Frequency and Time Domain Representation of Sinusoidal Signals

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Objectives

1. To review representations of sinusoidal signals in the frequency and time domain.
2. To become familiar with various bench top measurement instrumentation to be used throughout the course.

Reading/Reference Material

Tutorial Material from Lecture #1.

Excerpts from HP Application Note on Spectrum Analysis. Source: HP Application Note 150, "Spectrum Analysis Basics", Nov. 1, 1989, (HP P/N 5952-0292).

HP8590 Analyzer E Series and L-Series Spectrum Analyzer User's Guide: Ch2 - pp2-1 to 2-17; Ch 3 - pp3-1 to 3-5. (HP P/N. 08590-90234, June 1995).

Equipment

- Agilent 8594E Spectrum Analyzer (SA).
  (Replacement model: Agilent E4402B ESA-E Series Spectrum Analyzer)
- Agilent 8714 Vector Network Analyzer (VNA) used as signal source only in this lab.
  (Replacement model: Agilent E5062A ENA-L RF Network Analyzer)
- Digital Oscilloscope (OSCOPE).
- T-junction signal combiner.
- Cushcraft SX series mobile antenna.
- Patch Antenna.
- Mini-Circuits ZFL-1000LN Amplifier.
- +15 V Power Supply.
- Misc. cables and adapters.
- PC running Mathcad.

Basic Equipment Set-up

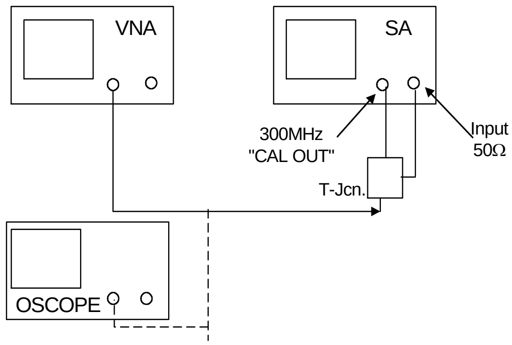


Figure 1. Basic measurement configuration. The VNA port 1 RF output is used in CW mode as the primary sinusoidal signal source. A second source is provided by the 300MHz calibration reference signal from a spectrum analyzer.

Lab Assignment Summary - (Detailed Procedures Below)

In this lab you will:

Part I: SA Measurement of 300MHz calibration reference signal.
Set-up and perform laboratory experiment to view frequency domain representations of a calibration reference signal on the spectrum analyzer. Learn how to adjust display settings to view input signals.

Part II: SA Measurement of two signals close in frequency.
Set-up a dual frequency input using the SA calibration reference signal as one source and the VNA as the second source. Explore variations in resolution bandwidth, span and frequency settings in terms of your ability to view the desired signals.

Part III: SA Measurement of VNA signal at varied frequency and amplitude.
Gain experience and confidence with changing frequency and amplitude levels using the VNA as signal source, while tracking the frequency and amplitude variations with the spectrum analyzer.

Part IV: Oscilloscope Measurement of VNA signal at varied frequency and amplitude.
Perform time domain measurements of a sinusoidal signal at varied frequencies and amplitudes. Make measurements of frequency, period and amplitude using oscilloscope. Increase frequency to point where sinusoidal signal can no longer be viewed on oscilloscope, due to oscilloscope sampling and BW limitations.

Part V: Oscilloscope measurement of noisy signal
Set-up demonstration wireless link and observe effect of oscilloscope acquisition modes on noisy signal display.

Part VI: Simulations and additional analysis.
Set-up and run Mathcad simulation of two sinusoidal signals of different amplitude and frequency. Perform additional post-lab analysis of results of Parts III and IV.

Detailed Procedures and Observations

<u>Part I: SA Measurement of 300MHz calibration reference signal.</u>

This part uses the spectrum analyzer only in the configuration shown in Figure 2. (Ref. see pp2-13 to 2-17 of the Spectrum Analyzer User's guide).

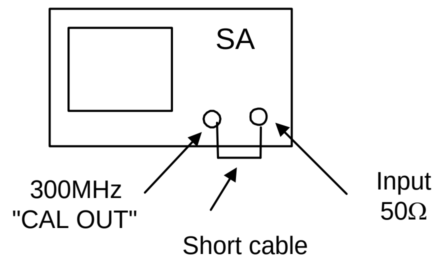


Figure 2. Test configuration for test of calibration reference signal on SA. Short gray cable is used to connect between "CAL OUT" and the input connector.

1. Turn on the spectrum analyzer (if not already on) and connect a short cable between the "CAL OUT" and the input connector. Push pre-set.

2. At this point the spectrum analyzer is in full-span sweep mode. You should be looking at several signal spikes evenly distributed across the screen. These consist of an SA generated dc signal spike, the desired 300MHz test signal and harmonics of the 300MHz test signal. <u>Use the PEAK SEARCH or MKR function keys to identify the amplitudes and frequencies of the first four signal peaks counting from the left of the screen</u>. Note that the soft keys NEXT PEAK LEFT and NEXT PEAK RIGHT under the PEAK SEARCH menu are useful for this type of measurement.

Table 1. Observed signal peaks with calibration reference signal and full-span frequency display (pre-set).

FREQ. OF PEAK (MHz)	AMPLITUDE OF PEAK (dBm)	COMMENTS

3. With a marker on the 300MHz signal peak, explore the effects of varying the SA's internal attenuator settings. Push AMPLITUDE then push the ATTENUATION soft key. Use the arrow keys, the knob or the key pad to increase the attenuation from the default value of 10dB to 20, 30 and 40 dB.

<u>OBSERVATIONS: What effects does varying the attenuator setting have on the displayed marker amplitude value at 300MHz?</u>

<u>What effects does varying the attenuator setting have on any other aspect of the display? (You should see some effect on the "noise floor")</u>

4. Set the center frequency by pressing FREQUENCY 300 MHz.

5. Set the "Span" by pressing the following keys: SPAN 20 MHz.

6. Use the peak search key again and re-measure the amplitude of the 300MHz test signal. Record the frequency and amplitude observed. Note that the amplitude should be around -20dBm. Check the reference level (value of the top of the SA display grid) by pressing AMPLITUDE and then the reference level soft key. With the reference level set to 0dB, the signal maximum should be two graticule divisions below the top of the screen.

Table 2. Observed freq. and amplitude of reference signal after zooming.

FREQ. OF PEAK (MHz)	AMPLITUDE OF PEAK (dBm)	COMMENTS

7. Push FREQUENCY 600 MHz, then SPAN 20MHz. Use the peak search key again and re-measure the amplitude of the 600MHz 2nd harmonic of the test signal. Record the frequency and amplitude observed. Compare the freq. and amplitude values obtained in parts 5 and 6 with those of part 2.

Table 3. Observed freq. and amplitude of 2nd harmonic of reference signal after zooming.

FREQ. OF PEAK (MHz)	AMPLITUDE OF PEAK (dBm)	COMMENTS

Additional comments on observations:

(Optional) 8. With the short cable still attached between the CAL OUT and the 50 ohm input, push the CAL key. Next push the soft key selection labeled CAL FREQ & AMPTD. This will initiate a self calibration routine on the SA that will take around 5 minutes to complete. When complete, push CAL STORE to store the calibration data. This procedure updates the corrections the spectrum analyzer uses in displaying frequency and amplitude information. (see SA User's Guide, pg 216.)

Part II: SA Measurement of two signals close in frequency.

NOTE: Chapter 3 of the handout material from the SA user's guide deals with measuring two signals close in frequency. It is recommended that you read this before completing this part. The test configuration for this part is shown in Figure 3.

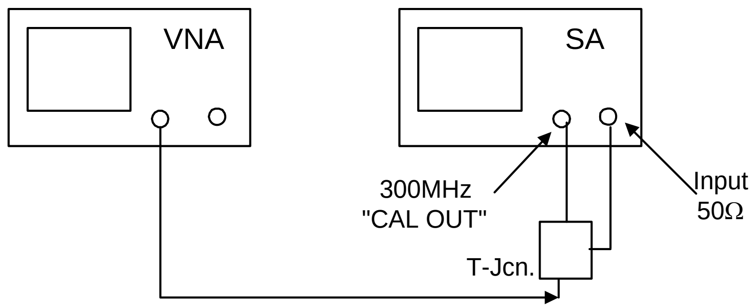


Figure 3. Test configuration for measurement of two frequencies near 300MHz.

1. Set-up the SA for a 300 MHz center frequency and a 1MHz span. Push FREQUENCY 300 MHz, and SPAN 20MHz. At this point, disconnect the cable from the CAL OUT so that the only signal displayed near 300MHz will be from the VNA.

2. Activate the Agilent 8714 VNA as a CW RF source

   a. Press "PRESET" on the VNA, next select FREQUENCY - CW and set the frequency, to begin with, to 301.0MHz. You should be able to view the signal clearly in the display. Put a marker on the peak. On the VNA select power - and then turn the RF on and then off to verify your control of the displayed signal.

   b. Adjust the power level to a setting of -5dBm, by selecting POWER on the VNA and then the LEVEL soft key. You can use the knob or the keypad to enter the desired power level.

   c. You should notice some flickering in the displayed signal. The analyzer is in a sweep mode even though we have asked it to give us a CW signal. Stabilize the signal by selecting, on the VNA, MENU then with soft keys TRIGGER then HOLD.

3. Re-connect the calibration reference signal so that both signals are input through the T-junction to the SA. This will establish two signals at each spectrum analyzer input that differ by 1MHz. Turn the RF off and on for the VNA source by selecting POWER and the RF ON/OFF soft key. With the specified SA settings you should be able to see two signal peaks on the SA. Record the frequency and amplitude of the two peaks corresponding to the two signal sources.

Table 4. Observed signal peaks with dual inputs from VNA and CAL OUT reference. (SA Center freq. = 300MHz, SPAN = 20MHz).

FREQ. OF PEAK (MHz)	AMPLITUDE OF PEAK (dBm)	COMMENTS

4. Using the arrow keys, increase the SPAN while keeping the center frequency fixed at 300MHz. Note that the resolution bandwidth automatically changes with the SPAN setting to keep the sweep time approximately constant. This is what we want to happen for this part.

OBSERVATION: For what span setting can you no longer distinguish between the two signals?

What is the corresponding (automatic) setting for the resolution bandwidth? (You can find this easily by pushing BW after you have the SPAN set).

5. Set the SPAN back to 20MHz. Increase the resolution bandwidth, while keeping the span and center frequency fixed. Do this by pressing BW then use the arrow keys or knob to increase the value of the resolution bandwidth.

Observation: For what setting of resolution bandwidth can you no longer distinguish that there are two frequencies present in the display?

6. Now decrease the resolution bandwidth using the arrow or knob functions.

Observation: For what settings of resolution can you clearly distinguish the two signals?

Part III: SA Measurement of VNA signal at varied frequency and amplitude.

Figure 4 shows the test set-up for this part of the experiment.

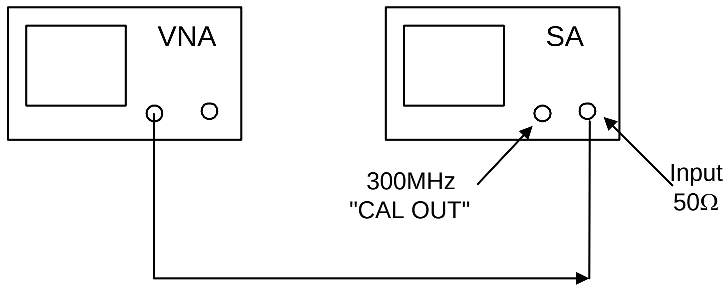


Figure 4. Test configuration for measurement of VNA as a single frequency source.

1. Remove the T-junction and connect the VNA test signal directly to the Spectrum Analyzer as shown in the figure above.

2. Push PRE-SET on the spectrum analyzer. Next add 20dB of input attenuation to help ensure that the SA remains in its linear operating region. This is done by pushing AMPLITUDE ATTENUATION 20 dB. Also, set the REF LEVEL to 10dBm by pushing AMPLITUDE REF LEVLEL 10 dB.

3. Using analogous procedures as in the previous part, set the VNA test frequency to CW frequency mode and a value of 0.3MHz. Stabilize the signal by selecting, on the VNA, MENU then with soft keys TRIGGER then HOLD. Use a power level setting of 0dBm. Under the POWER menu make sure the RF is ON.

4. On the SA set the center FREQUENCY to coincide with the VNA CW test signal frequency and set the SPAN to correspond to a 10% value of same. That is, for the 300kHz signal set the center frequency to 300kHz and the span to 30kHz. Use the PEAK SEARCH and/or MARKER keys to identify the observed frequency and amplitude peaks corresponding to the 300kHz (0.3MHz) VNA test signal.

5. Repeat steps 3 and 4 for varied test signals in order to make the measurements indicated in the table shown below. To do this you will be changing the frequency, and in some cases power level on the VNA, and the center frequency and span settings on the SA.

Table 5. Observed frequency and amplitudes for varied VNA CW test signals.

VNA Test Frequency (MHz)	VNA Power Level Setting (dBm)	SA Measured Peak Frequency (MHz)	SA Measured Amplitude (dBm)	Comment
0.3	0			
0.3	-3			
300	0			
300	-3			
600	0			
900	0			

OBSERVATIONS:

By how much does the SA measured signal amplitude drop at 0.3 and 300MHz when the VNA power level setting is reduced by 3dB?

Other comments and observations:

Part IV: Oscilloscope Measurement the VNA signal at varied frequency and amplitude.

The test configuration for this part is shown below. You should read the reference guide for the oscilloscope provided in handout material before completing this part.

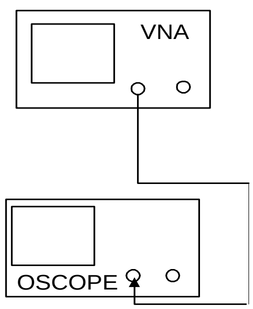


Figure 5. Configuration for time domain measurement of VNA CW test signal using oscilloscope.

1. Connect a cable directly between the VNA output and the Ch1 input connector of the oscilloscope.

2. Set-up the VNA for a CW test frequency of 0.3MHz, with a power level setting of 0dBm. (Stabilize the VNA CW signal by pushing MENU then with soft keys TRIGGER then HOLD.)

3. Press the CH1 Push AUTOSET on the OSCOPE, then adjust the vertical and horizontal position and scale as needed to see a sinusoidal signal with a few signal periods in the display. Press the VERT MENU button and select DC coupling.

4. Use the vertical line cursors to determine the period T of the displayed signal and calculate the frequency as f= 1/T.

OBSERVATION: T= ________ s f = ________ Hz

5. Use the horizontal line cursors to determine the peak-to-peak voltage levels for both coupling impedance options: 1MΩ and 50Ω. The coupling impedance can be changed by pushing the VERTICAL MENU button and then selecting the coupling impedance soft key until the desired coupling impedance is highlighted.

OBSERVATION Vpp (1MΩ coupling) = ________ mV

Vpp (50Ω coupling) = ________ mV.

6. With the VNA test frequency set to 300MHz and 0dBm explore the effects of hanging the Acquisition mode under the Acquire menu. Try each mode in sequence and notice the effects on the signal display. Record your observations below.

Table 6. Effects of Acquisition Mode on 300MHz signal Display

ACQUISITION MODE	OBSERVED EFFECT ON DISPLAY COMPARED TO "SAMPLE" MODE
PEAK DETECT	
HI RES	
ENVELOPE	
AVERAGE	

7. Use the automatic measurement features to take the same measurements made in parts 4 and 5. After pressing the 'MEASURE" key, the measurements you want to select are: Frequency, and Pk-Pk. Tabulate your measurements, along with the results of the next step, in the table (Table 7) shown below (i.e. in the row corresponding to 0.3MHz and 0dBm.)

8. Change the frequency and amplitude settings as indicated in the table shown below and use the automatic measurement features to complete the table. Use DC coupling with a coupling impedance of 50 ohms. You will need to hit AUTOSET on the OSCOPE each time frequency is changed.

When making the frequency measurement you will find that the readout changes as you look at it, making it difficult to specify a number. To estimate the precision of the measurement try to "eyeball" a nominal value and an uncertainty. For example if the 300MHz measurement is changing between 300.9 and 298.9, state the measured frequency as 299.9 +/- 1.0.

You should notice more difficulties in making the measurements at 600MHz and 900MHz than at lower frequencies. Comment on this in the space provided in and/or below the table.

Table 7. Summary of Oscilloscope Amplitude and Frequency Measurements.

VNA Test Frequency (MHz)	VNA Power Level Setting (dBm)	OSCOPE Meas. Frequency (MHz) f_o +/- Δ	OSCOPE Measured Vpp 1MΩ	OSCOPE Measured Vpp 50Ω	Comment
0.3	0				
0.3	-3				
300	0				
300	-3				
600	0				
900	0				

By what factor does the peak voltage Vpk (= Vpp/2) change when the power drops by 3dB?

Additional comments and observations:

Part V: Oscilloscope Measurement of Noisy Signal.

In this portion of the lab you will construct a simple wireless link and note the effect of link losses and noise on time-domain and frequency-domain measurements. The test configuration is shown below.

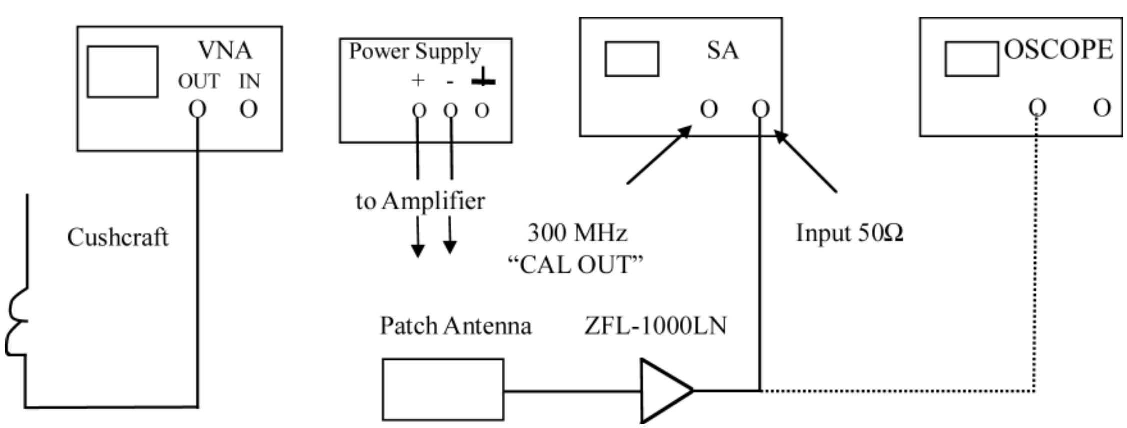


Figure 5(a). Configuration to observe the effect of link losses and noise on Time-Domain and Frequency - Domain measurements using OSCOPE and SA respectively.

1. Set the VNA to a CW frequency of 300 MHz **+** twice your bench number (in MHz); e.g., if you are working at bench #4, use 308 MHz. Make sure the VNA RF power is off.

2. With the power supply off, build the system, and connect the output of the ZFL-1000LN amplifier to the SA. If you have any questions, especially in connecting the power supply to the amplifier, be sure to request assistance from the TA. You can leave the patch antenna lying flat on the bench top.

Note: The patch antenna is constructed of duroid, a ceramic material that is extremely brittle. Take extra caution to make sure it is protected from any shock.

3. Call for the TA. He/ She will check out your configuration, set the VNA power to +7 dBm, and "power-up" the amplifier.

4. Cycle the VNA RF power on and off to verify that you are viewing your own signal. Do you see signals from any of the other benches? If so, what are their powers?

5. Carefully and slowly move the patch antenna around (a foot or two at most), and move your hand over it. Note the effect on the signal level in both cases. How much variation do you observe (in both dB and percent)?

6. Now connect the ZFL-1000LN output to the OSCOPE. Explore the effects of changing the Acquisition mode under the Acquire menu. Try each mode in sequence and notice the effects on the signal display. Record your observations below.

Part VI: Simulations and additional analysis.

1. Convert your peak-to-peak voltage values from part IV for the 50 ohm coupling case to power in dBm and compare to the results obtained with the spectrum analyzer in the Table below. Also summarize the frequency results from the SA and OSCOPE. The following equation may be used to convert the 50 ohm voltages to power in dBm.

$$P(\mathrm{dBm}) = 10\mathrm{Log}\frac{(V_{pp})^2}{400*10^{-3}}$$

where Vpp is the peak-to-peak voltage in volts measured on the OSCOPE. Use of Mathcad or a spreadsheet facilitates these calculations.

Table 8. Comparison of Spectrum Analyzer and Oscilloscope Measurements.

VNA Test Frequency Setting (MHz)	VNA Power Level Setting (dBm)	OSCOPE Meas. Frequency (MHz) f_o +/- Δ	SA Measured Frequency (MHz)	Power (dBm) From OSCOPE Measured Vpp (50Ω)	SA Measured Power (dBm)
0.3	0				
0.3	-3				
300	0				
300	-3				
600	0				
900	0				

OBSERVATIONS:

How well do the SA and OSCOPE frequency measurements compare?

How well to the SA and OSCOPE amplitude measurements compare?

Other comments:

The attached MATHCAD script can be modified to perform these calculations for you.

2. Try changing the frequency, amplitude, and phase of the second source in the attached MATHCAD file and observe the changes in the additive response of the two signals. For example try (f1=301MHz, f1=400Mhz, $\theta_1 = 0{,}180$, A1=0.01, 0.1)

Observations:

Below is a simple MATHCAD file that shows how two signals at different frequencies appear in the time domain.

Also included is a calculation of power from peak voltages in a 50 ohm system.
Amplitudes (V), frequencies (Hz), phases (rad) of sinusoids

$A_0 := .1$ $\quad A_1 := 0.0707$

$f_0 := 300 \cdot 10^6$ $\quad f_1 := 150. \cdot 10^6$

$\theta_0 := 0$ $\quad \theta_1 := 45 \cdot deg$

Sinusoid definitions

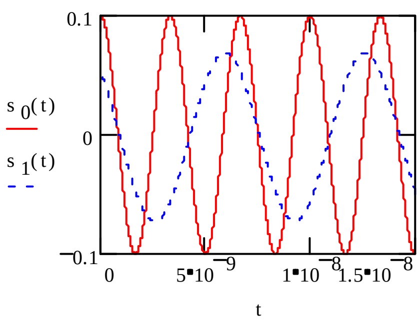
$s_0(t) := A_0 \cdot \cos\left(2 \cdot \pi \cdot f_0 \cdot t + \theta_0\right)$ $\quad s_1(t) := A_1 \cdot \cos\left(2 \cdot \pi \cdot f_1 \cdot t + \theta_1\right)$

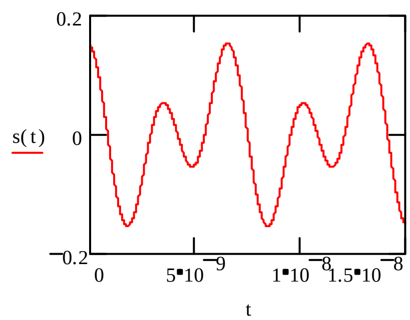
$s(t) := s_0(t) + s_1(t)$

t is a range variable for time (note we're using ns, that is the following range is 0.01 to 15ns)

$t := 0, 0.01 \cdot 10^{-9} .. 15.0 \cdot 10^{-9}$

Now plot the two waveforms, and then their sum, using an x-y graphs:





$Vpk := A_0$ $\quad R_0 := 50$

$$Vrms := \frac{Vpk}{\sqrt{2}}$$

$$P := \frac{Vrms^2}{R_0}$$

$P = 1 \cdot 10^{-4}$ (Watts)

$$Pdbm := 10 \cdot \log\left(\frac{P}{10^{-3}}\right)$$

$Pdbm = -10$ (dBm)

Figure 6. Mathcad File Example