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CALIBRATION OF A SIX-PORT RECEIVER FOR DIRECTION FINDING USING THE ARTIFICIAL NEURAL NETWORK TECHNIQUE

H. Peng*, Z. Q. Yang, and T. Yang

School of Electronic Engineering, University of Electronic Science and Technology of China, Chengdu, Sichuan 611731, P. R. China

Abstract—Because of the asymmetry of six-port junctions and the nonlinearity of diode detectors, the calibration of direction finding receivers have to be carefully considered. It is generally believed that an efficient tool for numerical approximations, the artificial neural network (ANN), may be used for such calibrations. In this paper, a new calibration technique based on the ANN is proposed for direction finding receivers at a bandwidth of 1 GHz. The direction finding system adopts a zero-intermediate frequency receiver architecture, which offers the advantage of fast response times. The key modules of this receiver consist of two six-port networks used to measure phase differences and operating frequencies. The results indicate that the calibration technique achieves a high accuracy of 0.192°.

1. INTRODUCTION

An earlier study about the six-port technique was proposed in 1972 by Hoer [1]. Galwas and Palczewski later published a series of papers on the ratio of complex amplitude measurements obtained by a six-port reflectometer [2, 3]. Several studies on the demodulation of modulated digital signals by six-port receivers are currently available [4–7]. The six-port technique can also be used for direction finding receivers and ranging receivers, among others.

Direction finding plays an extremely important role in modern electronic warfare reconnaissance. One kind of direction finding

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* Corresponding author: Hao Peng (ph1984.1.25@163.com).

receiver adopts a zero-intermediate frequency receiver architecture [8–10]. The key module here is called a six-port network. A zero-intermediate frequency receiver architecture can reduce costs and meet the growing needs of radar systems. As well, the response time of the hardware circuit is less than 50 ns, and the system can work in an octave bandwidth. However, the transmission coefficients between the input and output ports are not ideal in such a system, and its four diode detectors operate in nonlinear regions.

The artificial neural network (ANN) rapidly developed in the late 1980s, making major impacts in artificial intelligence, computer science, cognitive science, and other scientific fields. As a mathematical or computational model of the functional aspects of the human brain, ANN consists of an interconnected group of artificial neurons and processes information using a connectionist approach to computation. As a non-linear statistical data modeling tool, ANN is usually used to determine a complex functional model between input and output data [11].

Beam direction finding receivers [8–10] and calibration techniques for six-port networks [12] have been proposed in previous studies. The operating frequency in these studies, however, was set at a fixed value. In this paper, a direction finding receiver is allowed to operate at a frequency range of 5–6 GHz. Two modules based on the six-port network are used to detect phase differences and operating frequencies. Our main focus here is calibration of beam direction angles by ANN. The input data of the ANN model include four differential voltages, while the output data are the beam direction angles. The rest of this paper is organized as follows: The principle of direction finding receivers is introduced, and an example is given to demonstrate the effectivity of the ANN technique in calibrating beam direction angles.

2. THEORETICAL ANALYSIS

The six-port network was proposed as a suitable architecture for detecting phase differences and operating frequencies according to amplitude measurements [13, 14]. Two six-port networks are used to determine the beam direction angle. Figure 1 shows the block schematic of a direction finding receiver.

According to Figure 1, the direction finding receiver is divided into two parts: a phase difference detector module and a frequency detector module. This receiver includes antennas, microwave limiting amplifiers, six-port junctions and differential amplifiers, and so on. The outputs of two limiting amplifiers are injected into the phase difference detector module and the coupled signal is injected into the frequency

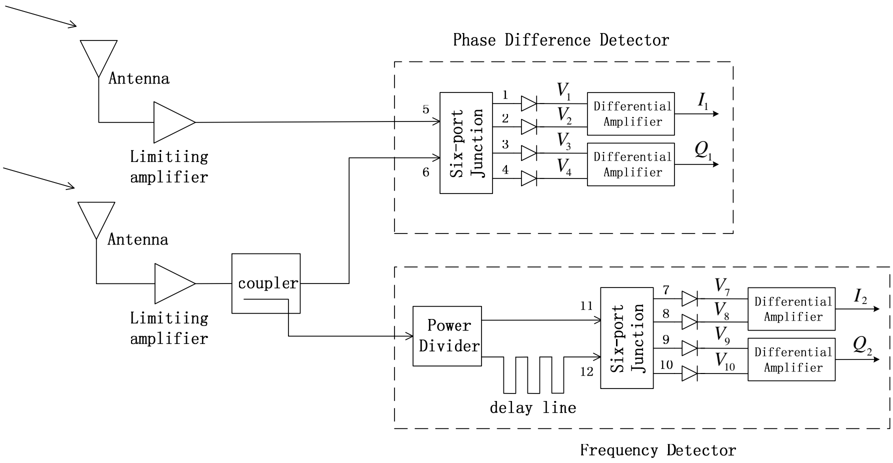


Figure 1. The block schematic of a direction finding receiver.

detector module.

The output voltages of detectors can be expressed as follows [13]:

$$V_i = K_1 \cdot A \cdot B \left[1 + (-1)^n \cdot \cos(\phi + j \cdot \pi/2)\right]/2 \quad \begin{cases} j = 0, \text{ if } n = 1, 2, 7, 8 \\ j = 1, \text{ if } n = 3, 4, 9, 10 \end{cases} \tag{1}$$

$$\phi = \tan^{-1}\left(\frac{V_2 - V_1}{V_4 - V_3}\right) \tag{2}$$

where n is the correlator output port index, ϕ the phase difference between the two input signals of the six-port junction, K_1 the constant factor, A and B the amplitudes of the two input signals of the six-port junction, and V_i the output voltage of the detector.

The relationship between the beam direction angle and the phase difference is as follows [8]:

$$\phi = \frac{2\pi}{\lambda} \cdot d \cdot \sin\theta \tag{3}$$

where θ is the beam direction angle, d is the center distance of two antennas, and λ is the wavelength.

In the frequency detector module, λ can be expressed as [14]:

$$\tan^{-1}\left(\frac{V_8 - V_7}{V_{10} - V_9}\right) = K_2 \cdot \frac{1}{\lambda} = K_2 \cdot \frac{f}{c} \tag{4}$$

where K_2 is the constant factor and c is the speed of light. Therefore, the beam direction angle θ can be expressed as:

$$\theta = \sin^{-1}\left(\frac{K_2}{2\pi \cdot d} \cdot \frac{\tan^{-1}\left(\frac{V_2 - V_1}{V_4 - V_3}\right)}{\tan^{-1}\left(\frac{V_8 - V_7}{V_{10} - V_9}\right)}\right) \tag{5}$$

Many factors will cause inaccuracies in the measurement, such as mismatches due to the source and load, errors of 90° hybrid couplers and power dividers, inconsistencies between and nonlinearity of detectors, and so on. Therefore, Equation (5) can be expressed as follows:

$$\theta = f\left[(V_2 - V_1), (V_4 - V_3), (V_8 - V_7), (V_{10} - V_9)\right] \tag{6}$$

where $f(\cdot)$ is some real nonlinear function. Obtaining the explicit function of $f(\cdot)$ is essentially impossible.

3. SAMPLE APPLICATION

In this section, an example based on the six-port network is given to demonstrate the accuracy of the ANN calibration technique. A programmable synthesized signal generator (Agilent 83752A) and a transmitting antenna are used. The system, which operates at a frequency range of 5–6 GHz, is composed of two six-port junctions, one transmitting antenna, two receiving antennas, two limiting amplifers, eight detectors, one power divider, one coupler, four broadband operation amplifiers and a delay line, and so on. The center distance between the two antennas is set to $d = 0.0867$ m. The system input is a pulse signal, and four pulse voltages can be directly displayed on the digital oscilloscope. Figure 2 shows a photograph of the test platform in the anechoic chamber.

The frequencies are set at about 100 MHz steps from 5 to 6 GHz, and the beam direction angles are set at about 0.5° steps from −15° to 15°. Receiving antennas are fixed at a rotary table. With the table rotation, the phase difference of two received signals and four output voltages of operational amplifiers could be also changed. A total of 671 standards are set up. All readings (I_1, Q_1, I_2, Q_2) are measured and recorded. Ninety percent of the data (600 samples) as the training data set, and the rest as the cross-validation data set (71 samples) are randomly selected.

The chosen ANN structure has two hidden layers, one output layer, four inputs corresponding to four operation amplifier voltages, and one output corresponding to the beam direction angle (in degrees). The first and second hidden layers have eight neurons, and hyperbolic tangent and logarithmic sigmoid transfer functions, respectively. The

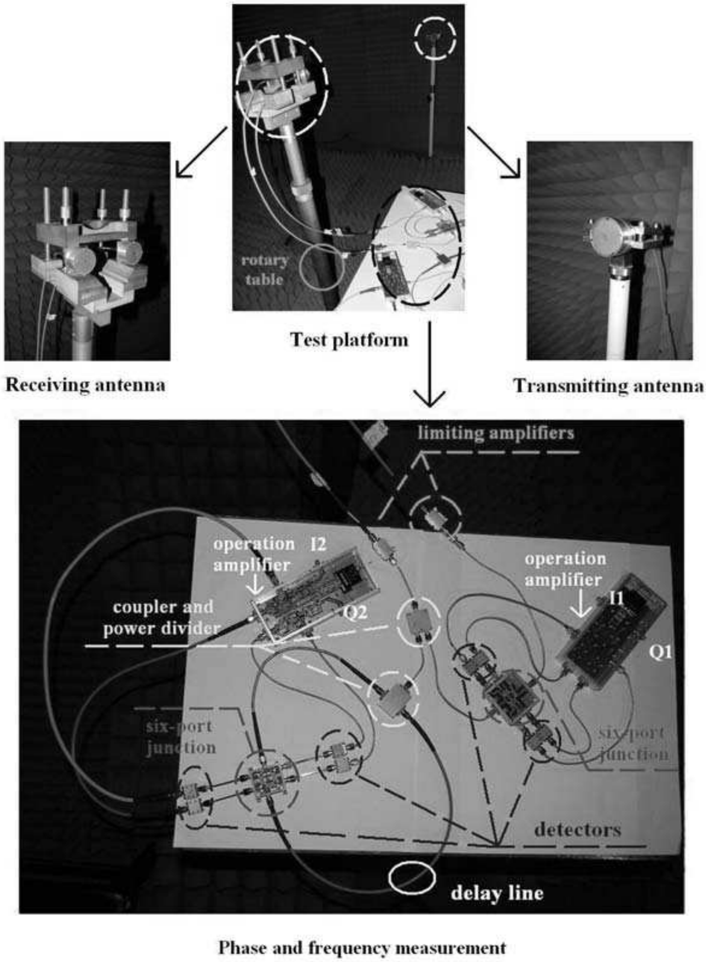


Figure 2. Photograph of the test platform.

output layer has one linear node. Compared with the standard back propagation and some of its variants, the Levenberg-Marquardt (L-M) method is chosen.

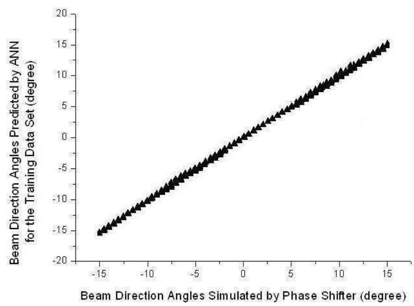
The Root Mean Square Error (RMSE) and Pearson Product-Moment correlation coefficient (R) are calculated to determine the accuracy of the ANN model. RMSE and R are given as:

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(a_i - b_i)^2} \tag{7}$$

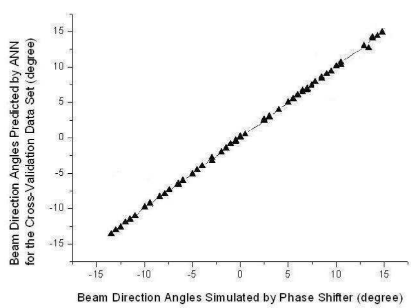
$$R = \frac{\sum_{i=1}^{N} \left(b_i - \bar{b}\right)(a_i - \bar{a})}{\sqrt{\sum_{i=1}^{N} \left(b_i - \bar{b}\right)^2 \sum_{i=1}^{N} (a_i - \bar{a})^2}} \tag{8}$$

where a_i is the predicted beam direction angle of training or cross-validation data set based on the ANN model, $\bar{a}$ is the predicted beam direction angle mean of training or cross-validation data set based on the ANN model, b_i is the real beam direction angle, $\bar{b}$ is the real beam direction angle mean, and N is the data number.

Figure 3(a) shows real beam direction angles against the values predicted by ANN for the training data set (600 samples). The RMSE of the beam direction angle is 0.134° over the range of −15° to 15°. The accuracy of the proposed ANN calibration technique was determined using the fresh cross-validation data set (71 samples). Figure 3(b) shows the real beam direction angles against the values predicted by ANN for the cross-validation data set. The RMSE of the beam direction angle is 0.192° over the range of −15° to 15°. These results are summarized in Table 1, which indicates that the ANN technique predicts the results well. The R values of the training and cross-validation data sets are extremely close to 1, but not completely identical, with the former being slightly larger than the latter.



(a)



(b)

Figure 3. Measured and calibrated results: (a) Real beam direction angles versus the values predicted by ANN for the training data set (600 samples) and (b) Real beam direction angles versus the values predicted by ANN for the cross-validation data set (71 samples).

Table 1. RMSE and R of the measured, training and cross-validation data set.

	Training Data Set (600 samples)	**Cross-Validation Data Set (71 samples)**
RMSE	**0.134°**	**0.192°**
R	**0.999**	**0.999**

4. CONCLUSION

Previous studies only calibrated six-port networks at fixed frequencies. This approach, however, is inadequate for direction finding receivers because of the uncertainty of the detected signals. In this paper, we propose an effective ANN calibration technique for direction finding at a bandwidth of 1 GHz. Two six-port networks are used as phase difference and frequency detector modules. The ANN calibration technique offers the advantage of high accuracy over a wide frequency range without necessarily considering the physical properties of the module, such as the six-port junctions, diodes, and so on. The changing range of beam direction angle is 30° and calibration achieves an RMSE of 0.192°.

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