Challenges for Phase Measurements

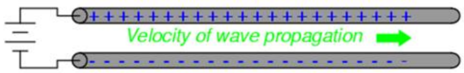
Consider this…

1 degree of phase difference at 400MHz is only 6.9 ps.

But, even worse, 1 degree of phase at 26 GHz is 0.1 ps!

And what is electrical propagation time through 1 in of coax?

Answer: 127 ps (assuming VF of 2/3, propagation = 2E8 m/s)



$$\text{Velocity factor} = \frac{v}{c} = \frac{1}{\sqrt{k}}$$

Where,

v = Velocity of wave propagation

c = Velocity of light in a vacuum

k = Relative permittivity of insulation between conductors

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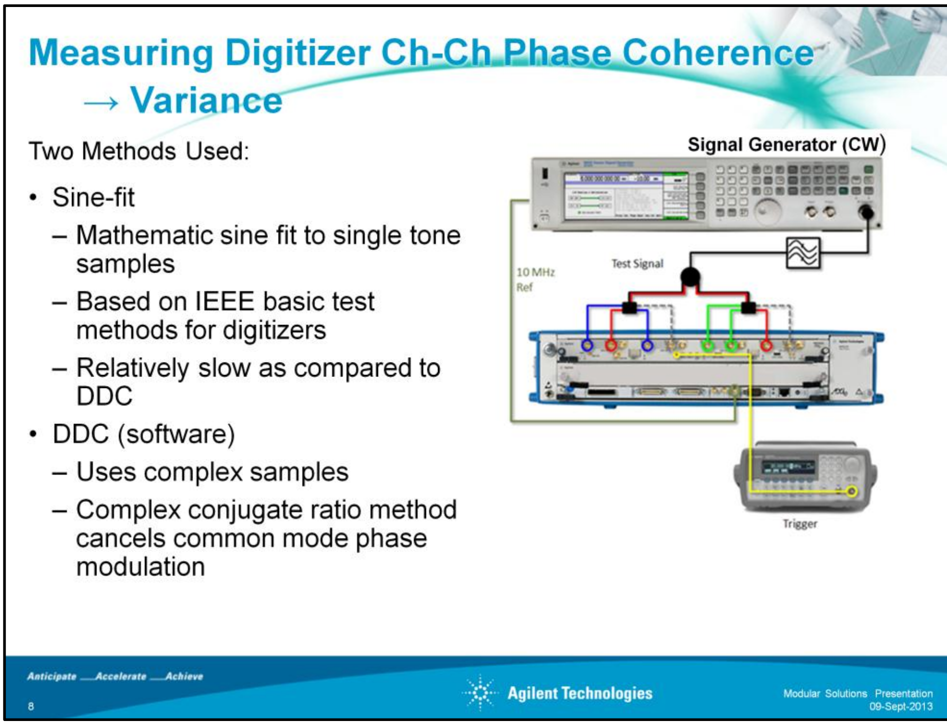
$$t(1°) = \varphi[d/(f^*360)$$

$$\Delta t = \frac{length\ [m]}{velocity\ [\frac{m}{s}]}$$

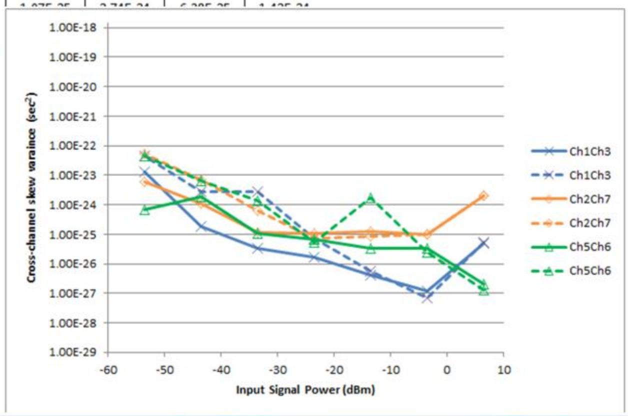
1 in = 2.54E-2 m



We used two methods to analyze the phase coherence of a multi-channel digitizer. Both methods have advantages depending on what software tools or algorithms are available. At the time these measurements were made, this digitizer did not have a hardware DDC to allow us to directly acquire complex samples (hence software DDC).

Measuring Digitizer Ch-Ch Phase Coherence

Input Power (dBm)	Sinefit Method Skew Variance (sec^2)			DDC Method Skew Variance (sec^2)		
	Ch1Ch3	Ch2Ch7	Ch5Ch6	Ch1Ch3	Ch2Ch7	Ch5Ch6
6.5	4.81E-26	2.02E-24	2.10E-27	5.49E-26	1.97E-24	1.30E-27
-3.5	1.17E-27	9.54E-26	3.25E-26	7.07E-28	9.90E-26	2.53E-26
-13.5	4.15E-27	1.26E-25	3.31E-26	5.81E-27	8.64E-26	1.75E-24
-23.5	1.61E-26	1.09E-25	6.65E-26	7.21E-26	7.23E-26	5.51E-26
-33.5	3.41E-26	1.16E-25	[illegible]	[illegible]	[illegible]	[illegible]
-43.5	1.79E-25	1.05E-24	[illegible]	[illegible]	[illegible]	[illegible]
-53.5	1.30E-23	6.16E-24	[illegible]	[illegible]	[illegible]	[illegible]



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9

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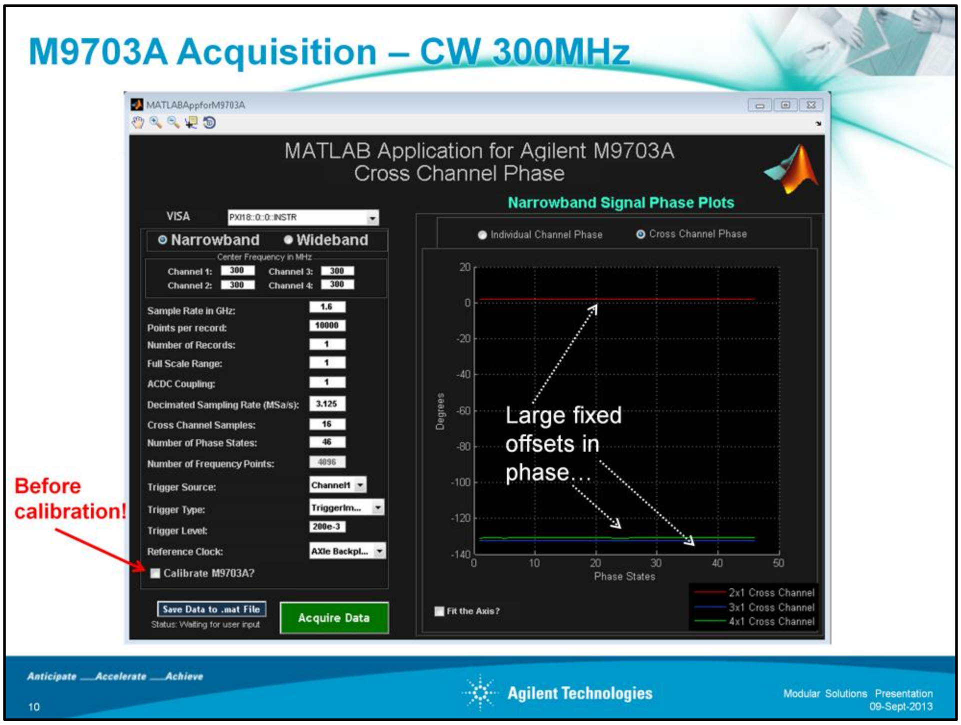
Example measurements taken from M9703A digitizer over ten measurements at various input power levels. As expected the variance isn't as good as you use less of the total dynamic range of the digitizer (M9703A has 1V/2V fixed full scale range – used 1V for these measurements).


M9703A Acquisition – CW 300MHz
MATLABAppforM9703A
MATLAB Application for Agilent M9703A
Cross Channel Phase
Narrowband Signal Phase Plots
VISA
PXI18::0::0::INSTR
Narrowband
Wideband
Center Frequency in MHz
Channel 1: 300
Channel 3: 300
Channel 2: 300
Channel 4: 300
Sample Rate in GHz: 1.6
Points per record: 10000
Number of Records: 1
Full Scale Range: 1
ACDC Coupling: 1
Decimated Sampling Rate (MSa/s): 3.125
Cross Channel Samples: 16
Number of Phase States: 46
Number of Frequency Points: 4096
Trigger Source: Channel1
Trigger Type: TriggerIm...
Trigger Level: 200e-3
Reference Clock: AXIe Backpl...
Calibrate M9703A?
Save Data to .mat File
Status: Waiting for user input
Acquire Data
Before calibration!
Individual Channel Phase
Cross Channel Phase
Degrees
Phase States
Large fixed offsets in phase…
Fit the Axis?
2x1 Cross Channel
3x1 Cross Channel
4x1 Cross Channel
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10
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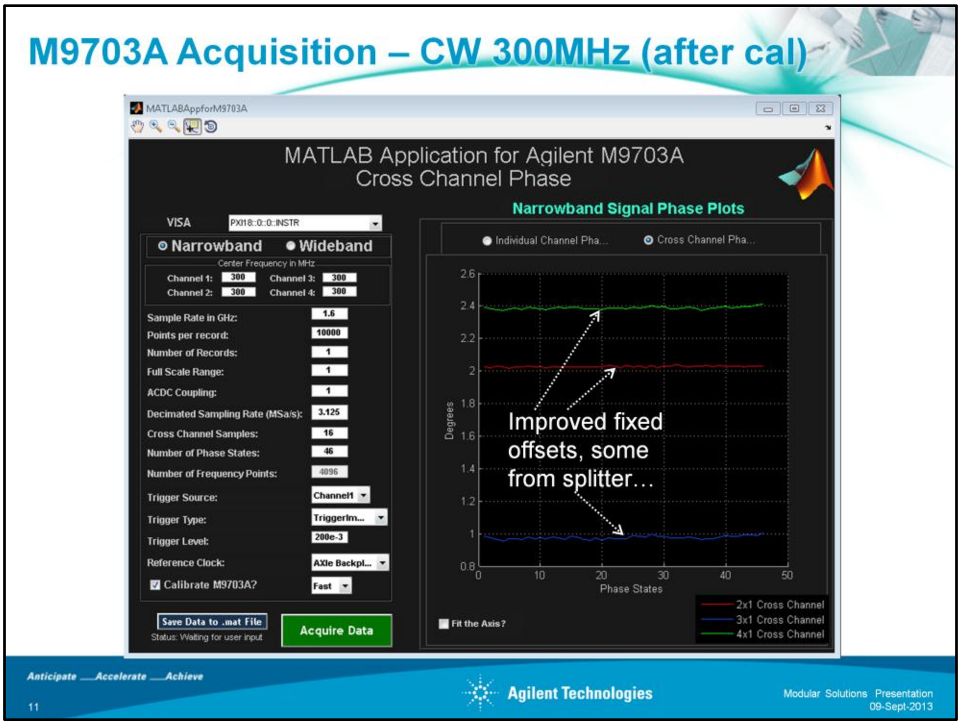
M9703A Acquisition – CW 300MHz (after cal)
MATLABAppforM9703A
MATLAB Application for Agilent M9703A
Cross Channel Phase
VISA
PXI18::0::0::INSTR
Narrowband
Wideband
Center Frequency in MHz
Channel 1: 300
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Cross Channel Samples: 16
Number of Phase States: 46
Number of Frequency Points: 4096
Trigger Source: Channel1
Trigger Type: TriggerIm...
Trigger Level: 200e-3
Reference Clock: AXIe Backpl...
Calibrate M9703A? Fast
Save Data to .mat File
Status: Waiting for user input
Acquire Data
Narrowband Signal Phase Plots
Individual Channel Pha...
Cross Channel Pha...
Degrees
Phase States
Improved fixed offsets, some from splitter…
Fit the Axis?
2x1 Cross Channel
3x1 Cross Channel
4x1 Cross Channel
Anticipate __Accelerate __Achieve
11
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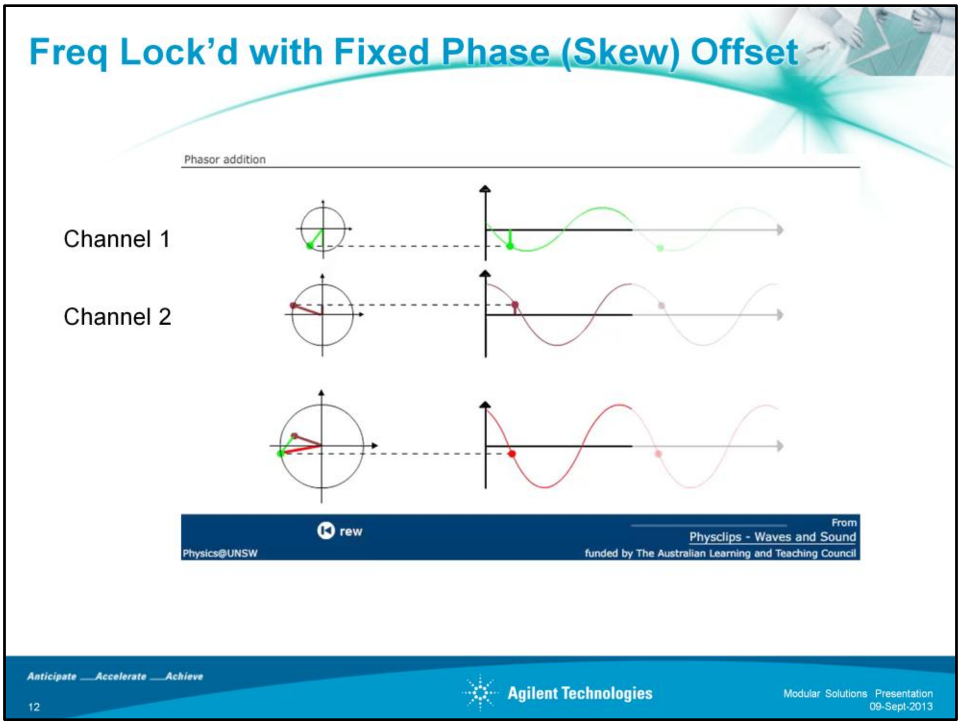
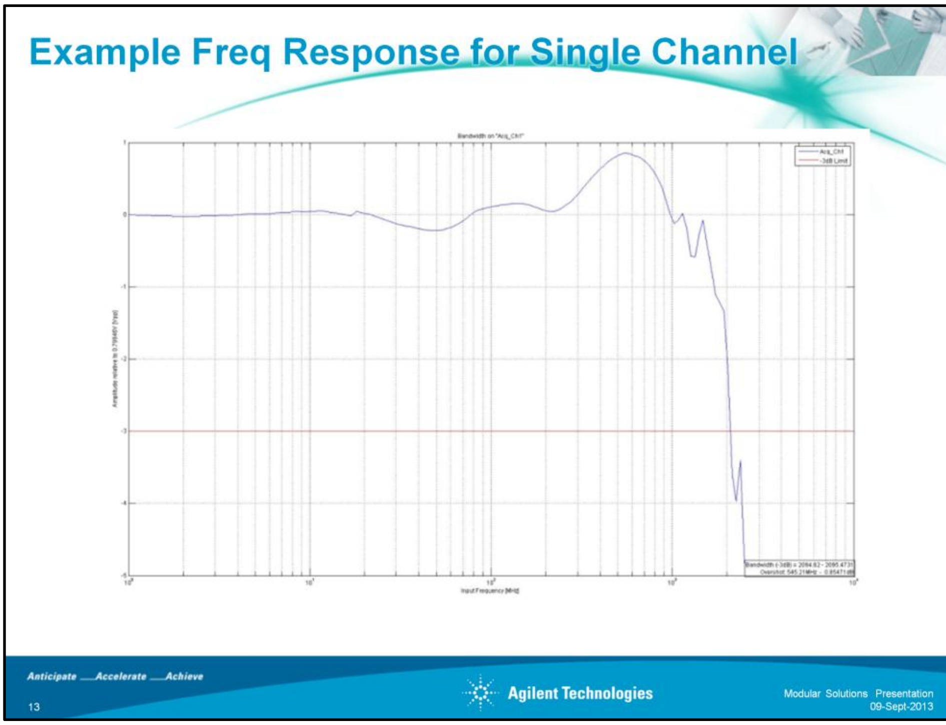
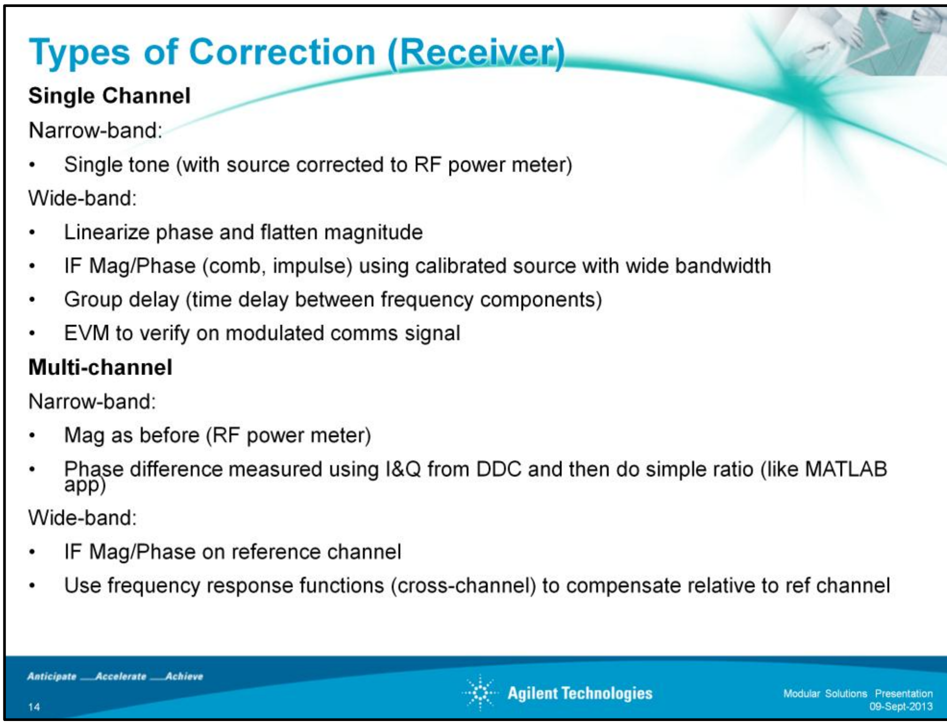


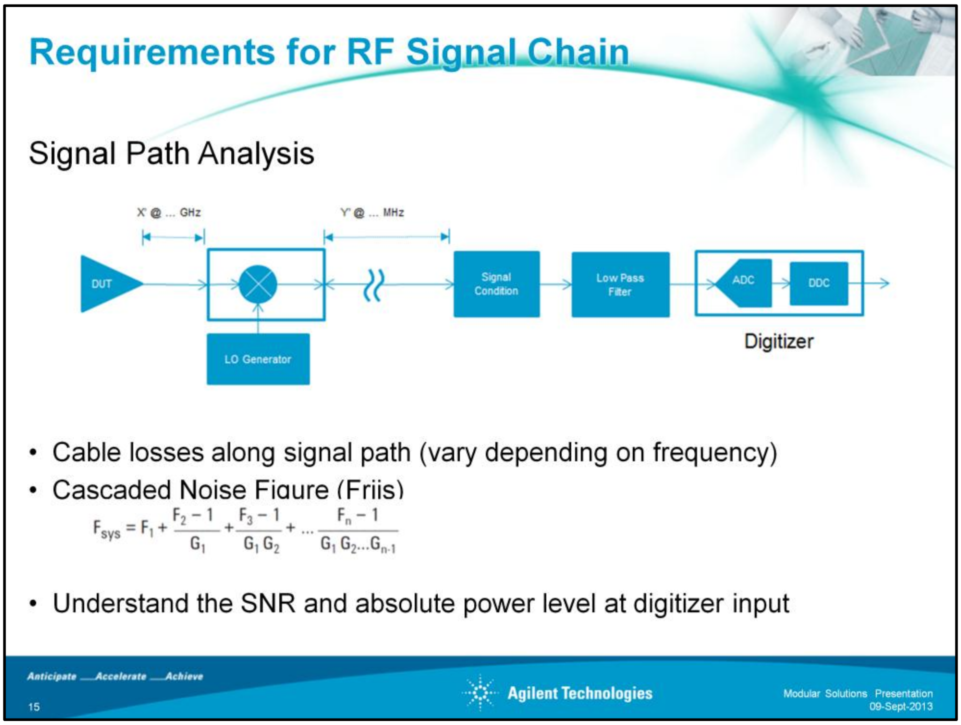
The calibration routine in the self-cal for M9703A gets us much closer to phase alignment between channels. But there is still some fixed offset. As long as it remains fixed relationship between the two channels and we can measure it (like previous example shows in MATLAB), then it can be corrected for quite easily. The current calibration routine is basically a skew cal which is not always sufficient, just depending on the customer requirements (like for beam forming with 1 deg or less coherence requirement).



This is an example as measured in Geneva for the M9703A on a single channel with the 1.6GSa/s non-interleave mode. As you can see we are flat to within about 1dB. This really isn't bad. However, because there are 4 A/D chips across an 8-channel M9703A, what is needed is to align the responses when making multi-channel measurements.



Narrow-band approaches are in time-domain. This means there is more sensitivity to the trigger to sample timing if you intend to average over multiple acquisitions to improve the measurement sensitivity. However, the wide-band approaches in frequency domain (although are not as sensitive to trigger timing) are more computationally intensive.



One typical question comes up when thinking about corrections…why aren't they just done inside the digitizer so we don't have to deal with this complexity ☺ But, for a digitizer-based solution there are many more pieces typically…

It is important to consider the entire signal path when optimizing a test system for RF measurements like this one. Generally we are talking about a DUT that produces signals in the RF/uW frequency range and therefore a mixer-based downconverter is first used to create an IF appropriate for the 3dB BW of the receiver (digitizer). Then several signal conditioning and filtering blocks (along with cabling) are involved in propagating the signal with as high of SNR and a dynamic range that matches the digitizer's input full scale range.

To calculate how a particular signal path will impact the signal's SNR and power levels, it is important to have a grasp on what each block along the path contributes as far as noise figure and gain. Using a calculation of cascaded noise figure and the digitizer's noise density, it is possible to predict what performance impact the signal path will have on measurement sensitivity.