RF Network Analyzer Basics

A tutorial, information and overview about the basics of the RF Network Analyzer. What is a Network Analyzer and how to use them, to include the Scalar Network Analyzer (SNA), Vector Network Analyzer (VNA) and the Large Signal Network Analyzer (LSNA).

One item of Test Measurement Diagnostic Equipment (TMDE) that is widely used by RF design laboratories is the 'RF Network Analyzer'. Not to be confused with a 'Network Analyzer' used for analyzing Data Networks. The RF Network Analyzer is used for characterizing or measuring the response of devices at RF or even microwave frequencies.

By measuring the response of a device or Network using an RF Network Analyzer, it is possible to characterise it and in this way understand how it works within the RF circuit for which it is intended. It is possible to use RF Network Analyzers for measuring a variety of components ranging from filters and frequency sensitive Networks, to devices such as transistors, mixers and any RF orientated device.

Typically RF Network Analyzers are more usually associated with microwave type frequencies. However the RF Network Analyzers that are available cover down to much lower frequencies than this, and some are even able to make measurements at frequencies down to 1 Hz.

Types of RF Network Analyzer

Within the broad scope of RF Network Analyzers, there are various types of instrument which can be bought and used. These types of RF Network Analyzer are very different, but they are all able to measure the parameters of RF components and devices but in different ways:

- ***Scalar Network Analyzer (SNA):*** The Scalar Network Analyzer (SNA) is a form of RF Network Analyzer that only **measures the 'Amplitude' response properties of the device under test - i.e. its 'Scalar Properties'**. In view of this it is the simpler of the various types of Analyzer.
- ***Vector Network Analyzer (VNA):*** The Vector Network Analyzer (VNA) is a more useful form of RF Network Analyzer than the Scalar Network Analyzer (SNA) as it **is able to**

measure more parameters about the device under test. Not only does it measure the 'Amplitude' response properties, but it also looks at the 'Phase' response properties as well. As a result Vector Network Analyzer (VNA) may also be called a gain-phase meter or an Automatic Network Analyzer.

- *Large Signal Network Analyzer (LSNA):* The large signal Network Analyzer, LSNA is a highly specialized for of RF Network Analyzer that is able to investigate the characteristics of devices under large signal conditions. It is able to look at the harmonics and non-linearities of a Network under these conditions, providing a full analysis of its operation. A previous version of the Large Signal Network Analyzer, LSNA was known as the Microwave Transition Analyzer, MTA.

The various types of RF Network Analyzer are quite different in their make-up and the way in which they are able to make measurements. **The Scalar Network Analyzer is the least expensive, although not cheap, but it also provides the least information.** The Vector Network Analyzer is able to provide considerably more information, but these RF Network Analyzers are also considerably more expensive.

Difference between RF Network Analyzers and Spectrum Analyzers

Although there are many similarities between Network Analyzers and Spectrum Analyzers, there are also several major differences, especially in the types of measurements that are made. In particular they make very different types of measurement.

1. An RF Network Analyzer generates a signal and uses this to analyze a Network or Device Under Test (DUT).

    a. It is a particularly useful item of RF design test equipment. They enable the RF Designer to see many aspects about the performance of a component or Network and in this way the circuit can be designed to ensure the optimum performance.
    b. It is used to measure components, circuits, and sub-assemblies.

c. It contains both a source and multiple receivers. It will display amplitude and often phase information (frequency or power sweeps) and normally in a ratio format.
d. It uses a known signal, (i.e. a known frequency), at the output of the device under test, since it is a stimulus response system.
e. With Vector-error correction, they provide much higher measurement accuracy than Spectrum Analyzers.
f. Typically they are not used within production environments because of the complicated nature of the measurements that are made and also the cost of the equipment.

2. A Spectrum Analyzer is intended for analzing the nature of signals that are fed into them.

   a. It is used to analze the nature of signals that are fed into them. They are most commonly configured as a single channel receiver, without a source.
   b. It is normally used to measure the characteristics of a signal rather than a device. The parameters measured may include: *signal or carrier level, sidebands, harmonics, phase noise, etc.*
   c. It can be used for testing Networks such as filters. *To achieve this they need a tracking generator. When used in this way, they can be used for Scalar component testing (magnitude versus frequency, but no phase measurements).*
   d. Because of the flexibility needed to analyze signals, Spectrum Analyzers generally have a much wider range of IF bandwidths available than most RF Network Analyzers.
   e. With Spectrum Analyzers, it is easy to get a trace on the display, but interpreting the results can be much more difficult than with a Network Analyzer.

RF Network Analyzer Operation & Circuit

- notes and details of how an RF Network Analyzer works and the main circuit blocks it contains.

An RF Network Analyzer contains a large amount of circuitry. In addition to this, an RF Network Analyzer is a precision item of test equipment, many of which are able to operate over a very wide bandwidth, often extending from a few MHz or less right up to several GHz. As a result of this, RF Network Analyzers are not normally cheap items of test equipment.

In terms of the actual circuitry that an RF Network Analyzer, the Analyzer can be split into several sections:

- *RF Network Analyzer stimulus / source:* An RF Network Analyzer is an active test instrument. This means that it generates a signal that it applies to the device under test, and then it measures the response. The stimulus or RF signal source is essentially a form of signal generator. There are generally two modes. One is to sweep the power level, and the other is to sweep the frequency. Typically the signal source for an RF Network Analyzer is separate to the main instrument, but this is not always the case. Also they may either be open loop voltage controlled oscillators, of they may be digitally synthesized. The open loop oscillators generally provide a good phase noise performance but their frequency accuracy and flexibility is relatively low. However they are much cheaper to design and build. Digitally synthesized oscillators are more expensive but they are able to provide an exact frequency signal which is essential for measuring narrow band frequency devices such as filters. However when measuring these devices, low levels of phase noise on the signal are essential otherwise the measurements are degraded and this considerably adds to the cost. Nevertheless most sources used with RF Network Analyzers are of the synthesized variety.
- *Signal separation:* The signal separation element within the RF Network Analyzer is often called the "test set". Often it may be a separate box, although in many instances it may be integrated within the main instrument. There are two functions that the signal separation hardware provides:

    1. Measure a portion of the incident signal to provide a reference for what is termed "ratioing". This may be accomplished using a splitter or directional coupler. Splitters are very broadband, but have the disadvantage that they introduce a loss of 6 dB. Directional couplers have a low loss through the main arm combined with good isolation and directivity. However they have an inherent high pass response usually giving them a low end frequency limit of around 30 - 40

MHz and as a result they are normally only used in microwave Network Analyzers.

2. Separate the incident (forward) and reflected (reverse) travelling waves at the input of the DUT. Couplers are usually the preferred method because they are directional and they have low level of loss combined with a high level of reverse isolation. Their drawback is that they have frequency limitations and as a result bridges are often used instead. Although bridges work down to DC, they have a higher level of loss.

In this way, it can be seen that they are decisions to be made about the optimum type of signal separation device.

- *Receiver and signal detection:* Once the signal has been passed through the device under test and separated from the source signal, it is necessary to start to process it in the RF Network Analyzer so that the results can be gained. The first stage of this uses what is essentially a radio receiver with a demodulator or detector. The receiver can take one of a variety of forms. It can be a simple diode detector, but this only provides amplitude information, although it does provide a very wide bandwidth that may be needed in some instances. For example, one application where broadband diode detectors are very useful is measuring frequency-translating devices, particularly those with internal LOs.

  Typically, though, a tuned radio receiver is used. This provides the best sensitivity, dynamic range as well as harmonic / spurious signal rejection. The narrow band filter within the receiver enables wide band noise to be limited and this provides a significant sensitivity improvement. Normally the radio receiver uses the superheterodyne principle.

- Note on the superheterodyne receiver topolgy:

  The superheterodyne radio receiver topology operates by changing the frequency of the incoming signal down to a fixed frequency intermediate stage where it can be amplified and filtered. A variable local oscillator signal is mixed with the incoming RF signal to achieve what is effectively a variable frequency filter.

Once through the analogue sections of the receiver, today's RF Network Analyzers then apply the signal output from the receiver to an analogue-to-digital converter (ADC). This is done in such a way that both magnitude and phase information are extracted from the IF signal. Then digital signal processing, DSP, techniques can be used to process the signal. The tuned receiver approach is always used in Vector Network Analyzers.

- *Processor and display:* With the processed RF signal available from the receiver and detector section it is necessary to display the signal in a format that can be interpreted. With the levels of processing that are available today, some very sophisticated solutions are available in RF Network Analyzers. Here the reflection and transmission data is formatted to enable the information to be interpreted as easily as possible. Most RF Network Analyzers incorporate features including linear and logarithmic sweeps, linear and log formats, polar plots, Smith charts, etc. Trace markers, limit lines and also pass / fail criteria may also be added in many instances.

These are the very basic blocks that can be found within RF Network Analyzers, whether a Scalar Network Analyzer (SNA), or a Vector Network Analyzer (VNA).

Scalar Network Analyzer (SNA)

- notes and overview of the Scalar Network Analyzer (SNA) detailing what it is, how it works and how it may be used.

As the name indicates, a Scalar Network Analyzer or SNA is a form of RF Network Analyzer that only measures the amplitude properties of the device under test. In view of this it is the simpler of the various types of RF Network Analyzer.

Effectively, a Scalar Network Analyzer (SNA), works just as a Spectrum Analyzer in combination with a tracking generator. When a tracking generator and Spectrum Analyzer are used together, their operation is electrically closely linked.

The Tracking Generator generates a swept signal on exactly the same frequency that the Spectrum Analyzer is receiving. Thus if the output from the tracking generator was connected directly to the input of the Spectrum Analyzer, then a constant line would be seen across the screen of the Analyzer indicating the amplitude of the tracking generator output. If a device is placed between the two items, then the Spectrum Analyzer will note any amplitude variations. In this way for example, the response of a filter can be plotted. The constant output of the tracking generator will pass into the filter, where the response of the filter will change it according to the frequency and the response of the filter at that frequency, and in this way the Spectrum Analyzer will be able to display the response of the filter. From this it can be seen that Scalar Network Analyzers(SNA), are very useful for measuring the amplitude response of a variety of components.

Vector Network Analyzer (VNA)

- a tutorial, information and overview about the basics of the Vector Network Analyzer (VNA), detailing what is a Vector Network Analyzer, how it works and using a Vector Network Analyzer.

The Vector Network Analyzer (VNA) is a form of RF Network Analyzer widely used for RF design applications. A Vector Network Analyzer is a test system that enables the RF performance of Radio Frequency (RF) and microwave devices to be characterised in terms of Network Scattering Parameters, or S-Parameters. The information provided by the Vector Network Analyzer VNA is then used to ensure that the RF design of the circuit is optimized to provide the best performance. Using an RF Network Analyzer in any RF design provides the RF design engineer with a view of the components and circuits that would not be possible with any other form of test equipment. In this way the Vector Network Analyzer (VNA) is an essential tool that RF design engineers should be able to use.

Although the name of the Vector Network Analyzer VNA is the most widely used name for this item of test equipment, sometimes it may be called a **gain phase meter** in view of the fact that they are able to measure both the gain, i.e. amplitude and also the phase of the device or item under test. Another name that is occasionally used is the Automatic Network Analyzer. However by far the most widely used is the name Vector Network Analyzer (VNA).

Magnitude and phase

The key element of the Vector Network Analyzer (VNA), is that it can measure both amplitude and phase. While an amplitude only measurement is much simpler to make, and can be undertaken by less complicated instruments. This may be quite sufficient for many instances. **For example when the only consideration is the gain of an amplifier over a certain bandwidth, or the amplitude response of a filter is needed.** However a measurement that includes phase as well as amplitude enables far more to be discovered about the device under test as phase is a critical element in Network analysis. This is because a complete characterization of devices and Networks involves measurement of phase as well as magnitude. Only with a knowledge of phase and magnitude from a Vector Network Analyzer can circuit models be developed that will enable complete simulation to be undertaken. This will enable matching circuits to be designed based on conjugate matching techniques. Time-domain characterization requires magnitude and phase information to perform the inverse-Fourier transform. Also, phase data is required to perform Vector error correction.

Summary

Vector Network Analyzers are particularly useful items of RF test equipment. When used skilfully, they enable RF devices and Networks to be characterised so that an RF design can be undertaken with a complete knowledge of the devices being used. This will provide a better understanding of how the circuit will operate. Vector Network Analyzers provide a much greater capability than their Scalar counterparts, and as a result the Vector Network Analyzers are more widely used, even though they tend to be more expensive.