Performance Comparison between 6-Port and 5-Port homodyne circuits for DOA Estimation

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Abstract

In this paper, we propose two approaches to provide direction of arrival using homodyne detection systems technologies like six-port and five port reflectometers. The choice of the reflectometers' type becomes critical in parallel of the circuit capability, i.e. in terms of the number of signals to be detected simultaneously. We present our study by implementing MUSIC algorithm at the output of two different homodyne receivers. The results are deduced from the simulation of the characteristics of each system, using the Advanced Design System (ADS) and MATLAB.

1. Introduction

The problem of localization of sources radiating energy by observing their signal received at spatially separated sensors is of considerable importance, occurring in many fields, including radar, sonar, mobile communications, radio astronomy, and seismology.[1]

Thus a variety of methods, using heterodyne or homodyne techniques, for the Detection Of Arrivals (DOA) estimation are used including spectral estimation, minimum-variance distortionless response estimator , linear prediction, maximum entropy, and maximum likelihood [2]. In addition to previous methods the most famous methods used in DOA are eigenstructure methods, including many versions of MUSIC algorithms [3], minimum norm method [4], ESPRIT method [5], and the weighted subspace fitting method.

While the most recently published papers describe the DOA for three signals at most [6], [11], the main goal of this paper is to implement MUSIC algorithm with two types of homodyne detection circuits. We use these types of circuits because of their simplicity, low cost and high efficiency in the detection of arrivals. The purpose is to compare the quality of the detected angles, in term of precision, for both circuits, especially when the number of the incoming RF signals increases till seven. This paper consists of six main sections. Section 2 presents a general introduction of smart antennas. Section 3 describes 5-port and 6-port homodyne receivers and their calibration techniques. Section 4 explains the theory of the MUSIC algorithm. The simulation results as function of local oscillator power, for 6-port and 5-port circuits, are presented in section 5. Finally the main conclusions are summarized in section 6.

2. Smart antennas design systems

Smart antennas are essential parts of the new generation mobile systems. They can be used to exploit spatial and spectral characteristics of the incoming signals to provide highly accurate location information [1]. The direction of arrival (DOA) algorithm is one of the most important parts of such techniques. A smart antenna system can contain an antenna array that receives the incoming signals to determine their arrival angles and to control the transmitted signals.

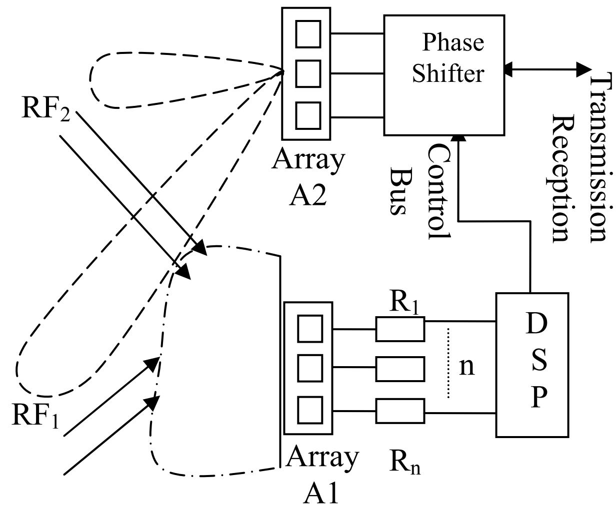
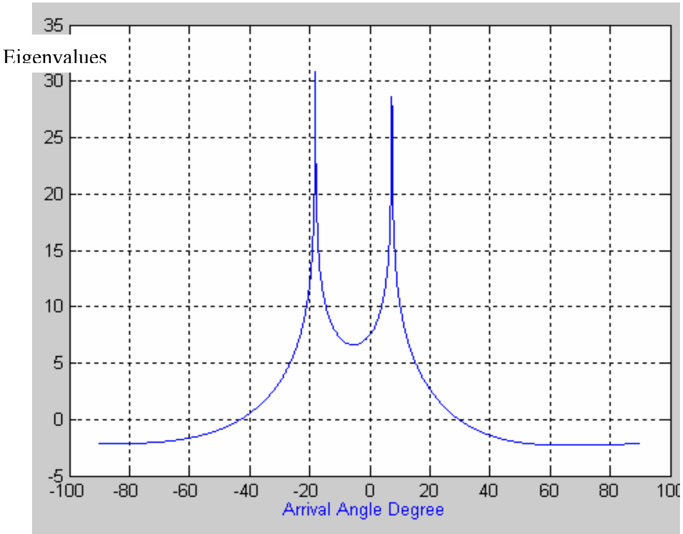


Figure 1: Smart antennas system.

Figure 1 represents a smart antenna system which can detect the DOA for two RF signals simultaneously. To do so, an antenna array A_1, that has three patches, receives the incoming waves from the signals RF_1 and RF_2. The output of each patch is directly connected to a reflectometer (R_i). From the linearized and calibrated outputs of the reflectometers, three or four depending on his type; five or six ports respectively, we can obtain three low frequency complex envelopes (ratio of incoming signal to a reference signal). These are the inputs for the MUSIC algorithm. This algorithm provide as an output a matrix that is the result of projecting the



signal plan over the noise plan as shown in figure2.

Figure 2: DOA of 2 signals using ADS

Figure 2 represents the result of simulation for the DOA of two incoming RF signals from a -18.1^0 and 7.3^0. The simulation is made using ADS (in a noiseless environment) to design the three reflectometers in addition to circuits for simulating the incoming signals [7]. As a conclusion, to detect N signals N+1 patches and reflectometers in addition to bigger capability of the DSP programs.

3. Homodyne receivers

The architectures of the homodyne receivers are simple, with low energy consumption and small number of components. Actually, there are two types of homodyne receivers that are used as network analyzers which are five-port reflectometers and six-port reflectometers. These reflectometers precisely determine the complex ratio between two input signals.

3.1 Six-port and five-port reflectometers

The six-port and five-port reflectometers are microwave measurement devices that were first introduced by G. F. Engen [8]. The five-port reflectometer consists of a five-port microstrip ring with three Schottky power detectors as shown in figure 3.

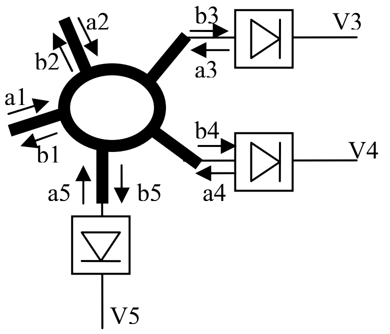


Figure3. Five-port reflectometer

In case of six-port, a coupler is required to provide a reference power from the Local Oscillator (LO) input for normalization as shown in figure4.

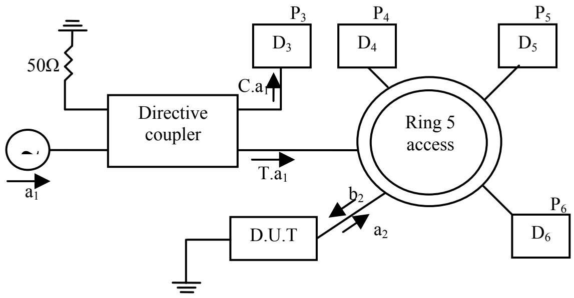


Figure 4: reflectometer six-ports

These devices permit the measurement of the reflection coefficient Γ of a device under test or the ratio of two RF input signals (complex envelope). The output detected powers are submitted to linearization and calibration functions to get Γ or the real part I(t) and imaginary part Q(t) of the complex envelope.

3.3 Designing power detectors for the homodyne receivers

The power detector HSMS2852 is made as shown in figure 5.

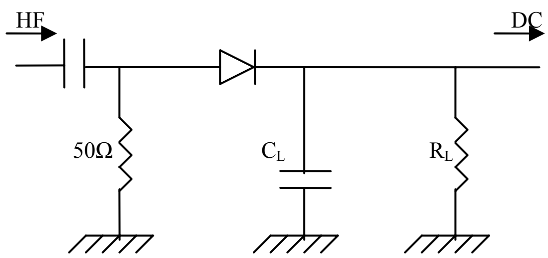


Figure 5: Power detector

It is located at each of the output of the homodyne receivers. It converts RF signals to Low frequency signals or to DC signals. The relation between input power and the output voltage of this detector is presented in figure 6.

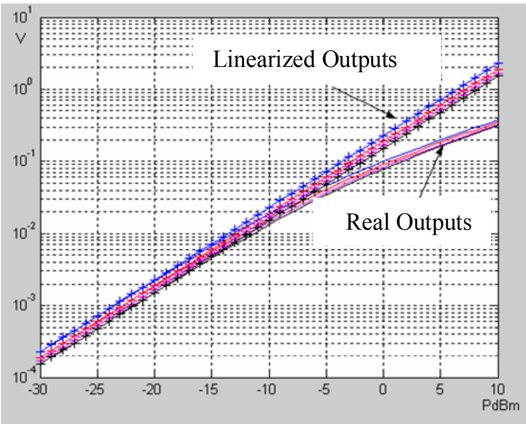


Figure6: Linearization of power detectors

For low input power, the law of operation of diode detector is quadratic, the output voltage is linearly dependant of input power. However, for higher input power (-15dBm), the output voltage is proportionnal to the amplitude of input signal (enveloppe detector), so a linearization function is required [10], [11].

3.4 Calibration of the homodyne receivers

Many calibrating methods were proposed for the six port reflectometer. Some of them determine the constants of the reflectometer by using certain known loads with matrix calculations. An accurate technique is the "six port to four port" reduction methods, provided by Engen. The main goal of the reduction is to provide the complex ratio between the incident waves of two of the four detectors as function of the four measured powers. In this paper we use this method provided by Wiedmann [10]. Figure7 presents the calibration method.

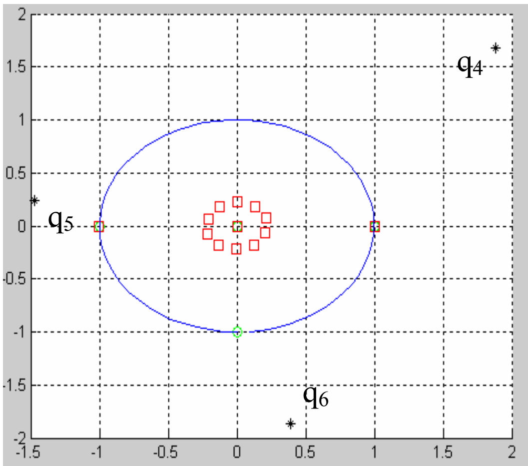


Figure7: Calibration of a six port reflectometer

Figure7 presents the result of the simulation of a mobile short circuit. This mobile short circuit is obtained by applying 0dBm and -20dBm as input powers to the local oscillator and the test measurement port. The theoretical value of the reflection coefficient is 0.25 (-12dB) since the coupling coefficient of the coupler is -8dB. A good agreement is obtained with the simulated results and as consequence it can be used with high efficiency for our systems.

Two methods are used to calibrate the five port reflectometer [9], [14]. The first one uses the five port as a I(t), Q(t) demodulator. This method detects the complex envelope of two RF signals at the input of the five-port system. This envelope will be served as input for MUSIC algorithm to get the DOA as mentioned before. While the second method permits to obtain the reflection coefficient. As in case of six-port, the theoretical magnitude is 1 which agrees with the result of the application of a mobile short circuit, as shown in figure 8.

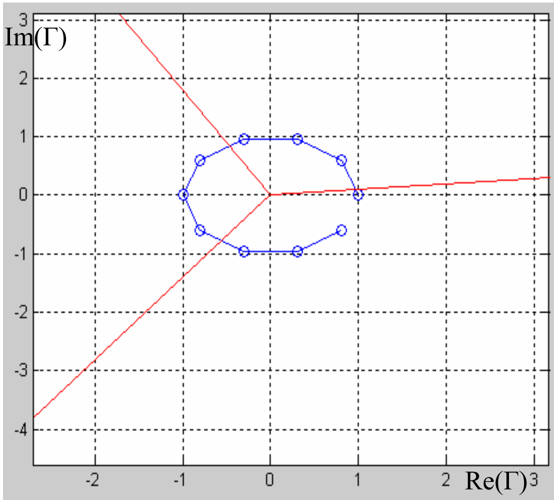


Figure8: Calibration of a five port reflectometer

4. MUSIC algorithm

The multiple signal classification (MUSIC) [3] method is a relatively simple and efficient eigenstructure that uses subspace decomposition method for estimation of the frequencies of complex sinusoids observed in additive white noise [12]. For m receiving antennas, a signal $y(m)$ can modeled as:

$$y(m) = \sum_{K=1}^{P} A_K e^{-j(2\pi F_K m + \phi_K)} + n(m) \quad (1)$$

Where A_k, F_k, Φ_k, are respectively the amplitude, the phase and the frequency of each of the P incoming source.

An N-sample vector **y**=[y(m), . . ., y(m+N–1)] of the noisy signal can be written as:

$$\begin{aligned} y &= x + n \\ &= Sa + n \end{aligned} \quad (2)$$

Where the signal vector $\boldsymbol{x}=\boldsymbol{Sa}$ is defined as

$$\begin{pmatrix} X(m) \\ X(m+1) \\ \vdots \\ X(m+N-1) \end{pmatrix} = \begin{pmatrix} e^{j2\pi F_1 m} & e^{j2\pi F_2 m} & \cdots & e^{j2\pi F_P m} \\ e^{j2\pi F_1 (m+1)} & e^{j2\pi F_2 (m+1)} & \cdots & e^{j2\pi F_P (m+1)} \\ \vdots & \vdots & \cdots & \vdots \\ e^{j2\pi F_1 (m+N-1)} & e^{j2\pi F_2 (m+N-1)} & \cdots & e^{j2\pi F_P (m+N-1)} \end{pmatrix} \begin{pmatrix} A_1 e^{j2\pi \phi_1} \\ A_2 e^{j2\pi \phi_2} \\ \vdots \\ A_p e^{j2\pi \phi_P} \end{pmatrix} \quad (3)$$

The matrix $\boldsymbol{S}$ and the vector $\boldsymbol{a}$ are defined on the right-hand side of Equation (3). The autocorrelation matrix of the noisy signal $\boldsymbol{y}$ can be written as the sum of the autocorrelation matrices of the signal $\boldsymbol{x}$ and the noise as follows:

$$\begin{aligned} R_{yy} &= R_{xx} + R_{nn} \\ &= SPS^H + \sigma_n^2 I \end{aligned}$$

With $\boldsymbol{R_{xx}}=\boldsymbol{SPS}^H$ and $\boldsymbol{R_{nn}}= \sigma_n^2\mathbf{I}$ are the autocorrelation matrices of the signal and noise processes, the exponent H denotes the Hermitian transpose, and the diagonal matrix $\boldsymbol{P}$ defines the power of the sinusoids as:

$$P = aa^H = diag[P_1, P_2, ..., P_P]$$

Where $P_i = A_i^2$ is the power of the complex envelope. The set of eigenvectors associated with the P largest eigenvalues span the signal subspace and are called the principal eigenvectors. The signal vectors $\mathbf{s}_i$ can be expressed as linear combinations of the principal eigenvectors. The second subset of eigenvectors spans the *noise subspace* and has σ_n^2 as their eigenvalues. Since the signal and noise eigenvectors are orthogonal, it follows that the signal subspace and the noise subspace are orthogonal. Hence the sinusoidal signal vectors ***si*** which are in the signal subspace, are orthogonal to the noise subspace, and we have:

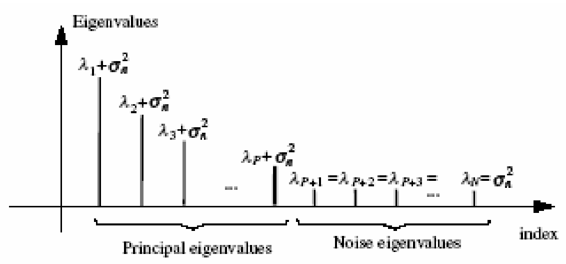


Figure 9: Decomposition of the eigenvalues of a noisy signal into the principal eigenvalues and the noise eigenvalues.

Figure9 concludes that the application of the MUSIC algorithm can lead to separate the incoming signals from each other as well as from the white noise, so indeed a precise detection of arrival angles.

5. Simulation results

5.1 Stable Local Oscillator Power case

In this section we will represent the results of smart antennas systems' outputs when using six port reflectometers and five port reflectometers with MUSIC algorithm and a local oscillator power of 0dBm. All simulations are made in a quasi-ideal environment where ~~we~~ the problem of interferences [13] is not considered.

The following figure represents the DOA of two incoming RF signals.

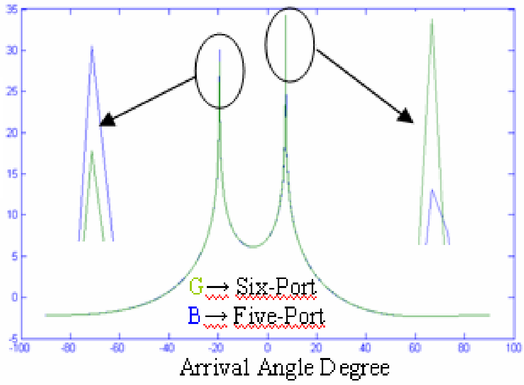


Figure10: DOA of two RF signals

The above figure shows the MUSIC response of two incoming signals to two smart antenna systems that one of them uses six port reflectometers and the second one uses five port reflectometers. The theoretical angles was 7.3^0 and -19.5^0, as shown in the experimental results both smart antenna systems gave equal and perfect results.

The same experiment was made to detect till 7 signals, the results were:

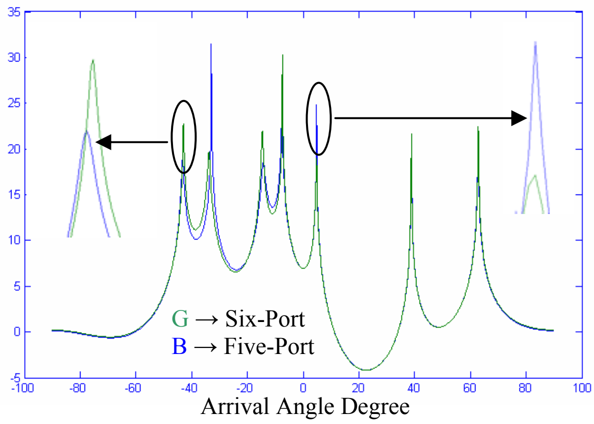


Figure11: DOA of seven RF signals

Again the results were equal and precise for both systems. So, we can use any system since the input LO power is stable.

5.2 Unstable Local Oscillator Power case

In this section, we will show the results of simulations for DOA of 7 signals using six-port and five-port reflectometer receivers in an unstable power environment for local oscillator.

5.2.1 Six-port case:

To do so, we simulated the six-port reflectometers by applying 0dBm, -3dBm, -6dBm as local oscillator power. While the calibration was done at 0dBm LO power, the results are represented in the figure below.

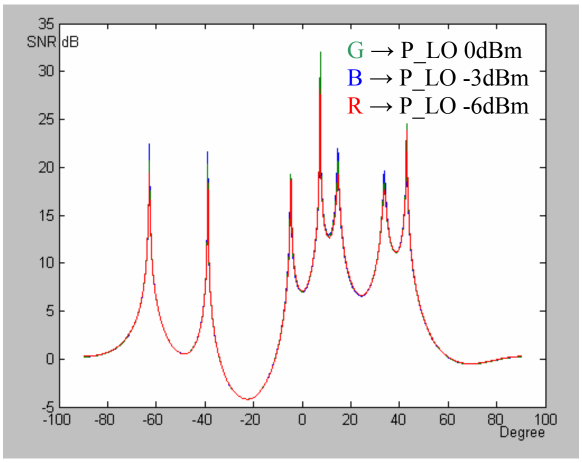


Figure12: DOA of seven RF signals for 3 six-port receivers

The above figure represents the result for DOA of seven signals for the 3 cases. To detect the effect of the local oscillator power (P_LO), we can make a zoom on areas in the figure13 as shown below.

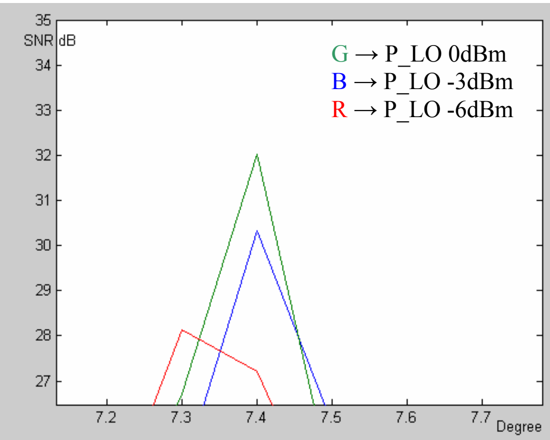


Figure13: comparison of the DOA of a 7.3^0 RF signals for six-port receivers

This figure shows the response of an incoming RF signal form a 7.3^0. We may say that the efficiency DOA for the six-port receivers did not affected badly by local oscillator power variations (Power instability). We may conclude from the above results that these kinds of receivers resists to the P_LO instability.

5.2.2 Five-port receivers case

In this section we followed the same steps as in 5.2.1 but instead of utilizing six-port receivers we used five-port receivers.

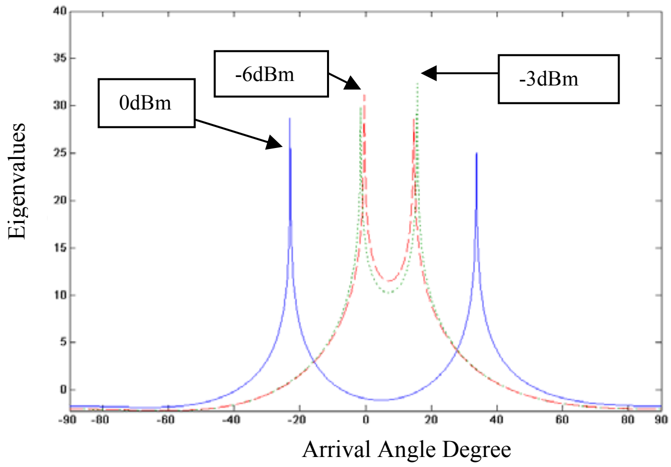


Figure14: DOA of 2 RF signals using five-port receivers

The above picture represents the DOA for two incoming RF signals which comes from -22.9^o and 33.8^o. As described above the five-port reflectometers are calibrated on a 0dBm as a local oscillator power. We can easily conclude that the system perform well if the LO power is 0dBm as in calibration. The angle of arrivals shows large errors if the LO power falls down to -3dBm and -6dBm. The respective arrival angles are -1.5^o and 15.7^o for the first case, while they are -0.4^o and 14.7^o for -6dBm. It is to be noted that the simulation is limited for two signals due this deficiency which shows clearly the difference between both systems.

6. Conclusions

This paper has shown the comparison performance of 5-port and 6-port homodyne receivers as applied to DOA in smart antenna receivers. A brief summary of structure and calibration of both systems are described. The MUSIC algorithm was used to estimate the direction of arrival. We have demonstrated that seven signal directions can be obtained using both systems. The simulations were made as function of the local oscillator power stability. We concluded that in a stable environment, both receivers worked properly, but in an unstable environment only the six-port receivers conserved good performance.

7. References

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