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White Paper

Top 3 issues when characterising wide bandwidth high performance wireless transmitters

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Wide bandwidth and high efficiency RF amplifier modules present new challenges to designers who need to characterise the performance in real signal conditions, taking account of bandwidth, compression and effects of device non-linearity. This paper provides an in-depth technical discussion of three top issues to consider when designing and optimising an RF test environment for characterising transmitters and amplifier modules.

Introduction

Front end modules are now embedding more complex circuits with amplifiers, switches, and active filters (e.g. SAW, BAW). These complex modules need comprehensive verification test to ensure specification and performance, and there needs to be a high speed test method to reduce cost of test in production. The move to wide bandwidth access systems such as OFDMA (used in LTE at 20 MHz bandwidth) and high order modulation schemes (such as 64 QAM) place even higher new demands on the trade-off between amplifier performances in terms of linearity versus efficiency.

Amplifier test sets comprise of an input reference and an output analyser, to provide an accurate reference input to the amplifier and then evaluate the transfer characteristics of the amplifier. So a signal generator is used to create an accurate reference input, and a signal analyser used to measure the output levels and frequencies to evaluate overall gain and linearity. Non-linear and wideband amplifier devices need to be characterised using modulated waveforms to characterise the behaviour correctly. Previously single tone or multi-tone signals were used, but because single tone is limited to narrow band and simple modulation applications an alternative wide bandwidth and modulated signal is required. So now a Vector Signal Generator is used for the input waveform and this needs accurate power level setting.

Linearity of RF amplifiers

Amplifier class of operation gives trade-off between linearity and efficiency. Users want high efficiency (low power consumption and long battery life) but engineers and designers want high linearity (accurate signals with low distortion). Where efficiency of the amplifier is of highest importance then traditionally Class C amplifiers are used, but these suffer from distortion and non-linearity that must be managed by correct load matching. However, such matching is usually only accurate at fixed or narrow frequency bandwidth, and not suitable for wide bandwidth or multi-carrier amplifiers. Latest generation RF Amplifiers use a combination of Amplifier design class (e.g. a Class AB design to give trade-off between linearity and efficiency) and then complex compensation schemes to further remove any non-linearity when driving the amplifier to extreme performance. Classical compensation schemes use "feedback" loops to send a small amount of the output signal back to the input to use as a correction factor (comparing output to input and adjusting for any errors). More modern designs may use "feedforward" or "pre-distortion" to remove any known and pre-characterised non-linearity that remains in the amplifier. With the advent of low cost and very small size Digital Signal Processing (DSP) capability in silicon, the use of "Digital Pre-Distortion" has become one of the most favoured and advanced forms of amplifier design for wide bandwidth and high efficiency RF amplifiers.

A lot of design work goes into balancing these design parameters, and key performance targets are based on this trade off of efficiency versus linearity. As communication systems move to higher speed, then wider bandwidth and more complex modulation schemes are used to increase data rates. This requires highly linear waveform output to support the higher order modulation schemes such as 64QAM. But designers are constantly challenged to improve power efficiency for issues such as heating, battery life, power consumption, and hence are required to meet minimum targets for linearity whilst chasing maximum targets for efficiency.

CCDF

The complementary cumulative distribution function (CCDF) is a plot of probability versus peak-to-average power ratio (PAR), which characterizes the statistical power of a signal. CCDF is one of the important measurements in designing OFDMA power amplifiers (such as those used in LTE) that must be capable of handling high PAR signals while constantly maintaining good adjacent-channel leakage performance and high efficiency.

The CCDF plot is primarily used in the wireless communication market for evaluating multicarrier power amplifier performance. It measures the percentage of time when the PAR is at or exceeds a specific power level. This is relevant because it indicates how often the signal requires a very high instantaneous output power level, and to what level. It is the need to output such high instant peaks that presents the greatest challenge in having a linear (un-distorted) output waveform. So the CCDF trace shows clearly how the trade-off of linearity versus efficiency is affecting the output signal.

Understanding the key test environment requirements

From the previous discussions we see that a key parameter to confirm is the output linearity of the device, and this needs a high accuracy input waveform. Designers and test/verification engineers need to develop suitable test environments to characterise the performance of the systems, and to verify the performance when in a production/acceptance test station. In the following sections we will examine in more detail three of the top issues related to optimising testing of wireless transmitters.

1. Effect of calibration accuracy on measurement uncertainty

Improved output power level accuracy improves accuracy of measurement.

- EVM
- Adjacent Channel Power.
- Harmonic Distortion.

As reviewed in the previous introductory section, the design of Tx amplifiers for digital wireless equipment aims to maximize mobile battery life. Generally, power consumption can be reduced by transmitting in the effective nonlinear domain in relation to output power and operating power (e.g. Class AB or Class C), but this domain tends to suffer from a lot of distortion, so there is a contradiction between efficiency and Tx amplifier distortion. In particular, OFDM modulation used by LTE gets worse as soon as the EVM characteristics exceed some region due to phase delay in the nonlinear domain. Designing a Tx amplifier requires setting the best operating range based on this trade-off. A test system requires high-accuracy power calibration for each measurement item, to test precisely in the power range determined by the design specifications.

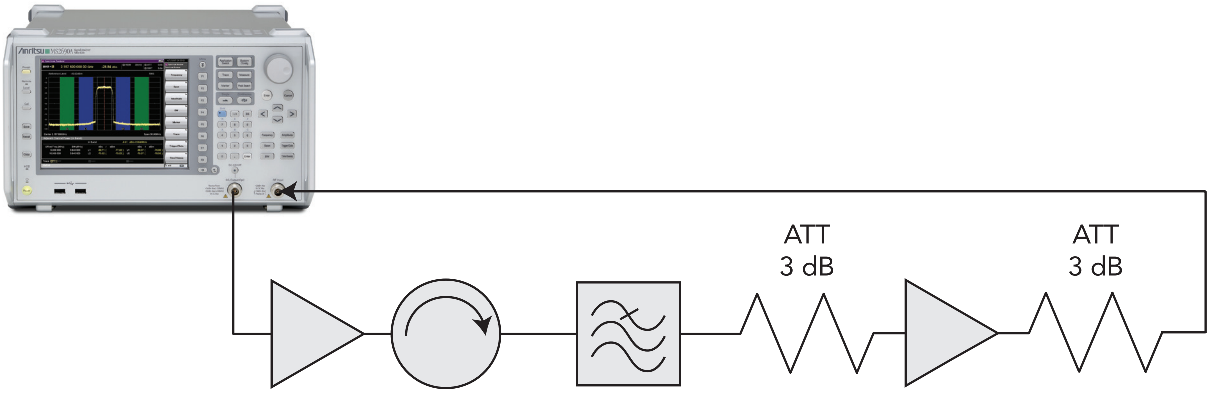
However, there are many measurement cases, such as EVM and ACP, where measurement repeatability is poor due to the poor repeatability of the test instrument power level calibration. The table below shows differences in distortion measurement repeatability (i.e. measurement errors) due to differences in Power calibration accuracy.

Power Calibration Accuracy	Measurement Repeatability			
	EVM	ACP_upper	ACP_lower	2HD
0.14 dB	1.96 dB	1.14 dB	1.12 dB	1.12 dB
0.03 dB	0.27 dB	0.27 dB	0.54 dB	0.40 dB

Table 1

- At Power calibration ranges of 0.14, and 0.03 dB as the target output power for the power amplifier 1 dB compression point, the EVM, ACP, and 2HD measurement repeatability errors increase in proportion to the Power calibration accuracy.
- EVM measurement, which is affected by both distortion and phase delay characteristics, has wider errors than the measurement repeatability of the other two distortion measurements (ACP and 2HD).

The 0.14 dB accuracy is the stated accuracy for a test system using typical separate signal generators and signal analysers, according to manufacturer data sheet. The evaluation circuit used to create the 0.03dB environment is shown in figure 1 overleaf.



Output Waveform from MS2692A-020 : Mobile WiMAX (10 MHz BW)
Frequency : 2.45 GHz
Target level of Power Calibration : +28.9 dBm (Originating point for 1 dB gain compression

<<Measurement Flow>>

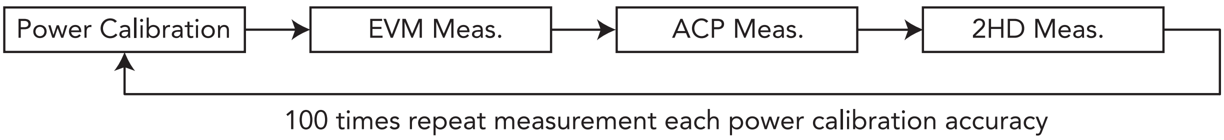
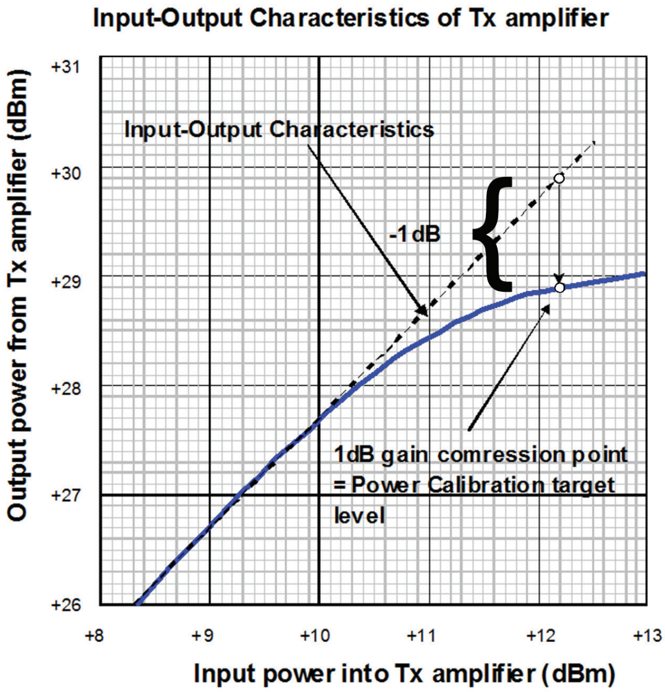


Figure 1 : Evaluation circuit



Power Calibration Range	Measurement Repeatability			
	EVM	ACP_upper	ACP_lower	2HD
0.14 dB	1.96 dB	1.14 dB	1.12 dB	1.12 dB
0.05 dB	0.44 dB	0.89 dB	0.88 dB	0.72 dB

* Sample Number: 100
(each power calibration accuracy)

Figure 2 : Repeatability result for distortion measurement due to power calibration difference

Power calibration is a key element in power amplifier tests. However, in Tx amplifier tests the optimization to correct the variations in output level and adjusting power levels takes time. In addition, when adjusting power in the nonlinear domain, the Tx amplifier characteristics may be different for an un-modulated continuous wave (CW) and modulated wave even at the same power level input. Specifically, a burst signal with repeated power ON and OFF has lower total power than a continuous CW signal when integrated over time, and differences in the Tx amplifier characteristics become striking. As a result, when adjusting the amplifier input power for measuring an OFDMA Tx amplifier in an ideal environment approximating a non-linear device, ideally power must be adjusted assuming the same burst modulation wave conditions as the real waveforms. However, use of a signal generator that can change the level while reading power at the rising edge of the burst signal and adjusting the signal analyser power and reading the power meter via GPIB requires extremely complex measurement algorithms and a lot of time.

The above example is made using a vector modulated signal source rather than a fixed CW tone, because for measuring non-linear devices we use a modulated signal rather than CW signal at the input port. This is required because input waveform CCDF characteristics are different for non-linear devices, and so the measurement results are different too, requiring measurement using a modulated signal to approach the true performance value when using non-linear devices with wideband modulated signals.

2. Improve performance when using a combined SG and VSA.

By combining both the Signal Generator and the Vector Signal Analyser into the same instrument, a significant improvement in measurement accuracy can be achieved.

Using an external trigger to attempt to synchronize separate signal generator and signal analyser for measurement includes analogue jitter in the trigger signal. Since it is impossible to cancel-out this jitter with hardware, the measured values incorporate randomness. It should be noted that locking together the timing reference from a separate generator and signal analyser does not reduce this trigger timing jitter problem, it will reduce the additional phenomenon of "timing wander" only.

The combined signal generator and signal analyser may overcome this problem, by using a special internal trigger timing marker function that supports measurement at precisely the same timing because the marker is matched to digital timing by the internal FPGA. Consequently, there is no random dispersion in the measurement results. This is because the trigger signal from the generator to the analyser is contained within the same processor (e.g. the same FPGA device). This minimises timing uncertainty between the two sections by running on a common clock signal within the same digital circuit.

The vector modulated waveforms used as input to the test system are by definition time varying signals, with power level fluctuating instantaneously from the nominal "average" signal power (see introduction section discussion on PAR and CCDF). The use of such a waveform is required to accurately recreate the actual use case of the device being measured, and hence characterise the performance of the device in the conditions in which it will be used. The challenge is to ensure repeatability between measurements, so meaningful comparisons can be made. Uncertainty in the trigger timing and exact start/finish of the capture period adds directly to uncertainty in the measurements.

One way to reduce this error is to use long time duration waveforms so that the % error contribution from trigger timing fluctuation is reduced. But this does not remove the problem, but just attempt to hide it by using longer time to measure the device and average out the error. This of course introduces a longer measurement time, which is often not an acceptable solution. The above approach, using combined generator and analyser circuits running inside the same digital circuits, enables a real reduction in trigger jitter uncertainty, and hence allows more accurate measurements in a faster time, with no trade off required between accuracy and measurement time due to triggering issues.

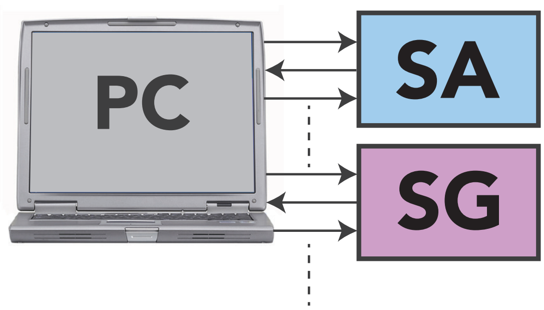
3. Reduce measurement time using a combined SG and VSA.

Simpler calibration, faster to calibrate, a single command "calibration and measure" reduces configuration and control time.

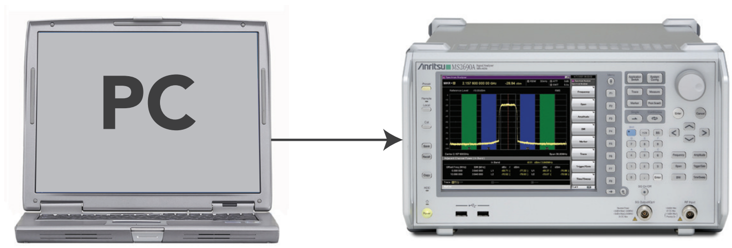
- A measurement system combining a signal generator and power meter requires about 1 s to adjust the input signal to ±0.05 dB accuracy.
- EVM Using the combined signal generator and signal analyser with a single command takes about 100 ms to achieve the same ±0.05 dB accuracy.

Normally, when controlling a signal analyzer and signal generator via PC, measurements are made by sending remote setting and reading commands one-by-one. These remote-command exchanges form a large part of the total measurement time (see figure 3).

Conventional
Send one command per instrument.



MX269074A Power Amplifier Measurement SW
Measurement using sequence measurement function, batch execution with only one command sending.



Measurement Sequence Example

Setting	SG modulation On
Setting	Change SG frequency
Setting	Change SA frequency (Carrier frequency)
Meas	Power adjustment (SG level control + SPA meas.)
Setting	EVM measurement setting
Meas	EVM measurement
Setting	SEM measurement setting
Meas	SEM measurement
Setting	ACP measurement setting
Meas	ACP measurement
Setting	SG modulation Off (CW)
Setting	Harmonic measurement setting
Setting	Change SA frequency (second)
Meas	Harmonic measurement (second)
Setting	Change SA frequency (third)
Meas	Harmonic measurement (third)

No spent time between PC and instrument for command control due to internal processing for whole sequence

Figure 3 : Sequence measurement function to achieve high speed measurement

High speed measurement using single batch command.

By using the MX26907A Power Measurement Software sequence measurement function, a pre-set measurement sequence can be executed by sending just one remote command, cutting measurement times. This is shown in concept as the difference in measurement time and sequence between column 1 and column 2 in figure 4-1. Note that this single batch command can provide the whole test sequence for setting the signal generator, measure and correct signal generator with the signal analyser, and then measure device output with the signal analyser. Normally these are sequential measurements requiring control time between each command. This allows the whole time to be reduced from 1 s to 100mS.

High-speed Control using External Macro Control Function.

Control of external equipment, such as multi-meters, can be integrated into the measurement sequence to cut tact time using parallel measurement of current. This further reduces the test time by allowing both the signal analyzer measurements and current measurements to be made and read in parallel. This is shown in the second reduction in test time in the third column in figure 4.1.

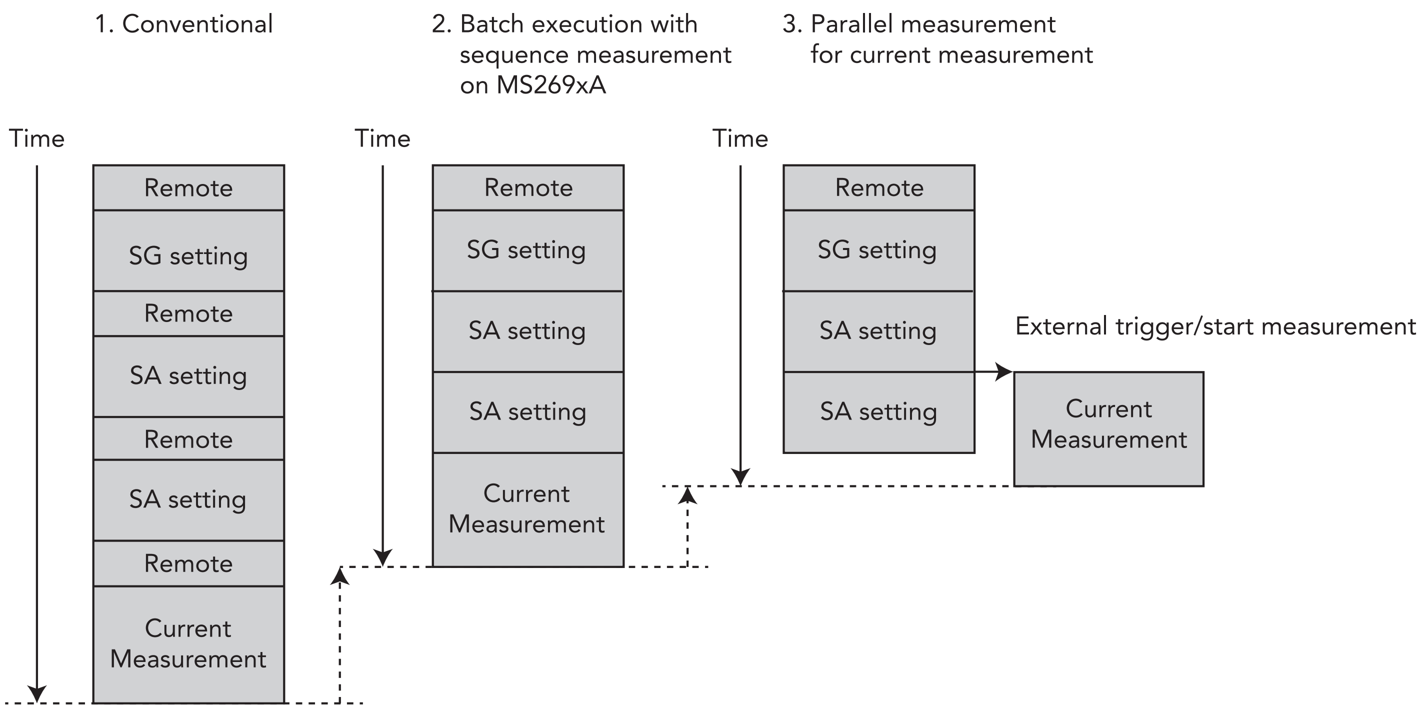


Figure 4.1 : Sequence measurement to achieve high speed measurement

Conclusion.

The test solution shown in figure 4-2 describes a high-accuracy and low-cost measurement solution for OFDMA Tx Amplifiers. This system meets all of the three key factors discussed, in terms of output power level calibration accuracy, measurement accuracy due to timing uncertainty, and measurement speed and simplicity.

The key features of the measurement system are:

(1) The sequence measurement function greatly reduces remote-command TRx times. Only 30 ms is required for ±0.02 dB Power calibration measurements, and 20 ms is required for EVM measurements (10-MHz bandwidth (typ.) modulation).

(2) Software drivers for controlling external equipment, such as a programmable power supply, multimeter, etc., can be integrated into the measurement sequence by using the built-in external macro function.

(3) The built-in vector signal generator in the signal analyzer supports synchronized measurements without external control.

(4) Operating with a combination of various parameters supports easy system configuration for acquiring curve data required for R&D as well as for mass production. All configuration data for both signal generator and signal analyzer are in a single configuration file, and this ensures that always the correct input waveform is used for the corresponding output measurements as they are combined into a single configuration file. Test results are output and saved in an open standard CSV format, supporting easy curve data creation.

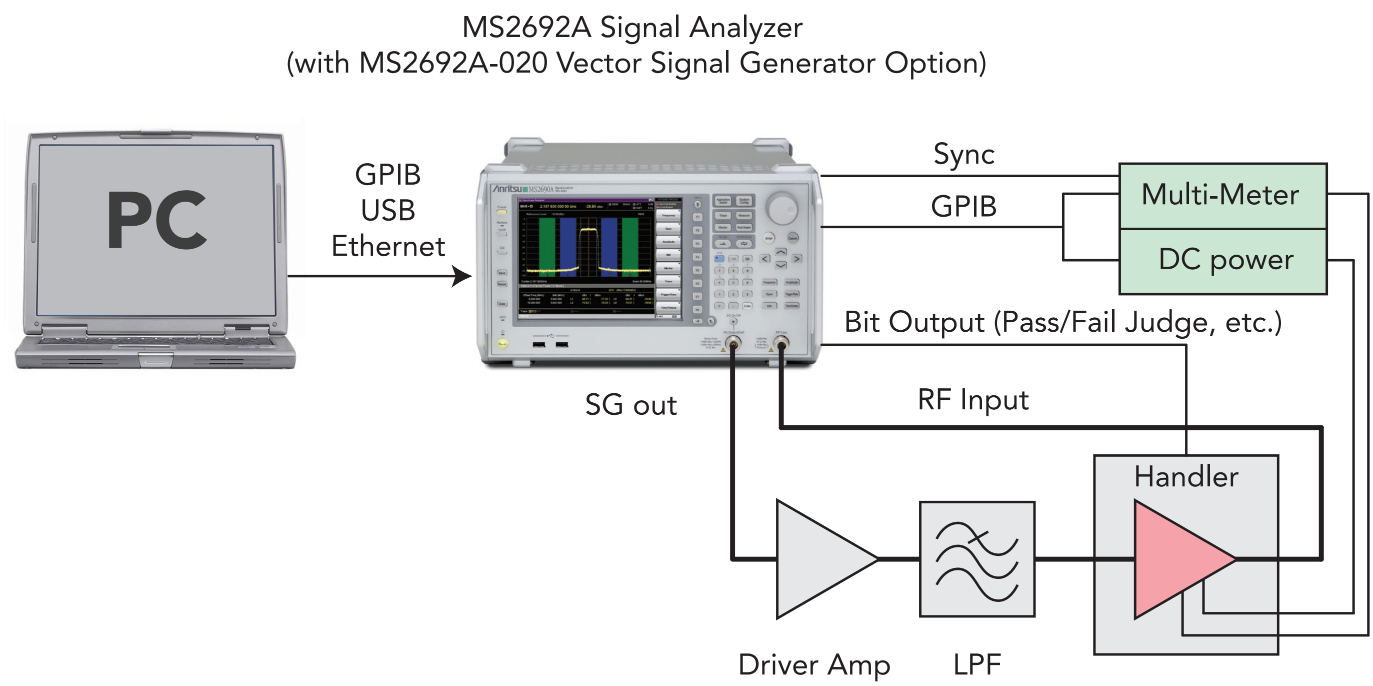


Figure 4.2 : Sequence measurement to achieve high speed measurement

Specifications are subject to change without notice.

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