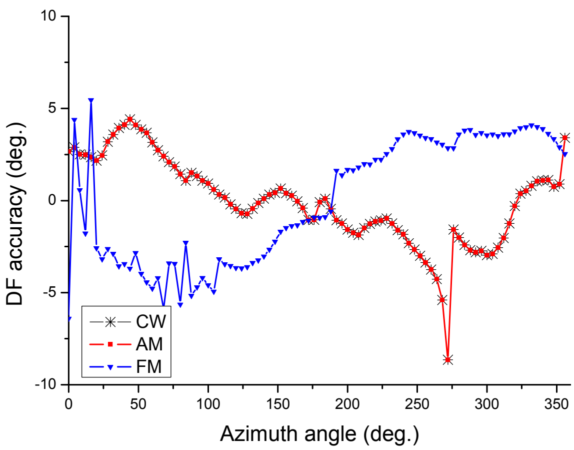



[Fig. 9] DF accuracy of Watson-watt algorithm

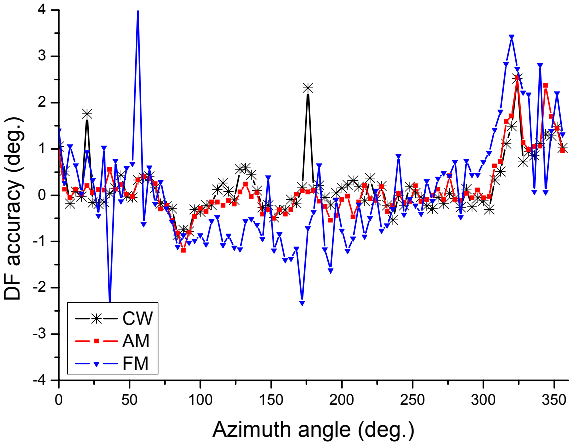
These results show the capability of obtainable DF accuracy according to the Watson-watt and CVDF algorithms. The RMS value of the emulated DOA error is found to be 4 deg. and 1 deg. over the azimuth angle of 0 to 360 deg. respectively. Usually, the carrier signal of the emitter is modulated signal. The modulation can affect the DF accuracy due to different envelop delay distortion in the DF receivers. Fig. 11 and Fig. 12 shows the DF accuracy according to the




[Fig. 10] DF accuracy of CVDF algorithm for $D/\lambda$




[Fig. 11] DF accuracy of Watson-watt for modulation types($R/\lambda$=0.03)




[Fig. 12] DF accuracy of CVDF for modulation types ($D/\lambda$=1.43)

modulation schemes. These results are observed that the DF accuracy of FM signal is worser than that of CW and AM signal. It can be caused by channel mismatch at frequencies approaching the edges of the band, particularly when processing wideband signals because the correction tables are only recorded at the nominal center of the receiver passband.

## 5. Conclusion

An efficient direction finding system test-bed compatible with communication-band applications is developed. It provides the test flexibility of DF accuracy including the different antenna configuration, DF algorithms and modulation schemes at the indoor test. The ability of test-bed is useful for system designers who are involved in the development of direction finding system at communication-band. Further research will be investigate the DF accuracy of the frequency hopped signal and compared the emulated data with open-field test data.

## 6. References

[1] J. B. Harrington and T. G. Callaghan, “UHF/VHF direction finding”, Watkin-Johnson co., 1981.

[2] J. R. F. Guy, D. E. N. Davies, “Studies of the Adcock direction finder in terms of phase-mode excitations around circular arrays”, The Radio and Electronic Engineer, Vol. 53, No. 1, pp. 33~38, Jan. 1983.

[3] H. H. Jenkins, “Small-aperture radio direction finding”, Artech House Inc., pp. 120~143, 1991.

[4] S. A. Hedges, “Triple-channel interferometer radio direction finder minimizes error-source effects”, MSN, 1984.

[5] Y. M. Park, W. Jang, J. W. Yang and J. H. Choi, “Simulator for direction finding array antennas”, Patent Application : 10-2006-0046288, May 2006.

[6] B. Razavi, “RF microelctronics”, Prentice Hall, pp. 118~165, 1998.

[7] J. H. Choi, S. P. Nah, C. S. Park, J. W. Yang, Y. M. Park, “Design and performance analysis of the fast scan digital IF FFT receiver for spectrum monitoring”, KIMST, Vol. 9, No. 3, pp. 116~122, Sep 2006.