Measurement and Characterisation of a Digital Predistortion Lineariser for Third Generation Cellular Base-stations

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Abstract
For the digital modulation format wideband-code-division-multiple-access (WCDMA) of the third generation (3G) cellular systems, a linear multi-carrier power transmitter is required. For this transmitter several linearisation methods have been developed amongst these is digital predistortion linearisation, which is an effective method in providing a moderate intermodulation distortion improvement suitable for the WCDMA modulation format. An evaluation of measurement and characterisation of a digital predistortion lineariser suitable for the third generation cellular base-stations is demonstrated in this paper.

Introduction
For the new generation of cellular base-stations, the system network operators are looking to upgrade their old networks from single carrier power amplifiers (SCPAs) to multicarrier power amplifiers (MCPAs). The new system of MCPAs has allowed the operators to overcome problems of channel capacity overload, complexity and therefore cost of the overall system, increase power transmission and improved spectrum efficiency.

The need for a highly linear MCPA has let to a number of new linearisation techniques for cellular base-stations. In general, predistortion and feed-forward techniques are the most commonly used methods in the linearisation of radio frequency power amplifiers (RF PA). The analogue and digital types of predistortion are both low cost solutions with low power consumption and low circuit complexity, which makes this technique much more appropriate than feed-forward for modest intermodulation distortion (IMD) improvements [1,2]. The combination of both predistortion and feed-forward techniques has been shown to combine high linearity with good overall spectral efficiency [3].

In this paper, measurement and characterisation of a digital predistortion linearisation technique suitable for use in the third generation of cellular base-station will be presented.

Amplifier distortion theory
Inherently a linear power amplifier is one in which the output signal is linearly proportional to the input signal. Such an ideal amplifier does not exist in the real world and this is due to the fact that no RF power transistor is perfectly linear. There are always spurious components added to the input signal by the nonlinear elements of the transistor in the form of IMD. The input/output power characteristic of an ideal amplifier is shown in Figure 1. The output power (P_{out}) exhibits linear operation at a low input power level and starts to become nonlinear at higher input levels. The curve

characteristics can be represented by a compressive transfer characteristic given in equation 1.

$$Y = a_1 x - a_3 x^3 - a_5 x^5 - a_7 x^7 - \ldots \ldots \quad (1)$$

Where 'a_1' is the magnitude of the fundamental component of the signal (i.e. amplifier's gain) and a_3, a_5 and a_7 are the magnitudes of the components of the unwanted nonlinearities.

Digital Predistortion

The concept behind predistortion is illustrated in Figure 2. From the figure the predistortion module located between the input signal and the amplifier calls for the insertion of a nonlinear characteristic in such a manner that its output signal is distorted in a precisely complementary manner to the IMD produced by the RF power amplifier, i.e. the IMD amplitude inserted by the predistorter is equal to that of the power amplifier but in anti-phase. The output of the amplifier is thereby an undistorted replica of the input signal.

Figure 3 shows the proposed digital predistorter scheme. Following the RF input path, the signal is down-converted to an IF and anti-alias filter before sampling by a 12-bit A/D converter. The sampled signal is split into in-phase and quadrature (I/Q) channels, which are predistorted independently. The predistortion of each channel is solely dependent on the feedback information of amplitude and phase responses (AM-AM[1] and AM-PM[2] characteristics) from the RF PA. The predistorted I and Q characteristics are then modulated by a quadrature modulator and fed back to the RF PA.

The I and Q predistortion processes are based on a Cubic Predistorter (CP). This type of CP is shown in Figure 4. The CP includes two distinctive paths (main and secondary), which when recombined result in a characteristic that is an inverse to that produced by the RF PA.

The main path is the linear path, which comprises a delay block to compensate for the delay through the various elements in the secondary path. The purpose of the delay line is to ensure that the signals are recombined with the correct time relationship.

The secondary path is the distortion path, which comprises a small signal amplifier followed by an attenuator and phase shifter element to adjust amplitude and phase of the signals so that the correct relationship is achieved at the summing junction. The distortion generator is diode-based. In most cubic predistortion linearisers, diodes are used due to their simplicity, compact size and a large bandwidth capacity. The resulting cubic signal is then amplified by a small signal amplifier to ensure the correct signal level just before the summing junction.

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[1] *AM-AM conversion is the amplitude dependent gain, which represent the non-linear characteristics (amplitude deviation) of power amplifiers.*

[2] *AM-PM conversion is amplitude dependent phase shift, which represent the non-linear characteristic of power amplifiers, which is a measure of an undesired amount of phase deviation (the PM) excited by the amplitude variation (the AM).*

RF power amplifier performance

Figure 5 shows the block diagram of the RF power amplifier. The amplifier consists of three amplification stages, preamplifier (GaAs HBT and LDMOS power transistors) with gain of 23dB, power driver (LDMOS) with a gain of 12dB and finally balanced power amplifier. The balanced amplifier contains two identical stages of LDMOS 60watt-power transistor combined in parallel, both with a gain of 12dB. Its configuration based on split input signal by 0° and 90° splitter, amplified and finally recombined in 0° and 90° combiner. The power amplifier was designed to provide overall gain of 45dB (minimum) with ripple ±0.5dB, broadband, class-AB and operates linearly and efficiently over 75MHz from 1.805GHz to 1.880GHz frequency band.

Figure 6 shows small signal measured results of available power gain (S21) and input return loss (S11) across 1.805GHz to 1.880GHz frequency band. Features of the implemented RF PA are summarised in the following Table 1:

Frequency (GHz)		Gain (dB)		Power (dBm)			VSWR	
F1	F2	Min	Flatness	Min	Max	Max in	in	Out
1.805	1.880	45	±0.4	45	48	10	1.2:1	1.4:1

Table 1: Features of the RF PA

Figure 7 shows a two-tone test measurement for the RF PA. The Generator frequencies ("tones") are set 1 MHz apart at 1.842GHz and 1.843GHz. The amplifier at its maximum output power near saturation exhibits IMD products better than −30dBc at an input power level of 0dBm.

Measurement and characterisation results

Figure 8-a illustrates the block diagram of the measurement setup for the digital predistorter. The setup encompasses the 8714C RF network analyser and the digital predistorter system. The aim of this setup is primarily to measure and investigate the static amount of the amplitude and phase distortion of the digital predistortion system. One simple way to achieve this is by utilising the single carrier power sweep measurement available from the 8714C RF network analyser. Figure 8-b and -c show measured result of insertion loss, S21, (amplitude and phase) versus power. The power was swept from −6 to +10dBm at a frequency of 14.230MHz. For this system the amount of sweeping power was enough to characterise the behaviour of the digital predistorter and thereby adjusting the exact level of amplitude and phase distortions required to lineariser the RF PA can be determined. The system was tested as an open loop and a computer program was used to control the amount of predistortion of amplitude and phase. The measured results showed a good dynamic range of predistortion of gain amplitude and phase. Gain is expanded by 3dB and compressed by −3dB and the phase is advanced by 12° and lagged by -40°. Both characteristics of amplitude and phase were subject to control by specific numbers via the computer program to the digital system. From the achieved results, it is clear that the signal amplitude compression/expansion and phase advance/lag characteristics are accomplished hence this system has the capability of predistorting amplitude and phase with inverse characteristics to that produce by power amplifiers.

Figure 9-a shows similar setup of measuring AM-AM and AM-PM conversions of the RF PA. Again a single carrier power sweep measurement was applied to the RF PA. Power was swept from -6dBm to +10.8dBm, 1.7dB in steps. Measured results are shown in Figure 9-b. Results were computed as amplitude and phase of S21 (transmission) versus power. The results show a typical characteristic for high power LDMOS transistor. Output power is expanding just before saturation, this is believed to be due the power gain behaviour of the LDMOS transistors. The amplitude (AM-AM) and phase (AM-PM[3]) conversions can be determined from the results as input power increases. At 1dB compression the amplifier producing 13^{o} phase distortion. The lineariser here was set to introduce approximate complementary characteristics to that produced by the RF PA. The resulted residual curves from both the distorted and predistorted characteristics of both AM-AM and AM-PM represent the characteristics of the linearised RF PA.

The method of the single carrier power sweep is a static measurement and is very simple to perform. By implementing it the actual dynamic response of power amplifiers will not be accurately determined. In 3G cellular communication WCDMA amplitude envelope varies continuously with frequency and modulation rate hence AM-AM and AM-PM effects occur dynamically. This method helps the designer in adjusting linearisation circuitries and predicts the amount of predistortion, but it does not provide precise details and full insight about the system's memory[4] (AM-AM and AM-PM effects) of power amplifiers, and therefore significant differences and discrepancies may result between predicted and measured performances [4]. The aforementioned measurement is only suitable for an amplifier with memoryless effects (small variations of AM-PM) [4]. For amplifier with memory effects, additional measurement setup has to be conducted in order to determine the dynamic amplitude and phase characterisations of power amplifiers [4].

Conclusions

In this paper, measurement and characterization of a digital predistortion lineariser for third generation cellular base-stations and RF PA distortion with average power of 47dBm has been demonstrated. It has been shown that AM-AM and AM-PM conversions can be characterised using the proposed technique.

References

[1] J. Yi, Y. Yang, M. Park, W. Kang and B. Kim, "Analogue Predistortion Linearizer For High Power RF Amplifier," IEEE MTT-S Symp. Dig., June 2000.

[2] E. Jeckeln, F. Beauregard, M. Sawan and F. Ghannouchi, "Adaptive passband/RF Predistortion For Power Amplifiers Through Instantaneous AM-AM and AM-PM Characterization Using Digital Receiver," IEEE MTT-S Symp. Dig., June 2000.

[3] K.J. Parson, R.J. Wilkinson and P.B. Kenington, "A Highly-Efficient Linear Amplifier for Satellite and Cellular Applications," pp. 203-207, 1995.

[4] W. Bosch and G Gatti, "Measurement and simulation of Memory Effects in Predistortion Linearizers," IEEE transactions on microwave theory and techniques, Vol.37, No.12, December 1989.

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[3] AM-PM conversion is a scalar quantity, usually expressed in degrees-per-decibels (°/dB), and is *equal to "rate of change of Mag(PM_{out}) / rate of change of Mag(AM_{in})" (deg/dB)*

[4] *RF PA memory- is the instant output signal directly proportion to the instant value of the input signal and previous input values spanning the RF PA's.*

Some LDMOS transistors have low power non-linearity.

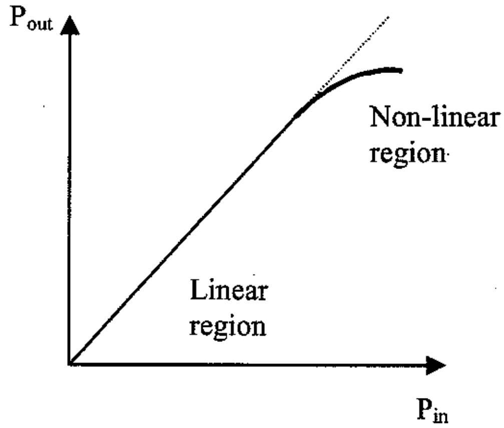
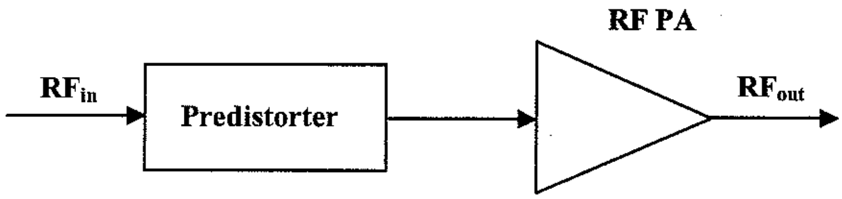
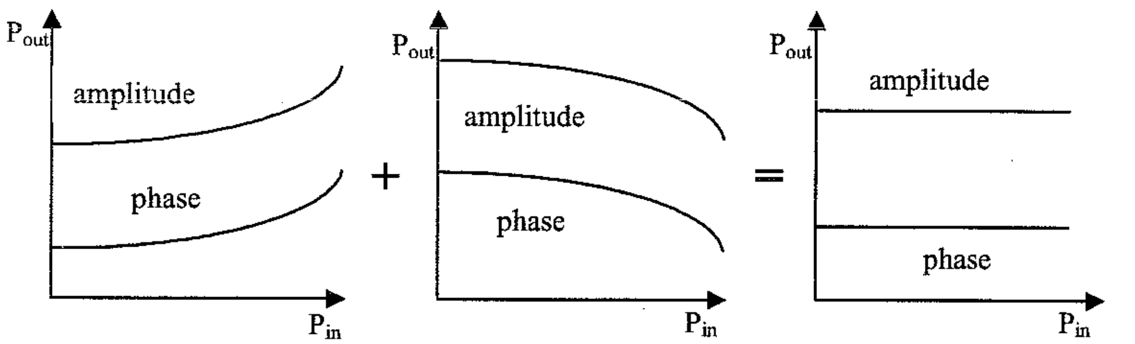


Figure 1: RF PA characteristic



(a)

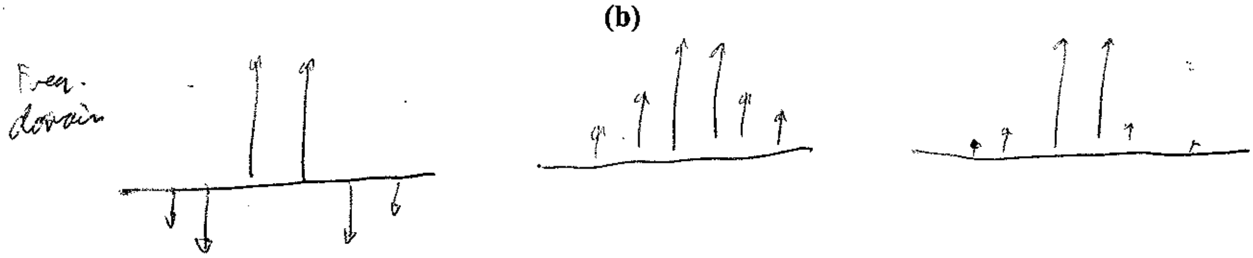


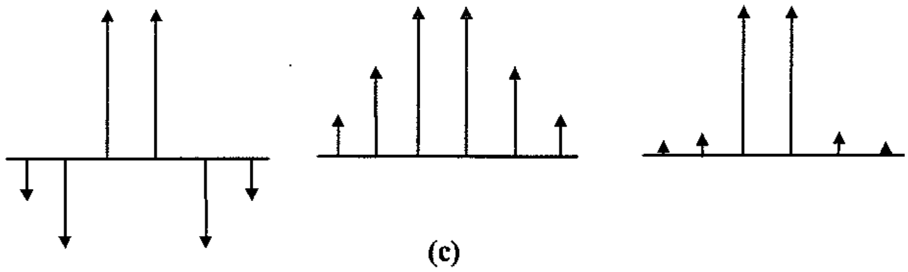
predistorted amplitude and phase

distorted amplitude and phase

linearised amplitude and phase

(b)





(c)

Figure 2: Linrariastion process for RF power amplifiers, (a) block diagram (b) transfer functions of the system and (c) frequency chcracterstics of the system

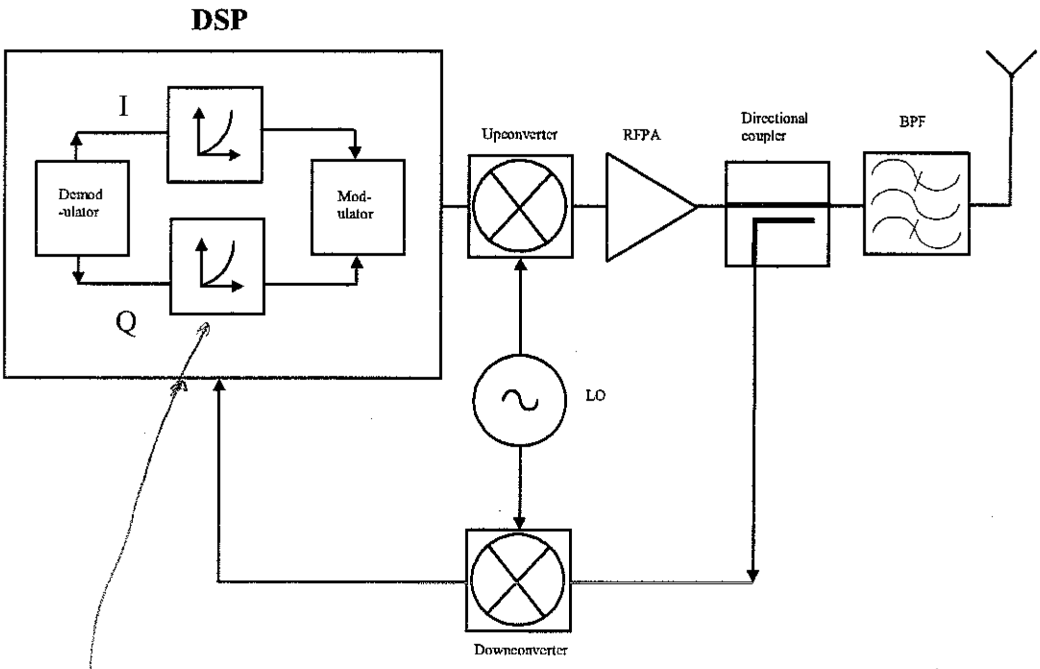


Figure 3: Digital predistorter lineariser architecture

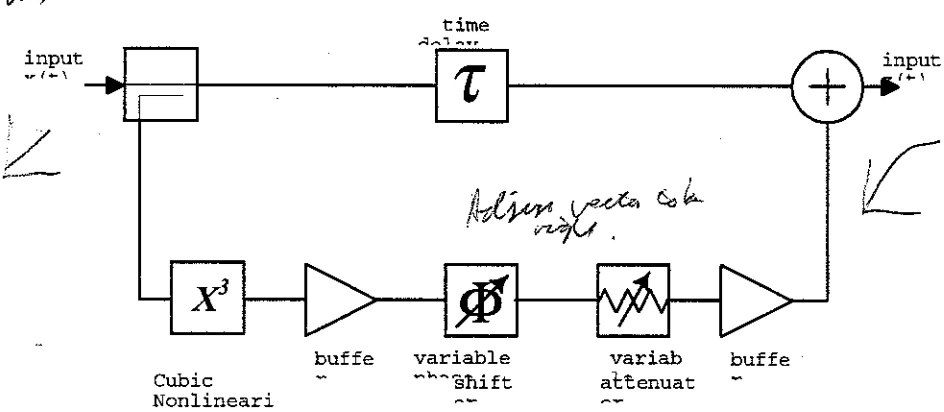
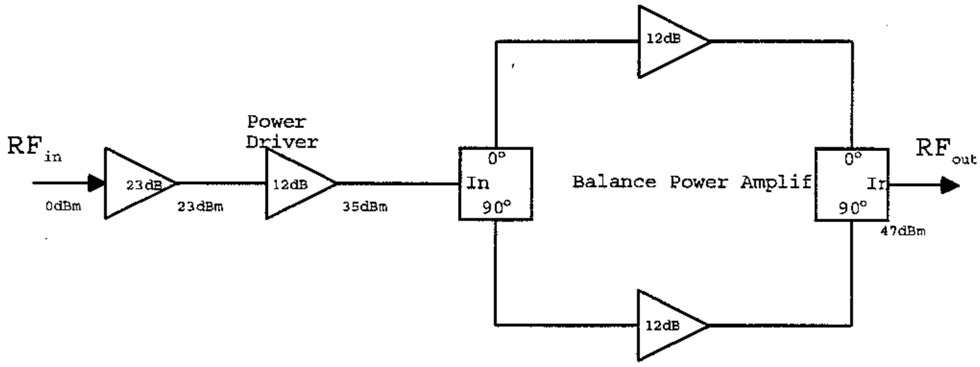
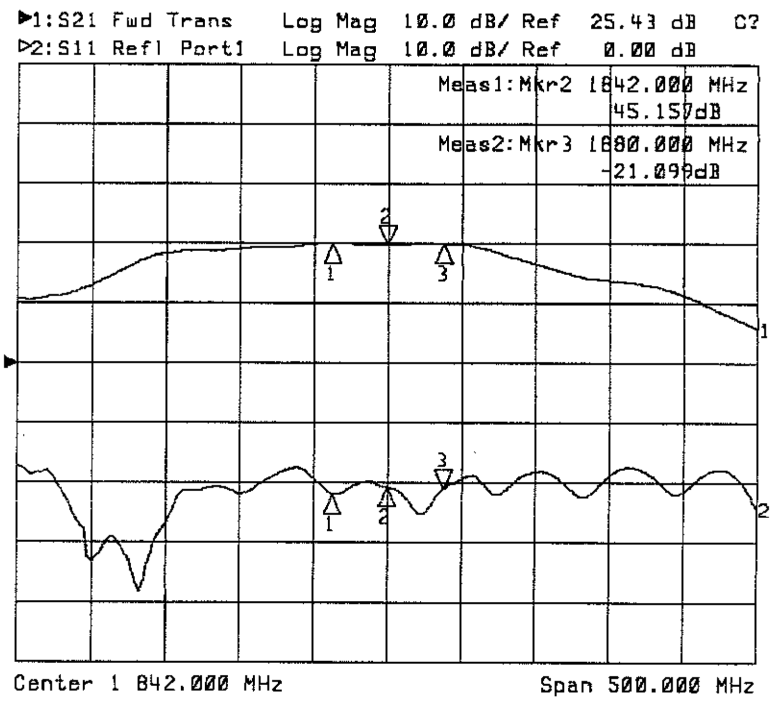


Figure 4: Cubic predistorter block diagram



GSM EDGE

Figure 5 Block representation of the RF PA



1:Mkr (MHz)	dB	2:Mkr (MHz)	dB
1: 1805.0000	45.458	1: 1805.0000	-21.923
2> 1842.0000	45.157	2: 1842.0000	-20.691
3: 1880.0000	45.376	3> 1880.0000	-21.099

Figure 6 Small signal measured results of the RF PA

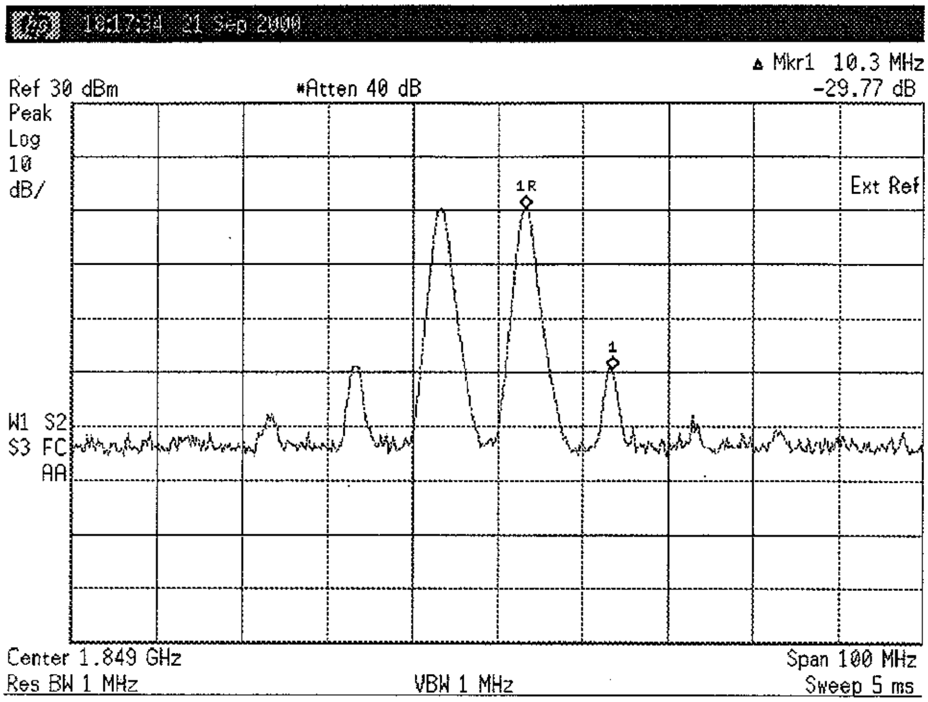
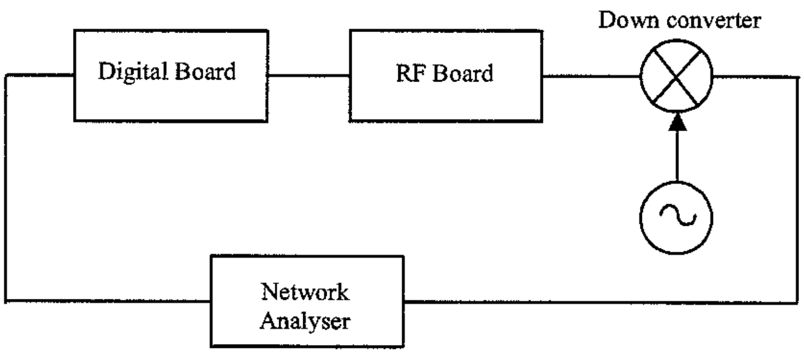
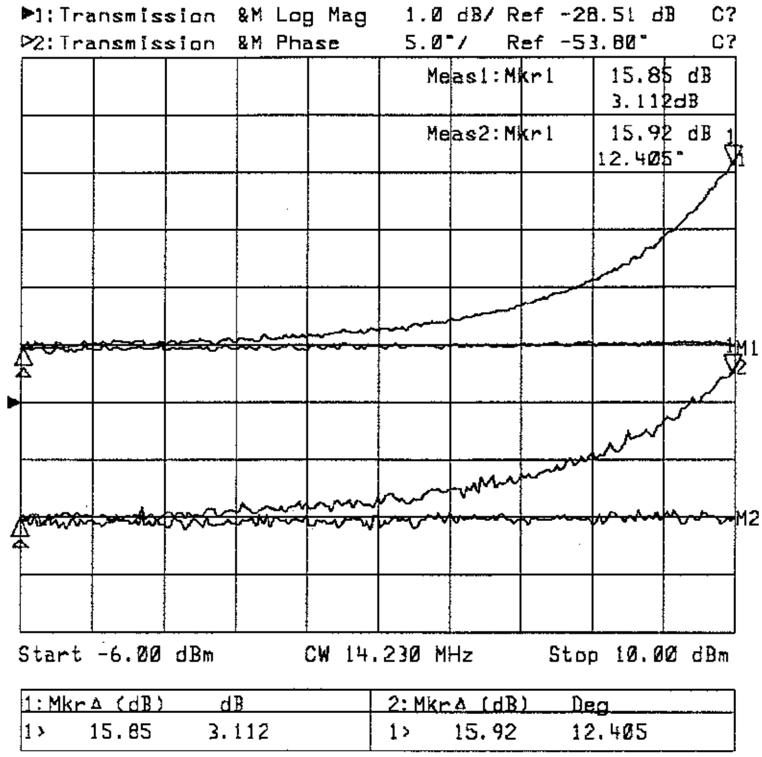


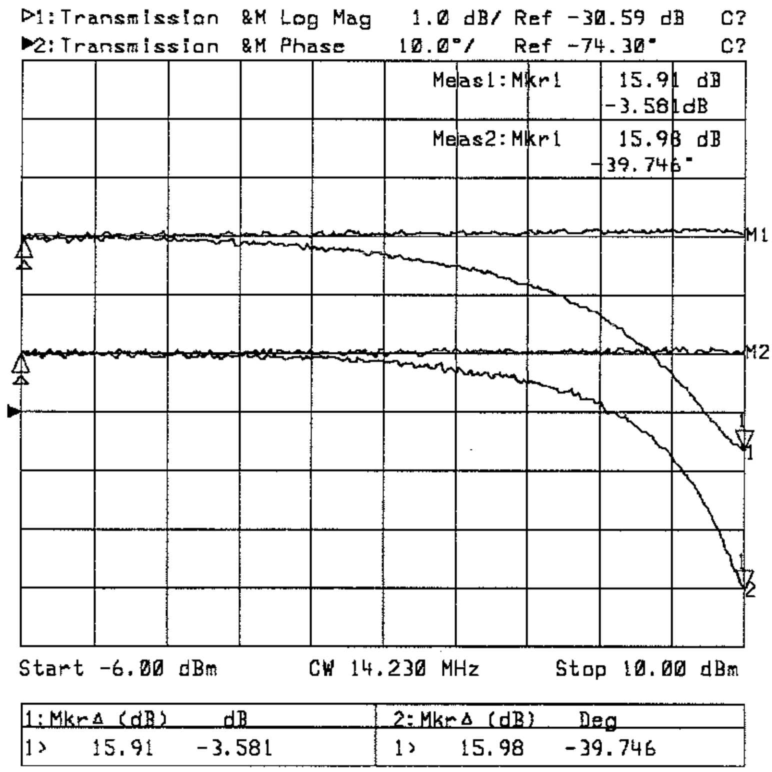
Figure 7 Two tone measured result



(a)

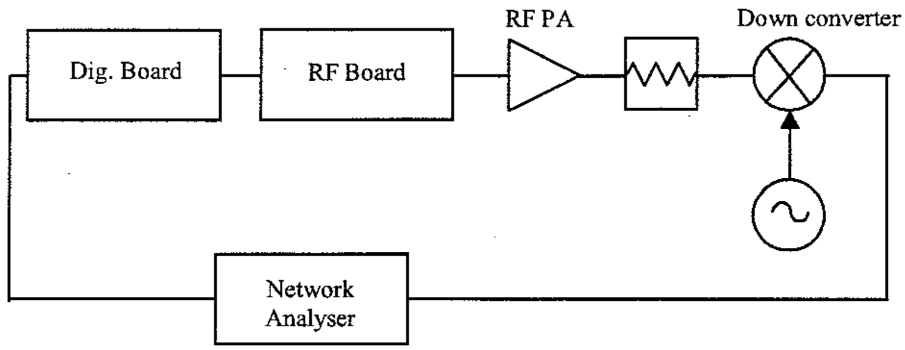


(b)

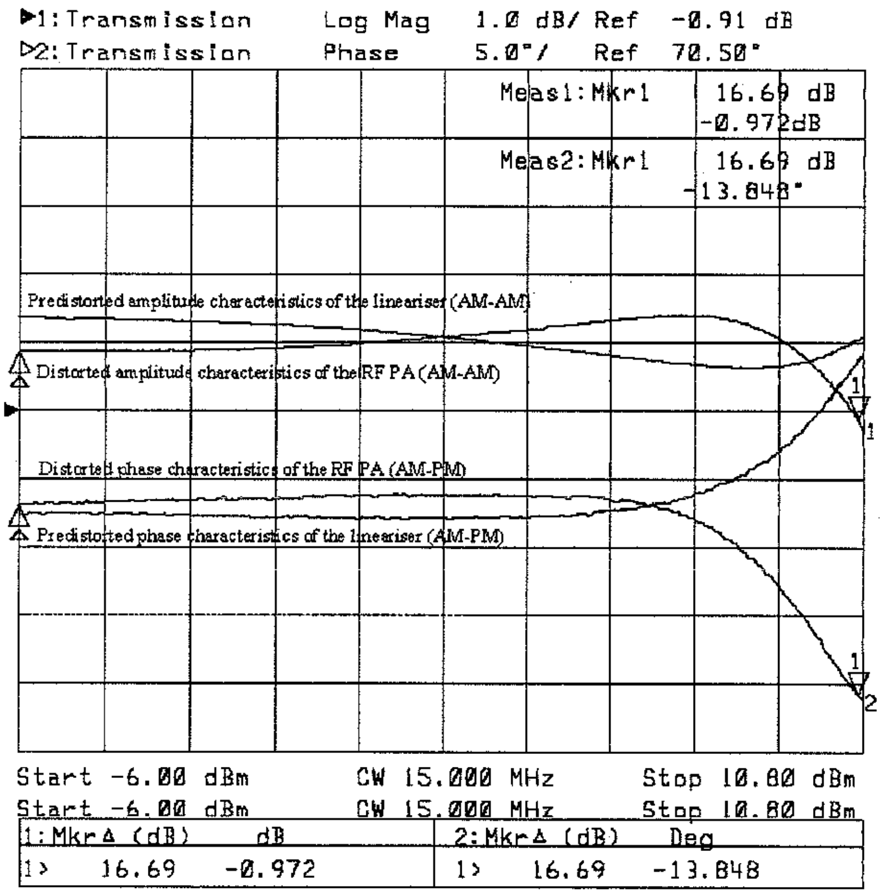


(c)

Figure 8 Power sweep setup of the predistorter, (a) measurement setup and (b) gain expansion and phase advance and (c) gain compression and phase lag.



(a)



(b)

Figure 9 Power sweep setup for the system, (a) measurement setup and (b) power amplifier characteristics and corrections.