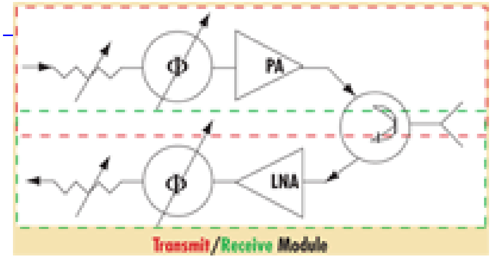
Phase Noise Testing on Phased Array Antenna Modules

Moving into phased array antenna technology, test instruments must be capable of performing both phase and amplitude analysis.

By Guillaume De Giovanni, Aeroflex Inc.

Phased array antennas are made of multiple modules that can transmit and receive RF or Microwave signals. Those modules are arranged in groups forming a usual flat



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surface that replaces a traditional mechanically steered antenna. Their main advantages are: &#149Capable of aiming at different directions simultaneously; &#149No need to move the assembly providing easier integration and better reliability; &#149Module failure tolerance and individual plug-in replacement.

The principle of operation comes from the wave combination of those multiple modules output. Arranging the phase of the various outputs, a wave-front is generated creating similar behavior as if a traditional antenna was steered in this direction.

There are mainly two kinds of such modules: passive and active. The active modules include a power amplifier in the transmit section on top of the phase shifter and variable attenuator. This is where the active module becomes interesting. The amplifier component in the module will have to be tested.

Testing traveling wave tubes (TWT) can be done with commonly available test and measurement equipment, as the power is high and dynamic range request limited. Spectrum analyzers, power analyzers and pulsed vector analyzers can be used to perform most of the required test, but can present limits that are not compatible with the latest generation of such amplifiers.

Pulse stability, residual noise, moving target indication, carrier and pulse cancellation residual and inter-pulse noise power are different measurements or specifications that are linked altogether and are based on the same test equipment core. They all express limitations of radar to detect a given cross-section.

Why Measure the Pulse-to-Pulse Stability?

The pulse-to-pulse stability determines the threshold of detection for targets with a weak echo, thus the instability of radar introduces a main detection limit. In particular, it causes problems to the fixed echoes processing. These can be identified by a Doppler process, but a big phase and amplitude instability can generate false data on the Doppler signature of the targets &#151 therefore generating a risk of triggering wrong alarms.

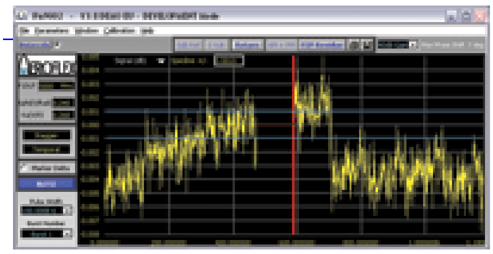
On the other side of the radar, the pulse-to-pulse stability impacts the dynamic of several components of the receiver like the analog-to-digital converters (a higher dynamic of these components would be limited by this signal instability).

The main causes of the stability degradation is strongly linked to the shape of burst, but more specifically to changes in the pulse sequence. The limitations of the stability is mainly due to the thermal effects in the power amplifiers, the electrical fluctuations of power supply and other electromagnetic interferences.

Now, moving into the phased array antenna technology, the dynamic range requirements have gotten worse, the amplifier technology has changed and the widely used tools cannot measure the higher performance of this latest technology. The instrumentation had to change to better look at the imperfections added by the active devices such as the amplifier.

As the antenna relies on accurate phase relation between modules, it is capital to be able to quantify and verify that each module does not negatively impact the performance of the total assembly. This is one of the reasons why so many radar manufacturers test these assemblies so often. Ideally, a perfect radar system and environment would be the best structure to test the modules. Economically not viable, a commercial off-the-shelf solution is desired and two options can be found.

The first option is the traditional phase noise test set, either in-house built or available from a few vendors. This is the only solution that actually existed for a long time, but its capabilities decrease with



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the pulse duty cycle and do not allow full analysis of phase transients within various pulse bursts. This solution is widely used today, it is excellent for all CW applications but can be enhanced for gated CW (pulsed) ones.

The second option is almost always a phase and amplitude oscilloscope with outstanding residual noise. It is derived from the first approach but allows accurate phase changes measurement within a pulse, from pulse-to-pulse and compute spectrum, phase differences, drifts and equivalent stability (MTI). Both the first and the second solution are based around a heterodyne demodulator that can be in-phase or in-quadrature to analyze either the amplitude or the phase of the incoming signal. The second solution, however, also introduces the time domain information and accuracy. The use of this technique provides better dynamic range for the sampler as it does not have to digitize a complete IF and then extract information, but directly digitize the information after phase or amplitude demodulation. There is no more carrier-to-noise dynamic range to deal with and the use of baseband amplification can greatly extend the performance of the analog-to-digital converter. It is very interesting that this technique does not present any limitation due to small duty cycle. It is not unusual to see duty cycle lower than 1% and even lower than 0.1%; this would not be a good case for standard noise testing.

Having a high performance noise analyzer will not be enough as the phase-array antennas are made of multiple modules that can reach a quantity of a thousand. Automation and speed must be considered and included in the test gears. The phase and amplitude analyzer, Aeroflex PN9002, is a commercial solution that combines the ultra-high dynamic range for phase and amplitude and automation. Most of the radar manufacturers have developed their own in-house solution achieving very good performance but at a very high cost. Basically, designing such system means putting together a very clean radar core or using another golden radar receiver, then developing test software that both handles the hardware core and process and presents data in a meaningful format to the operator.

The Aeroflex Stability Test System is an amplitude-and-phase receiver triggered by pulse events. For each of the events, the demodulated signal is digitized for a selected amount of time, recording the phase variations across many pulses. The various processing algorithms allow the operator to quantify many statistics of the signal with amazing dynamic range. Comparing phase changes during short or longer pulses, between different duty cycles, the change from a short to long duty cycle, and so on. This analysis can easily provide feedback on the phase behavior of the device temperature changes due to various pulse patterns.

The spectrum analysis functions provide important noise power information and their frequency distribution enabling designers and developers to improve their designs and manufacturers to quickly narrow down to the source of the issue.

Based on the comparison between the input and the output signal of the device-under-test (DUT), this stand-alone PN9002 system can characterize separately its radar component. It is equipped with a low noise (phase and amplitude) synthesizer (PN9100), a pattern generator board linked to a modulator. This equipment generates a radar type stimulus from VHF to Ku band. In addition, the generated signal is synchronized to the analyzer-sampling clock providing great timing accuracy and reproducibility.

The system can automatically tune its stimulus characteristics and receiver section through the software allowing knob-free measurements. It includes various ways of computing the same measurement value based on multiple choices related to the type of pulse burst. All measured data can be computed based on a unique segment sample.

Two time domain methods can be used: (1) The RMS process where the pulse-to-pulse stability represents the phase and amplitude variations between successive pulses of a same burst. (2) The standard deviation process where

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Figure 3. PN9002 Architecture.

the pulse-to-pulse stability is considered as the average deviation of the phase and amplitude of each pulse when compared with the average value of the phase and amplitude on the whole burst. Both are usually equivalent, but the simple RMS method is not always applicable. The system residual stability is in the order of 0.005&#176 RMS and 0.001 dB power ripple.

A complete spectral analysis method based on FFT analysis provides information about the spectral distribution of the instability. The power spectral density process can be weighted (pondered) by the FFT filters and all raw data exported to text files for external custom analysis. The signal power and the noise power are computed with regards to the number of pulses defined for the stability process. The pulse-to-pulse stability is quantified for each pulse by the ratio of the noise power to the signal power (dBc).

The stability calculation depends on the type of selected FFT filtering and to the number of pulses. This spectral method can only be used for the bursts with constant pulse repetition frequency (PRF) but can be done for a given sequence present in the middle of other ones.

Summary

As phased array antenna techniques spread through defense, space and even now commercial applications, engineers need higher performance and more practical tools to face tomorrow's challenges. The PN9002 offers phase and amplitude analysis with an amazing dynamic range and flexibility. This open architecture will also allow users to master the ultimate dB.

About the Author

Guillaume De Giovanni is the director of business development, Aeroflex phase noise systems. Mr. De Giovanni is the signal integrity specialist for RF & microwave transmission channels. He can be contacted at guillaume.degiovanni@aeroflex.com; +33 1 30 51 73 03.

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