Simulation Of Direction Finding Algorithm And Estimation Of Losses In An RWR System

Gowri Satheesh, Athena Karumbaya

Abstract: Radar warning receiver (RWR) systems are used to detect radio emissions of radar systems. Its primary purpose is to issue a warning when a radar signal that might be a threat is detected, and subsequently, evade it. RWR systems can be installed in all kind of airborne, sea-based, and ground-based assets and is used for identifying, avoiding, evading or engaging threats. This paper focuses mainly on airborne military RWR systems. The RWR usually has a visual display somewhere prominent in the cockpit to provide visual cues to the pilot regarding the position of the incoming threat. A suitable method of direction finding is required to detect the position of the threat. In this paper, the design of the radio direction finder is based on amplitude comparison to find the angle of arrival (AOA) of the received signal by four antennas circularly distributed. The characteristics of the signal (maximum amplitude and frequency) are specified to provide the identification of the source in addition to the direction. The AOA is determined by taking the ratio of the signal amplitudes between two adjacent antennas due to their associated AOA over 360 degrees direction. This system operates in a wide band of frequency (over 2-18GHz). Software simulations are carried out to validate and find the DF accuracies of the algorithms under various conditions. The effect of external Gaussian white noise, cable losses and phase losses are simulated and studied.

Index Terms: RWR, direction finding, Gaussian noise, amplitude comparison, phase loss, cable loss,radar,AOA.

1 INTRODUCTION

With the development of radar technology and the complication of target background, more and more information which is not range but also angle need be known to target in order to track and orientate accurately. Passive radio direction finders (DF) are used for finding the angle of arrival of the received signal over the whole (360^o) direction. This facility makes these systems important in military and civilian applications. To simplify the amplitude comparison analysis, the ratio between signal levels which are fed from receiving antennas of the proposed DF is used. This method makes the system simple in analysis and implementation and gives a good accuracy and resolution over a wide range of frequencies. The proposed system operates over a wide band of frequencies and covers the whole (360^o). In this system, the amplitude comparison is applied between each two adjacent antennas to select the largest and next to the largest amplitude to provide the AOA of the received signal. In real radio communication channels, it is often found that the dominant source of interference contains a significant noise component that is impulsive, indicating the probability of large interference levels.

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2 SYSTEM DESIGN

The type of antenna proposed to be used in such system must be frequency independent antenna such as cavity backed spiral antenna, with a half power beam width of 75^o. Each antenna is followed by a Low Noise Amplifier (LNA) with high stability over the frequency band (2-18) GHz. All amplifiers must be identical in all lines. Each amplifier is followed by a detector to detect the envelop signals. The analog to digital converter is used to convert the analog values of signals to digital forms to be fed to the signal processing unit which is used to calculate the angle of arrival of the signal. There exists a Pulse Descriptor Word (PDW) Generator block. The purpose of this block is to extract the properties of the received signal, like frequency, pulse amplitude, pulse width etc. Then pulse amplitudes of the received signal from each receiver channel are input to the amplitude comparison block [1]. The SPU also has two memories: one is for database including the specifications of the signals and their associated sources to provide the source identification. The other is for lookup tables including the pre calculated values of the gain for each antenna at their associated angles over 360^o direction. The final part of the system is the console which displays the results.

3 THEORY

A. Gaussian Field Pattern

It can be assumed that the antennas type is circular aperture with Gaussian current distribution and has Gaussian field patterns. The field pattern of the antenna assembly system is shown in Figure 1

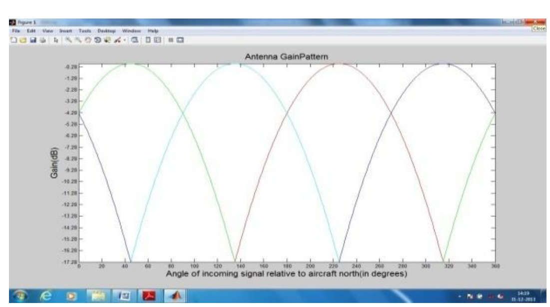

Fig. 1: Antenna Gain Pattern

Receiver	Boresight Direction (in deg)
Forward Left (FL)	45
Forward Right (FR)	135
Aft Left (AL)	225
Aft Right (AR)	315

TABLE I: Antenna boresights relative aircraft north

When a signal strikes the antenna assembly, the individual channel amplitude is measured as well as the difference between each two adjacent antennas to allow the selection of the channels having the largest and next to the largest amplitude. Amplitude comparison RWRs typically use broad-band cavity-backed spiral antenna elements whose patterns can be approximated by Gaussian-shaped beams. Gaussian-shaped beams have the property that the logarithmic output ratio slope in dB is linear as a function of angle of arrival. Thus, a digital look-up table can be used to determine the angle directly. Each antenna has 180 coverage [2]. The boresight (pointing direction) of the antenna in each receiver is directed relative to the aircraft pointing direction, according to Table I. Antenna gain is approximated by the following formula

$$G_{db}(\alpha) = G_{maxdB} - 3\left(\frac{\alpha}{\theta/2}\right)^2 \qquad (1)$$

B. Gaussian White Noise

A white noise signal is constituted by a set of independent and identically distributed random variables. In a discrete sense, the white noise signal constitutes a series of samples that are independent and generated from the same PDF. The PDF can be described mathematically for a Gaussian distribution. White Gaussian noise can be generated using 'randn' function in Matlab that generates random numbers that follow a Gaussian distribution. The algorithm implements the discrete Fourier transform to transform data from time into the frequency domain. Via the inverse Fourier transform we filter out the noise. The filtered signal is plotted. The signal is now ready for amplitude comparison Figure 5 is a possible Gaussian distribution, where the mean (μ) is 0 and standard deviation (α) is 1. This type of probability distribution curve is called the Standard Normal Distribution.

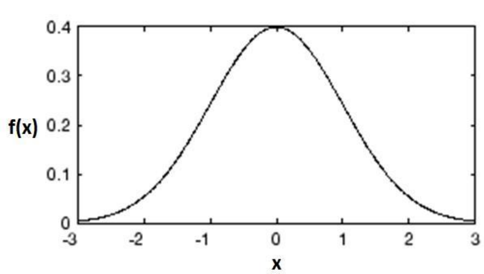

Fig. 2: Gaussian distribution curve

4 AMPLITUDE COMPARISON ALGORITHM

The amplitudes from two antennas, which are directed to the emitter, are used instead of using all of the received amplitudes. The signals received by remaining two antennas are eliminated, since they are mainly receiving the receiver noise. The antenna that receives the maximum amplitude is determined. Then amplitude received from the antenna, which are adjacent to this antenna, is selected. These two amplitudes are taken into consideration to be used in the DF algorithm. The direction finding system considered consists of a circular array of 4 equally spaced antennas. It is assumed that there is a single transmitter and the signal arrives at the antenna at the angle of arrival.
The received signal is given by

$$s_t = AR_t(\theta - \theta_i) + n_i \qquad (2)$$

Where θ and A represents AOA and amplitude of the incoming signal respectively. R_i denotes the gain pattern of the antenna, $_i$i is the angular position of the i^{th} (i=1,2,3,4,) antenna and ni is the receiver noise. The gain pattern of the antenna is given by

$$G(\emptyset) = \theta^{-k\left(\frac{\emptyset}{\emptyset_B/2}\right)^2} \qquad (3)$$

Where ∅ is the angle of incoming signal, and $\emptyset_B$is the antenna half-power beamwidth [3]. The received signal is calculated for all the four antennas. The two antennas receiving the maximum amplitude are deter-mined and the ratio of the two amplitudes is found. A lookup table of gain ratios of adjacent antennas is made for angles at an interval of 5.625. The amplitude comparison algorithm relies on the fact that ratio of the amplitudes received by the antennas is equal to the ratio of the gains corresponding to the two antennas. The amplitude ratio found is compared with the gain ratio lookup table until a match is found. The corresponding angle is displayed.

5 LOSSES

A few other losses have been taken into account when a signal is received. A suitable correction factor must be devised to minimize the effect of these losses.

A. Cable Loss

A coaxial cable carries radio frequency (RF) energy be-tween the antennas and the radio equipment. An antenna cable introduces signal loss in the antenna system for both the transmitter and the receiver. Loss of signal strength is directly proportional to the length of the cable segment. As signal frequency increases, loss increases. The loss is called attenuation, which can be measured in decibels per meter. Choosing the appropriate coaxial cable is vital to the success of any antenna installation. If the correct cable is not used, signal loss will be high and transmit/receive performance poor. Important factors to be considered are:

1. Frequency- The higher the frequency, the higher the signal loss over any given cable run distance.
2. Length of cable run- The longer the cable run, the more signal lost.
3. Cable attenuation- The better quality solid core cables deliver lower signal loss

The transmission losses due to the cables used in the antenna assembly are calculated using the formula given below. The cable considered is an Ultra Low Loss (solid inner conductor) SHF3M cable, manufactured by RADIALL

$$Attenuation(dB/m) = 0.365/\sqrt{F} \qquad (4)$$

Where F is in Ghz

This is used to determine the value of the attenuated signal after transmission through the cables. The correction factor per meter for the cable loss is determined from the lookup table provided by the cable manufacturers. This correction factor is then added to the attenuated signal to get back the original signal.

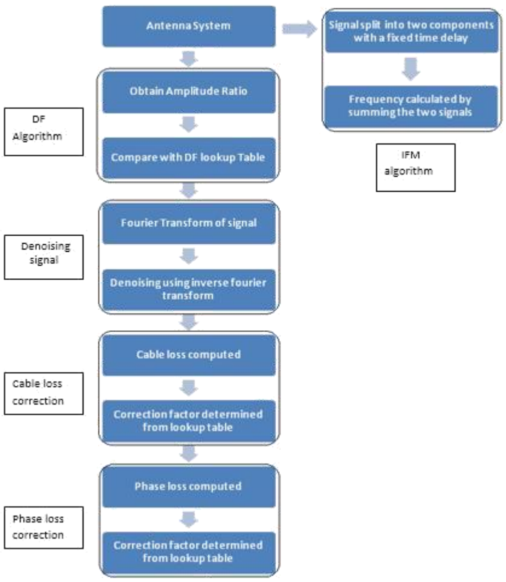

Fig. 3: Block diagram describing the algorithm used

B. Phase Loss

Phase losses are observed due to difference in transmission/receiver cable lengths. The delay in receiving the signals is found to increase linearly with its length. The two signals received at the ends of two transmission cables of different lengths can be given by

$$\alpha_1(t) = A_o \cos \omega t \quad (5)$$

$$\alpha_2(t) = A_o \cos(\omega t + \tau) \quad (6)$$

For two cables of varying lengths, the phase difference between input and output will also increase with the frequency

$$\emptyset = 2\pi f * Delay \quad (7)$$

delay = difference in lengths/c (8)

This delay needs to be compensated for and a phase correction factor must be introduced at the receiving end to minimise this phase loss [4]. A phase look up table is made for 2-18 GHz frequencies for various length differences at an interval of 0.25mm for determining the phase shift. This correction factor is added to the shifted signal to reduce the phase shift to a minimum.

5 INSTANTANEOUS FREQUENCY MEASUREMENT

An instantaneous frequency measurement (IFM) is a relatively simple component which measures the frequency of the incoming signal. It measures the frequency by splitting up the input signal into two paths where one has a constant time delay. An IFM receiver can cover a wide dynamic range (2-18) GHz. An RF signal $v_{in}(t)$is received from an antenna. This signal is then split into two equal portions using a wideband power splitter. One portion is time delayed by amount τ, relative to the other portion. Both portions are then summed with a combiner. The output of the combiner will be an RF signal with an amplitude that depends on frequency. The output signal can be described to have an amplitude equal to $\sqrt{2}V_o \cos(\frac{wt}{2})$

4 RESULTS

An incoming signal is simulated by specifying the values of amplitude, frequency and direction of the signal. The amplitude received at each of the four antennas is calculated and amplitude comparison technique is employed to determine the approximate angle of arrival of the received signal. The antennas with the maximum value of signal amplitudes are only considered and their waveforms are observed, after suitable denoising (Figure 4).

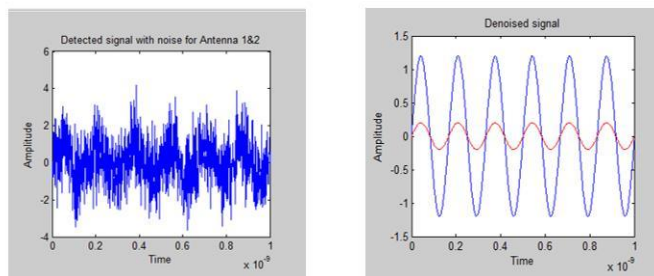

Fig. 4: Denoised Signal

Phase loss and cable loss that would have been experienced by the signal are then calculated and the corresponding correction factors are incorporated in the final output (Figure 5).

4 CONCLUSION

The purpose of this paper is to better understand the process of AOA calculation and to estimate the error in signal due to external whiteGaussian noise and other additional losses such as cable loss and phase loss in an RWR system. The amplitude comparison system consists of a circular array of four equally spaced antennas with reference direction taken as due north. The antenna that receives the maximum pulse amplitude is determined; then the pulse amplitude received from the antenna, which is adjacent to this antenna, is determined. These two pulse amplitudes are taken into consideration and used in the DF algorithm. The main feature of the system is to compare the amplitudes between all antennas to provide the AOA of the incoming signal that makes it suitable for application in Radar Warning Receiver (RWR), which is used to detect the pulse radar signals. This system is developed to determine the frequency of the system using instantaneous frequency measurement. White Gaussian noise has been introduced to the system to simulate external noises that need to be filtered out at the receiver by using Fourier transforms. Additional corrections for cable and phase losses have also been discussed in this paper. A steady increase in both cable and phase loss is observed with an increase in length and frequency of the transmitting cables. Choosing the appropriate coaxial cable is hence, vital to the success of any antenna installation. If the correct cable is not used, signal loss will be high and transmit/receive performance poor.

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