

RF multicarrier amplifier for third-generation systems

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Multicarrier transmitters traditionally have one power amplifier per carrier and a combiner circuit at the output, or they combine the carriers at low power level and then utilize a common multicarrier power amplifier (MCPA) for power generation. This latter solution seems to be simpler, but the need for high linearity—to avoid intermodulation distortion—makes the multicarrier amplifier more complex.

The modulation scheme in third-generation (WCDMA) mobile systems involves a high degree of amplitude modulation, which requires a certain amount of linearization even for single-carrier amplifiers. Notwithstanding, the high capacity and flexibility of the multicarrier amplifier makes it a logical choice for third-generation systems.

The authors describe the technical challenges and Ericsson's solution for building the MCPA for WCDMA.

BOX A, TERMS AND ABBREVIATIONS

3GPP	Third-generation Partnership Project
ACLR	Adjacent channel level ratio
ACP	Adjacent channel power
ADC	Analog-to-digital signal converter
DAC	Digital-to-analog signal converter
DC	Direct current
DSP	Digital signal processor
EPA	Error power amplifier
FF	Feed-forward
GaAs	Gallium-arsenide
LD-MOS	Lateral-diffusion metal-oxide semiconductor
MCPA	Multicarrier power amplifier
MPA	Main power amplifier
MTBF	Mean time between failures
RBS	Radio base station
RF	Radio frequency
Si	Silicon
TDMA	Time-division multiple access
WCDMA	Wideband code-division multiple access

RF power amplifier techniques

The composite RF signal is amplified and fed to the antenna via a transmitter band-pass filter (Figure 1). The coverage and capacity of the base station define the required amount of output power. Several transistor stages connected in series constitute the gain, and the final stage delivers the output power. High-power amplifiers often have multiple transistors connected in parallel at the output. Consequently, the output stage consumes large amounts of power. Silicon (Si) or gallium-arsenide (GaAs) field-effect devices are adequate choices at an operating frequency of 2 GHz.

The low-power stages at the input side are biased in a linear mode called class A. The high-power transistors operate in a more ef-

ficient but less linear mode called class AB. As seen from the input-output characteristics in Figure 2, class A mode is more linear for small signals.

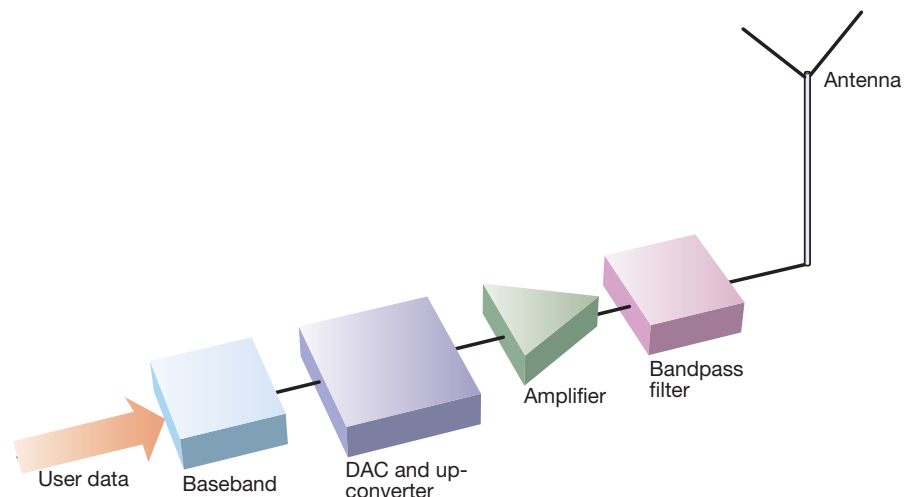
The complex modulation schemes in WCDMA systems have a high peak-to-average power relationship, which produces amplitude and phase distortion in non-linear amplifiers. This distortion is even more pronounced as the output power level of the amplifier approaches saturation. Some amplifiers also experience a memory effect—that is, the output signal at a given moment is affected not only by the instantaneous input signal, but also by the previous signal history. Distortion causes signal quality to deteriorate and adjacent channel power (ACP) to increase; it also gives rise to spurious emissions.

Amplifier efficiency is dependent on the characteristics of the power transistors and the bias scheme. Efficiency improves with higher output power, but distortion increases rapidly as the power level approaches saturation. The high peak-to-average power relationship is thus fraught with compromise.

Figure 3 shows a simulated example of how a two-carrier WCDMA signal is distorted by the gain transfer characteristic of the class AB amplifier. The figure shows the frequency spectrum before and after amplification. The output signal does not satisfy system requirements for spurious emissions.

The best solution for multicarrier amplifiers is to operate the power transistors in efficient but slightly non-linear class AB

Figure 1
Transmitter power amplifier in radio base station (RBS).



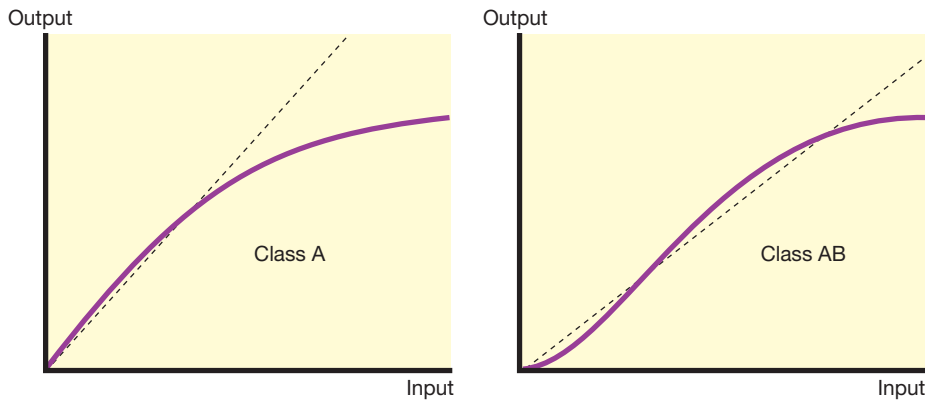


Figure 2
Input-output characteristics for transistor amplifiers.

mode, which will need a linearizing technique that complies with system requirements for spurious emissions and adjacent channel power.

First generation MCPA for WCDMA

Technical challenges

The MCPA is part of the RBS 3000 for WCDMA systems.¹ The primary technical goals in developing MCPAs for WCDMA have been to achieve

- high linearity—to satisfy requirements set by the Third-generation Partnership Project (3GPP); and
- optimum efficiency—to reduce the power consumption of the base station.

Another goal was automated, large-volume

production of MCPAs at different facilities around the world.

Stringent 3GPP requirements for adjacent channel power, the spectrum mask, and spurious emissions make it necessary to linearize the power amplifier. A minimum requirement of four-carrier operation (WCDMA) stipulates a bandwidth of at least 20 MHz. For detailed WCDMA radio requirements, see 3GPP TS 25.104.²

MCPA technology for WCDMA

Selection of technology

Feed-forward technology was selected as the main linearization method for the first-generation MCPA for WCDMA, since it can yield the necessary linearity and bandwidth. It is a mature linearization method that can achieve good linearity over fairly large band-

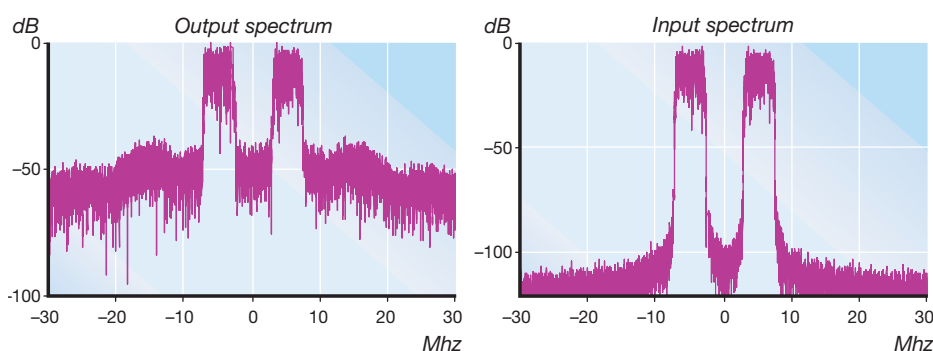
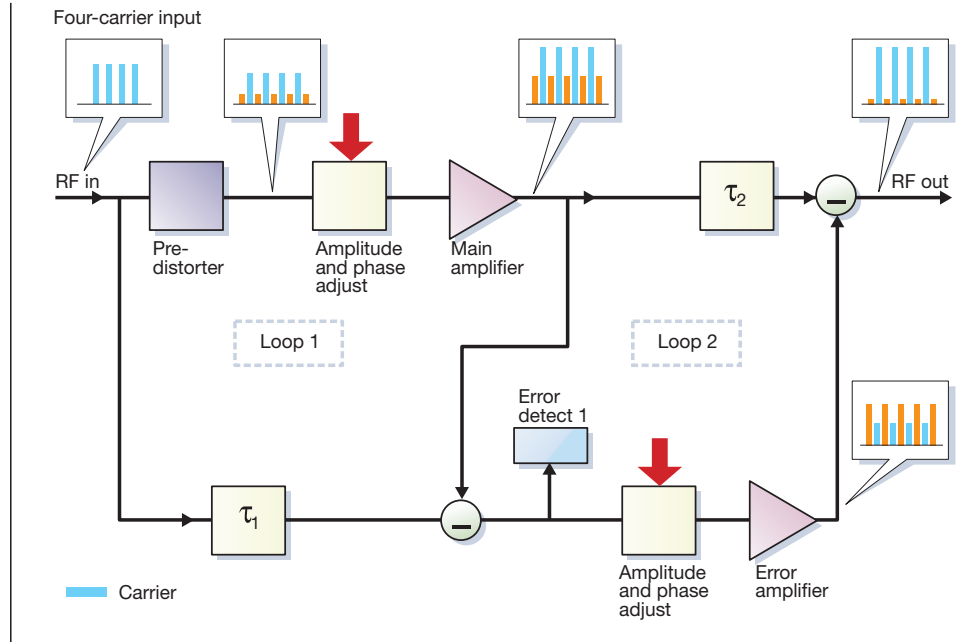


Figure 3
A simulated two-carrier WCDMA signal spectrum at output and input of a non-linear power amplifier.

Figure 4
Block diagram of a feed-forward MCPA for WCDMA.



widths. Feed-forward MCPAs for TDMA systems, which have been on the market for some years, have bandwidths of up to 20 MHz and a spurious emission level of around -60 dBc. A drawback to the feed-forward technology has been low efficiency—approximately 6-7%. Therefore, to yield greater efficiency, and to be suitable for high-volume production, the technology had to be improved.

Feed-forward concept

Figure 4 shows a block diagram of the feed-forward architecture. The input signal is

split into two paths. The signal in the top path is amplified by the main power amplifier (MPA), which operates in class AB. The non-linearities in the MPA result in inter-modulation distortion, which adds to the original signal. A sample of the MPA output signal is fed to the subtractor—a directional coupler—where the signal is subtracted from a delayed portion of the original signal (present in the lower part). This results in an error signal that contains the distortion signal. Ideally none of the original signal energy should remain. But in reality it is possible to suppress the carriers

BOX B, MCPA TECHNICAL DATA

Gain	52 dB
Gain flatness	+/- 0.5 dB
Output power	46 dBm (40 W)
Linearity	- First adjacent channel ACLR 1 < -51 dBc - Second adjacent channel ACLR 2 < -60 dBc
Efficiency	> 9%, typically 10% including DC/DC converter
Temperature range	+5° to +45°C
Hot-swapping	Allowed
Volume	7 liters
Weight	7 kg
Bandwidth	Any 20 MHz band within 2110 – 2170 MHz, field-adjustable

with 25–30 dB. In Figure 4, the carrier-cancellation operation is marked Loop 1. The feed-forward cancellation loop is marked Loop 2. The error signal is amplified linearly in an error power amplifier (EPA)—to a level needed to cancel the distortion in the main path—and is then fed to the output coupler. The MPA output signal is delayed to match delay through the error amplifier path. The contributed distortion from the two paths is added in opposite phase and ideally only the amplified original signal remains at the MCPA output.

Analog RF predistortion

The main power amplifier can be improved by employing a predistorter whose transfer characteristic complements that of the main power amplifier. A configuration in which the predistorter and main power amplifier are cascaded ensures that the resulting system has low distortion (Figure 5). The non-linear predistorting element operates at the final carrier frequency. This method has the advantage of linearizing the entire bandwidth of an amplifier.

Predistortion does not add losses at the carrier output, since distortion is compensated for at the input. Thus amplifier efficiency is not affected. In fact, the efficiency can be increased by driving the MPA closer to compression with the same intermodulation level.

Product technology

Several design challenges had to be overcome in order to achieve the function as described:

- Because the MPA must have inherently good linearity and bandwidth as well as corresponding efficiency, a class AB amplifier was designed using lateral-diffusion metal-oxide semiconductor (LD-MOS) transistors. With this technology, at adjacent channel level ratio (ACLR) values of approximately -40 dBc, the MPA efficiency is around 20%.
- Loops 1 and 2 must have very good gain and phase flatness to ensure good cancellation in each loop. Flatness is tuned electronically during production, which means that manual trimming is not required.
- Adaptive loop control ensures good loop stability. A digital signal processor (DSP) is used for this control.
- The delay (τ_2) in Loop 2 must have low loss to reduce the amount of output power lost as heat. Excessive loss reduces MCPA efficiency. To minimize loss, the delay element has been implemented as a cavity bandpass filter.
- To cancel distortion, the EPA must have a bandwidth three to five times greater than the MCPA signal bandwidth in order.

A combination of good linearity and good efficiency is needed for the EPA, which must amplify distortion from the MPA without introducing further distortion. Since good efficiency is one of the primary design goals, power consumption in the EPA must be minimized.

In classical MCPA designs, the EPA is a very linear class A amplifier (to achieve superior linearity). Nonetheless, advances in

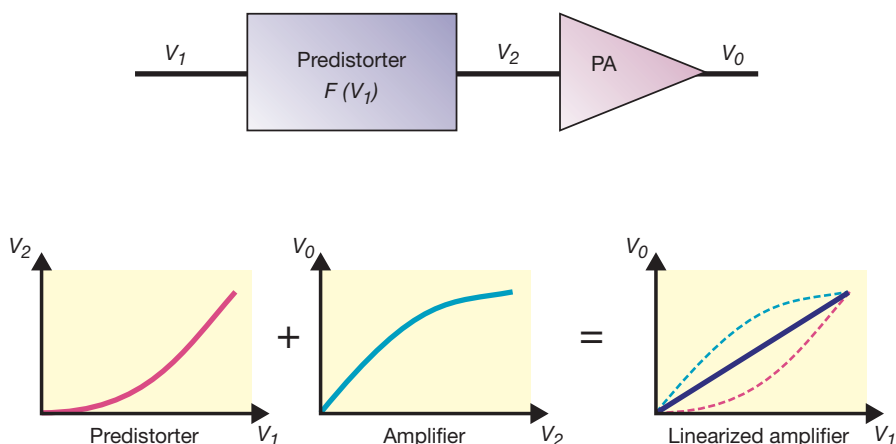


Figure 5
The predistortion concept.

Figure 6
Ericsson's MCPA for WCDMA.



LD-MOS transistor technology have made it possible to design a class AB amplifier with considerably lower power consumption.

For optimum efficiency, an analog predistorter has been added in front of the MPA. The predistorter improves MPA linearity by 5 to 10 dB. The linearity en-

hancement allows for more output power from the MPA with improved efficiency.

The final MCPA design (Figure 6)—including the DC/DC converter—yields an efficiency of 10%.

Measurements

Figure 7 shows a typical measurement with two WCDMA carriers at total average output power of 40W/46 dBm. The distance between the center frequencies of the two carriers is 10 MHz.

The adjacent channel level ratio and spurious emission levels are far below the maximum values allowed.

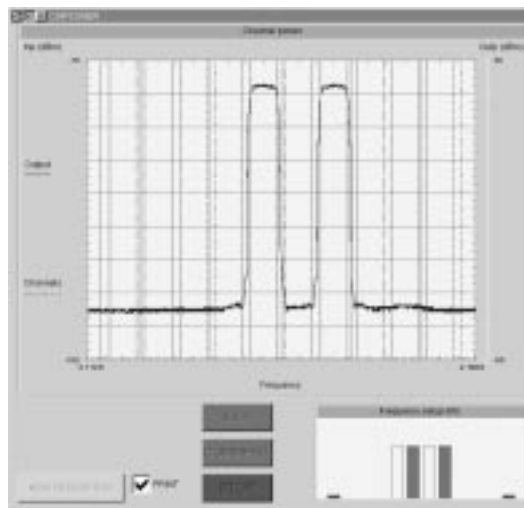
Future MCPA technologies

Present-day RF power linearization techniques employ the feed-forward technique and variants thereof. To further enhance performance, attempts are being made to improve amplifier linearity by predistorting the signal to a power amplifier. Predistorted signals can be generated in either analog or digital techniques.

Digital linearization techniques

Given that semiconductor technology has improved DSP, ADC and DAC techniques, steps have been taken to design an MCPA based solely on predistortion in the digital domain. This approach makes use of modern signal-processing techniques and promises to be cost-effective. A down-converted sample of the RF output signal is compared to the digital input signal. The

Figure 7
Measured output power spectrum of the MCPA.



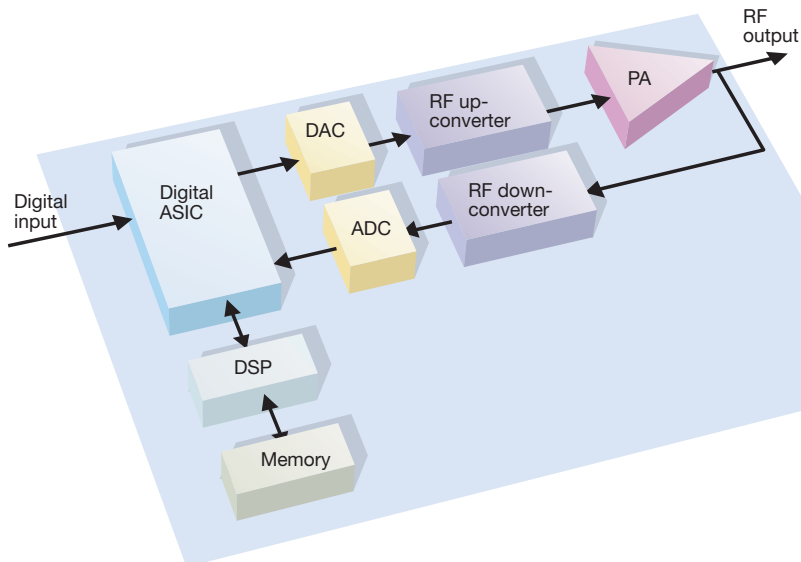


Figure 8
Digital predistortion MCPA for WCDMA.

difference is minimized by predistorting the input signal in a digital ASIC controlled by a DSP for adaptive update. Figure 8 shows the basics of digital predistortion. Greater efficiency is feasible, since distortion is compensated for at the input of the power amplifier.

Ericsson is conducting intensive research in the area of digital predistortion, and the application is expected to become a mature solution for future WCDMA systems.

Ericsson is also investigating power amplifier concepts (efficiency-enhancement technologies) that will yield greater efficiency in the power amplifier itself.

Conclusion

The growing market for third-generation systems requires a base station RF power amplifier designed for large-volume production. Ericsson has chosen the feed-forward technique with analog predistortion, which gives excellent spurious emission values and high production yield. A design for efficiency and cooling guarantees the best MTBF in a small-size amplifier.

Progress in semiconductor technology and improved power amplifier designs have set the stage for a next-generation MCPA with better efficiency, smaller size, and high MTBF.

REFERENCES

- 1 Zune, P.: Family of RBS 3000 products for WCDMA systems. Ericsson Review 3/2000, pp. 170-177.
- 2 Third-generation Partnership Project; Technical Specification Group Radio Access Networks; UTRA (BS) FDD; Radio Transmission and Reception.
- 3 GPP TS 25.104.