Dynamic Time-Frequency Waveforms for VSA Characterization of PA Long-term Memory Effects

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***Abstract* — This paper presents a signal with two-tone amplitude and dynamic frequency characteristics for PA memory evaluation by using the Vector Signal Analyser, VSA, as the instrumentation measurement tool. This new dynamic frequency waveform is able to characterize the PA over frequency with a single measurement similar to what is done for a two-tone excitation when the tone spacing is varied over multiple static frequency measurements. Measurements will be conducted in order to characterize a PA with memory effects manifestation. Moreover all the previous measurements capabilities that were made with a Transition Analyser will be expanded here to the use of a VSA. This will impose synchronization problems that will also be described on the paper.**

I. SUMMARY

Recently it was proved in [1] that a PA presenting memory can be characterized, up through the third-order nonlinear distortion, with a simple two-tone excitation, but by performing several measurements of a two-tone signal stepped in frequency to extract the long-term memory effects exhibited by the PA.

That characterization approach was based on the assumption that the second harmonic filtering of the PA and the fundamental frequency filtering is constant all over the tone spacing of the two tone excitation.

In that case the output can be described by:

$$Y(2\omega_2 - \omega_1) = [K - 2F_2(\omega_2, -\omega_1)]3X(\omega_2)X(\omega_2)X(-\omega_1) \tag{1}$$

where $F_2(\omega_2, -\omega_1)$ is nothing more that the long term memory effects contribution arising from the base band PA response.

Despite the good results presented on [1-2], the method is based on two fundamental measurement procedures. First the correct identification of the amplitude and phase of $F_2(\ldots)$ should be obtained, and that was done in [2] by using the procedure presented in [3], where a Microwave Transition Analyzer is used. Unfortunately as is well known the TA instrument despite being extremely expensive it has a degraded dynamic range due to several factors.

Moreover the full characterization of the PA is based on repetitive measurements of a two tone signal for various tone spacing's, which implies a complex and hard measurement procedure.

Due to these reasons in this paper this two drawbacks will be addressed. First a VSA will be used instead of the TA solution, which will improve the dynamic range of the measurement. Moreover a special waveform will also be presented that will allow the measurement of all the functions $F_2(\ldots)$ simultaneous with a simple single sweep measurement.

WAVEFORM DESIGN

The measurements done in [2-4] consists in a series of two tone measurements, where the spacing between them is varied from measurement to measurement, this as drove us to think in a better waveform that is nothing more that a frequency modulated carrier where the frequency is changing over time, in a way that the instantaneous spectrum is in fact, or can be considered, a two tone excitation.

The waveform can mathematically be described by:

$$x(t) = A\cos\left[2\pi(f_c - \frac{\delta(t)}{2})t\right] + A\cos\left[2\pi(f_c + \frac{\delta(t)}{2})t\right] \tag{2}$$

As can be seen the tone spacing in this function is actually varying with the time t.

One of the possible implementations of that function could be:

$$\delta(t) = \sum_{k=0}^{N} \rho_k rect(t - t_k) \tag{3}$$

The value of t_k, should be the minimum possible for a correct evaluation of the signal spectrum in that timed waveform, in fact that evaluation will only be possible by using a time-frequency transform as the short time frequency transform [5].

Next figures present the RF time domain and spectrum domain of the now proposed waveform for the overall sampled time.

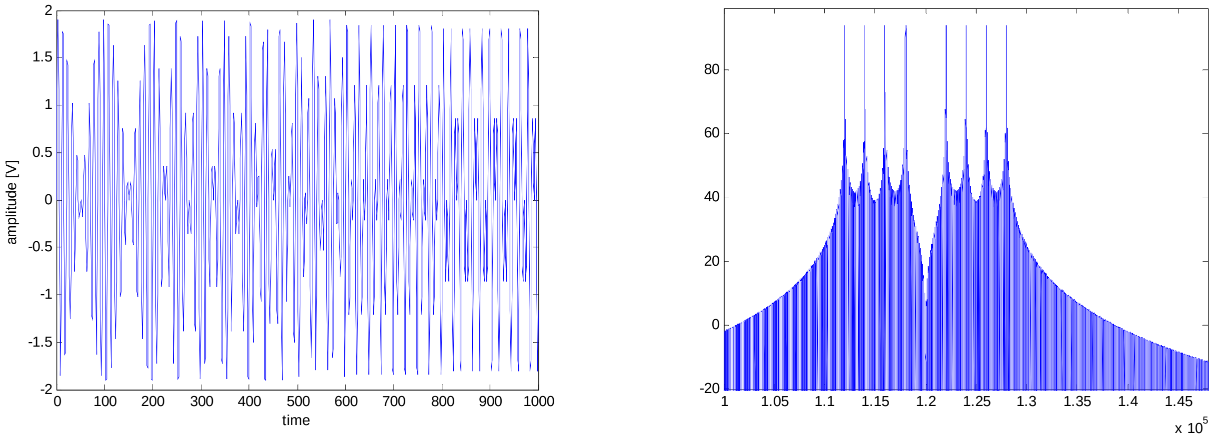

Fig. 1 – Time domain and spectrum of the proposed varying two tone waveform.

To construct this waveform using an arbitrary waveform generator the waveforms are decomposed into the complex carrier envelope representation

$$x(t) = \left|\tilde{z}(t)\right| \cos\left(\omega_c t + \angle \tilde{z}(t)\right) \quad (4)$$

where

$$\tilde{z}(t) = e^{-j2\pi\frac{\delta(t)}{2}} + e^{j2\pi\frac{\delta(t)}{2}} \quad (5)$$

The baseband interpretation of this modulation is two single sideband tones moving away from each other over time.

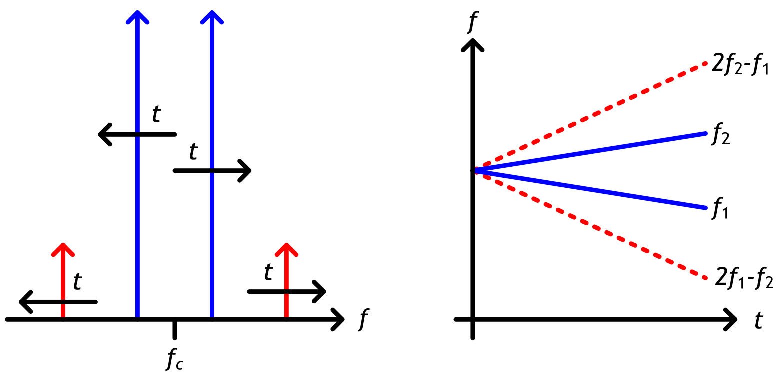

Fig. 2 – Graphical explanation of the waveform generation.

VSA Measurement Evaluation

Contrary o the TA that is similar to a sub sampling oscilloscope, where the dynamic range is corrupted by all the down converted noise to the sampler in-band, the VSA works by first down convert the seek signal for the band of interest by using a scheme similar to a Spectrum Analyzer, and then samples that signal with a higher sampler.

Next figure presents the typical VSA configuration.

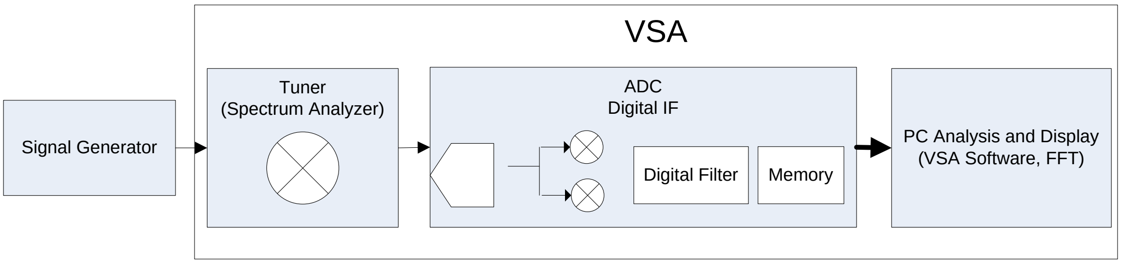

Fig. 3 – VSA Diagram Block.

In a TA the input and output are sampled simultaneous, while in a VSA that is only true if we have a two channel VSA, if that is not the case, then an alternative way to make that synchronization should be done.

That can be done by using an artificial marker generated at the waveform generator, that marker will be responsible for the triggering of the VSA and thus for the artificial synchronization, this allow us to acquire the input and output signals at different events, and thus will allow the correct evaluation of the phase and amplitude of each frequency component. Moreover it should be referred that the synchronization time should be at the envelope time scale and not at RF, simplifying the synchronization problem for our analysis case.

Next step includes the use of a short time frequency transform that will allow to calculate the two dimensional spectrum of the output signal waveform.

Next Fig, presents the contour graph of a simulated varying two tone test.

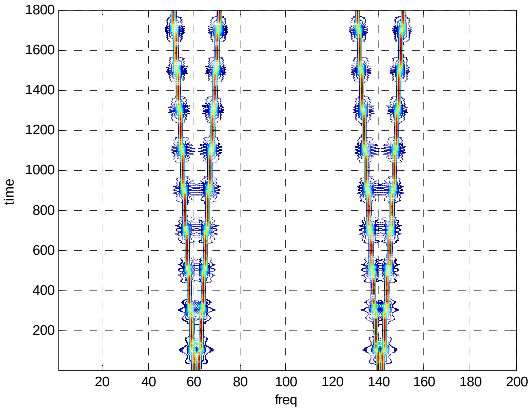

Fig. 4 – Periodogram of the proposed varying two tone waveform.

This type of time-frequency signal representation allow us to obtain the seek information need for the nonlinear operator value extraction.

MEASUREMENT RESULTS

In order to evaluate our proposed technique we have characterized a PA that presents some memory effects, as was confirmed by the presence of IMD asymmetry.

The tone spacing in this case was varied from 1KHz to 20KHz, by using the proposed waveform as described above.

Fig. 5 presents the input frequency domain waveform, when using the overall FFT of the signal.

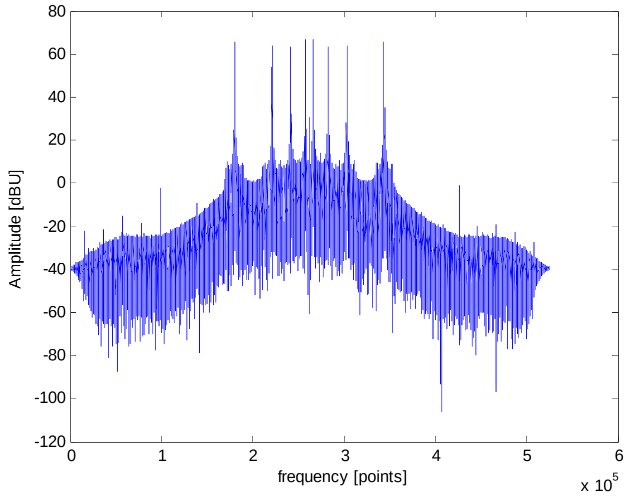

Fig. 4 – FFT of the overall varying two tone waveform.

This signal was then treated using the short time fast fourrier transform, and the two-dimensional periodogram obtained, Fig. 5.

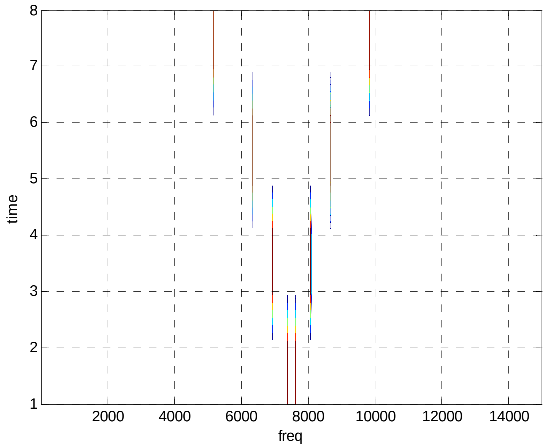

Fig. 5 – Periodogram of the proposed varying two tone waveform.

Further more we have also taken some slices of this periodogram, as can be seen in Fig. 6.

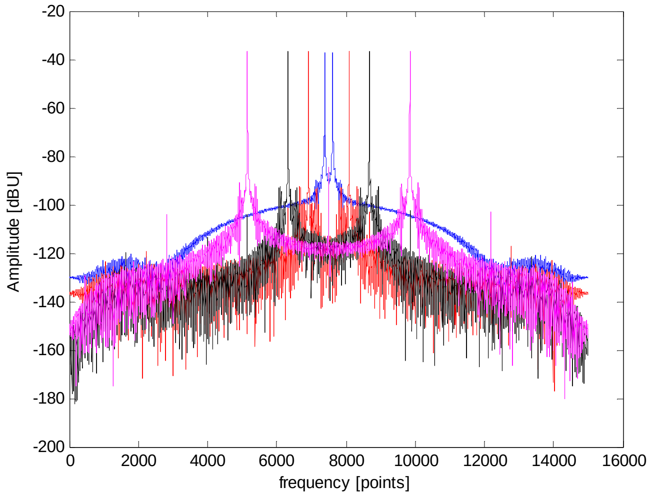

Fig. 6 – Short Time Frequency Transform Applied to the Measured Waveform at different times.

This states that the seek signal is equivalent of a two tone varying spacing waveform. Then the method presented in [1] was applied to the input and output signal of the PA. The values of $H_3(.)$ nonlinear operator can be seen on Fig. 7 when changing the tone spacing.

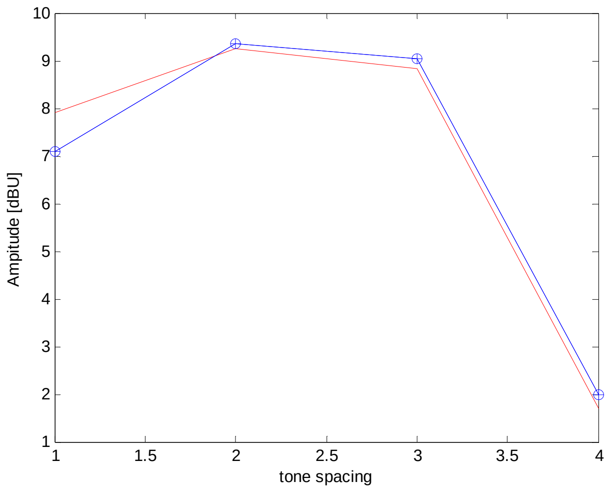

Fig. 4 – Periodogram of the proposed varying two tone waveform.

As can be seen form Fig. 4, the measured PA presents some degree of memory since the magnitude of the $H_3(.)$ nonlinear operator changes with frequency.

Conclusions

The proposal now presented allows the nonlinear characterization circumventing the inherent problems associated with the Transition Analyser. Moreover the usual two tone varying spacing scheme that is normally used is here improved, and it allows the measurement of the nonlinear operators by using higher order statistics in a very fast and efficient way.

References

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