# DESIGN CONSIDERATIONS FOR MULTI-CARRIER CDMA BTS POWER AMPLIFIERS

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Keywords: Power amplifiers, amplifier linearization, multi-carrier CDMA, multi-tone testing, feed forward, pre distortion, cellular design, 1 dB compression point, PAPR, BTS, emission mask, Gaussian distribution.

Abstract: System manufacturers that provide wireless telecommunications equipment to cellular operators, often do not manufacture their own transceivers. They get their own supplies from various base station power amplifier vendors. Unfortunately cellular operators and system providers take design considerations of those primary power amplifiers for granted. The consequences are: Operators are overpaying for base station amplifiers to meet power and capacity demands. Base stations are complicated systems and the optimum technical design considerations of the power amplifier sub-systems have a major impact on multi-carrier Code Division Multiple Access (CDMA) Base Transceiver Station (BTS) performance. This paper discusses those power amplifier vendor claims, demonstrates design considerations and economic design solutions of consequent savings for the operator, based on a realistic market case. We realize that upfront savings, in power amplifier units, in a US market of approximately 550 multi carrier basestation sectors would exceed $ 10 M.

## 1 INTRODUCTION

Capacity enhancement of the 3G CDMA 2000 network rests essentially upon the optimized performance of the multi-carrier amplifier in the BTS. This is because the CDMA channel capacity, is primarily power dependent. The input 1dB compression point is a quantity measure of the amplifier linearization. It is defined as the input power value where the corresponding output power falls by 1 dB from the linear slope of the amplifier output characteristic curve. An underestimated power backoff from the 1 dB compression point, necessary to restrain occurring peaks from entering the saturation region in the BTS amplifier would result in a non-linear output performance, an increase in the BER and consequently an increase in the dropped call rate. An overestimated power backoff on the other hand, has two major drawbacks:

- Inefficient power utilization of the BTS amplifier.
- Possible increase in amplifier size and uneconomic cost impact (Price roughly doubles for every extra 3 dB requirement in the amplifier's max. power output)

The problem here is that some vendors are reluctant to provide essential information on BTS amplifier specifications pertaining to backoff power requirement.

An assumption of 12 dB backoff power requirement is taken for granted by many vendors. Indeed, a large 12 dB backoff is a major drawback in OFDM (Orthogonal Frequency Division Multiplexing) technology which is definitely not the case in multi-carrier CDMA 2000. Unlike multicarrier CDMA amplifiers, the required power backoff in OFDM amplifiers is research and experimentation proven. Unfortunately, CDMA amplifier vendors, take the OFDM backoff power of 12 dB for granted and apply it on CDMA amplifier design. On a different front, CDMA operators aspire for having up to 6 carriers per BTS amplifier, despite the CDMA vendors accepted restriction on power backoff in CDMA amplifier design.

Hence the objectives of this paper are three folds:

- To get a better understanding of the backoff power BTS amplifier design requirements and promote consequent awareness amongst major cellular operators and vendors.
- To shed some light on current multi-carrier BTS amplifier considerations of a CDMA

2000 cellular operator in an interesting US market.
- To simulate a multi-carrier example and compare it to a single carrier case.

An example will be shown to demonstrate an actual case in a real multi-carrier CDMA 2000 scenario.

# 2 MODELING

## 2.1 Assumption

Two cases representing a two-tone signal and a nine-tone signal were considered. The two-tone signal is a representation of a real-time sinusoidal signal in the frequency spectrum domain. The nine-tone signal, on the other hand, may be considered as a real-time sum of four sinusoidal signals in the frequency domain with a DC component in the middle of the spectral symmetry.

The frequency deviation between two successive tones was considered to be 1.25 MHz. The effect of amplitude variation of the individual tones was, however, not considered since the application of a suitable modulation scheme would take care of that. Consequently, the isolation of the amplitude change of the individual tones would only allow for the effect of the phase variation together with the effect of the peak to average power ratio of the input signal to be studied.

## 2.2 Simulation

The baseband nine-tone signal is simulated by considering an array of size (257x1), with zero values except for the middle part representing the nine tones i.e. nine spectral lines of equal amplitude and uniformly random phase, in the frequency domain. A random generator in the MATLAB software is used to generate nine uniformly distributed random numbers between zero and one. These numbers are manipulated to convert the original range to a modified one between -1 and +1. The numbers are then multiplied by 180 to simulate the random phases of the nine tones (i.e. four carriers) between -180 and +180 degrees. The Fourier transform of the array is computed and the absolute values of the resulting array are plotted, after normalization, to represent a clip of the nine-tone signal in the time domain.

Figure 1a shows the normalized nine-tone signal in the time domain while the uniformly random phase values generated in the composition of the resulting time varying signal are shown in Figure 1b.

A histogram of a close fit to a Rayleigh distribution of the multi-carrier signal resulted, as in Figure 2, after repeated generation of the uniform random phases. The Signal in Figure 1a was hence determined as relatively the nearest representative signal for multi-carrier BTS applications. The variation of input average power for two-tone and nine-tone signals versus same scale of input peak voltage, could then be determined, as shown in Figure 3. A constant power drop of 5.35 dB resulted, with the nine-tone variation of input peak voltage, indicating the relative back-off of input average power away from the 1dB compression point towards the amplifier linear region.
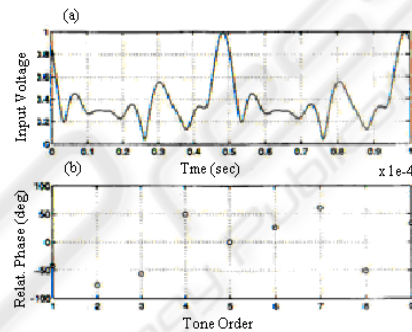


Figure 1: (a) Normalized nine-tone signal in time domain. (b) Uniformly random phase values.

# 3 TWO-TONE AND MULTI-TONE TESTING

## 3.1 Two-Tone Testing

The two-tone test has been the most common one for measuring the inter modulation distortion (IMD) of a power amplifier for many years. The test consists of two unmodulated carriers at the input port of the non-linerar amplifier (NLA) and the resulting Peak /Average Power Ratio (PAPR) is only 3dB.

In a multicarrier composite signal, the modulation of each tone determines the distribution of power within the peak/average range. The absolute PAPR of "n" modulated signals may be obtained using

$$P_n = 10\log(n) + P \qquad (1)$$

Where, P= PAPR of an individual signal in dBs
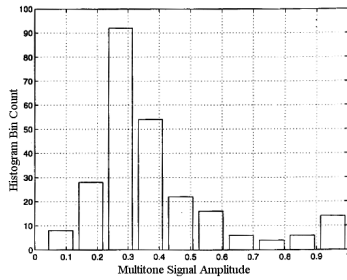$P_n$= PAPR of the composite signal.

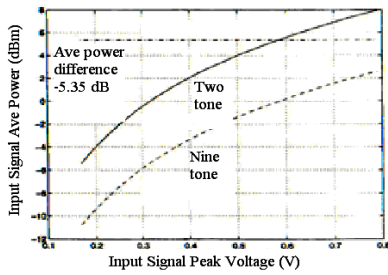Figure 2: Histogram of multi-tone signal in Figure 1a.



Figure 3: Comparative average signal input power versus signal peak voltage.

Figure 4 shows the 1 dB compression point, defined as the input power value; 6 dBm, at which the corresponding output power value drops by 1 dB from the extended slope solid slope line.
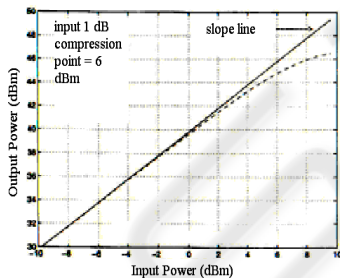


Figure 4: A modeled power amplifier power curve.

## 3.2 Multi-Tone Testing

It is important to note that PAPR of a CW multitone is a probability distribution, not a unique number. This is demonstrated in Figure 5 which shows a 16-tone CW signal distribution in which all carriers are locked to a common reference [7] (i.e. phase aligned). The same Figure shows a distribution of 16 tones but randomly phase modulated (much like a set of AMPS carriers). While the relative PAPR in both cases is 12 dB (i.e.10 $\log_{10}(16)$), the random phase case shows a much lower normalized power value at any shown probability of peak occurrence. Furthermore, because the carriers are independent

random variables, the central limit theorem implies a Gaussian distribution for a large number of carriers. Therefore the addition of more carriers would not increase the PAPR at a particular probability.
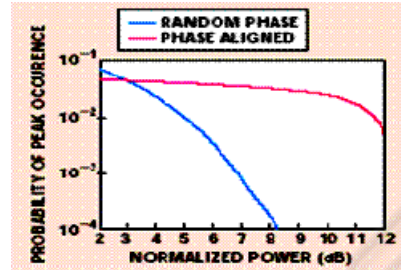


Figure 5: PAPR probability of 16-tone continuous signal.

The PAPR of a single-carrier CDMA signal may be rigorously calculated. The calculation becomes exceedingly complicated for multi carrier CDMA signals. For the purpose of this article, Figure 6 shows three different curves for CDMA PAPR distribution , comparing 3 different scenarios .
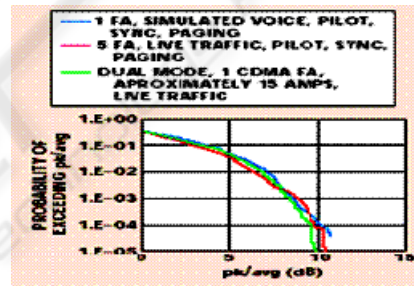


Figure 6: PAPR probability of a multicarrier CDMA signal.

It is interesting to observe that the three scenarios of a single CDMA carrier, 5 CDMA carriers and a dual mode live traffic of a CDMA carrier and 15 AMPS signals have close distributions. Below 1E-4 probability, for the multi-carrier scenarios the PAPR varies about a 10 dB value.

## 4 CDMA BACKOFF DESIGN REQUIREMENTS

In designing a CDMA power amplifier, here are a few factors to consider. These are:

- What is the IMD level resulting from maximum input power at the input of amplifier?
- What is the amplifier technology choice?

- What is amplifier correction technology choice?
- What is the PAPR probability threshold choice?
- Is the FCC spectral mask complied with?
- Is there a hard clipping requirement in the design?

## 4.1 Amplifier and Correction Technology Choices

### 4.1.1 Amplifier Technology Choices

Here are popular choices for amplifiers where gains are normalized to 1GHz bandwidth:

- Bipolar : IMD= -30 dBc, Gain = 8 dB
- LDMOS: IMD= -40 dBc, Gain = 11 dB
- GaAsFET: IMD= -45 dBc, Gain = 14 dB

### 4.1.2 Amplifier Correction Technologies

The following are linearization techniques of amplifiers where correction capacity means the range where the worst IMD (relatively largest magnitude) products reside, below the fundamental carrier, after linearization or correction takes place. Effective bandwidth of correction and relative cost are also indicated:

- Feedforward: Correction capacity from 30 to 35 dB, BW > 25 MHz, relative cost is high.
- Envelope Feedback: Correction capacity from 15 to 20 dB, BW< 5 MHz, relative cost is medium.
- Predistortion: Correction capacity from 3 to 7 dB, BW > 25 MHz, relative cost is low.
- Adaptive Predistortion: Correction capacity from 10 to 20 dB, BW= 10 to 15 MHz, relative cost is medium.

## 4.2 PAPR Probability Tolerance

A $10^{-4}$ probability that a signal would exceed its PAPR average value is a reasonable one that can be tolerated in the design of a power amplifier. In concept , when hard clipping an amplifier, a -20 dBc IMD is produced, with a $10^{-4}$ PAPR probability occurrence. This probability means a fraction of 1 in 10,000 signals. The IMD power works out to be $10\log_{10}(10^{-4})$ = -40 dB, below this -20 dBc level. A total -60dBc of IMD power level, below the fundamental power, would comply with the FCC spectral mask of the CDMA signal.

When examining Figure 6 for a relationship between probability of exceeding PAPR value and PAPR in dB for a realistic multicarrier CDMA signal, here is what can be observed:

- For $10^{-4}$ probability, PAPR ~ 10 dB
- For $10^{-3}$ probability, PAPR ~ 8 dB
- For $10^{-2}$ probability, PAPR ~ 6 dB
- For $10^{-1}$ probability, PAPR ~ 4 dB.

## 5 DESIGN CHOICES

The CDMA Emission mask (FCC Part 24 rules) calls out for better than -57 dBc at greater than 1.25 MHz offset.
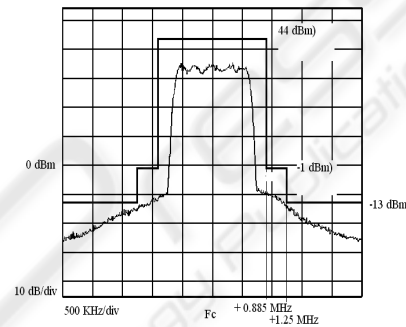


Figure 7: FCC CDMA Emission Mask.

The conventional design choice of amplifiers utilizes bipolar transistor technology with -30 dBc of IMD level and feedforward linearization with a minimum of 30 dB correction capability. This is -60 dBc of IMD level from the 1 dB compression point, which looks 3dB lower than the minimum required -57 dBc in the FCC CDMA Emission mask. A $10^{-4}$ probability of occurrence matches approximately a 10 dB PAPR value. This means going 10 dB below the -57 dBc level to meet the $10^{-4}$ probability of not exceeding the PAPR value. In other words this is only 7 dB below the calculated -60 dBc of IMD level which implies a 7 dB power backoff from the 1dB compression point.

More recently, the choice of amplifier technology has developed to GaAsFET with -45 dBc of IMD level and correction technology of adaptive predistortion linearization with a minimum 15 dB of correction capability at the 1 dB compression point. Again this is -60 dBc at the 1 dB compression point. For a change, a $10^{-3}$ distribution probability might be chosen to match a PAPR occurrence of 8 dB. This means going 8 dB below the -57 dBc level to meet the $10^{-3}$ probability of not exceeding the PAPR value. In other words this is only 5 dB below the calculated -60 dBc of IMD level which implies a 5 dB power backoff from the 1dB compression point.

# 6 COMMERCIAL BASESTATION AMPLIFIERS

Commercial basestation power amplifiers (PA) need be evaluated against the analyzed technology choices and design criteria, if cellular operators are to optimize the number of power amplifier units required in their multicarrier basestation network and save on capital and operational expenditure. Here are typical specifications of basestation power amplifiers, supplied by US PA vendors to system vendors of cellular operators:

- PA rated at 50W (47 dBm) maximum average power output per sector.
- Power available after insertion and cable losses equals 35.4 W.
- Input power backoff claimed to be 10 to 12 dB
- Nominal PA Gain = 58 dB.
- Conventional bipolar feedforward technology
- Maximum input average power = - 5 dBm.
- PA unit automatically reduces gain above -5 dBm to prevent it from being overdriven.
- Two cascaded PA units are required for two carriers and a maximum of three carriers (16-20 W per carrier).

## 6.1 Design Specs Implications

Considering a 47 dBm average power output per sector and the minimum claimed 10 dB input power backoff, this means that the average output power before backoff would work out 57 dBm. If now instead we consider the researched 7 dB backoff requirement, then the maximum average output power after backoff would be 57-7= 50 dBm ( 100 W).

Taking out the insertion/cable losses as referenced by the cellular operator vendor, the maximum available output power is now 70.8% x 100W = 70.8 W.

## 6.2 Lessons Learned

- Cellular Operator Vendors claim a maximum available transmission power of 35.4 W per power amplifier unit. Hence two cascaded power amplifier units would be required to accommodate up to three carriers, where each carrier is rated at 16 – 20 W.
- Our researched analysis shows that, based on a combination of a sufficiently conservative 7 dB backoff power consideration, the insertion/cable losses, Part 24 FCC spectral

mask and a maximum transmission power /carrier not exceeding 20 W, a single amplifier unit of 70.8 W should accommodate up to three carriers.
- The backoff power is not a hardware design specification. It should be possible, through the power amplifier unit software control to relax it from 10 or 12 dB down to a sufficient 7 dB value.
- A $10^{-4}$ probability (1 in 10,000 signal occurrences), that a multicarrier CDMA PAPR threshold would not be exceeded is a conservative one that can be met by a 7 dB power backoff and still be under the -57 dBc level dictated by the FCC emission mask.
- Estimated savings in sparing a 2nd power amplifier unit for a mere second carrier in a multicarrier deployment could well exceed $ 10 Million for less than 200 tri-sector cells.

## 6.3 Assessment of Risks

It is fair to assess some of the risks involved in optimizing the number of basestation amplifier units in a multi carrier cellular infrastructure. Life expectancy of the power amplifier would be an issue to some degree, depending on the output percentage power. Cooling the power amplifier, on the other hand, is a prime factor in maintaining its higher output power. The Mean Time Between Failures (MTBF) is impacted by the those conditions.

# 7 CONCULSIONS

- The analysis, in this article, is vendor specific, given the maximum information we could secure, at the time.
- Further analysis from other vendors would highly depend on obtaining the information, necessary for the analysis.
- Resolving the risk assessment factors would translate the value of implementing two and up to three carriers into a single 50 W Power Amplifier.
- There would be a definite cost saving in optimizing the number of amplifier units needed in a two and three carrier basestation/sector.
- We realized that upfront savings in a US market of approximately 550 multi carrier basestation sectors would exceed $ 10 M.

138

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