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Ultra-Linear Power Amplifier Characterization Using Dynamic Range Extension Techniques

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***Abstract* — The rapid growth of the wireless industry requires more efficient utilization of the available frequency spectrum. This has resulted in requirements for highly linear Multi-Channel Power Amplifiers (MCPAs) to support increases in voice and data traffic. To characterize the resulting ultra-linear MCPAs and to comply with inter-modulation levels less than -80 dBc requires measurement systems with dynamic range performance beyond what is currently available. A new instrument, which extends the dynamic range of current distortion measurement systems by at least 25 dB, has been developed to meet this challenge.**

I. Introduction

Significant modulation format changes are on the way for wireless systems evolving to 3G. The goal of these format changes is to enable efficient data access over the wireless networks and to increase utilization of wireless communication for data as well as voice. Efficient data access requires enhanced air interface data rates and the European Telecommunications Standards Institute (ETSI) has set new standards for GSM, EDGE, and W-CDMA. EDGE (Enhanced Data rates for Global Evolution) moves GSM from GMSK to 8-PSK modulation, which increases the Peak to Average power Ratio (PAR) and significantly increases the linearity requirements of current GSM amplifier systems -- especially where multiple carriers are employed.

Table 1 summarizes the in-band spectral requirements for transmission of these signals in accordance with European Spectral requirements. For offsets > than 6 MHz from the carrier, spurious emission within a 100 kHz bandwidth must be less than –70 dBc relative to the carrier power in the same bandwidth. This is measured using a peak hold setting on the spectrum analyzer, which is equivalent to about –80 dBc when using averaging.

Table 1
Intra Base Station System Intermodulation Requirements

Power Level (dBm)	Maximum relative level (dB) at specified carrier offsets (kHz)			
	RBW & VBW: 30kHz, Averaging over 200 sweeps.		RBW & VBW: 100kHz, Averaging over 200 sweeps.	RBW: 300kHz, Detector: Max Hold
	600 to 1200	1200 to 1800	1800 to 6000	> 6000
>= 43	-70	-73	-75	-70
41	-68	-68	-73	-70
39	-66	-66	-71	-70
37	-64	-64	-69	-70
35	-62	-62	-67	-70
<= 33	-60	-60	-65	-70

Table 1. Relative spurious emission mask requirements for transmission of GSM and/or EDGE signals in a MCPA in accordance with European spectral standards (GSM 11.21 version 7.2.0 Release 1998)
Table 2. Spectral Mask requirements for 3GPP amplifiers

Table 2 shows the equivalent standards for amplifiers which are in compliance with the 3GPP standards. This table summarizes the key spectral constraints on these units. It can be seen that ACP measured in a 1 MHz bandwidth centered at 4 MHz from the carrier is the most challenging specification.

To meet these challenging standards especially in the presence of multiple carriers, Power Amplifier manufacturers such as Powerwave Technologies, are developing increasingly linear amplifiers. Characterizing amplifiers with spurious rejections in excess of 80 dB has become increasingly difficult. Measurements of these levels of spurious are commensurate with or even better than the current measurement systems capabilities. To meet the challenge, Powerwave Technologies and Agilent jointly worked to productize a cancellation technique which has the potential to add about 30 dB of dynamic range to any measurement system and facilitates the accurate characterization of this new generation of Ultra Linear Power Amplifiers.

II. Limitations of Existing Test Methods

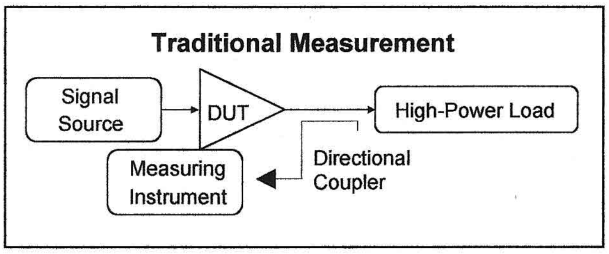

Fig. 1. High-Power Amplifier Measurement Setup

Fig. 1 shows a typical setup for measuring ACP (Adjacent Channel Power) and inter-modulation distortion (IMD) of a base-station power amplifier. The output of the DUT is connected to a high-power load and a portion of the output signal is coupled to the measuring instrument. The coupled level to the measuring instrument, typically a spectrum analyzer, is commensurate with its input power level. A precision calibrated coupler is used so that the absolute power at the output of the amplifier may be precisely measured.

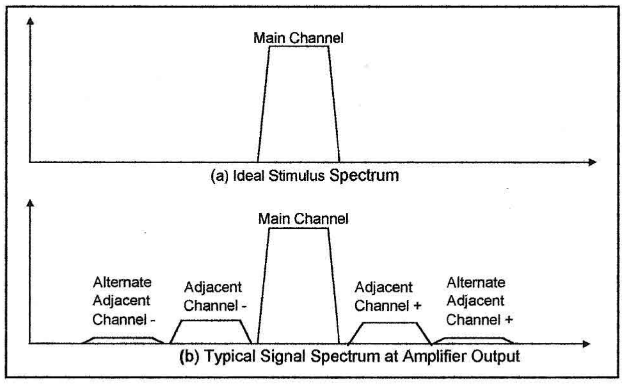

Fig. 2. Signal Spectrum Patterns

Under ideal measurement conditions, the input to the DUT would have a spectrum that would contain spectral components only in the desired signal channel, as shown in Fig. 2(a). The DUT, however, has non-linearities that cause the desired spectral components of the signal to mix with each other and with other signals to create additional spectral components. These extra components result in spurious spectral energy in the adjacent channels as indicated in Fig 2(b). This is the spectral power that must be measured. Another common term for such power is "spectral regrowth". A measurement system must be able to determine the ratio of the spurious spectrum to that of the desired spectrum and/or the absolute power of the spurious spectrum. The problem is that the power difference between the main channel and the adjacent channel of ultra-linear MCPAs exceeds the dynamic range capability of typical broadband measurement systems. Once the dynamic range of the measurement system is exceeded, the internal IMD generated in the signal source and the measuring instrument, which are similar to that generated in the DUT, results in additional spurious that mask the effects in the DUT. This, of course, limits accurate measurement of the DUT performance.

III. Discussion of Dynamic Range Extender

A. Theory of Operation

This measurement technique uses a cancellation signal during part of the process to remove unwanted signal components from the measurement. Fig. 3 shows the new measurement setup. It includes two signal paths from the signal source to the measuring instrument. The signals from the two paths are combined in the power combiner just before the measuring instrument. The ratio measurement consists of two parts: the measurement of the total signal power out of the DUT, and the measurement of the DUT produced spurious spectral power.

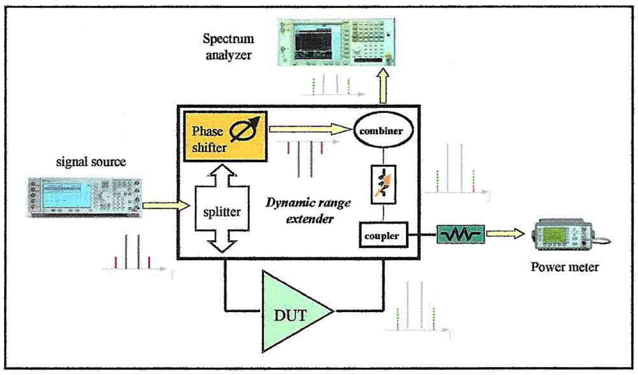

Fig. 3. Proposed Measurement System

In step one, a reference signal is obtained from the DUT by disabling the cancellation signal through the lower path. This establishes the reference power for the ratio measurement. In step two, the leveled and conditioned loop signal is applied to the coupled DUT signal, producing a signal cancellation to the spectrum analyzer. Cancellation occurs when the signal conditions along the two paths are equal both in magnitude and time delay, but opposite in phase. The cancellation subtracts at least 25 dB of the linearly amplified input spectrum to the measuring instrument. This improves the analyzer's dynamic range by allowing its internal attenuation to be reduced, without consequence of self generated non-linearities. The cancellation also subtracts spurious spectral power generated by the signal sources. The cancellation, however, has no effect on the distortion products caused by the DUT. The DUT spectral components are generated inside the loop and cannot be subtracted, so they are still present at the measuring instrument. Cancellation should now be viewed as "the removal of 25 dB of the linearly amplified input stimulus spectrum" to the spectrum analyzer. This allows measurement of both the lower noise floor and the DUT spectral contribution (independent of the input contribution

In general, use of the measurement system offers the following benefits:

- Spurious and noise contributions from the Spectrum Analyzer and the Input Signal are greatly reduced.
- Only spurious products generated by the DUT are measured.

B. Bandwidth of Cancellation

Optimal operating band cancellation occurs when the two signals that are summed in the power combiner of Fig. 3 are precisely equal, both in amplitude and time delay, but opposite in phase (180° apart.) In this section, we will consider the conditions necessary to achieve at least 25-dB of cancellation as well as the signal bandwidth over which this cancellation is valid.

Setting the amplitude of the signal in the DUT path with a resolution of 0.5-dB steps leads to a cancellation of at least 30-dB, when the phase reversal of 180° is established. Close time delay of the paths will allow the 180° phase shift to be maintained over frequency. Thus narrow and wide band cancellation performance is related to the time delay equality. The DRE allows a coarse coaxial delay line to be externally mounted to facilitate equalizing these delays.

With the proper delay line attached, the amplitude is equalized between the paths. The variable step attenuator in the coupled DUT path is used to best match the amplitudes of the signals to the spectrum analyzer. Then the phase shifter is used to bring the paths into the opposite phase condition required for cancellation.

The cancellation bandwidth needs to be sufficient to assure proper measurements when dealing with wideband signals such as multi-carrier WCDMA. That signal occupies a band of approximately 15 MHz. To account for the alternate adjacent channel on each side, a cancellation bandwidth of 45 MHz is required.

Cancellation bandwidth is maximized when the difference in delay between the 2 signal paths is held to the minimum of $\lambda/2$. Under this condition, the bandwidth for 30-dB cancellation is approximately ±0.7% of the carrier frequency. This amounts to about 28 MHz for a 2 GHz carrier, which is somewhat marginal.

Two conditions are necessary to achieve wide cancellation bandwidth:

1. Achieving the required 180° phase shift without an incremental time delay in one of the paths.
2. Maintaining uniform amplitude and phase response in the 2 signal paths.

Both these conditions are met in the Agilent 8760A KE4 Dynamic Range Extender, which provides a 30-dB cancellation bandwidth in excess of 100 MHz. Because of the dependence of path equality, the DUT may degrade these numbers.

C. Determining the Compensating Delay

The delay required to assure maximum bandwidth is determined by measuring the delay of the DUT as well as the delays in the signal and reference paths using a network analyzer. The Agilent 8760A KE4 provides up to 8 ns of adjustable delay. The delay of the DUT may be larger than the 8 ns range that can be accommodated within the product. In this case, an external delay in the form of cable of adequate length is connected to the appropriate ports on the instruments.

IV. MEASUREMENT RESULTS WITH DRE

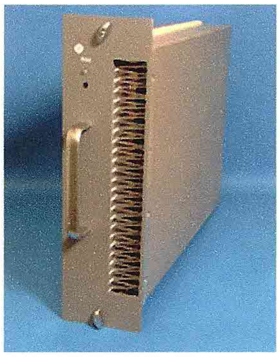

Figure 6 illustrates a 30-watt DCS1800 GSM MCPA. This ultra-linear wideband amplifier has been designed to handle the multiple GSM channels required for new multi-carrier base station operation.

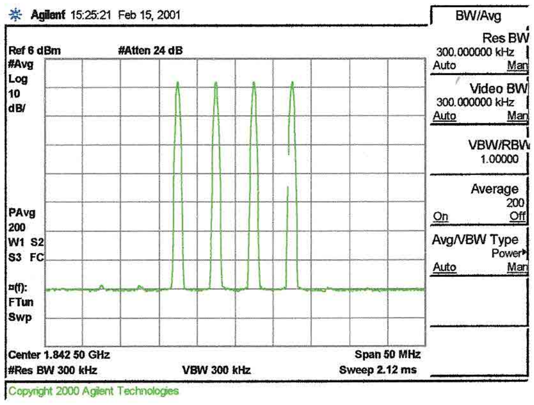

Figure 7: GSM output spectrum (BW will be changed for proper measurement.)

Figure 7 shows the RF output spectrum of the GSM MCPA with four independent +39.3 dBm GSM-modulated signals at 5 MHz separation for a total RF output power level of 45.3 dBm (33.9 Watts). The right tone value on the signal analyzer is at –1.7-dBm and represents the reference for the measurement. Figure 8 shows that the carrier cancellation due to the DRE is greater than 30 dB and reveals a number of intermodulation components that were not visible in figure 7. Note also that the ratio of carrier to intermodulation is ≥ 80 dB, for the test data above 6 MHz (the specification is –70 dB with max hold.)

The additional dynamic range provided with the DRE shows that the spurious signal is 80 dB below the GSM output spectrum as measured using peak hold on the spectrum analyzer. Without use of the DRE, the MCPA output level would exceed the dynamic range of the spectrum analyzer and not allow the spurious products to be seen or measured.

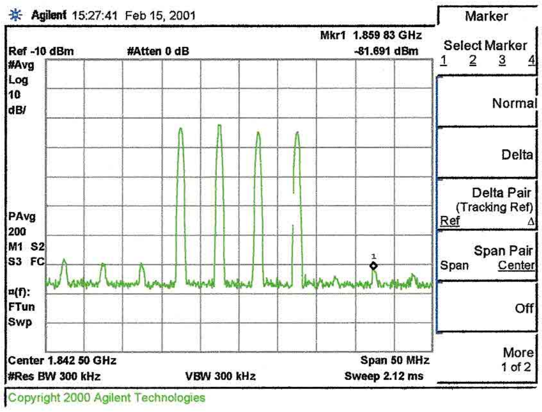

Figure 8: GSM spectrum after cancellation

Similar types of comparisons can be made for amplifiers utilizing 3GPP waveforms. Figures 9 to 11 show measurements made on a 3G amplifier operating in the 2.11 to 2.17 GHz frequency range. These measurements were made for the power level in adjacent channels (±4 MHz from center frequency over a 1 MHz bandwidth). These measurements were made for 3 W-CDMA carriers combined for a total RF output power level of 46.5 dBm (45 Watts). Figure 9 shows the direct measurement of the RF output spectrum without the DRE. As shown, the ACP levels at ±4 MHz are shown to be approximately –16 dBm. This level is very close to the specified –13 dBm limit. Figure 10 shows the same measurement made with the DRE demonstrating about 30 dB of cancellation. The ACP levels are now shown to be less than –24 dBm. It can be seen that the characterization of the amplifier could be as much as 8 dB in error without the use of the DRE. Figure 11 shows the cancelled measurement when the total RF Output power has been reduced by 1 dB. The ACP levels are now less than –35 dBm indicating that without the DRE, the error would have been greater than 18 dB and allowing the augmented measurement system to demonstrate the effects of Power Amplifier compression on the output spectrum.

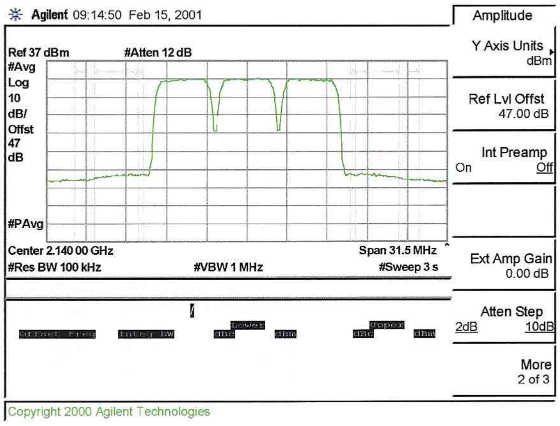

Figure 9 W-CDMA with 3 carriers prior to cancellation

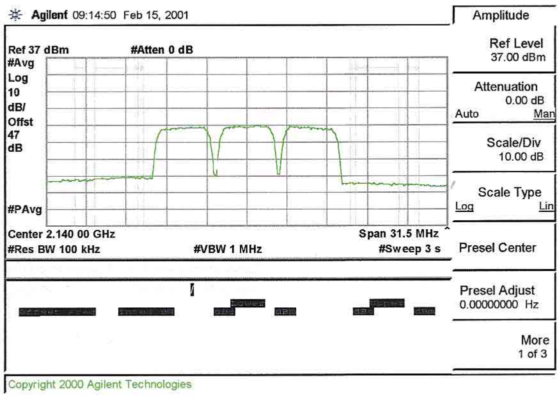

Figure 10 Same as figure 9, but after cancellation

V. Conclusion

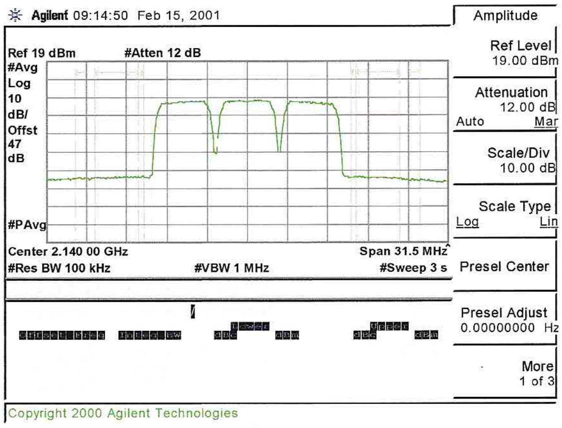

Figure 11 Output power reduced 1-dB, ACP reduced at least 7-dB (Analyzer internal preamp was used to perform this measurement.)

The challenge of achieving compliance with very stringent wireless transmission standards has resulted in the development of both extremely linear multi-carrier power amplifiers and of a new measurement instrument to facilitate proper characterization of these new MCPA designs. It has been shown that the new cancellation technique increases the range of intermodulation distortion measurement, including ACPR, by at least 25 dB over traditional IMD measurements. The cancelled signal removes most of the stimulus source IMD effect from the distortion-measuring instrument. The cancelled signal also reduces the power level to the spectrum analyzer by the same amount so that it can operate with less attenuation at its input. Less attenuation reduces the measuring instrument's effective noise figure and increases its dynamic range.

The examples in this article show improvement in excess of 11 dB in the measurement of spurious spectral products, ACPR, and noise power ratio measurements. The technique has been shown to be vital to the proper performance characterization of the new generation of Ultra Linear Power Amplifiers. This technique can also apply to other types of intermodulation distortion measurement, such as Noise Power Ratio.

References

[1] ETSI EN 301 0787 V7.2.0 (1999-12) Digital cellular telecommunications system (Phase 2 & Phase 2+); Base Station System (BSS) equipment specification; Radio aspects (GSM 11.21 version 7.2.0 Release 1998)

[2] UTRA (BS); Radio Transmission and Reception (3G TS 25.104

version 3.3.0)

[3] UWC 136 HS

[4] N. Kuhn, B. Matreci, P. Thysell, "Proper Stimulus Ensures Accurate Tests Of CDMA Power," Microwaves & RF, January, 1998, pp. 125-132

[5] "Noise Power Ratio (NPR) Measurements Using the HP E2507B/E2508A Multi-format Communications Signal Simulator," Hewlett-Packard Product Note E2508-1.

Table 2: Spectrum emission mask values, BS maximum output power P ≥ 43 dBm

Frequency offset of measurement filter – 3dB point, Δf	Frequency offset of measurement filter centre frequency, f_offset	Maximum level	Measurement bandwidth
2.5 ≤ Δf < 2.7 MHz	2.515MHz ≤ f_offset < 2.715MHz	-14 dBm	30 kHz
2.7 ≤ Δf < 3.5 MHz	2.715MHz ≤ f_offset < 3.515MHz	- 14 – 15·(f_offset- 2.715) dBm	30 kHz
	3.515MHz ≤ f_offset < 4.0MHz	-26 dBm	30 kHz
3.5 ≤ Δf < 7.5 MHz	4.0 MHz ≤ f_offset < 8.0MHz	-13 dBm	1 MHz
7.5 ≤ Δf MHz	8.0 MHz ≤ f_offset < f_offset_{max}	-13 dBm	1 MHz