Antenna Lab – Report#4

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Report #1

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Summary: How a VNA (Vector Network Analyzer) works

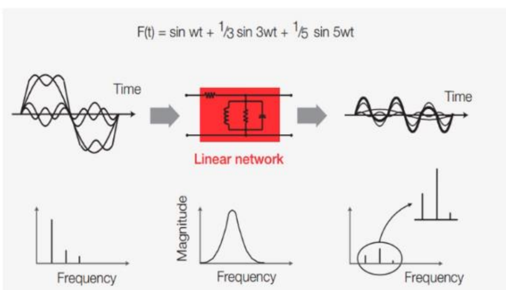
Measurement in Communication Systems

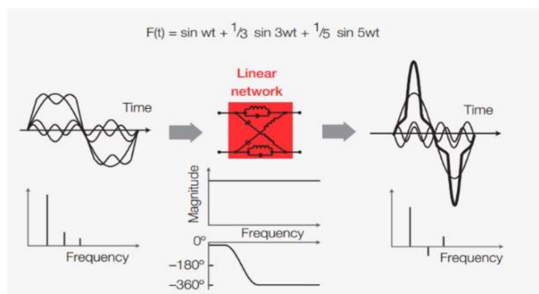
Every input signal in a communication system can be represented by a linear combination of sine waves according to Fourier transform. Therefore, **we can obtain a system's behavior** by **analyzing its response to single sinusoidal in different frequencies.**

Linear and **Non-linear** systems, have different properties in response to a single sinusoidal (monotone):

1. **Linear systems don't produce new frequencies**. Response can be described as **phase shift** or **magnitude change** (filters, passive antennas)
2. **Non-linear systems** response can also include **frequency shifts**, modulations and harmonics (ex: amplifiers, mixers, etc.)

We need to have information about magnitude and phase of different frequencies, and these are used all together to describe a systems behavior. Variations in magnitude result in a completely different response from variations in phase for a common input signal.





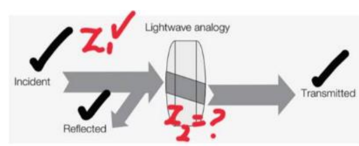
Distortive effects caused by non-linear systems include: **saturation**, **crossover, intermodulation,** etc.

Importance of Network Measurement:

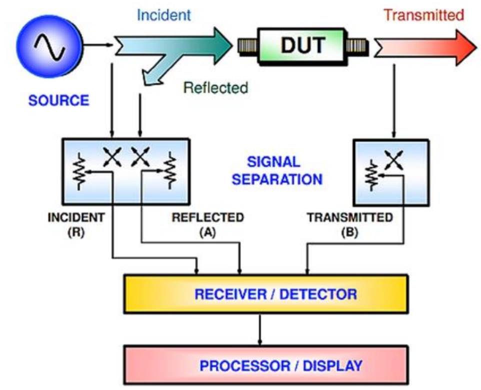
- We study the impulse response to gain information about a network.
- Designing efficient matching networks based on device antennas, measuring complex impedances.
- We need phase and magnitude characteristics to compute FFT and IFFT.

VNA basics:

In order to investigate any environment's electromagnetic properties, we can send an incident wave we know (have complete information about magnitude and phase of each frequency), then by measuring reflected and transmitted portions of this wave through the secondary environment (test), and also having knowledge about the first environment (impedance), a system of equations gives us information about the impedance of the test environment (DUT).



As we can see in the block diagram the source of a VNA, inputs a known signal, through the DUT (device undertest), reflected (in case of mismatch) and transmitted energy levels measurements aid the VNA to detect and display differences between the transmitted and signal, thus the network properties can be analyzed.



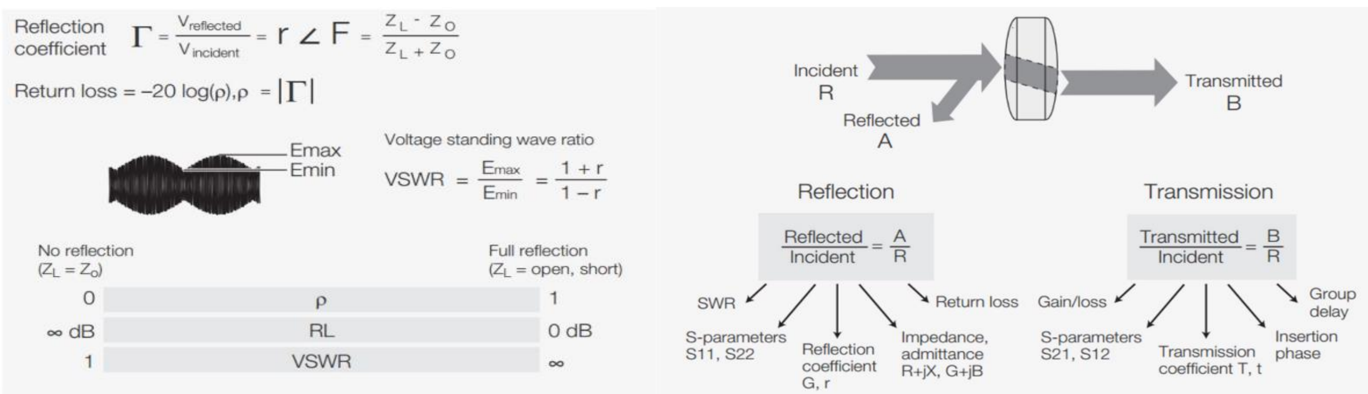
General Network Analyzer block diagram

We could do all this with signal generator, spectrum analyzer and antenna tests, **So why VNA's?**

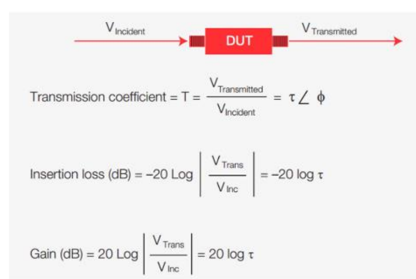
1. Everything is done in a compact fashion in VNA's in one device.

2. Spectrum analyzers don't have the ability to measure phase but VNA's can cause both receiver and transmitter are packed and we have a phase reference.

- For measuring phase delay and everything related to phase, we can only use VNA. By using VNA, we can calculate reflection and transmission ratios and derive parameters such as SWR, S parameters of a network (in a matrix form), reflection and transmission coefficients, impedance, admittance, return loss, insertion phase and phase delay.



All these parameters can be converted to one another but in measurements for an antenna, S11 and S21 are very common to report. A good antenna should have low return loss, usually S11 = -10dB (VSWR<2) is a quality threshold that defines this goodness. So, an antenna has proper radiation and reception in frequencies that S11 is lower than -10dB. We need an S11 graph, or other parameters such as VSWR, reflection and transmission ratio to determine the bandwidth of an antenna. The bandwidth is equal to the frequency range with an S11 lower than -10dB. In other words, these frequency ranges correspond to a less than 10% power reflection.



S21 and S12 are equal in passive devices. S21 shows the filter response for filters. It's actually the magnitude in the frequency response.

By plotting group delay over frequency, we can determine how much each frequency component is shifted in phase. If group delay deviation is low, frequencies are shifted more similar. We want an antenna to not distort our input signal as much as possible. High deviation in group delay causes distortion, therefore we want a low deviation in phase.

VNA specifications:

- Frequency Range
  - The higher the frequency is, the harder phase measurement becomes.
- Dynamic Range
- Output Power
  - Output power should be large enough to drive the power amplifier (PA)
- IF Bandwidth
- Number of ports
  - An N-port network can measure an N-by-N matrix.
- Options
  - The availability of the options is due to the compact structure of the VNA where is has both transmitter and receiver within it.

VNA parameters:

- S - parameters
  - Scattering parameters should be measured by the VNA.

- X-parameters (Non-linear parameters)
  - Frequencies, harmonics and phase delays in active devices are important

- Gain compression
  - Find out which power levels are saturated.

- IMD (Inter-modulation distortion)
- Spurs (Unintended signals)
- Noise Figure

Bonus: Comparing N5242A & E8361C

These two models are rather old relative to the ones in Keysight's main page for VNAs. The datasheets on the website weren't specifically about these 2 models. I used 3 older datasheets. One is for PNA-X series including N5241A, N5242A, N5249A. The other two is E836xC series that also apply to E8361C

The specifications extracted belong to 3 main categories:

1. Corrected System Performance (I've considered the corrected system performance[1])
2. Uncorrected System Performance
3. Test Port Output
4. Test Port Input

1. System Performance:

1.1 – Frequency Range: **N5242A:** 10 MHz – 26.5 GHz / **E8361C:** 10 MHz – 67.5 GHz (Up to 70GHz)

E8361C has a wider frequency range, thus is more compatible with high frequency devices

- **1.2 - Dynamic Range:** System dynamic range is calculated as the difference between the noise floor and the source maximum output power. Wider dynamic range means compatibility to more input and output devices and also can show less noise sensitivity. These devices also work on some optional modes that have different ranges.

Description	Specification (dB) at test port 2
Dynamic range	
Standard configuration (E8361C)	
10 to 45 MHz 4	61
45 to 500 MHz 5	87
500 to 750 MHz	112
750 MHz to 2 GHz	111
2 to 10 GHz	111
10 to 24 GHz	114
24 to 30 GHz	103
30 to 40 GHz	104
40 to 45 GHz	96
45 to 50 GHz	100
50 to 60 GHz	97
60 to 67 GHz	94
67 to 70 GHz 4	94

E8361C

Table 2b. System Dynamic Range at Test Port (dB), Options 219 or 419

Description	Specification		Typical	
	Ports 1, 3[1]	Ports 2, 4[1]	Ports 1, 3[1]	Ports 2, 4[1]
10 MHz to 50 MHz	93	93	106	104
50 MHz to 100 MHz	103	103	115	114
100 MHz to 500 MHz	117	117	130	129
500 MHz to 3.2 GHz	124	127	130	135
3.2 GHz to 8.5 GHz	127	127	135	134
8.5 GHz to 10 GHz	127	127	135	134
10 GHz to 13.5 GHz	126	125	132	131
13.5 GHz to 16 GHz	126	125	132	131
16 GHz to 20 GHz	124	122	130	127
20 GHz to 24 GHz	118	117	127	124
24 GHz to 26.5 GHz	110	106	121	117

N5242A

As we observe, in most of the frequency ranges **N5242A has a higher dynamic range, thus is better in this factor**.

- **1.3 – Reflection Uncertainty coefficients S11, S22: (1.85 mm connectors used for E8361C and 3.5 mm connectors for N5242A)**
  For measuring these parameters, a calibration module is also needed that N4694A calibration kit is used for E8361C VNA and 85052D calibration kit is used for N5242A VNA.

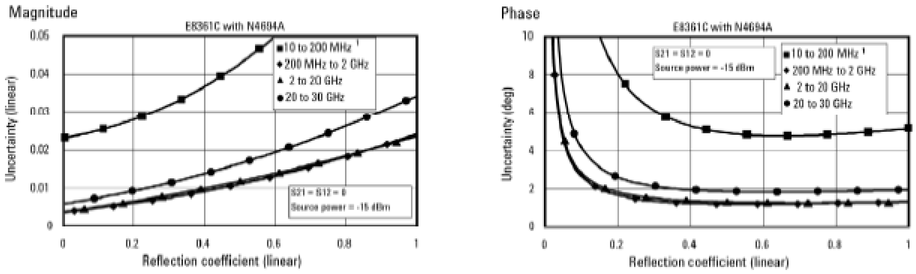
For any Sii reflection measurement:
- Sjj = 0.

For any Sij transmission measurement:
- Sji = Sij when Sij ≤ 1
- Sji = 1/Sij when Sij > 1
- Skk = 0 for all k

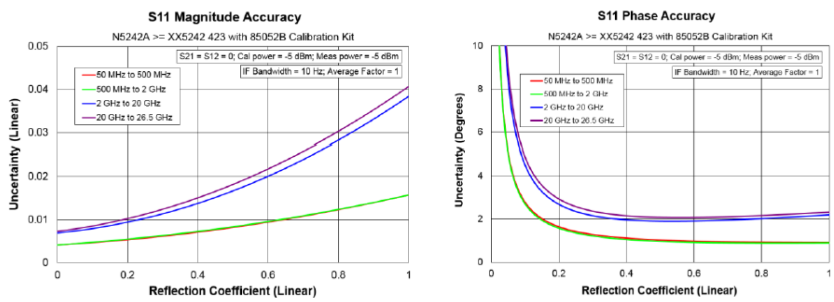
For any reflection measurement the reflection coefficient of the other side is set to zero and for any transmission measurement, the other side transmission coefficient measure maxent can be easily obtained. We should also do comparison in the frequency range where both are in common.

[1] Corrected system performance for both models is measured in 10Hz IF BW and no averaging is applied to data.

Reflection uncertainty (specifications)

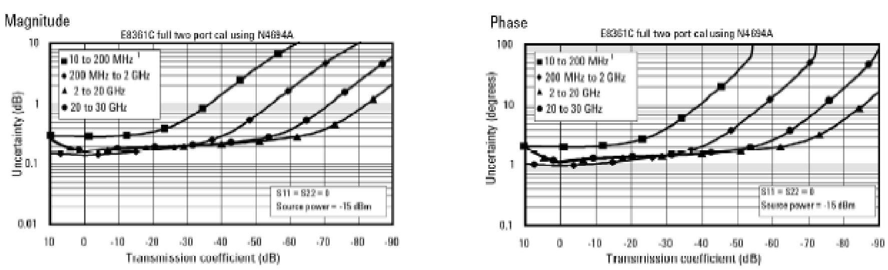


Reflection Uncertainty

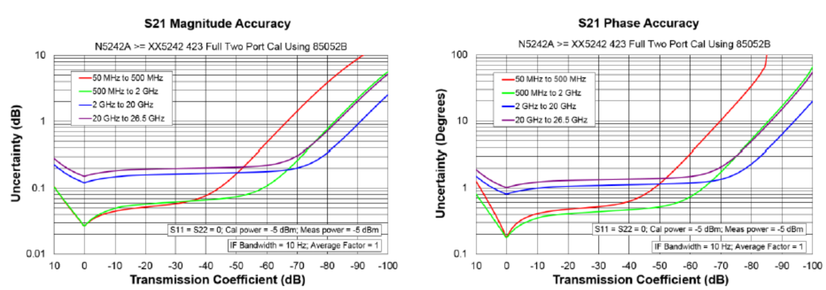


As we can see, uncertainty in magnitude of S11 is an increasing function of Gamma (reflection coefficient), so we expect to have higher deviation in our measurements in devices with higher gamma. Therefore, we want uncertainty to be low in our intended operation frequency. **For both phase and magnitude, N5242 shows less uncertainty** in **high and low frequencies** (Higher than 20 GHz and less than 500 MHz but it seems that **EC8361C has less uncertainty for 2-20GHz frequencies**. N5242A wins this factor in general.

Transmission uncertainty (specifications)



Transmission Uncertainty



The 2 devices **respond roughly the same to the transmission coefficient test,** except for a **better performance in 0 dB (No gain)** that **N5242 acts a little better** because of the undershoot on the graph

2. Uncorrected System Performance: (Directivity, Source and Load Match)

- Standard mode on E8361C (no additional options)

Description	Specification	Typical
Directivity		
10 to 45 MHz [2]	22 dB	22 dB
45 MHz to 2 GHz	24 dB	27 dB
2 to 10 GHz	20 dB	24 dB
10 to 20 GHz	16 dB	20 dB
20 to 30 GHz	14 dB	17 dB
30 to 50 GHz	13 dB	17 dB
50 to 60 GHz	13 dB	17 dB
60 to 67 GHz	10 dB	18 dB
67 to 70 GHz[2]	14 dB	14 dB

Table 7a. Directivity (dB)

Description	Specification		Typical	
	Options 200, 219, 224, 400, 419, 423	Option 029	Options 200, 219, 224, 400, 419, 423	Option 029
	All Ports	Ports 1, 2	All Ports	Ports 1, 2
10 MHz to 50 MHz	16	16	23	22
50 MHz to 500 MHz	24	24	28	28
500 MHz to 3.2 GHz	24	24	32	32
3.2 GHz to 8.5 GHz	23	23	25	25
8.5 GHz to 10 GHz	23	23	25	25
10 GHz to 13.5 GHz	16	16	22	20
13.5 GHz to 16 GHz	16	16	22	20
16 GHz to 20 GHz	16	15	22	20
20 GHz to 24 GHz	16	15	22	20
24 GHz to 26.5 GHz	16	15	22	20

E8361C N5242A

Directivity of **N5242A** is **more** than E8361C, in most ranges **except for very low frequencies (10-45 MHz)** that E8361C with is more directive. (Typical values show the average among similar models)

Description	Specification	Typical
Source match - standard		
10 to 45 MHz [2]	7 dB	7 dB
45 MHz to 2 GHz	18 dB	23 dB
2 to 10 GHz	14 dB	18 dB
10 to 20 GHz	12 dB	15 dB
20 to 30 GHz	8 dB	11.5 dB
30 to 40 GHz	7.5 dB	10 dB
40 to 45 GHz	8 dB	11 dB
45 to 50 GHz	7 dB	10 dB
50 to 60 GHz	6 dB	8.5 dB
60 to 67 GHz	5.5 dB	7.5 dB
67 to 70 GHz[2]	7.5 dB	7.5 dB

Table 7b. Source Match (dB)

Description	Specification			Typical		
	Options 200, 219, 224, 400, 419, 423	Option 029		Options 200, 219, 224, 400, 419, 423	Option 029	
	All Ports	Port 1	Port 2	All Ports	Port 1	Port 2
10 MHz to 50 MHz	11	9	9	14	13	12
50 MHz to 500 MHz	18	18	13	28	28	15
500 MHz to 3.2 GHz	18	17	9	22	22	12
3.2 GHz to 8.5 GHz	14	12	6	18	18	7
8.5 GHz to 10 GHz	14	12	6	18	18	7
10 GHz to 13.5 GHz	12	11	6	16	16	8
13.5 GHz to 16 GHz	12	11	6	16	16	8
16 GHz to 20 GHz	10	9	7	15	13	9
20 GHz to 24 GHz	10	8	6	14	13	9
24 GHz to 26.5 GHz	8	7	6	12	12	9

E8361C N5242A

N5242 has higher source matching (except when only using port 2)

Description	Specification	Typical
Load match - standard		
10 to 45 MHz [2]	5.5 dB	5.5 dB
45 MHz to 2 GHz	9 dB	10 dB
2 to 10 GHz	9 dB	11 dB
10 to 20 GHz	8.5 dB	10 dB
20 to 30 GHz	7 dB	9 dB
30 to 40 GHz	6 dB	8 dB
40 to 45 GHz	6.5 dB	9 dB
45 to 50 GHz	6.5 dB	8.5 dB
50 to 60 GHz	5.5 dB	7.5 dB
60 to 67 GHz	5.5 dB	7.5 dB
67 to 70 GHz[2]	5 dB	5 dB

Table 7c. Load Match (dB)

Description	Specification			Typical		
	Options 200, 219, 224, 400, 419, 423	Option 029		Options 200, 219, 224, 400, 419, 423	Option 029	
	All Ports	Port 1	Port 2	All Ports	Port 1	Port 2
10 MHz to 50 MHz	11	11	9	18	18	12
50 MHz to 500 MHz	17	17	13	25	24	15
500 MHz to 3.2 GHz	17	15	9	22	19	12
3.2 GHz to 8.5 GHz	13	10	5.5	17	15	7.5
8.5 GHz to 10 GHz	13	10	5.5	17	15	7.5
10 GHz to 13.5 GHz	10	9	5.5	15	15	7.5
13.5 GHz to 16 GHz	10	9	5.5	15	15	7.5
16 GHz to 20 GHz	9	8	5.5	14	13	7.5
20 GHz to 24 GHz	9	7	5.5	14	13	7.5
24 GHz to 26.5 GHz	8	7	5.5	13	11	7.5

E8361C N5242A

N5242 has higher source matching

Table 17. Phase Noise (dBc/Hz), All Options, All Ports - Typical

Description	1 kHz Offset	10 kHz Offset	100 kHz Offset	1 MHz Offset
10 MHz to 500 MHz	-85	-85	-85	-120
500 MHz to 1 GHz	-105	-115	-110	-127
1 GHz to 2 GHz	-100	-110	-105	-121
2 GHz to 4 GHz	-95	-105	-100	-115
4 GHz to 8 GHz	-89	-100	-94	-110
8 GHz to 8.5 GHz	-83	-94	-88	-105
8.5 GHz to 13.5 GHz	-83	-94	-88	-105
13.5 GHz to 16 GHz	-83	-94	-88	-105
16 GHz to 26.5 GHz	-78	-89	-82	-100

E8361C

Description	Specification	Supplemental information
Phase noise (10 kHz offset from center frequency, nominal power at test port)		
10 to 45 MHz		80 dBc typical
45 MHz to 10 GHz		70 dBc typical
10 to 24 GHz		60 dBc typical
24 to 70 GHz		55 dBc typical

N5242A

Phase noise is **lower for N5242A (10kHz) offset**

- **Conclusion**: In most cases N5242A performs better than E8361C, except for the wider frequency range E8361C has.