Direction Finding Antennas and Accuracy : Part 2

By Johan Fuhri, Product Owner

About Alaris Antennas

From its roots in 1990, Alaris Antennas has grown to become a substantial supplier of advanced Electronic Warfare (EW) antennas.

Alaris Antenna's mission is to deliver high quality antenna solutions on time through technical and service excellence.
Furthermore, it is our mission to deliver innovative, customised, high quality antenna and related RF product solutions to global RF system integrators speedily through technical and service excellence.

For the global defence, security and telecommunications markets, Alaris Antennas delivers on time high quality antenna solutions, offering customisation supported by technical and service excellence, as Alaris Antennas is the trusted and innovative partner to its clients for over a decade.

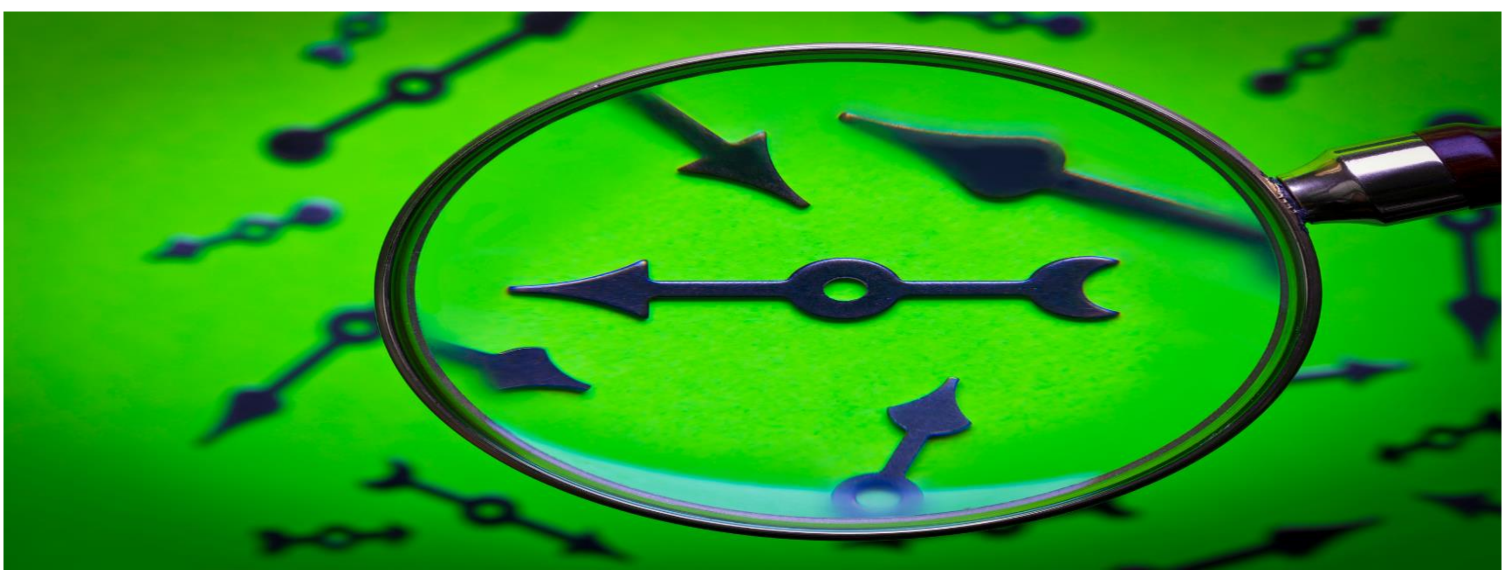
Introduction

In the previous blog post we considered some of the ways in which we can express the performance of an DF antenna, and we noted that simply stating the 'accuracy' of a DF antenna is not quite that simple.

We also noted that there are various algorithms that can be used along with a typical DF antenna, and that the accuracy and sensitivity of DF system is dependent on both the quality of the antenna and the direction-finding algorithm.

In this blog post we will discuss the process of 'characterizing' a DF antenna array to generate a table of values which can be used in correlative algorithms.

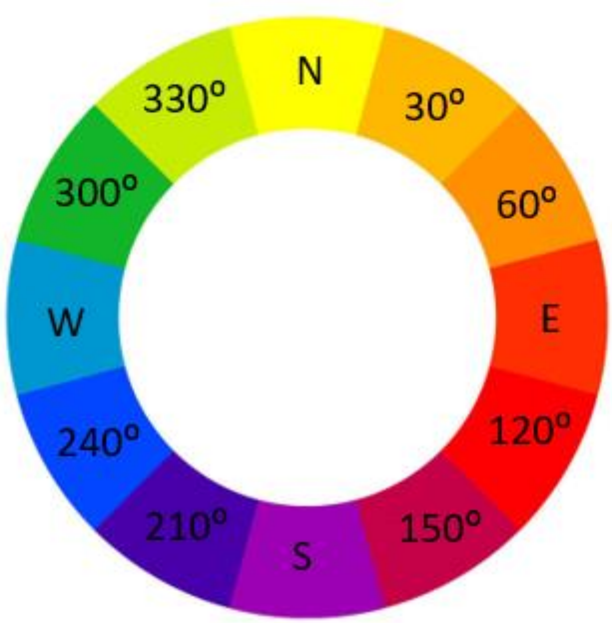
We will also look at a few real-life problems that cause inaccuracies in DF systems, specifically when using basic correlative algorithms.



What is a correlative algorithm?

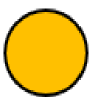
Correlation is a mathematical and statistical tool that can be used to quantitively express how similar two or more sets of data are to each other. It is basically a fancy way of playing 'pick the closest match'.

To illustrate the process, we are going to use colour swatches (the type that adorns the walls of the paint department at your favorite hardware chain store) and create a simple direction-finding system. Consider the image below, which is a circle divided into six sectors and a colour assigned to each sector. Let's suppose we have a DF antenna right in the center of this circle, and the lines/sectors represent the various directions from which a signal can arrive. This, however, is a very special antenna, in the sense that it will tell you the colour of an incoming signal.

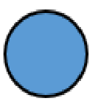


If we are clever, we can make sure that we install the antenna in such a way that a colour of our choosing, yellow in this case, is always pointing due north. If we then receive a signal from our antenna (which will be a color, remember), we can compare the color that we received from the antenna with the image above to determine which direction the signal came from! That's not too hard now, is it?

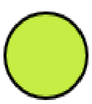
Let's look at an example or two.



This signal clearly agrees with the orange colour in the 30° sector, and hence we can confidently conclude that the signal has arrived from that direction.



Again, nice and easy, obviously agreeing with the colour from the due West direction, so we conclude that this is where our signal of interest originated from.



This colour is most similar to the green just to the left of North, and thus we conclude that our signal arrived from a 330° direction.

On a very basic level, this is what correlative DF algorithms do. The DF antenna is spun through 360° and the incoming signal from each direction, on each of the elements on the antenna, is sampled and stored in a table. This table is called the 'characterization table' (although different people might name it something else), and it effectively allows a DF system to calculate the exact direction from which a signal arrives by comparing the signal with those stored in the characterization table, just like we did with the colours. The circle indicating which colour is in which direction is effectively our own 'characterization table'.

Alaris Antennas offer characterization of our DF antennas and systems as a service to our clients. These characterization measurements are most often done at an outdoor reflection range at the National Antenna Test Range just north of Pretoria, which we affectionately simply refer to as ‘Paardefontein’ (https://www.paardefontein.co.za/).

The measurements entail mounting the antenna on one of the turntable towers and setting up a signal source some distance from the tower. The DF antenna is then turned through 360 degrees in 4^{o} steps (depending on client requirements) and a sample captured from each of the elements of the antenna at each step. This data is then compiled into a characterization table which we make available to our clients.

When life hands you green lemons…

As you might expect though, in real life things are not quite as simple. There are various factors that can influence the accuracy of a DF system in real life scenarios, and in this section we are going to consider just a few of these, using our colour-wheel to illustrate why they cause problems.

Resolution of the characterization table

In our colour wheel example, we divided the circle into 12 sections, each representing an angle of 30^o. It is thus (nearly) impossible for us to determine the direction of an incoming signal to anything more accurate than about 30^o. Note that the signal to noise ratio, or the strength of the electric field, or the amount of noise has very little influence in the accuracy we can achieve, since we are fundamentally limited by the number of colours we have in our characterization table.

We can significantly increase our accuracy by dividing the circle into 36 smaller sectors, giving us many more options to compare our incoming signal to! We can now determine the direction of our incoming signal to within a 10^o sector.

The original orange signal we received is most similar to the third sector, indicating that our signal arrived from a direction of 25°±5°.

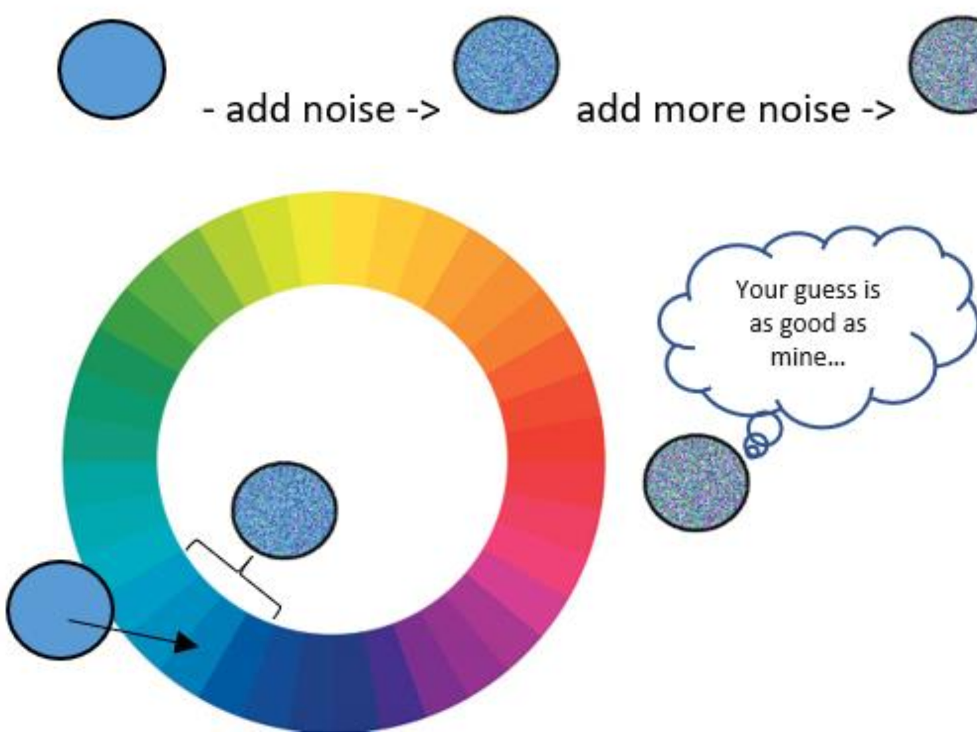
The same is true for DF systems in practice as well. When the antenna is characterized, the angle steps, or angle resolution, can be freely chosen by the person doing the measurement. While it is tempting to choose super small steps (let's measure a sample every 0.1°), this implies that the DF processor has do deal with a table that has 3600 entries, which can potentially slow things down to a crawl when limited processing power is available. In practice, steps of between 2° and 5° are typically used, depending on the specific implementation of the client.

It is also worth mentioning that certain more sophisticated algorithms can achieve resolutions smaller than the characterization table resolution by employing all kinds of clever mathematical techniques. It is the equivalent of being able to look at a greenish-yellow signal and inferring that it must be somewhere between the green and yellow sectors, and thus giving a better guess than simply choosing the green or yellow sectors purely by similarity. The details of these 'super-resolution techniques' are, however, often part of the proprietary magic that system integrators implement as their own competitive advantage.

The effects of noise

Up to now we assumed that the incoming signal that we are evaluating is perfectly clear, and that our accuracy is only limited by the resolution of the table against which we can compare our incoming signal. In antenna terms this is called the ‘large signal accuracy’ of the antenna, as it assumes that no noise is present in the measurements.

Real life signals, however, rarely qualify as large signals and often has noise superimposed on the signal of interest. Let’s look at an example in our colour wheel example.



Adding noise to the signal makes it harder and harder to find the colour that best matches the characterization table. If there is noise present on the signal, invariably the DF processor will look at the 'colours' it can choose from and make mistakes. At best it can tell you that the signal belongs to one of these four sectors, and this reduces the RMS accuracy of the overall system.

Adding even more noise, at some point it becomes practically impossible for the DF processor to make any sense of the incoming signal, and it may start taking 'random' guesses. These wild guesses can be in any direction whatsoever, and are called appropriately called 'wild bearings'.

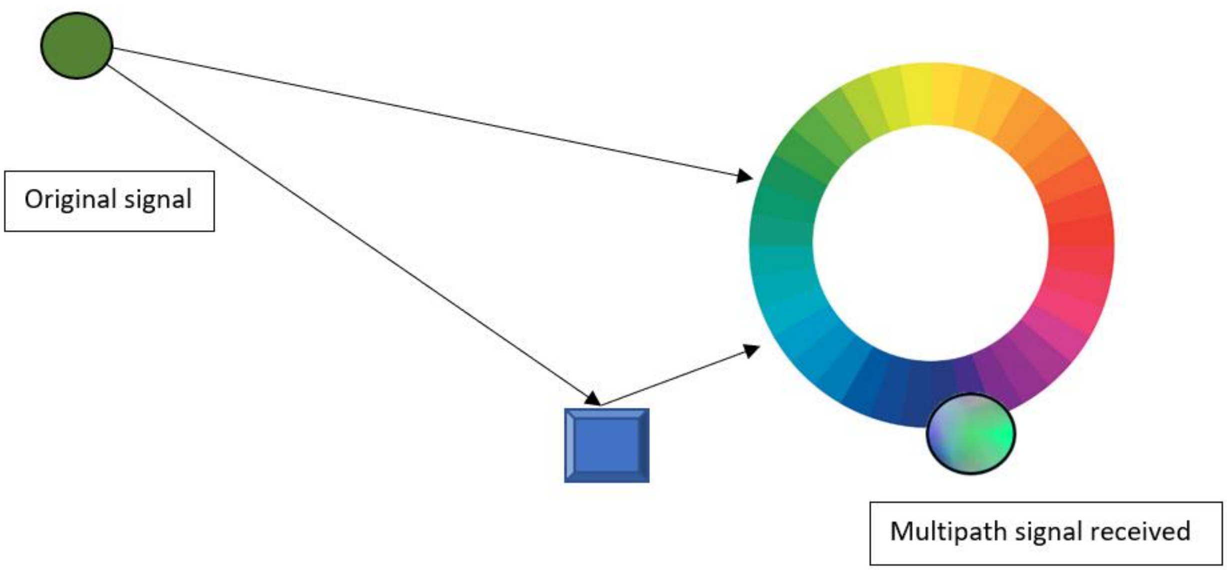
The main source of noise in a DF system is the internal electronic components of the system. Every amplifier, transistor and resistor contribute a bit of noise, and all this noise is added to the incoming signal before the DF processor has the opportunity to compare this signal to the characterization table. We can thus see that it is important to ensure that the received signal is as strong as possible while keeping the noise as small as possible to get a good signal-to-noise ratio.

The design of the DF antenna, specifically the gain of the antenna elements, directly contributes to keeping the SNR as high as possible by ensuring that the incoming signal is converted to a large as possible voltage for the receiver to work with. For a more detailed discussion on this topic, refer to the previous blog post in this series.

Multipath interference

In certain scenarios it might be possible for a signal to bounce off objects, typically large buildings, and the signal that arrives at the DF antenna may end up being a combination of copies of the same signal, arriving from different directions.

These multipath signals, which we will illustrate as a mix of two colours, are very difficult for DF processors to deal with, and is very likely to a reduction in accuracy at best, or wild bearings at worst.



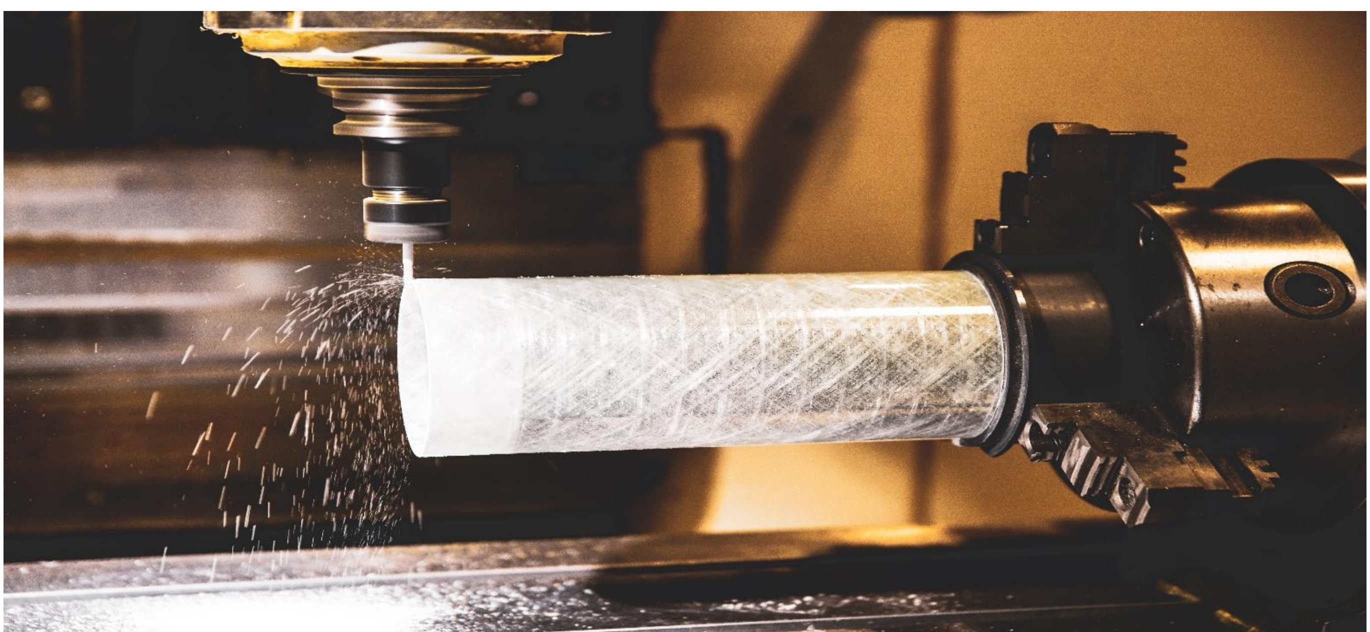
Using our colour wheel example, we can see that a pure green signal leaves the source that we are trying to find, but along the way a signal bouncing off a building also makes its way into the DF antenna. The 'colour' making its way into the DF processor is mostly green, with a dash of blue mixed in. This mixed signal will certainly cause problems for most simple correlative algorithms, as the received signal does not match any of the signals in the correlation table, causing inaccuracies and wild bearings.

Having said that, there are a few clever algorithms, like MUSIC, which can actually use these strange signals to its advantage and can figure out that there are multiple paths in play. How these clever algorithms work is beyond the scope of this blog post (and the authors current intellectual grasp…).

Conclusion

This blog post attempted to explain the principle behind most correlative algorithms while trying to stay away from the complicated math that make it work. We also looked at a few real-world effects that influence the accuracy of DF systems in general, and specifically the mechanism that causes problems in correlative algorithms. Most of these inaccuracies are caused by external factors, ie. they are not so much caused by the design of the DF antenna, but by the environments in which they are employed.

In the last post of the series, we will discuss a few of the intricacies of DF antenna design and how they can cause inherent inaccuracies (ie. non-environmental causes) in poor designs. This will be a rare glimpse into the everyday challenges that antenna engineers at Alaris Antennas deal with on a daily basis!



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