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To: EDGES Group

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Subject: Checks of VNA linearity

The linearity of a VNA receiver can be measured using the “reversed 2-port” method described in memos 130, 131. Since most VNA receivers use a fixed I.F. frequency measurements of the ADC linearity are best made at a low frequency.

A 2-port made by connecting a 50 ohm load to the center of an SMA tee optimizes the sensitivity to deviations from Linearity. This 2-port has nominal values of S11=S22=-9.542 dB S12=S21=-3.522 dB. The SOL through the 2-port provides reflection levels of about -1, 0, -0.333 in linear units. This wide range of signal level provides a good check of linearity. A marginally greater sensitivity to non linearity should be obtained using a 43.32 ohm load instead of the 50 ohm load which maximizes the sensitivity.

The non linearity is determined a one dimensional search for the value of *a*, which represents a first order correction to a non linear transfer curve

$$\Gamma_c = \Gamma_m \left(1 + a\left|\Gamma_m\right|\right)$$

Which minimizes the “sum” defined in memo 131. Γ_m are the measured S11 and Γ_c are the values of linearity corrected S11. At a frequency of 1 MHz the SOL values are -1, 1, 0 within 3 ppm and errors in these values have a negligible effect on the determination of the non linearity. Also the method is insensitive to errors in the assumed resistance of the load. At D.C. this test is equivalent to checking the linearity of an ohmmeter by measuring two resistors individually and then in parallel.

Results of linearity measurements

Measurements of the linearity of the HP85047A/8753C and Agilent N5222A were made at low frequency ranges of 0.5 to 2 MHz and 10 to 11 MHz for the VNAs respectively. While the linearity can be measured at a single frequency it was decided to use a range of frequencies. The calibration kit shown in Figure 1 of memo 134 was used. The 2-port used the SMA “tee” in which the short was replaced with a 50 ohm load.

The results are given in table 1.

VNA	Test#	Date	Non linearity	Sum
HP	1	3 Feb 14	-6×10^{-4}	4×10^{-4}
HP	2	3 Feb 14	-5.5×10^{-4}	3×10^{-4}
HP	3	3 Feb 14	-6.5×10^{-4}	3×10^{-4}
HP	4	5 Feb 14	2×10^{-4}	3×10^{-4}
HP	5	5 Feb 14	-2×10^{-4}	3×10^{-4}
Agilent	1	3 Feb 14	4×10^{-4}	2×10^{-4}
Agilent	2	3 Feb 14	1.5×10^{-4}	5×10^{-4}
Agilent	3	3 Feb 14	6×10^{-4}	5×10^{-4}
Agilent	4	3 Feb 14	3.5×10^{-4}	6×10^{-4}

Table 1 Values of non linearity parameter, a, and values of sum at best fit.

The Integral non linearity (INL) for a ADC is defined as the maximum deviation from the straight line between endpoints.

$$INL = \max_{o<c<c\max} \left| V_{out}(c) - V_{out}(o) - cm \right|$$

Where $m = \left(V_{out}(c\max) - V_{out}(o)\right) / c\max$

Substituting $\Gamma_{\max} = 1 + a$

$\Gamma_o = 0$

$$INL = \max \left| c + ac^2 - c\left(1 + a\right) \right|$$

$= a/4$ since max is at c=0.5

For our purpose we conserve the sign and assign a positive sign if the VNA ADC compresses at the high output. While the results from 3 Feb 14 appear to be consistent with values of signed INL of 150±50 and -90±50 ppm for the HP and Agilent respectively the results for the HP appear to be significantly different from measurements of 5 Feb 14. The difference between the results appears to be due to drifts within the VNA and not due to noise. Owing to the large number of manual operations it will probably take a fully automated system to pursue the original of the drifts. However it is reasonable to assume that for both VNAs the effects of non linearity are probably at or below about an INL of 100 ppm.

Estimated effect of VNA non linearity

A simulation of the effect of an INL value of 100 ppm shows that while it has no effect on the phase it limits the S11 magnitude accuracy to 0.001 dB at -3 dB increasing to 0.003 dB below a S11 of about -15 dB.

References

Agilent Vector Network Analyzer Receiver, Dynamic Accuracy (Linearity Overs its Specified Dynamic Range) Specification and Uncertainties, 13 September 2011, N5247-90003, p. 19.