A New measurement system for large bandwidth NPR characterization of satellite transponders SSPAs.

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Abstract – Nowadays, the large expansion of the telecommunication market has an important impact on the space segment. In the satellite payloads, transponders SSPAs are the most critical element for the power dissipation budget. To optimize the trade off between output power, efficiency and linearity, a new accurate experimental tool is increasingly required to test and characterize the linearity of power amplifiers implemented by the different French agencies (CNES, France Télécom and DGA) in the technological program STENTOR.

The linearity characterization of multicarrier power amplifiers is based on Noise Power Ratio (NPR) measurements. In the last past years, to realize NPR measurements power amplifiers are driven with a signal coming from an analog band pass noise source with a notch in the center bandwidth.

This paper presents a new NPR measurement system based on a numerical generation of band-pass Gaussian noise. It uses an Arbitrary Waveform Generator (AWG) to generate the input signal with the notch and a digital sampling oscilloscope to measure the output envelope of the signal supplied by the Device Under Test (DUT).

This characterization technique provide valuable information to validate NPR simulation techniques since the measurement principle is similar as the NPR simulation approach using the envelop transient method.

A comparison between NPR measurements realized with the new characterization system and the conventional analog noise source technique is presented.

Moreover, the great interest of this new characterization system lies in that any kind of modulated test signals can be generated (QPSK, QAM, CDMA…). The conclusion of the paper presents other measurement applications allowed by the same new measurement system.

I. INTRODUCTION

It is now well known that non linear devices such as power amplifiers used for large bandwidth multi-carrier amplification in satellite communications systems exhibit distortions due to their non linear dynamic behavior. Non linear memory effects must be taken into account, and classical prediction of distortion by using classical AM/AM and AM/PM conversion characteristics is no longer sufficient. Moreover, the characterization of power amplifier linearity by using two tone test signals becomes obviously not suitable in the case of multi-carrier amplification [1]. The characterization of non-linear devices in terms of noise power ratio (NPR) is of prime importance, since the test signals are representative of complex modulated signals encountered in real applications. So, the NPR becomes a criteria as important as the output power and the power added efficiency [2]. As the future satellite telecommunication systems will be defined to work with signals bandwidth equal to 125 or 250 MHz, a large bandwidth NPR criteria will be required.

In such a context, to ensure a sufficient quality of service, the design and the final test of satellite transponders SSPAs (as those used for STENTOR) requires the use of a novel accurate measurement system of non-linear devices driven by complex modulated signal.

Gaussian band-limited noise is a representative and a well suited signal to determine the Noise Power ratio criterion. Conventional NPR measurement systems are based on the use of an analog white noise source as depicted in the global overview of the analog system (Figure 1) developed by ALCATEL Space Industries [3].
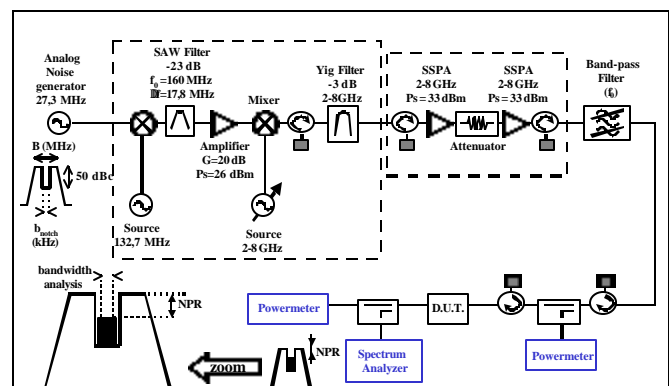
The test-bench is composed of :
- an analog white noise source, a band-pass filter and a notch filter to realize the spectral shape of the noise stimuli,
- a first mixer is used with a 132.7 MHz local oscillator to enhance the frequency conversion from 27.3 MHz to 160 MHz.
- a SAW Filter is then used to eliminate the spurious frequencies resulting from the frequency conversion,
- a linear amplifier with a 20 dB power gain amplifies the filtered signal without degrading the NPR signal,
- a second mixer allows the frequency conversion from 160 MHz up to a microwave frequency from 2 to 8 GHz depending on the value of frequency imposed by the second local variable C. W source,
- a Yig filter is used to eliminate the spurious frequencies resulting from this second frequency conversion,
- One or two linear amplifiers can be used to have a sufficient power to drive the device under test.

The noise power is measured in the "quiet" channel (notch) thanks to an accurate spectrum analyzer. The NPR is the ratio between the noise power measured in a specific bandwidth (a hundred kHz) determined with the spectrum analyzer without the notch filter to that measured with the notch filter. The difference between these two values is directly displayed by the spectrum analyzer.

The input and output noise powers are measured thanks to two powermeters.

Such a measurement system is only dedicated to NPR characterization. Other kind of useful modulated signals like QPSK, QAM, CDMA signals cannot be synthesized and cannot be used as test signals for the device under test.

For that purpose, a new characterization tool has been developed.

II. DESCRIPTION OF THE NEW NPR AND MODULATED COMPLEX SIGNALS MEASUREMENT SYSTEM.

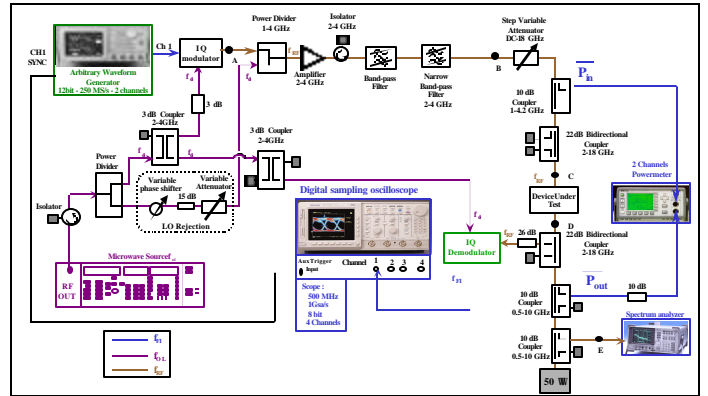The principle of the measurement system is described in Fig. 2.

Fig. 2. : Configuration of the new measurement system for NPR measurements

The measurement system is based on the use of :
- an Arbitrary Waveform Generator (AWG) to generate base-band test signal,
- a module for the up-conversion from the base-band frequencies to the RF frequencies,
- a module for the down-conversion from the RF frequencies back to the base-band frequencies,
- a digital sampling oscilloscope for the envelope measurement.

Covering frequency band from 1GHz to 4 GHz, this system simplifies characterizations by automatically sweeping the input power applied to the device under test because of a computer controlled step attenuator.

The Arbitrary Waveform Generator has a 250 Msample/s Clock that provides up to 125 MHz Waveforms. The 12 bits vertical resolution authorized the generation of 72 dBc NPR test signals.

With this controlled AWG, the base-band signals are easily generated.

An example of the power spectrum of a test signal used for the NPR characterization is shown in Fig. 3.

This is a coarse representation of a Band-pass gaussian white noise with a notch usually impressed around the center carrier frequency. Practically the spectrum is made of a large number (1000 to 10000 CW carriers from DC to 125 MHz) of equi-amplitude and regularly spaced frequency carriers (between f_1 and f_4) having independent random phases with a uniform distribution.
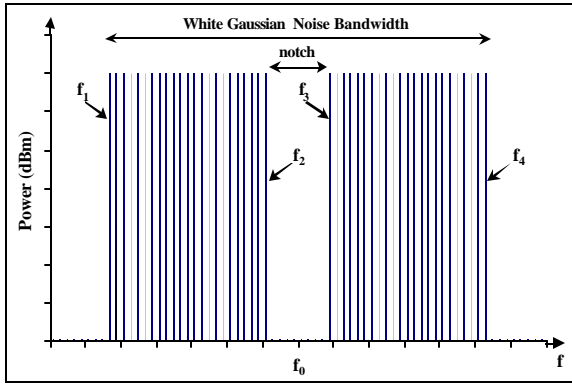
Fig. 3. : Power spectrum of the input NPR test signal

An ideal notch is realized by removing few carriers (W_{notch} equal to 1 to 10 %) within a channel bandwidth between f_2 and f_3. The notch is centered around the low frequency f_0. The resulting NPR test signal can be written as :

$$I_{[k]} = \sum_{i=1}^{N_{freq}} A \sin\left(2\pi \frac{k}{f_e} f_i + \varphi_i\right)$$

(1)

where   A :   magnitude of each frequency component of interest
   f_i :   frequency of interest
   φ_i :   random phase
   f_e :   sampling frequency
   k :   sample index

and where $f_i \leq \dfrac{f_e}{2}$ (2)

The value of the index k is dependent on the sampling frequency f_e, the number of frequencies, N_{freq}, taken into account in the gaussian noise bandwidth, B_{WGN}. It means that k varies between 0 and M-1 where M is equal to the number of samples or data points in the time domain :

$$M = E\left[\frac{f_e\left(N_{freq} - 1\right)}{B_{WGN}}\right] \quad \text{and } 0 < k < \text{M-1} \quad (3)$$

As an example, the $I_{[k]}$ signal with the following parameters is sketched in the Figure 4 :

   f_0 =45 MHz
   B_{WGN} = 30 MHz
   W_{notch} = 1%
   N_{freq} = 4000
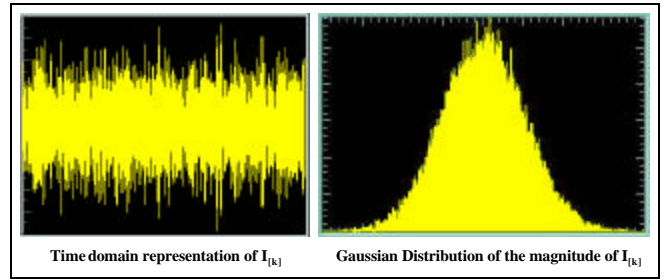 F_e =250 MHz
   M = 33325

Fig. 4. : Example of test signal

The basic measurement principle which consists in generating a large number of carriers with random different phases is very attractive because it's similar as the computation of NPR (ADS) using the transient envelope analysis [4].

When this NPR test signal is fed into the power amplifiers, intermodulation products fill up the notch, as depicted in Figure 5, so that the ratio of the average output power within the notch to the average output power outside the notch defines the NPR.
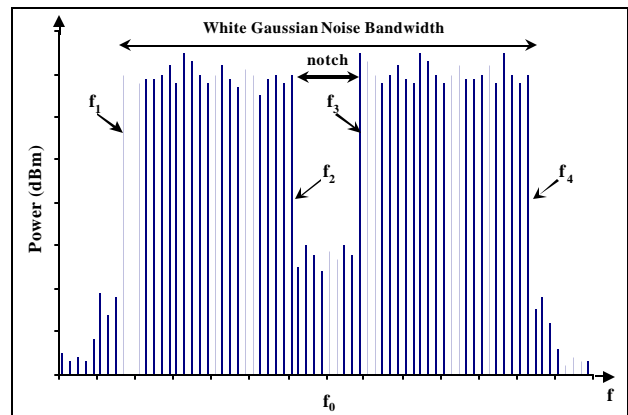

Fig. 5. : Power spectrum of the output signal

The second important instrument in the set-up of the Fig. 2 is the digital oscilloscope. This instrument has a bandwidth of 500 MHz, a maximum sampling frequency of 1 Gsamples/s and a 8 bits vertical resolution allowing the analysis of maximum 48 dBc NPR test signals. A DFT is performed once the output signal is recorded to compute the NPR as define above.

The up-conversion from the base-band frequencies to RF frequencies is realized by mixing the test signal with the CW signal generated by an local oscillator. The same mixing principle and the same local oscillator is used for the down-conversion, from the RF frequencies to the FI frequencies.

The mean input and output power of the test signal is measured at both ports of the device under test thanks to a 2 channels powermeter.

A classical power calibration, once the device under test is removed, is required before measurements.

III. COMPARISON OF NPR MEASUREMENT RESULTS.

The SSPA used for the comparison has been realized by ALCATEL Space Industries under a CNES contract with PHEMT (pseudomorphic high electron mobility) field effect transistors.
The features of this amplifier sketched in Figure 3.1 and composed of a variable attenuator (MMIC), an amplifier driver (MMIC + Hybrid PHEMT 1 mm), a power amplifier (2 PHEMT) and an isolator are the following ones :

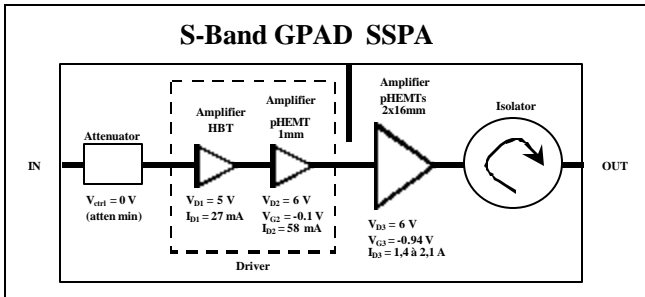| Frequency	2180MHz
Frequency bandwidth	40MHz
Nominal gain	> 50 dB
RF Output Power at 14dB NPR	> 36.3 dBm
Associated Power added efficiency	> 35 %
weight	< 75 g
Input overdrive	20 dB
lifetime	10 years min.

S-Band GPAD SSPA

Fig. 6. : Overview of the SSPA and its biasing

The NPR measurements were realized with the following different configurations :
   ☞ Traditional analog NPR measurement system :
   -   B = 16 MHz around 2.18 GHz
   -   b_{notch} = 0.4 % (64 kHz)
   -   Bandwidth analysis : 20 kHz around 2.18 GHz in the 64 kHz notch bandwidth
   ☞ New measurement system :
   -   f_0 = 2.18 GHz
   -   B_{WGN} = 20 MHz
   -   W_{notch} = 1% (200 kHz $\Leftrightarrow$ 10 carriers removed)
   -   N_{freq} = 1000
   -   F_e = 250 MHz
   -   M = 12488
Bias parameters of the amplifier are the following ones :
   V_{G1} = -0.1 V I_{G1} = 0 mA

V_{G2} = -0.94 V I_{G2} = 15 mA
V_{CTRL} = 0 V
V_{D1} = 5 V I_{D1} = 27 mA
V_{D2} = 6 V I_{D2} = 61 mA
V_{D3} = 6 V I_{D3} = 1.99 A

The Figure 7 represents the different following results obtained with the SSPA :
   -   the top figure is the NPR measured with the two systems as a function of the noise output power,
   -   the bottom figure is the multicarrier gain and the mean output power as a function of the mean input power.
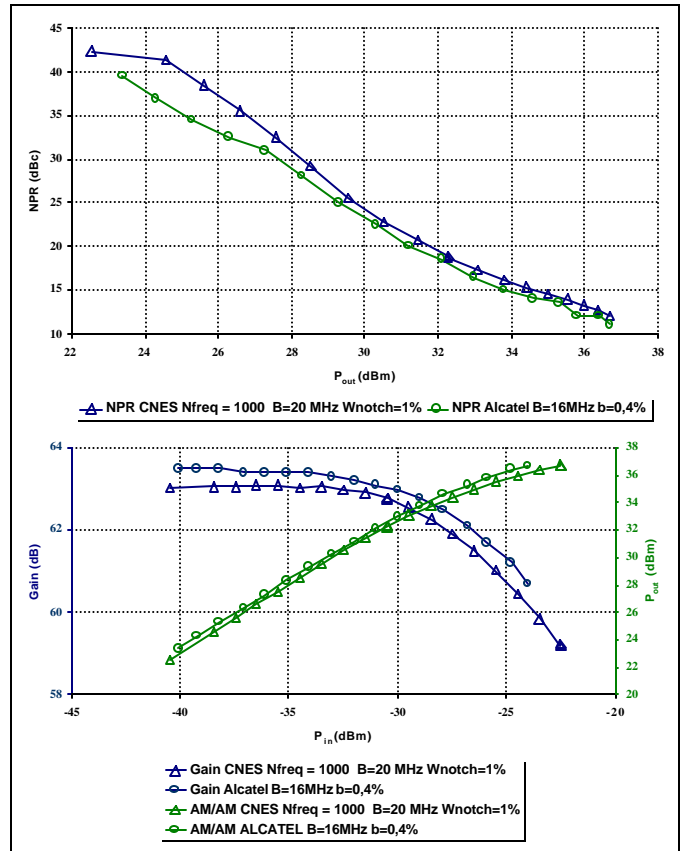

Fig. 7. : Noise power performance and power performance of the SSPA

There's a good agreement between the different results. The discrepancy between "analog" NPR and "digital "NPR can be explained by the discrepancy between the excitation signals that feed the amplifier. For instance the results will be better if the number of carriers (N_{freq} = 10000) is increased in the case of the NPR measurement with the new measurement system.

IV CONCLUSION

A novel approach for the characterization of power amplifier linearity in terms of NPR has been proposed. It

provides valuable information in the sense that this method based on a numerical generation of a gaussian noise is similar to what can be done in the field of NPR simulations using the envelop transient technique. Another important point is that the proposed system can be applied to other investigations.

For example, other test signals like digital modulation can be synthesized for non linear amplifier characterization and black box modeling.

Investigations on linearization of amplifiers can also be performed as base-band signals can be computed and or pre-distorted.

The principle of this new approach at L and S band can be easily extended to upper frequency bands (Ku, Ka, X…).

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