# MEASUREMENT OF MEMORY EFFECTS IN PREDISTORTION LINEARIZERS

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## ABSTRACT

A typical method for designing a predistortion linearizer is to realize a circuit that creates an AM/AM and AM/PM characteristic inverse to that of the power amplifier to be linearized [1]-[3]. This strategy is correct only if the predistortion circuit maintains this characteristic also at signal envelope frequencies. This is often not true due to the time constants present in the linearizer circuits that limit its effectiveness. We refer to these effects as memory effects. This problem is not limited to linearization techniques but affects the operation of non-linear systems in general. The purpose of this paper is to review the major consequences of memory effects and to present efficient techniques to measure them.

## THEORETICAL BACKGROUND

In general a non-linear memoryless system may only cause an amplitude, but never a phase distortion. If a phase distortion is present, the system must possess a certain amount of memory[4].

Non-linear systems with a small memory (in the sense that the circuit time constants are much smaller than the reciprocal value of the maximum envelope frequency) can be considered as quasi-memoryless systems. In this case at a certain time the amount of amplitude and phase distortion only depends on the input signal level at that time.

Therefore most of the quasi-memoryless systems can be modelled only by their Pin/Pout characteristics (AM/AM conversion) and their amplitude dependent phase shift characteristic (AM/PM conversion) [5].

For systems with larger memory, however, the AM/AM and AM/PM characteristics do not contain the complete information about the nonlinearity, so that the accuracy of this model is reduced. A precise characterization and simulation requires, for example, the use of Volterra Series representation [6].

## EXPERIMENTAL RESULTS ON A LINEARIZED L-BAND POWER AMPLIFIER

The following example illustrates clearly the effects of memory in a 20W power amplifier, utilizing bipolar devices and linearized by means of a predistorting network. Figure 1 and 2 show the characteristics of the non-linearized and the linearized amplifier. Even though the AM/AM and the AM/PM characteristics of the linearized amplifier appear much more linear, the gain compression of the linearized amplifier has been reduced by 3dB, the two-carrier intermodulation test does not show any improvement compared to the non-linearized power amplifier (figure 3).

This is a typical consequence of the presence of a non-negligible memory in this system. In fact, even though the amplifier is statically linearized, its characteristics change with envelope frequencies. Therefore, if memory is present, the dynamic behavior of a linearized amplifier could be far from linear.

## NEW DYNAMIC AM/AM and AM/PM MEASUREMENT TECHNIQUE

A single carrier power-sweep measurement is very helpful during the design of power amplifiers and to adjust linearizing circuits, but as the previous example illustrates, it doesn't provide any information about the system's memory and therefore significant differences may result between predicted and measured performance.

On the other hand, performing a two-carrier measurement, which provides the memory information, does not directly give information about the AM/AM and AM/PM characteristics of the system and therefore it is not very useful in optimizing a linearizer characteristic on the bench.

Figure 4 shows a schematic of a new dynamic power sweep measurement which combines both advantages [7].

The input signal is a two-carrier signal, which is swept over power. During the power sweep both carriers are synchronized, hence their amplitude is equal all the time. By means of two network-analyzers (NWA) the amplitude distortion and the phase distortion of both of these carriers is measured.



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Compared to a traditional power sweep measurement performed with one carrier, the envelope of the input signal is varying with the two carrier frequency separation ('delta f' in fig. 4) and the AM/AM and AM/PM characteristics are measured dynamically.

Figure 5 illustrates an amplifier with a non-negligible memory. Clearly there is a 'resonance frequency' where the compression and the phase characteristics are strongly dependent on the modulation frequency.

In contrast Figure 6 shows the characteristic of another amplifier, which is clearly demonstrated b this technique to be quasi-memoryless, and thus well behaved at all modulation frequencies. Such an amplifier can be successfully described by a traditional AM/AM and AM/PM measurement.

Utilizing the same measurement set-up and operating the amplifier at constant input power we can also monitor with a NWA the amplitude and the phase of one carrier, while the other carrier is swept over frequency. In that way the changes in compression and phase are measured in dependency of different envelope frequencies at a certain signal power level.

Figure 7 gives a typical example of an amplifier with memory. The fixed carrier is located in the centre of the plot. The traces show the change in compression (phase) of both the fixed and the swept carrier over envelope modulation frequency. Clearly a resonance effect can be seen at about 15MHz modulation frequency.

By monitoring the memory effects in real time the predistorter, the amplifier (and especially their biasing networks) can easily be tuned to reduce the memory effects.

## PULSE POWER MEASUREMENT SYSTEM

This alternative system has the advantage of allowing the detection of very long time constant memories such as those caused by thermal effects or long time constants in biasing circuits, that are not clearly shown by the system previously described.

Figure 8 shows the basic measurement set-up. The input signal is pulse modulated and drives the non-linear system under test. The degraded output signal is detected by a wide-band power detector and visualized on an oscilloscope.

In order to avoid overlapping of different pulse distorting effects the pulse rise time has to be well selected between the lower limit, the smallest time constant of the memory to be detected, and the upper limit, the reciprocal value of the RF-bandwidth of the amplifier and the detector system. A value of 0.5 micro-seconds has been practically used in the tests performed.

Measurement curves are reported in figure 9 where a significant long time constant memory is shown. Some kind of over-shooting is visible, where in the first moment the amplifier delivers more output power than after several micro-seconds. In this particular case the amplifier operates 'more linearly' for higher modulation frequencies.

Taking into account the pulse distortion due to th band-limitations of the NWA, the system described in this paragraph is presently being modified to perform power swept measurements.

## TYPICAL LOCATION OF MEMORY EFFECTS

The large time constant memory effects are typically due to the thermal time constants of the devices and to some of the components in the biasing circuit. Especially for bipolar devices, the structure of the biasing network (regulation of the base-current as a function of the collector current) has an inherent time delay and causes long time constant memory effects. This effect is normally not present in FET amplifiers due to the more simplified biasing schemes and in particular to the absence of feedback loops.

The capacitance of the blocking coil, the resonance frequency of the blocking capacitor as well as a proper grounding are important parameters to reduce troublesome short-time memory effects. Figure 10 reports the most sensitive parts leading to memory effects of a widely used biasing circuit for bipolar amplifiers.

## CONCLUSIONS

Detrimental effects of memories in linearizers have been described and two different, efficient techniques have been presented to measure them. These techniques allow a 'real-time' adjustment and correction of the linearizer and/or amplifier circuits and an overall improvement of the intermodulation performance over a wide envelope frequency band.

Predistortion linearization in presence of strong memory effects becomes extremely complex if not impossible. In fact the compensation of the amplifier non-linearities (amplitude and phase) is significantly affected and limited by the time delay characteristics of the system.

A good knowledge of memory effects and ways to detect and reduce them is also of extreme interest when alternative linearization methods are considered, such as adaptive or loading techniques.

## ACKNOWLEDGEMENT

The authors would like to thank ESA/ESTEC for the permission to publish this paper and Miss B.Guignand for the editing and typing.

REFERENCES

[1]-A.M.Khilla, 'Linearizers for Power Amplifiers in Communication Satellites', Workshop on Linearization Techniques during IEEE MTT-S Symp. 1988

[2]-J.Czech, 'A Linearized L-Band 200 Watt TWT Amplifier for Multicarrier Operation', Proc. 16th Europ. Microwave Conf., 1986, pp.810-815

[3]-P.Hetrakul and D.P.Taylor, 'Compensators for Bandpass Nonlinearities in Satellite Communications', IEEE Trans. Aerospace and Electronic Systems, vol. AES-12, no.4, July 1976, pp. 509-514

[4]-J.Minkoff, 'Intermodulation Noise in Solid-State Power Amplifiers for Wideband Signal Transmission', Proc. of AIAA 9th-Communications Satellite System Conference, 1982

[5]-O.Shimbo, 'Effects of Intermodulation, AM-PM Conversion, and Additive Noise in Multicarrier TWT Systems', Proc. IEEE, Vol. 59, no.2, pp. 230-238, Feb. 1971

[6]-M.Schetzen, 'The Volterra and Wiener Theories of Nonlinear Systems', John Wiley & Sons, 1980, ISBN 0-471-04455-5

[7]-W.Boesch, 'Untersuchung zur Linearisierung und Leistungsoptimierung von bipolaren Leistungs-verstaerkern beim Vieltraegerbetrieb im Satelliten-Mobilfunk', Ph.D. dissertation, Techn. University of Graz / Austria, Nov.1987

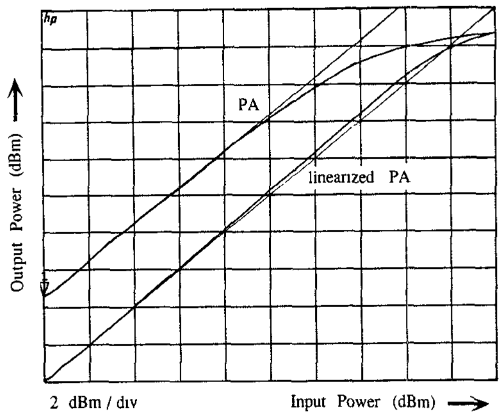



Figure 1 AM/AM characteristic of a not-linearized and a linearized power amplifier (PA).

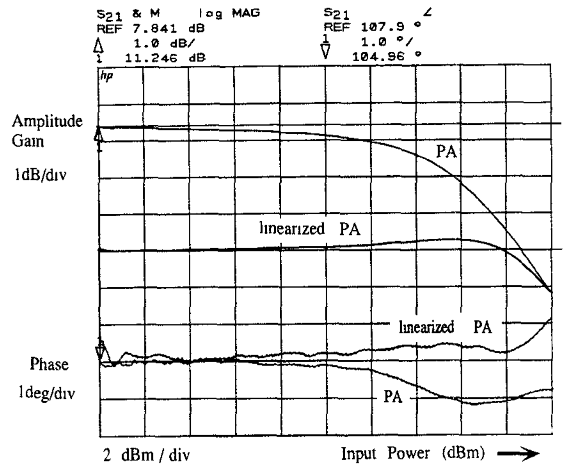



Figure 2 AM/AM and AM/PM characteristics.

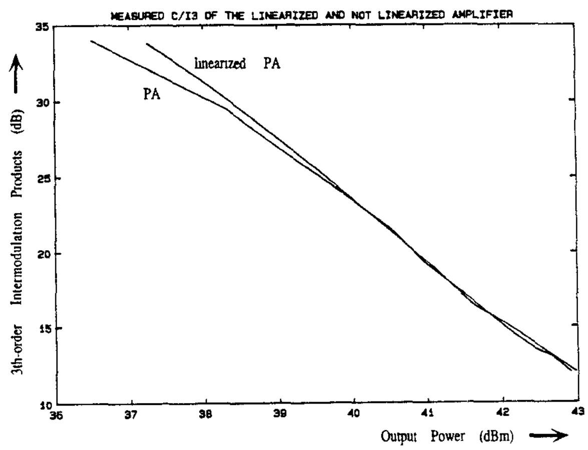
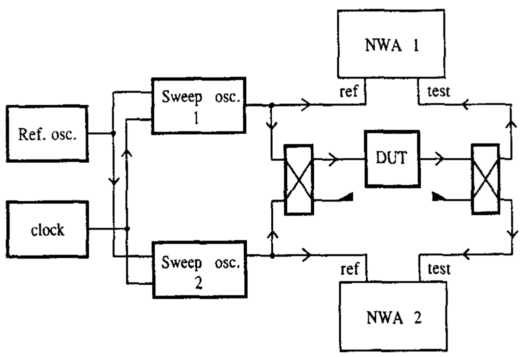



Figure 3 Intermodulation measurement of a not linearized and a statically linearized amplifier with memory.



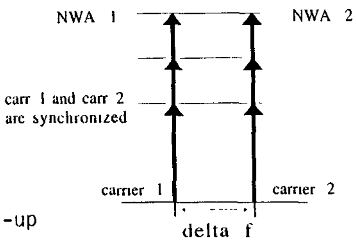




Figure 4

Dynamic AM/AM and AM/PM measurement set-up (Dynamic power sweep)

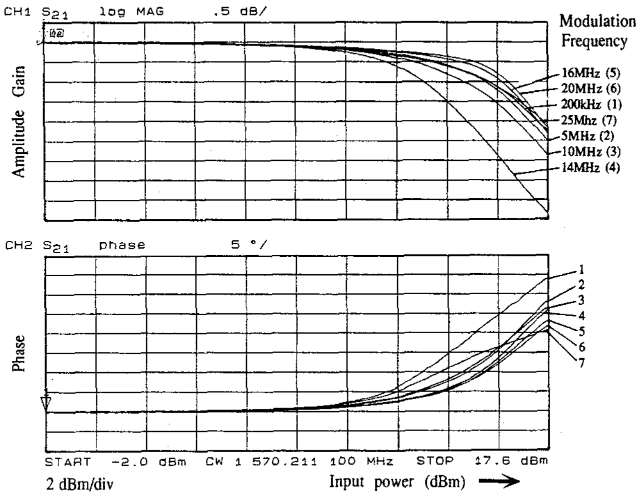



Figure 5 Dynamic AM/AM and AM/PM measurement with memory effects.

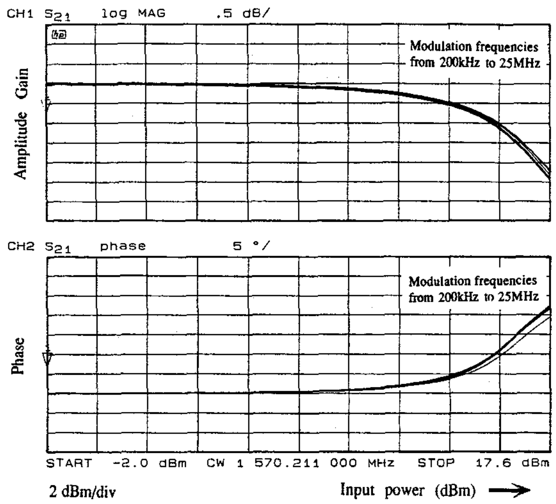



Figure 6 Dynamic AM/AM and AM/PM measurement of a quasi-memoryless system.

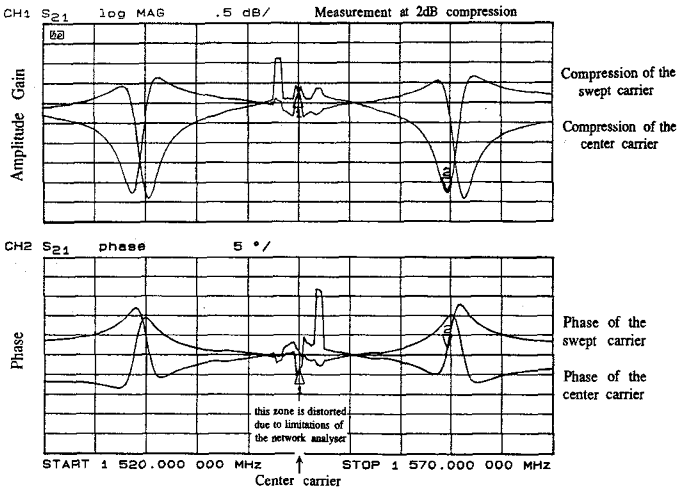



Figure 7 Dynamic measurement in the frequency domain.

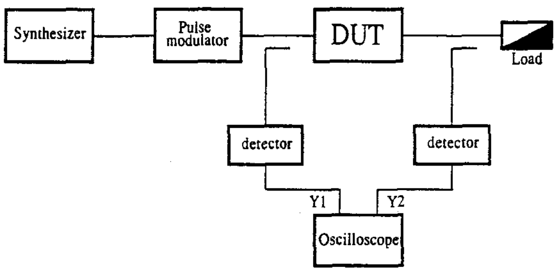



Figure 8 Pulse power measurement set-up.

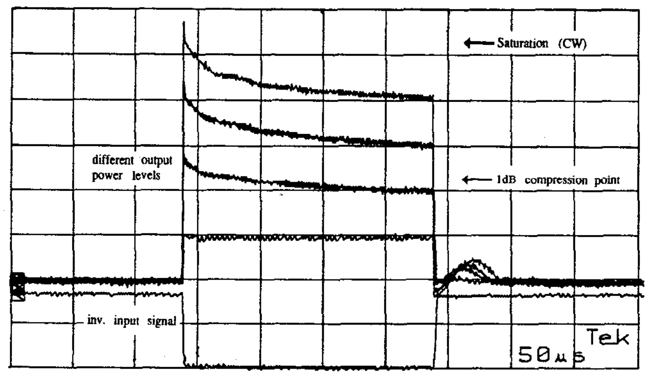



Figure 9 Pulse power measurement of an amplifier with memory effects.

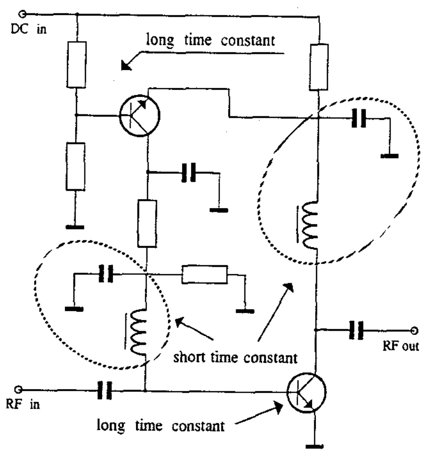



Figure 10 Biasing circuit of a bipolar amplifier and the typical location of memory effects.