THE SINGLE CHANNEL INTERFEROMETER USING A PSEUDO-DOPPLER DIRECTION FINDING SYSTEM

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ABSTRACT

A new technique for obtaining high performance, low power, radio direction finding (RDF) using a single receiver is presented. For man-portable applications, multichannel systems consume too much power, are too expensive, and are too heavy to easily be carried by a single individual. Most single channel systems are not accurate enough or do not provide the capability to listen while direction finding (DF) is being performed. By employing feedback in a pseudo-Doppler system via a vector modulator in the IF of a single receiver and an adaptive algorithm to control it, the accuracy of a pseudo-Doppler system can be enhanced to the accuracy of an interferometer based system without the expense of a multichannel receiver. And, it will maintain audio listen-through while direction finding is being performed - all with a single inexpensive low power receiver. The use of these techniques provides performance not attainable by other single channel methods.

1. INTRODUCTION

This paper describes a new technique for high performance, low power, radio direction finding (RDF). The basic requirement for obtaining high-accuracy direction-of-arrival (DOA) information in the HF through UHF frequency spectrum using a man-portable system has been a virtually impossible challenge in past years. In particular, these requirements specify better than 3 degrees rms. accuracy, a few to several watts of power consumption, operational bandwidth of 2-2000 MHz, and a cost effective price. The size and weight specifications requires the system fit into a single backpack suitable for an individual to carry. This includes batteries, antennas, cables, headphones, solar blanket, tripods, etc. The unit must be rugged, reliable, and operate over wide (industrial) temperature ranges. [1]

Accessing these requirements, one realizes the single biggest driver is the weight specification. And, because a major component of the weight is batteries, lowering power consumption lowers weight as well. In recent years, even with the advances in low power integrated circuits (i.e. cellular telephones, laptop computers), this challenge is still difficult.

Most of the present DOA technology has been focused on multichannel techniques such as the super-resolution eigenanalysis (MUSIC [2], Root MUSIC [3], ESPRIT [4], etc.) or autoregressive techniques (Levinson-Durbin recursions, forward/backward linear predictors, Kumeresan & Tufts linear predictions, etc.[all 5]). All of these techniques require at least 3 coherent receivers in which the phase (and usually amplitude) are matched. These receivers require closely matched filters, common local oscillators (LOs), and a matched automatic gain control (AGC) circuit that must operate over 80 dB or more of dynamic range. The match must be maintained over time, frequency, and temperature. Periodic calibration techniques [6], can be employed to minimize these matching requirements but these receivers are still, large, bulky, expensive to build, and consume many watts of power. Also, the more sophisticated algorithms usually require a higher end (preferably floating point) processor which often are prohibitively power hungry. These multichannel systems are more suited for fixed site installations than a man-portable application.

2. INTERFEROMETER

Another, somewhat older and simpler, multichannel technique is the well known interferometer [7]. While many forms of the interferometer can be realized [8], a particular form of interest employs a 4 element circular array of omni-directional antennas. In this form the interferometer is built with 2 receivers, which are switched between the east-west and north-south elements. The interferometer accuracy is a function of its antenna baseline. Like the super-resolution techniques, however the interferometer requires at least 2 matched receivers.

3. SINGLE CHANNEL WATSON-WATT

On the other hand, single channel techniques such as the single channel Watson-Watt [9], or pseudo-Doppler [10] system can be made low power and less expensive, but suffer from other problems. For example, the single channel Watson-Watt technique employs two antennas that have "figure-8" patterns oriented at right angles to each other and an additional omni-directional sense element. This technique employs two distinct low frequency sinusoidal audio tones to encode the respective north-south (NS) and east-west (EW) antenna outputs. These tones are generated in the bearing processor and amplitude modulated onto the respective antenna signals via a pair of matched linear modulators - one in each antenna. The two antenna outputs are then combined with the omni-directional sense element to form a "synthesized" double sideband AM signal. Since the DOA information is encoded into the amplitude ratio of these two tones, the received signal is AM demodulated. The demodulated tones are then synchronously demodulated in the bearing processor to extract the DOA information. To allow audio listen-through while direction finding (DF), the demodulated signal can be high pass filtered to remove the two tones. This filtering works if the underlying modulation is AM, or SSB. FM modulation usually doesn't require any special processing to remove the tones.

The implementation of the single channel Watson-Watt system has several problems. Probably the most difficult problem is finding a pair of matched linear modulators that maintain match over the wide frequency and temperature range. The match of these two modulators directly impacts the bearing accuracy. Since these linear modulators are at the front end of the receiver (i.e. the antenna), they must have low noise figures to maintain system sensitivity, and very high intercept points to minimize intermodulation distortion caused by strong nearby emitters. High intercept points usually means higher bias currents and hence they consume precious power, thereby adding weight (via more batteries) to the system.

4. PSEUDO-DOPPLER

Another single channel technique is the pseudo-Doppler DOA system [11]. This system employs a circular array of (usually) 4 omni-directional antennas (i.e. dipoles or monopoles). A commutation switch samples the antennas such that the resulting phase modulation on the received signal encodes the direction of arrival. Because the antenna electronics consists entirely of switches, it is easier to build than the Watson-Watt antenna. If GaAs FET switches are used, phase matching over temperature and frequency is quite easy, intercept points are high, and the power consumption is extremely low (<100 microwatts). Like the Watson-Watt system, however, the Doppler system modulates the incoming waveform such that the audio must be filtered. However, because the "synthesized" modulation is phase modulation (PM), filtering is usually not effective if the underlying modulation is SSB or AM.

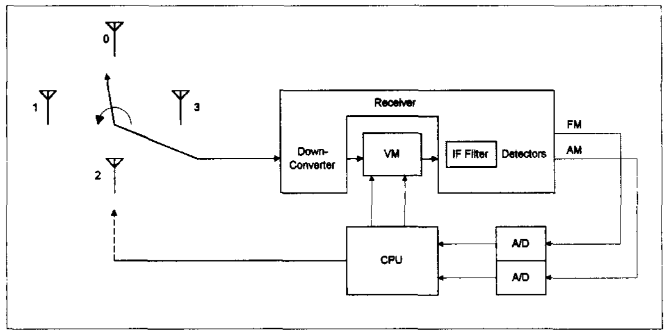

Figure 1: Block Diagram of a Single Channel Interferometer DF System

5. SINGLE CHANNEL INTERFEROMETER

Show in Figure 1 is a simplified block diagram of a Single Channel Interferometer DF System [12]. Key elements are the antenna with an SP4T RF switch, receiver with the IF routed to a vector modulator (VM) and back into the receiver. Both the AM and FM detected outputs can be used but for a spatially distributed array of antenna elements, only FM is necessary for line of bearing measurements. The detected outputs are digitized and passed to a CPU which controls the entire system and makes line of bearing calculations.

To understand how the system works, consider first, the system with the vector modulator fixed at unity gain and no phase shift (i.e. $h_{vm}(t) = 1 + j0$). Shown in Figure 2 is the FM response to a quad antenna array as the array is commutated around the elements. An unmodulated (CW) signal is arriving across the array. The antennas are assumed to be independent ideal field sensors and the maximum spacing between adjacent elements is somewhat less than $\lambda/2$. The received signal at each element i is phase shifted by an amount corresponding to the element position in the array with respect to the arriving wavefront. At each element i, the received signal is given by:

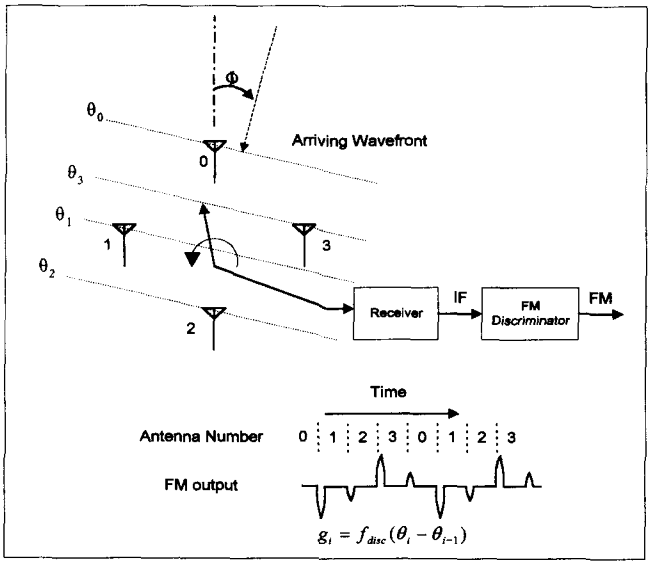

Figure 2: FM response to Antenna Commutation. Impulse outputs are approximately proportional to the phase step between elements.

$$x(t,i) = s(t)m_i$$

where the *i*th element response is:

$$m_i = e^{j\frac{2\pi r}{\lambda}\cos(-\frac{2\pi i}{N_a}+\Phi_{AOA})} = e^{j\theta_i(\Phi_{AOA})}$$

Here, *s(t)* is the received RF signal at the center of the array, *r* is the array radius in meters, λ is the wavelength of the RF signal in meters, N_a is the number of elements in the array, Φ_{AOA} is the angle of arrival referenced clockwise from element 0, and *i* is the element index.

As the elements are commutated (CCW in this example) from element 0 to element 1 and so on, the FM discriminator will respond with impulses of size which is *approximately* proportional to the phase step between each element as shown.

In a pseudo-Doppler system, these impulses are used to ring a narrow band-pass filter of center frequency equal to the commutation rate. The phase of the sine wave output of this filter with respect to the commutation index is equal to the angle of arrival to within a constant..

6. ADAPTIVE ALGORITHM

In the single channel interferometer system, the peaks of the impulses are sampled with an A/D converter. After the

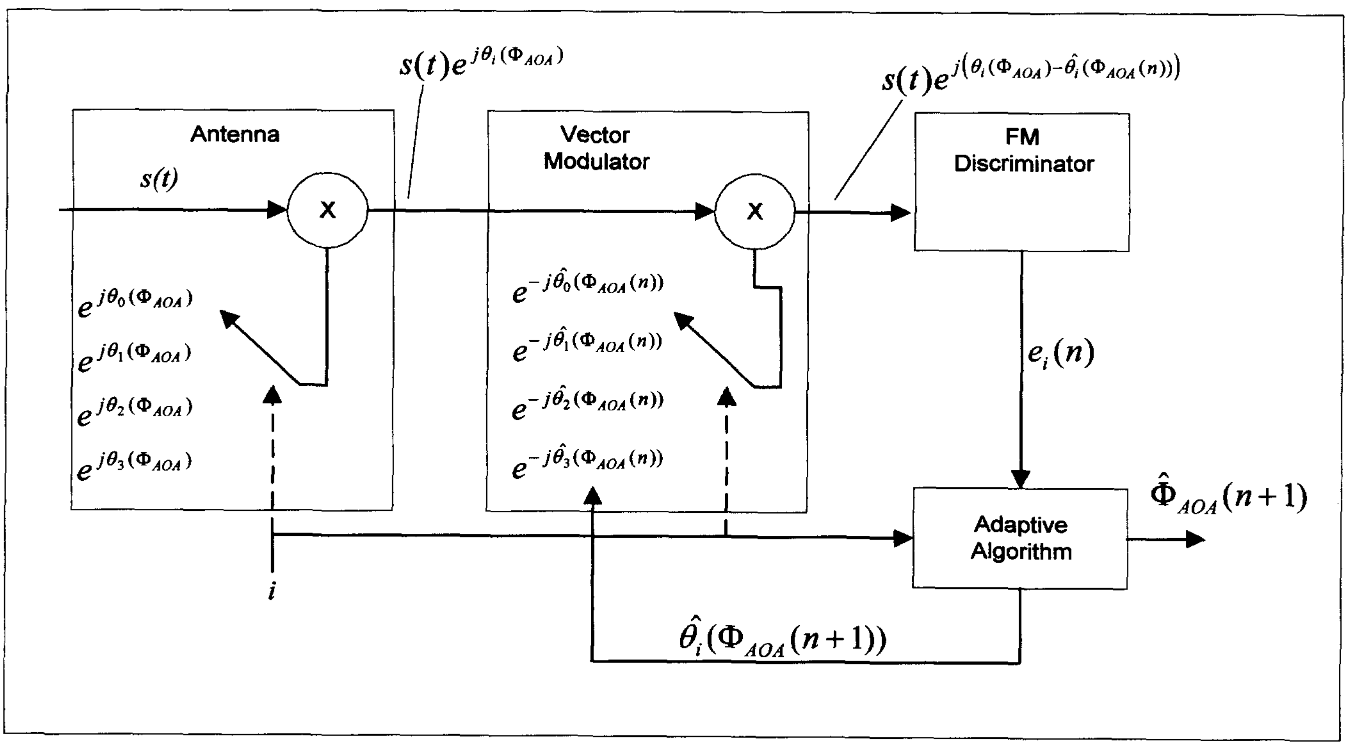

Figure 3: Signal flowgraph of a 4 element single channel interferometer.

first commutation around the antenna array, the algorithm (using the 4 measured impulses) has its first estimate of the phase steps (θ_i-θ_{i-1}) between each antenna element. During the subsequent rotations, the algorithm removes these phase steps by applying the negative phase steps at the IF[1]. The inverse modulation is performed by the vector modulator synchronously with the antenna commutation. That is, as the antenna is switched, from element i-1 to i, the antenna applies a phase step $e^{j(\theta_i-\theta_{i-1})}$, and the algorithm apples a simultaneous phase step of $e^{-j(\hat{\theta}_i-\hat{\theta}_{i-1})}$. The impulses out the of the FM discriminator then become error signals for each phase step. This is shown diagrammatically in Figure 3. In the figure f_{disc} is the FM discriminator's response to a phase step and is represented by

$$e_i(n) = f_{disc}\left\{\left(\theta_i-\hat{\theta}_i\right)-\left(\theta_{i-1}-\hat{\theta}_{i-1}\right)\right\}$$
$$= f_{disc}\left\{\left(\theta_i-\theta_{i-1}\right)-\left(\hat{\theta}_i-\hat{\theta}_{i-1}\right)\right\}$$

Positive values of $e_i(n)$ indicate that the difference $\hat{\theta}_i-\hat{\theta}_{i-1}$ is too small and the phase pair should be moved away from each other. Negative values imply that they should be moved closer to each other. Iterating the adaptive algorithm after each rotation (n) improves the estimate of antenna phases. The ultimate accuracy of the system is limited by the accuracy of the vector modulator, whereas the pseudo-Doppler system is limited by the linearity of the FM discriminator

Once the θ_i's have been estimated, the line of bearing can be calculated directly by:

$$\hat{\Phi}_{AOA} = \tan^{-1}\left[\frac{\hat{\theta}_3-\hat{\theta}_1}{\hat{\theta}_0-\hat{\theta}_2}\right]$$

7. SUMMARY

In summary, the single channel interferometer minimizes costs and power consumption by avoiding a multitude of expensive receivers, and by employing the cost effective pseudo-Doppler antenna. It can be implemented using a simple receiver with an IF tap, a single frequency vector modulator, and an inexpensive microcontroller.

[1]Since phase is relative, only the phase difference between elements is important. Hence we do not measure θ_i directly but the phase *difference* between each element. We arbitrarily assign 0 phase to the first element and compute the remainder of the phases based on that assignment. We then remove the average phase from the set of phases. This effectively puts the 0 degree phase reference at the center of the array.

REFERENCES

[1] Conkle, J. & Peavey, D., "Technology Drivers in Manpack Systems: Signal Acquisition, Small Antennas, and Single Channel Interferometry", *Proceedings of the Symposium on Radiolocation and Direction Finding*, Volume 1. Southwest Research Institute, June 1995.

[2] Schmidt, R. O., "A Signal Subspace Approach to Multiple Emitter Location and Spectral Estimation", Ph.D. thesis, Stanford University, CA., 1981.

[3] Therrien, Charles, "Discrete Random Signals and Statistical Signal Processing", © 1992 Prentice-Hall, ISBN 0-13-852112-3.

[4] Roy, D., "ESPRIT: Estimation of Signal Parameters via Rotational Invariance Techniques", Ph.D. thesis, Stanford University, CA., 1987.

[5] Haykin, Simon, "Adaptive Filter Theory", © 1986 by Prentice-Hall, ISBN 0-13-004052-5.

[6] Adamy, D., "Interferometric Direction Finding", EW Technical Issues #90-5, 1990, Association of Old Crows, Ph.(800) 262-6958.

[7] Gething, P. J. D., *Radio Direction Finding and the Resolution of Multicomponent Wave-Fields*, © 1986 by Peter Peregrunus Ltd., London, UK. ISBN 0 86341 055 3.

[8] Sherrill, "A Survey of HF Interferometry for Ionospheric Propagation Research", *Radio Science.*, 6, pp. 549-566, May 1971, © by American Geophysical Union.

[9] Rainer, R., & Burwasser, A., "An Approach to HF Tactical Radio Direction Finding and Signal Monitoring", *Journal of Electronic Defense*, Oct. 1983.

[10] Cianos, Dr. Nicholas, "The New Generation of Direction Finding and Intercept Systems", *Journal of Electronic Defense*, Oct., 1992.

[11] Cianos - op. cit.

[12] Peavey, et al. "Method and Apparatus for Adaptively Determining the Bearing Angle of a Radio Frequency Signal", *US Patent #5,426,438*, June 1995.