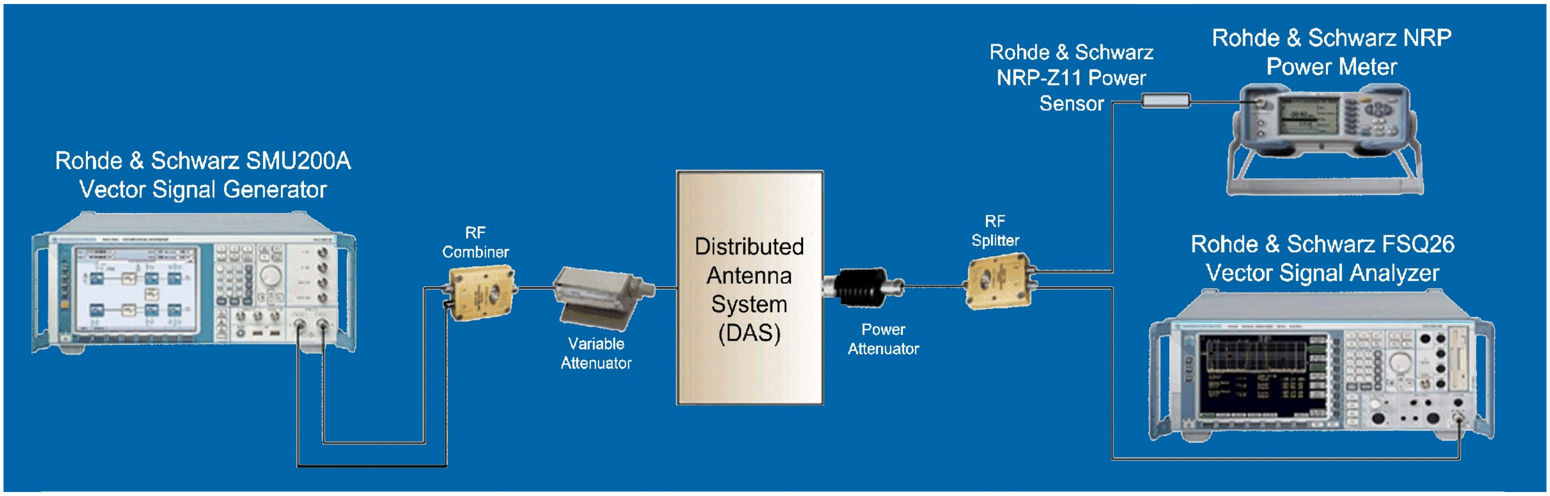

Rohde & Schwarz products: Vector Signal Generator R&S®SMU200A, Vector Signal Analyzer R&S®FSQ26, Power Meter R&S®NRP, Power Meter Sensor R&S®NRP-Z11

Experimental Study of 3G Signal Interaction in Nonlinear Downlink RAN Transmitters

Application Note 1MA110

Abstract - While RF communication signal distortions in nonlinear transmission paths have been predicted theoretically and studied experimentally for various signals, it is interesting to examine a wideband nonlinear system reaction to a wideband 3G signal and a narrowband 2G signal. Research and testing have demonstrated that, while most vital signal parameters remain within the limits specified by applicable standards even if composite signal power approaches specified maximum power, a relatively high level of spurious emissions caused by cross- and intermodulation can result. To avoid degrading both existing and new systems, this and other signal quality issues must be considered when designing and deploying multitechnology systems.

Reprint of: Igor A. Chugunov, Aleksey A. Kurochkin, Alex M. Smirnov
EXPERIMENTAL STUDY OF 3G SIGNAL INTERACTION IN NONLINEAR DOWNLINK RAN TRANSMITTERS
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Contents

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1 Abstract

While RF communication signal distortions in nonlinear transmission paths have been predicted theoretically and studied experimentally for various signals, it is interesting to examine a wideband nonlinear system reaction to a wideband 3G signal and a narrowband 2G signal. Research and testing have demonstrated that, while most vital signal parameters remain within the limits specified by applicable standards even if composite signal power approaches specified maximum power, a relatively high level of spurious emissions caused by cross- and intermodulation can result. To avoid degrading both existing and new systems, this and other signal quality issues must be considered when designing and deploying multitechnology systems.

2 Introduction

This paper presents the experimental study of signal distortion in third generation (3G) radio access network (RAN) downlinks caused by nonlinearity. The common nonlinear element in downlink transmitters is the power amplifier (PA); however, in a distributed antenna system[1] (DAS), the up and down converters and digitizers may be factors as well. Most contemporary base station (BS) transmitters and DASs use multichannel PAs, which only increase nonlinear distortion. The amplification of several signals leads to cross-modulation in addition to other well-known phenomena, such as saturation and intermodulation (IM). Cross-modulation is a fundamental performance-limiting factor that is responsible for co-site interference and jamming [1]. It is especially important to evaluate cross-modulation and accompanying nonlinear phenomena in wideband nonlinear radio frequency (RF) systems such as DASs, which may distribute and amplify the communication signals of various technologies.

[1] Distributed antenna systems, or DASs, have been widely implemented in state-of-the-art cellular communication systems to cover spots with poor or no coverage. Such spots can occur within the cell coverage area due to shadowing, building attenuation, terrain or clutter features, etc. A DAS usually consists of a central unit, or hub, and several radio heads interconnected by cables. In a typical case, the hub is fed by the signal(s) from a BS, while radio heads are distributed across the area of coverage (indoor or outdoor installation). A DAS can be analog or digital; i.e., the communications between hub and radio head via cable can be in analog or digital format. Digital DASs offer several advantages, including two especially desirable features: precisely controlled signal delays between hub and radio heads and great tolerance to cable attenuation.

3 Background

Major cellular and personal communication system (PCS) carriers in the US have implemented global system for mobile communications (GSM) technology (along with general packet radio service [GPRS] or enhanced data rates for GSM evolution [EDGE] data service) and are adding universal mobile telecommunication system (UMTS) wideband code division multiple access (WCDMA) service to their networks. The downlink signals of these technologies are likely to be mixed at low power levels and then amplified in one multichannel amplifier. Similar multichannel amplification (along with other signal transformation) takes place in a multicarrier DAS, which is widely used to provide coverage in complicated areas. Consequently, the problem of signal interaction in the case of multichannel, multitechnology amplification becomes significant. This paper focuses on the practical aspects of overlay deployment of WCDMA on a GSM network and, specifically, on the results of co-amplification and co-processing of the two signals at the same site in the same transmission path.

Nonlinear distortions of communication signals are well known and have been studied widely. References cited here focus on the study of wideband signal (CDMA and the like) behavior in nonlinear systems. In a theoretical and experimental study of cross-modulation in multichannel amplifiers [1], cross-modulation was examined for CDMA Interim Standard 95 (IS-95) signals in the presence of a single tone being offset in frequency. Based on computer simulation confirmed by measurements, it was shown that cross-modulation manifested itself as two band-limited spectral components centered at the tone frequency and at the CDMA carrier frequency. The distortions of a single WCDMA signal were examined in [2], and distortion and interaction of two WCDMA signals were analyzed in [3]. The case of a single CDMA (IS-95) signal was studied in [4]. Although [5] examined the performance of a WCDMA 1900 MHz system in the presence of a GSM interferer, this study was aimed at evaluating high-level system parameters such as coverage and capacity. Moreover, the GSM interferer was assumed to have originated at a neighboring cell, and no comparable data was presented in [5]. Therefore, it was necessary to collect measurements from a nonlinear system. In this case, extensive measurements were taken of multitechnology (GSM and WCDMA) signals in a DAS.

4 Measurements of 3G Signal Parameters in DAS Fed By Signal Mixture

Based on the references cited above, the following metrics were chosen in this paper to characterize nonlinear distortions: (a) the level changes of adjacent/alternate channels and (b) modulation accuracy degradation. In addition, cross modulation was qualitatively characterized. The observed nonlinear signal impairment was not attributed to a specific component of the DAS (amplifier, down converter, etc.).

The measurements presented here were taken using various Rohde & Schwarz devices: an SMU200A vector signal generator, an FSQ26 vector signal analyzer (which can also operate as a spectrum analyzer), and an NRP-Z11 power meter. The input signals for the transmission device to be studied were forward link GSM and frequency duplex division (FDD) WCDMA signals imitated by the SMU200A vector signal generator. GSM signals contained all eight active time slots; five were full-rate voice slots and three were EDGE slots. (It should be noted that the proportion of EDGE and GSM slots was arbitrary. The presence of one or more EDGE time slots affects the signal spectrum; however, the particular ratio of EDGE to GSM slots does not noticeably affect the system's response.) The WCDMA signal was a 3.84 Mchips/sec 3G signal with a spreading factor of 256 in the pilot channel, loaded with 64 physical channels, each with a 15 ks/sec rate.

Signal impairments were measured with the FSQ26 vector signal analyzer using its firmware options for Third Generation Partnership Project (3GPP™)-compliant signals. For spectrum scans, resolution bandwidth (RBW) was set to 30 kHz, with video bandwidth (VBW) of 100 kHz; the power reference level and frequency scan parameters were adjusted in accordance with output signal characteristics. The composite output power was monitored by the power meter. Figure 1 depicts the measurement setup.

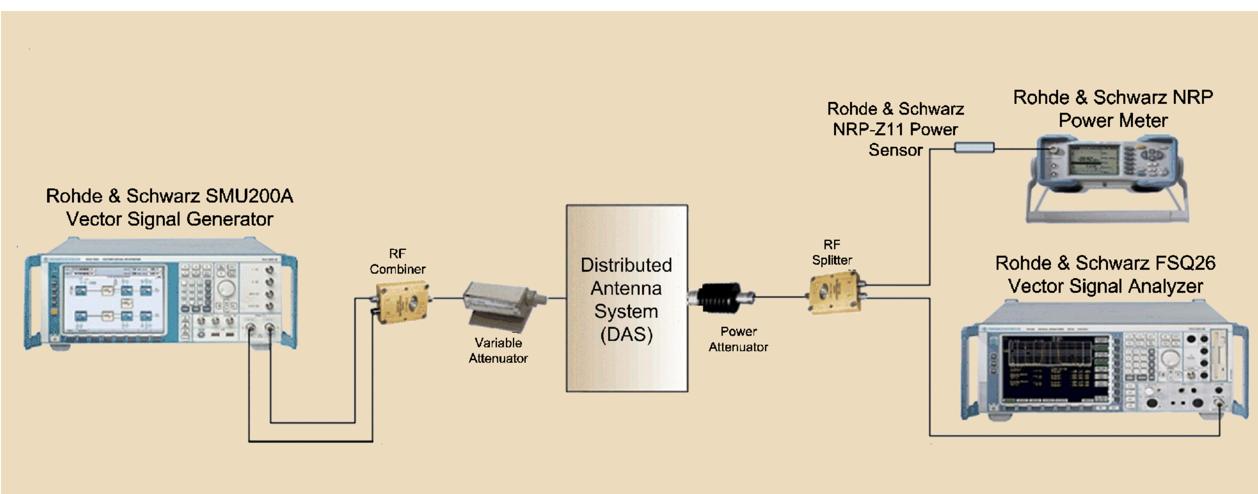

Figure 1. Measurement Setup Diagram

A typical multichannel DAS having one central unit and one remote radio unit interconnected by digital cable was used as a subject of study. It operated in the North America PCS frequency band (1900 MHz). Only the forward path (downlink) of this wideband system was investigated.

As a part of system baselining, common measurements included a 1 dB compression point, a third-order intermodulation intercept point (IIP3), and input saturation power measurements. The measurements were needed to define the maximum output power of the PA radio unit for a continuous wave (CW) signal. Later in this paper, the maximum output power value is used as a reference point for power/spectrum measurements, and all signal parameters are evaluated relative to power backoff (BO), which is the difference between current composite output power and maximum output power for a sine wave signal. This kind of presentation of results is more general than a simple relationship to output power. It should be noted that the maximum power value obtained in the evaluation strictly equals the maximum composite power specified by the manufacturer.

5 Cross-Modulation Study

Cross-modulation was studied for a mix of GSM and WCDMA signals with various GSM-to-WCDMA mean power ratios. The spectral diagrams in Figures 2 and 3 show two cases: P_{GSM}/P_{WCDMA} = 15 dB and P_{GSM}/P_{WCDMA} = 0 dB, with BO being a parameter. In these diagrams, relative power value is defined as output power less maximum output power. Signal carrier frequencies were 10 MHz apart and were placed in different sub-bands of the 1900 MHz PCS frequency band.

Figures 2 and 3 reflect the whole spectrum of nonlinear phenomena. The WCDMA spectrum demonstrated regrowth when IM and cross-modulation products appeared around the fundamental WCDMA spectrum. The cross-modulation products also showed up around the narrow-band GSM spectrum, and third-order IM products appeared at 10 MHz below the GSM carrier spectrum and at 10 MHz above the WCDMA carrier spectrum.

As expected, the cross-modulation level was inversely related to power BO.

The fact that the products of GSM-to-WCDMA cross-modulation were centered around the GSM spectrum, i.e., in a sub-band other than that occupied by the WCDMA signal, is important. At the same time, IM products were observed in yet another sub-band. In other words, transmitter spurious emissions (in the form of nonlinear products) polluted neighboring sub-bands of the forward 1900 MHz band. Figure 4 shows the relative power level of IM products in upper neighboring sub-bands versus power BO, with P_{GSM}/P_{WCDMA} being a parameter.

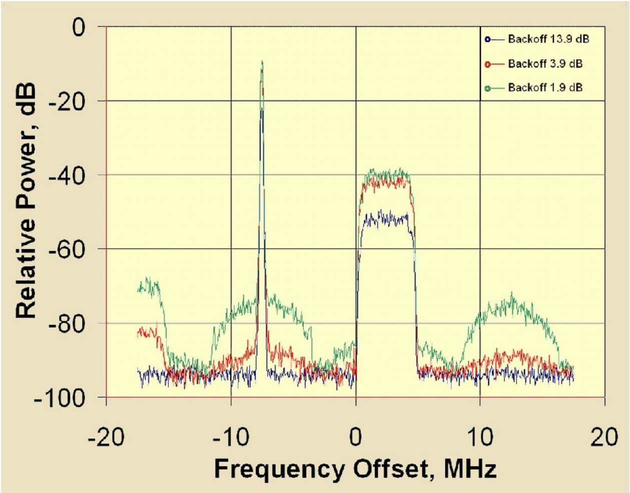

Figure 2. Output Spectrum, P_{GSM}/P_{WCDMA} = 15 dB

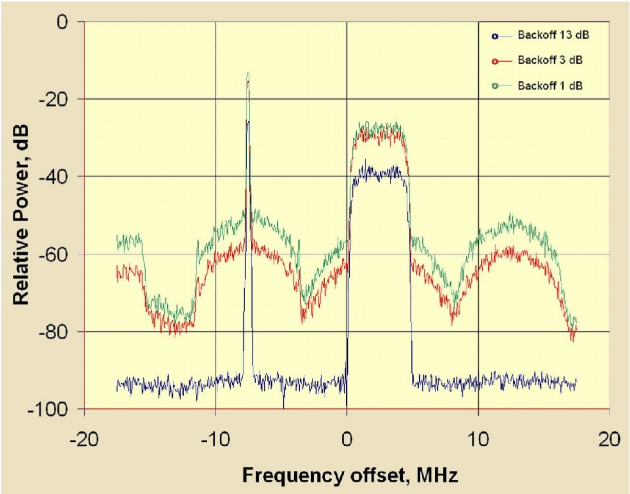

Figure 3. Output Spectrum, P_{GSM}/P_{WCDMA} = 0 dB

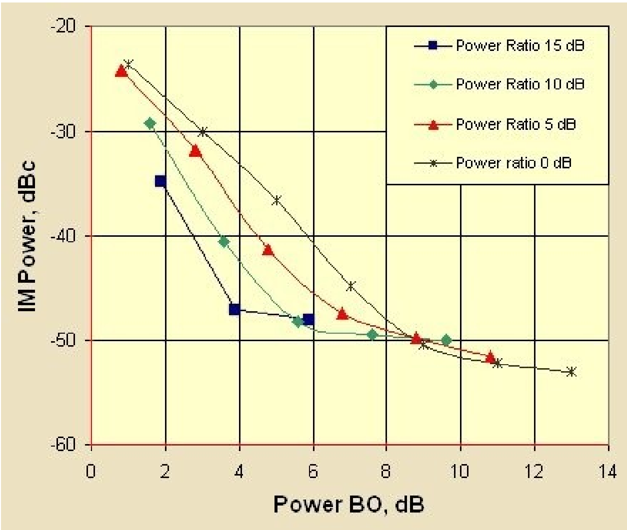

Figure 4. Relative IM Power Versus Power BO

6 Intermodulation Study: Adjacent and Alternate Channel Levels

In the same signal mix, levels of adjacent channel leaking ratio (ACLR) for WCDMA channels and alternate channel power ratio (AltCPR) for GSM channels were evaluated. While ACLR is defined in the respective 3GPP specification [6], no definition of either adjacent or alternate channels appears in the GSM 3GPP specification for transmitters [7]. Instead, an emission spectrum mask is defined for GSM signals. For this paper, an alternate channel level with an absolute frequency offset value between 400 kHz and 600 kHz was chosen to characterize IM distortion of a GSM signal. The GSM 3GPP specification for transmitters [7] states that the level of this channel must be -60 dBc or less. Figures 5 and 6 show neighboring channel levels for both WCDMA and GSM signals, with the P_{GSM}/P_{WCDMA} ratio being a parameter.

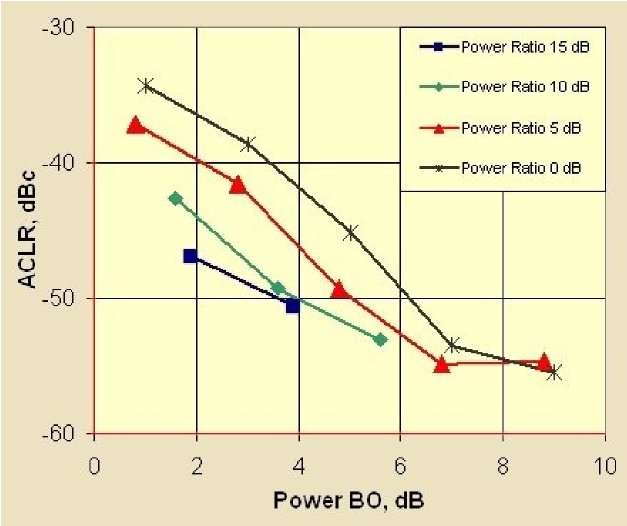

Figure 5. WCDMA ACLR Versus Power BO

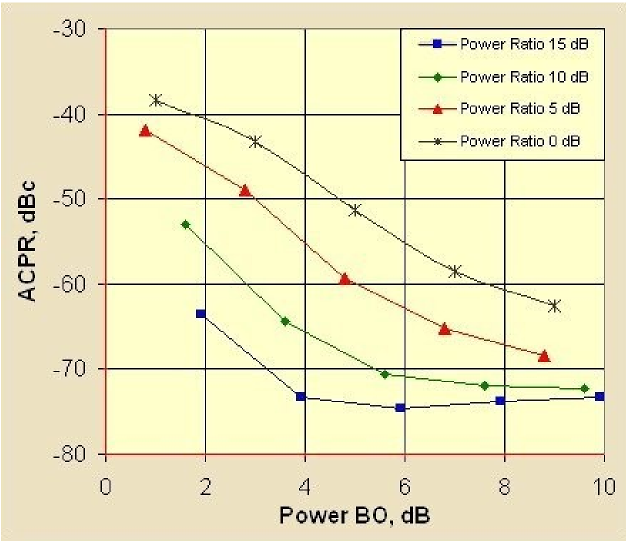

Figure 6. GSM ACLR Versus Power BO

The WCDMA ACLR level remains within the range specified in [6], even in the worst case (P_{GSM}/P_{WCDMA} = 0 dB, power BO = 1 dB). The ACLR level just approaches the value of -33 dBc specified in [6]. At the same time, the GSM alternate channel level easily rises above the value specified in [7] as soon as power BO decreases to 7 dB or less (assuming roughly equal mean powers for both signals).

7 Modulation Accuracy Study

For GSM, phase error measurements did not reveal any substantial dependence on power BO or power ratio. Phase error values remained well below the level specified in [7], even in the worst case.

Modulation accuracy indicators for the WCDMA signal demonstrated a different behavior. These indicators exhibited degradation as power BO decreased. Figures 7 and 8 show the dependence of three major accuracy indicators (peak code domain error [PCDE], error vector magnitude [EVM], and Rho) on power BO.

Measurements showed that modulation accuracy stayed within the limits specified by [6].

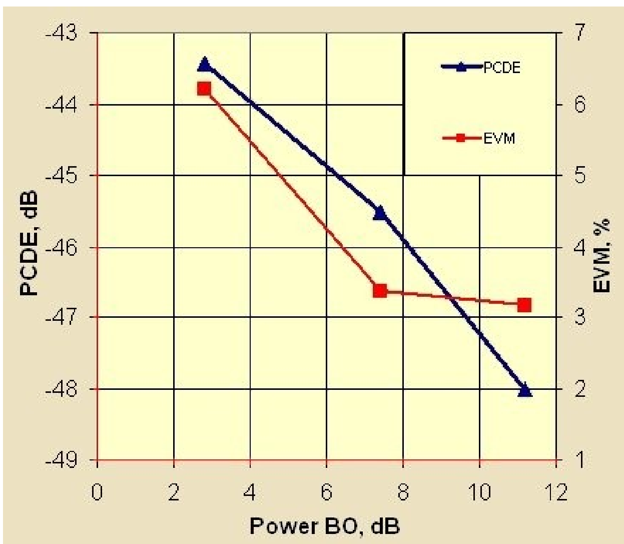

Figure 7. PCDE and EVM Versus Power BO

Figure 8. Rho Versus Power BO

8 Network Design Implications

The use of nonlinear devices in the downlink path leads to elevated levels of spurious emissions as well as to an increase in neighboring channel levels. Such emissions can cause unwanted interference with the signals of other systems, either through overlapping coverage or by being amplified in the same downlink path (except for a sole radiator in an isolated area, such as a single DAS radio head within the building). Therefore, steps need to be taken at the network planning stage to eliminate interference.

When performing link budget and expected coverage radius calculations, the network planner should properly identify the allowable composite output power of the PA. An amplifier should not be driven to the maximum power specified for a CW signal. This is why attention must be paid to the type of maximum output power stated in the manufacturer's specifications[2]. It is important to distinguish between statements of (a) maximum CW power and (b) maximum mean WCDMA power.

In case (a), the maximum composite power of all signals in the mix (taking into account future RF channel addition) must be at least 7 dB less than that specified by the manufacturer. For case (b), the stated power value should be used as a maximum composite of all signals (even if some signals in the mix are GSM). Such an approach, although somewhat conservative, allows interference to be eliminated, reduces the noise floor level, and only negligibly degrades the modulation accuracy indicators in the downlink.

[2] Brief Internet research on six major amplifier/DAS manufacturers by the authors showed that a wide variety of power values exists: maximum power for sine wave, maximum power for one or more WCDMA signals, maximum power for GSM signals, and even all of these values for one product. None of the manufacturers provided data for signal mix, however.

A simplified link budget calculation for a known CW power output is given in Table 1. In this hypothetical example, a DAS with a maximum CW output power of 30 dBm (0 dBW) was intended to radiate two signals with equal mean power. Note that the maximum output power per radio channel was determined by taking power BO into account.

RX BAND FREQUENCIES (MHZ)			
BS/DAS	1850 1865	SU	1830 1845
FORWARD LINK		**REVERSE LINK**	
BS/DAS Antenna Gain (dBd)	10.5	SU Antenna Gain (dBd)	0
Max Amplifier Output CW Power (dBW)	0	Amplifier Output Max (W)	0.2
Power BO (dB)	**7**		
Number of RF Channels/Antenna	2		
Max Amplifier Output/Channel (dBW)	-10		
BS/DAS to Antenna Cable Run (m)	6	SU to Antenna Cable Run (m)	0
SU Diversity Gain (dB)	0.0	BS/DAS Diversity Gain (dB)	0.0
BS/DAS Receive Sensitivity (dBm)	-105	SU Receive Sensitivity (dBm)	-105
LINK BUDGET CALCULATION AREA			
Central Frequency for Calibration (MHz)	1890		1890
BS/DAS RF Cable Loss (dB)	0.64	SU RF Cable Loss (dB)	0
FW Max Allowable Path Loss (dB)	134.9	RV Max Allowable Path Loss (dB)	138.5
Suggested Amplifier Output/Channel (dBW)	-10		
Suggested Amplifier Output/Channel (W)	0.1		
Balanced Model ERP (dBm)	29.9	System ERP (dBm)	29.9
Balanced Model ERP (W)	1	System ERP (W)	1
		Balanced Link (dBm)	**134.9**

Table 1. Link Budget Calculation - 30 dBm maximum CW Output Power

9 Conclusions

Signal interaction and signal parameter degradation were experimentally studied for the GSM/WCDMA signal mix that was processed and amplified by the DAS sample. The study showed that when power BO decreased below 7 dB, most of the signal quality metrics degraded.

Nonetheless, the metrics were still within the limits defined by the respective recommendations in [6] and [7]. One exception, however, was the AltCPR for GSM signals. If GSM and WCDMA mean powers were roughly equal and BO fell below 7 dB, the alternate channel level exceeded the value specified in [7].

Another phenomenon to be considered is power leakage into neighboring sub-bands caused by cross- and intermodulation. For signal co-amplification in various sub-bands by a DAS (the most likely use of a DAS), such leakage might cause serious interference problems. To avoid the degradation of both existing and new systems, these signal quality and interference issues must be taken into account when designing and deploying multitechnology systems.

These manifestations of nonlinearity have direct implications for link budget calculations in the network planning process if a multichannel PA is intended to amplify a GSM/WCDMA signal mix. In determining downlink output power, the PA must not be driven to the maximum power specified for a CW signal. Instead, the composite mean power of all signals to be amplified must be at least 7 dB less than the maximum specified power. Under this condition, the system will not cause harmful interference in either occupied or neighboring sub-bands.

As a follow-on to the study of possible nonlinear communication signal distortions, future research steps might focus on a theoretical and experimental examination of the downlink performance in cellular or PCS networks. The presence of nonlinear products in the BS or DAS emissions reduces the signal-to-(interference + noise) ratio and could degrade vital system parameters such as coverage, interference level, probability of successful call setup, and dropped calls. The study should evaluate the possible dependence between system performance and equipment nonlinearity.

A similar study of uplink performance would also be valuable.

10 Abbreviations and Terms

3G	3rd generation (of mobile communication systems)
3GPP	3rd Generation Partnership Project
ACLR	Adjacent Channel Leaking Ratio (defined for WCDMA)
AltCPR	Alternate Channel Power Ratio (for GSM)
BO	Power Back-Off
CDMA	Code Division Multiple Access system
CW	Continuous Wave (sine wave signal)
DAS	Distributed Antenna System
dB	Decibel (logarithmic ratio of the two values)
dBc	Power level of interfering signal in relation to carrier power
dBd	Unit of antenna gain measurement in relation to the gain of dipole antenna
dBm	Unit of power measurement in relation to 1 mW
dBW	Unit of power measurement in relation to 1 W
EDGE	Enhanced Data Global Evolution for GSM
EVM	Error Vector Magnitude
ERP	Effective Radiated Power
FDD	Frequency Division Duplex
FW	Forward path (from base station to phone) in cellular network; same as downlink
GPRS	General Radio Packet Service
GSM	Global System for Mobile communications
IIP3	Input Intermodulation Point of 3rd order
IM	Intermodulation
IS-95	Interim Standard no. 95, describing CDMA communication system
MHz	Megahertz (frequency measurement unit)
PA	Power Amplifier
PCDE	Peak Code Domain Error
PCS	Personal Communication System
RAN	Radio Access Network
RBW	Resolution Band Width (in spectrum analysis)
RF	Radio Frequency
RV	Reverse path (from phone to base station) in cellular networks; same as uplink

SU	Subscriber Unit
UMTS	Universal Mobile Telecommunication System
VBW	Video Band Width (in spectrum analysis)
WCDMA	Wideband Code Division Multiple Access system

11 References

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12 Biographies

Igor Chugunov is currently a senior engineer in the Bechtel Telecommunications Training, Demonstration, and Research (TDR) Laboratory in Frederick, Maryland. He is experienced in wireless network design and optimization, as well as in software and hardware testing. His engineering background gives him both theoretical and practical knowledge of wireless access technologies.

Before joining Bechtel, Igor was a senior RF engineer with Cingular Wireless and Hughes Network Systems, where he designed radio access networks for data and voice communication.

Igor has an MSEE/CS degree from Kazan Tupolev State Technical University, Russia.

Aleksey Kurochkin, executive director of Site Development and Engineering for Bechtel Telecommunications, manages the Network Planning and Site Acquisition departments. He is responsible for process and team integration and oversees the functional operations of more than 300 telecommunications engineers, specialists, and managers. Aleksey is also a member of Bechtel's Chief Engineering Committee, Global Technology Team, and BTTJ Editorial Council.

Formerly, Aleksey was senior director, Network Planning, in Bechtel's Telecommunications Technology group, which he originated. He also introduced the Six Sigma continuous improvement program to this group. Aleksey is experienced in international telecommunications business management and network implementation, and his engineering and marketing background gives him both theoretical and hands-on knowledge of most wireless technologies.

Before joining Bechtel, Aleksey established an efficient multiproduct team at Hughes Network Systems, focused on RF planning and system engineering. In addition to his North American experience, he has also worked in Russia and the CIS.

Aleksey has an MSEE/CS degree in Automatic Telecommunications from Moscow Technical University of Communications and Informatics, Russia.

Alex Smirnov is currently a test engineer in the Bechtel Telecommunications Training, Demonstration, and Research (TDR) Laboratory in Frederick, Maryland. He conducts tests and prepares test reports for telecommunications equipment. He has also performed DAS testing to demonstrate product compliance with functional specifications for Cingular Wireless. Earlier, as a network planning engineer, he planned and designed an FTTP project for Maryland and Delaware.

Before joining Bechtel in 2004, Alex was an electronic engineer at Technology Device International, Inc., and Re-Certify, Inc. He has over 10 years of information technology experience in all areas of life-cycle program development, including analysis, design, maintenance, support, and testing of various systems and platforms.

Alex holds a master's degree in Science and Optical Engineering from Moscow State University, Russia. In addition, he has a bachelor's degree in Financial Management from the Russian Academy of Management, Moscow.

13 Additional Information

This Application Note is a reprint of

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14 Ordering Information

Name	Description	Ordering number
Vector Signal Generator		
R&S® SMU200A		1141.2005.02
R&S® SMU-B102	RF Path A: 100 kHz to 2.2 GHz	1141.8503.02
R&S® SMU-B103	RF Path A: 100 kHz to 3 GHz	1141.8603.02
R&S® SMU-B104	RF Path A: 100 kHz to 4 GHz	1141.8703.02
R&S® SMU-B106	RF Path A: 100 kHz to 6 GHz	1141.8803.02
R&S® SMU-B202	RF Path B: 100 kHz to 2.2 GHz	1141.9400.02
R&S® SMU-B103	RF Path B: 100 kHz to 3 GHz	1141.9500.02
R&S® SMU-B10	Baseband with ARB (64 Msamples)	1141.7007.02
R&S® SMU-B13	Baseband Main Module	1141.8003.02
R&S® SMU-K42	Digital Standard 3GPP FDD	1160.7909.02
R&S® SMU-K43	3GPP Enhanced Tests	1160.9660.02
Signal Analyzer and Options		
R&S® FSQ3	20 Hz to 3.6 GHz	1155.5001.03
R&S® FSQ8	20 Hz to 8 GHz	1155.5001.08
R&S® FSQ26	20 Hz to 26,5 GHz	1155.5001.26
R&S® FS-K72	Application Firmware 3GPP-FDD BTS Transmitter Test	1154.7000.02

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