Understanding the Performance of RF Amplifiers Used in Base Station Applications

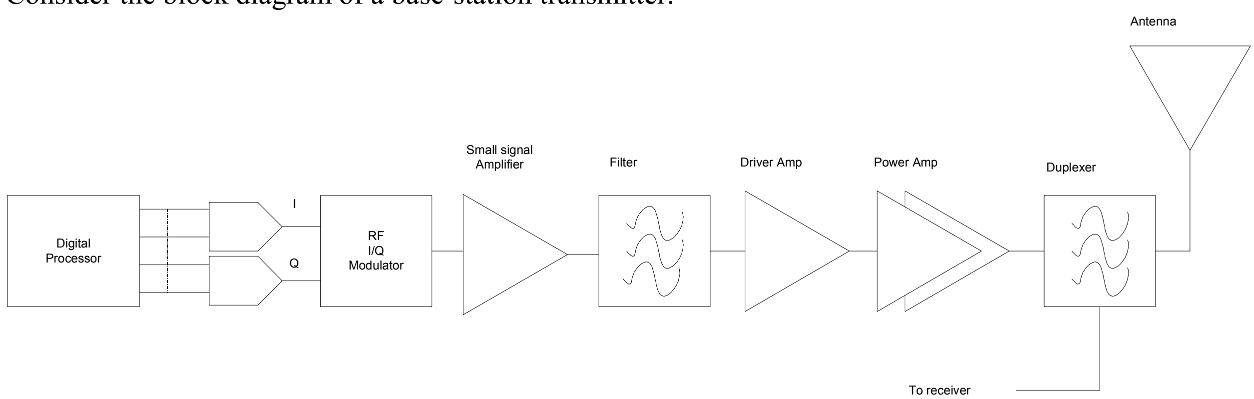
Abstract

In order to properly configure a base station transceiver, designers must understand the performance parameters of the RF amplifiers being used. This not only includes the standard parameters such as gain, noise figure, P1dB and IP3, but also includes more subtle parameters including spectral re-growth and power efficiency. The performance of various types of amplifiers will be analyzed in this article to illustrate the advantages and tradeoffs of each type. Also, performance will be analyzed under various bias conditions to understand the tradeoffs between ACPR/ACLR (adjacent channel power) and power efficiency. The article will compare various types of RF amplifiers including GaAs MESFET, InGaP HBT, and GaAs HFET amplifiers.

Introduction

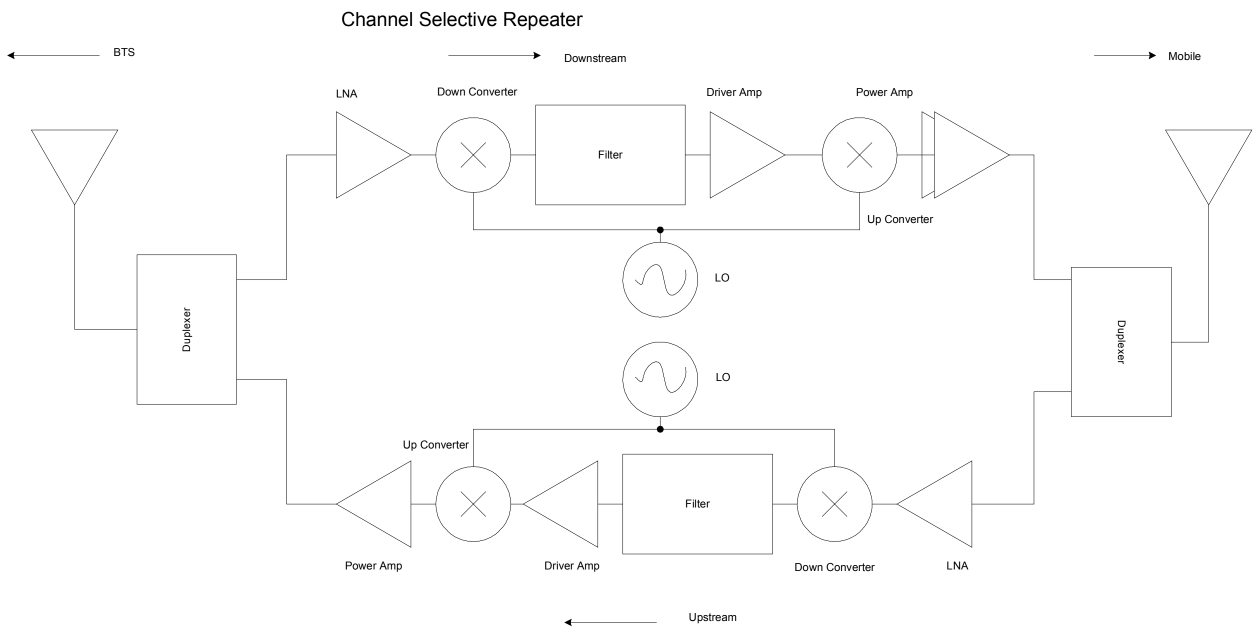
The increasing demand for wireless communications and enhanced services throughout the world has lead to the continual evolution of the wireless networks. Today, third generation (3G) systems are being deployed including various forms of CDMA and UMTS (WCDMA) networks. Each protocol has specific standards that must be complied with in order to operate a wireless network. Spurious emissions from a wireless base-station are limited, depending on the particular protocol being employed.

Consider the block diagram of a base-station transmitter.



In most cases today, the I and Q signals are up-converted in an I/Q RF modulator that translates the baseband signals to the desired RF frequency. This signal is then amplified and filtered before being transmitted through the antenna.

Alternatively, a repeater must also comply with the protocol requirements for CDMA and UMTS (WCDMA). The signal coming into a repeater from the base-station may already exhibit spurious outputs so the repeater must be designed taking this into consideration so the output of the repeater does not exceed the specified levels for a given protocol.



Protocol Requirements

The spurious emission requirements for a particular protocol are well defined. Let's review the requirements at the RF output of the base-station close to the carrier that often determine the selection and operation of the amplifiers used in the transmitter.

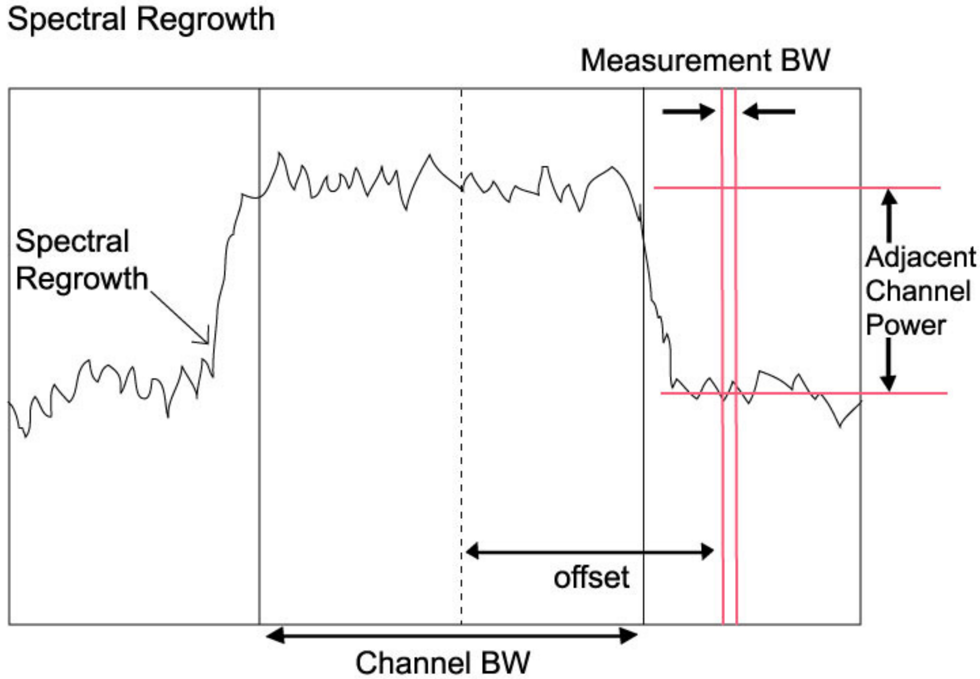
CDMA (IS-95) Spurious Requirements (Adjacent Channel Power Rejection = ACPR), 9 Ch. Fwd

ACPR = Power in dBm @+/-885 kHz (30 kHz BW) – Power main signal in dBm (1.23 MHz BW) < -45 dBc

UMTS (WCDMA) Spurious Emission (Adjacent Channel Leakage Power Ratio = ACLR), 3GPP WCDMA, Test Model 1 + 64 DPCH, BW = 3.84 MHz

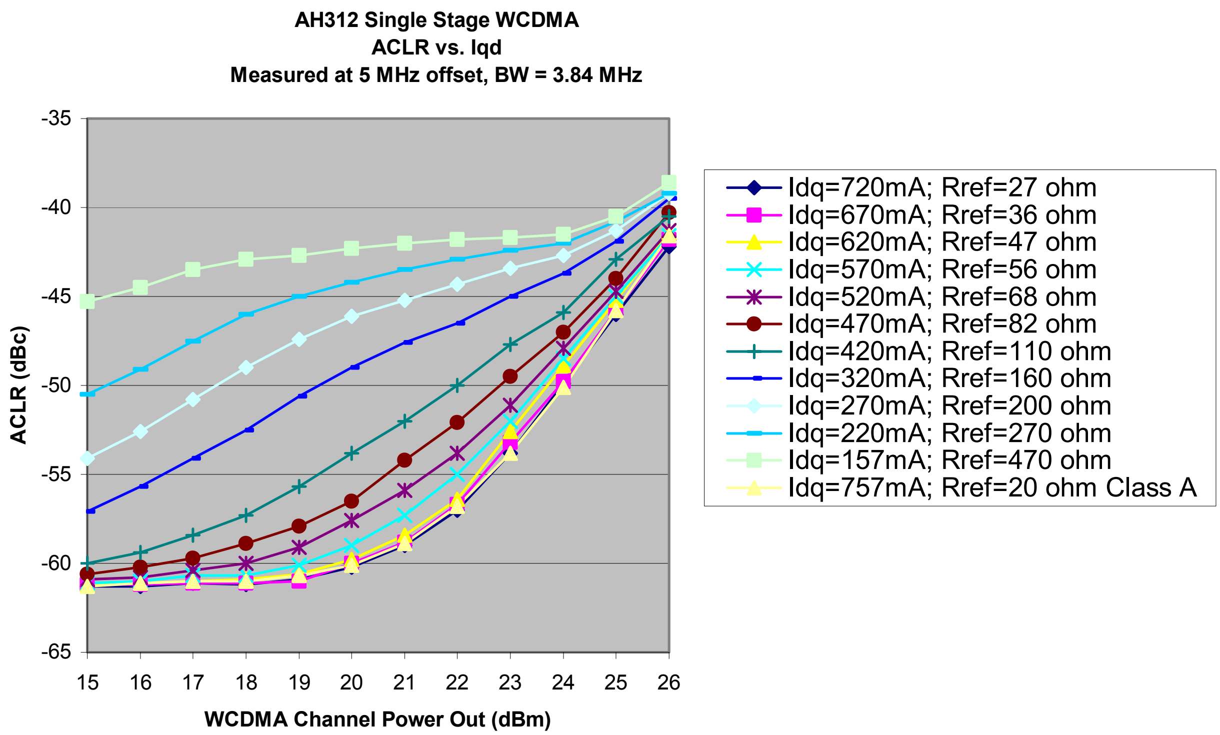
ACLR = Power in dBm @+/-5 MHz – Power main signal in dBm < -45 dBc

While filters are used to attenuate "out of band" spurious signals, those close to the RF signal must be limited by proper design of the baseband and RF circuits. In particular, the RF amplifiers must be properly selected and biased to prevent the transmitter from exceeding the spurious emission specifications. As the power output of an amplifier is increased, distortion of the output signal increases. While many different ways are used to characterize this distortion, for RF amplifiers it is common to use P1dB and IP3 as specifications for determining the output power level that a particular RF amplifier can achieve. However, for spread spectrum signals such as CDMA and UMTS (WCDMA), the distortion is referred to as spectral regrowth as illustrated in the following chart:



As is specified for a particular protocol, the adjacent channel power is often used as a way to characterize the spectral re-growth of an RF amplifier. Adjacent channel power is measured using a spectrum analyzer to observe the spurious level of the signal a specified distance from the carrier in a given bandwidth.

The other key factor used to select RF amplifiers for a given application is the power efficiency. Being spread spectrum signals, CDMA and UMTS (WCDMA) signals have high peak to average ratios. In order to limit the amount of distortion of the peak signals, the RF amplifier must be operated well below P1dB so the power efficiency is relatively poor when the amplifier is operated in Class A (Note: pre-distortion techniques are not being discussed in this paper). By operating the amplifier in Class AB or a higher mode, it is possible to improve the power efficiency while still maintaining acceptable spectral regrowth characteristics. A good comparison of the adjacent channel leakage power ratio (ACLR) of an AH312 2W amplifier, as the amplifier is adjusted to operate from Class A to Class AB is illustrated below:



As can be observed from the graph, it is possible to select an operating point for the amplifier that still meets the ACLR requirements with improved power efficiency compared to Class A operation.

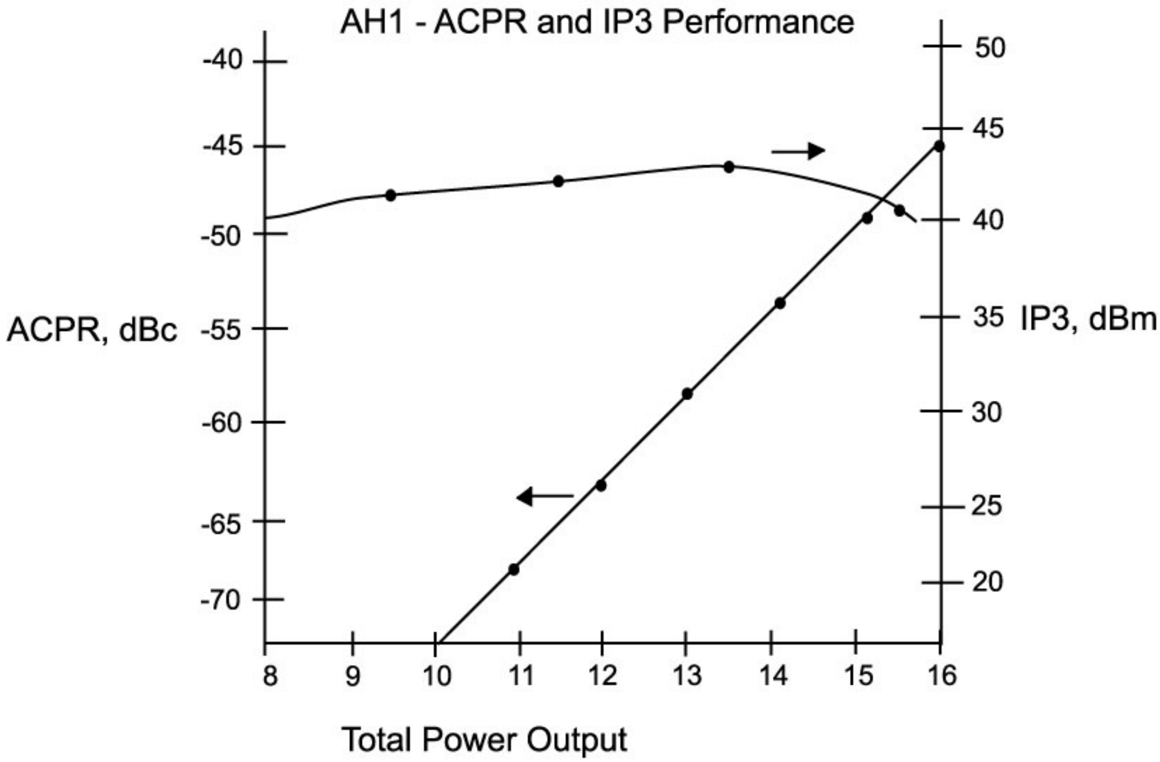
Base-station Transmitter Design

The final output stages of the transmitter or repeater dissipate the most power, and therefore it is desirable to operate these in Class AB. By operating the small signal and driver amplifiers in Class A or near Class A so their spectral re-growth is minimized, it is possible to allocate most of the spectral regrowth to the output amplifier stage(s). A typical IS95A transmitter is configured as shown in the chart below:

Amplifier	IS95A ACPR	PWR Efficiency	Class of Operation
Small Signal	>-60 dBc	2%	A
Driver	-55 dBc	3-7%	A to AB
Output	-50 dBc	>10%	AB

Amplifier Types

The adjacent channel power rejection (ACPR for IS95A) or adjacent channel leakage power ratio (ACLR for WCDMA) of an RF amplifier also varies depending on its design, the actual circuit around the amplifier and the process technology used.



Small signal and driver amplifiers are often designed to peak the IP3 characteristic over a selected range of output powers to improve ACPR/ACLR as illustrated below:

It is possible to improve the ACPR/ACLR of an amplifier by configuring the actual RF circuit to optimize the P1dB and IP3, however the input and output VSWRs may then be degraded to a point that makes it very difficult to integrate this amplifier with the next one in the chain. Also, the impedances of the device may require matching circuits that limit the usable bandwidth in actual operation.

So we have many factors that enter into the selection of an RF amplifier in a base station transmitter or repeater, including:

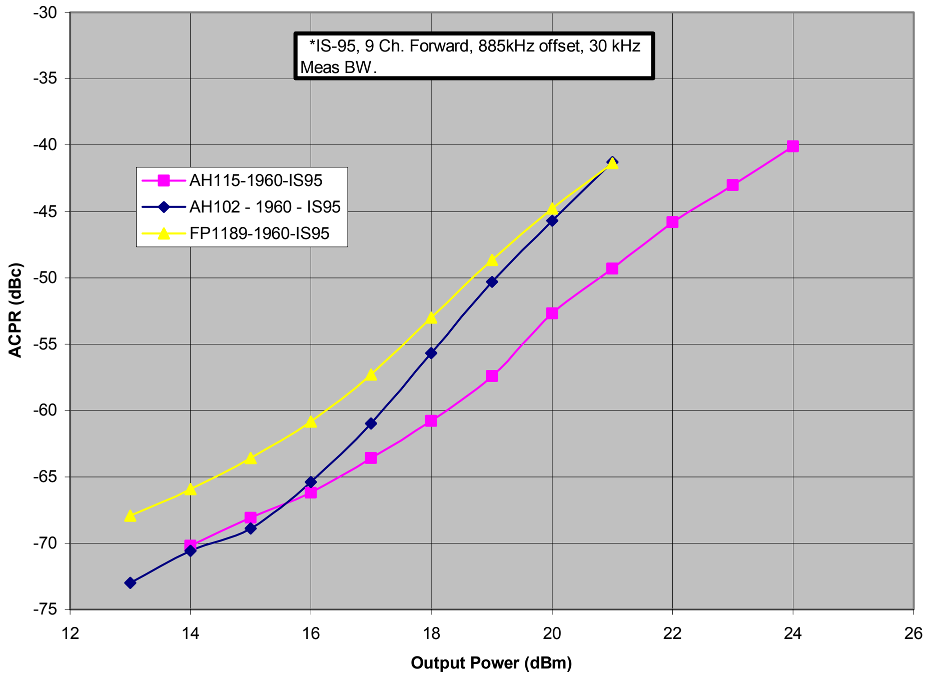
- Protocol requirements and peak to average ratio (CDMA, UMTS (WCDMA) or other)
- Bias (Class A vs. Class AB and others)
- Design (IP3 peaking to improve ACPR/ACLR)
- Amplifier circuit design

Now, let's analyze the performance of various types of amplifiers including GaAs MESFET, GaAs HFET, InGaP HBT. For comparison purposes let's study three amplifiers with P1dB = 0.5W.

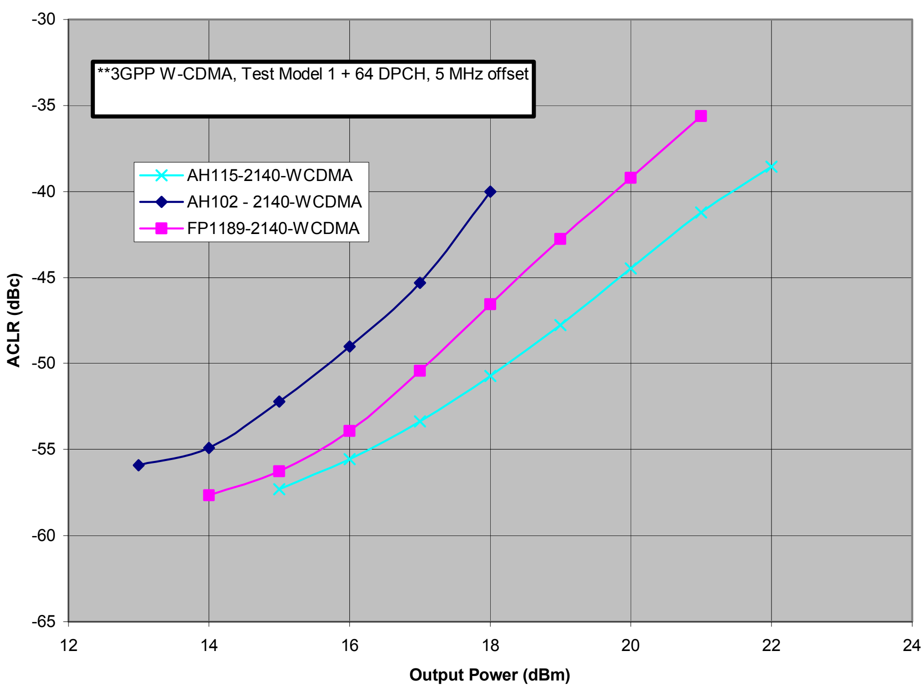
Model	Type	Gain, dB	P1dB, dBm	IP3, dBm (12 dBm/tone)	Bias	Pdiss, W	Amplifier Circuit Design	
							Amplifier Match	Effective RF bandwidth @ 2 GHz
AH102	MESFET	13.9	27	44	+9V	1.8	Wideband	>300 MHz
FP1189	HFET	15.7	27.2	40.4	+8V, -Vg	1.0	Narrowband	60-100 MHz
AH115	HBT	14.3	28	44	+5	1.25	Narrowband	60-100 MHz

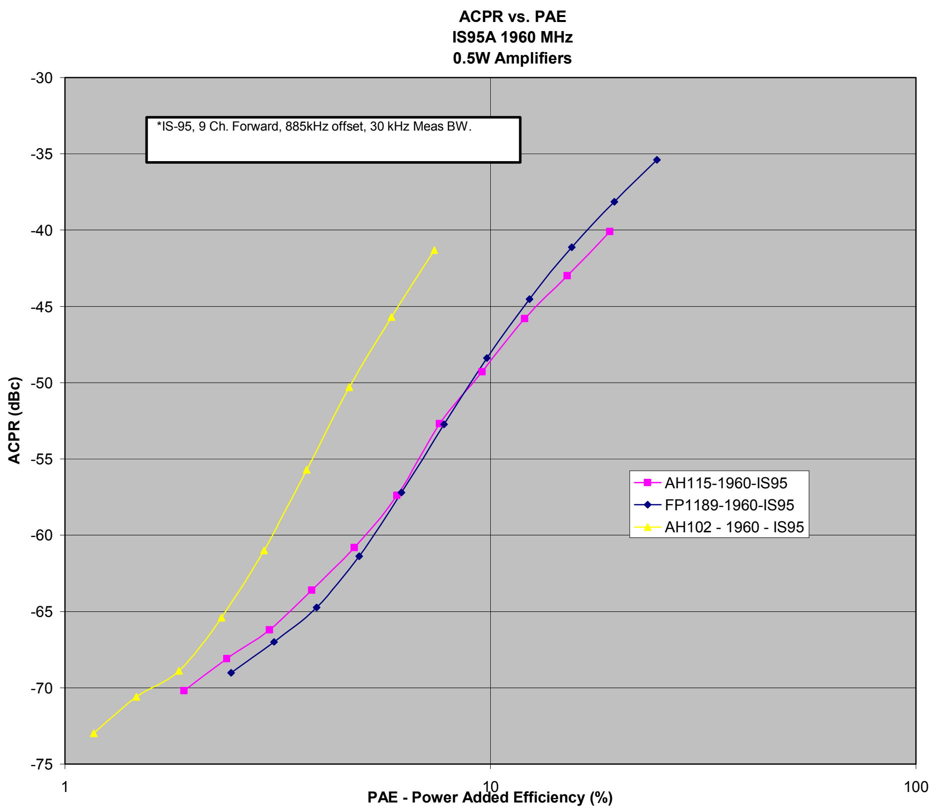
All data taken at 1960 MHz unless otherwise noted.

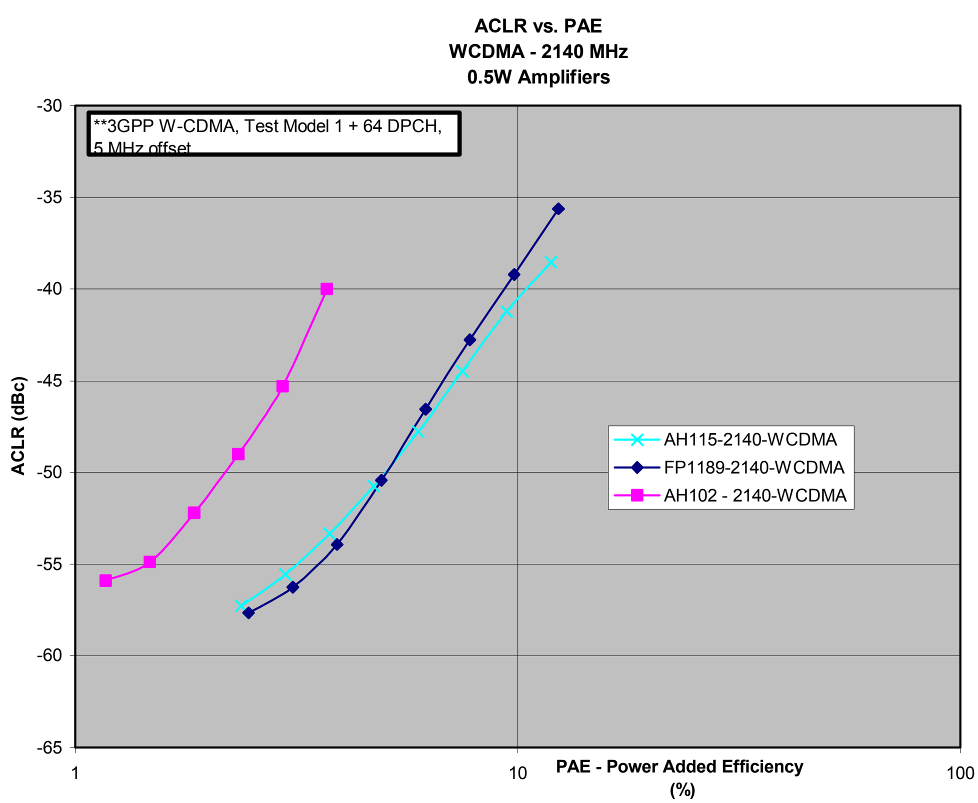
ACPR vs. Pout
IS95A 1960 MHz
0.5W Amplifiers



ACLR vs. Pout
WCDMA 2140 MHz
0.5W Amplifiers




ACPR vs. PAE
IS95A 1960 MHz
0.5W Amplifiers
*IS-95, 9 Ch. Forward, 885kHz offset, 30 kHz Meas BW.
ACPR (dBc)
PAE - Power Added Efficiency (%)
AH115-1960-IS95
FP1189-1960-IS95
AH102 - 1960 - IS95
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
1
10
100

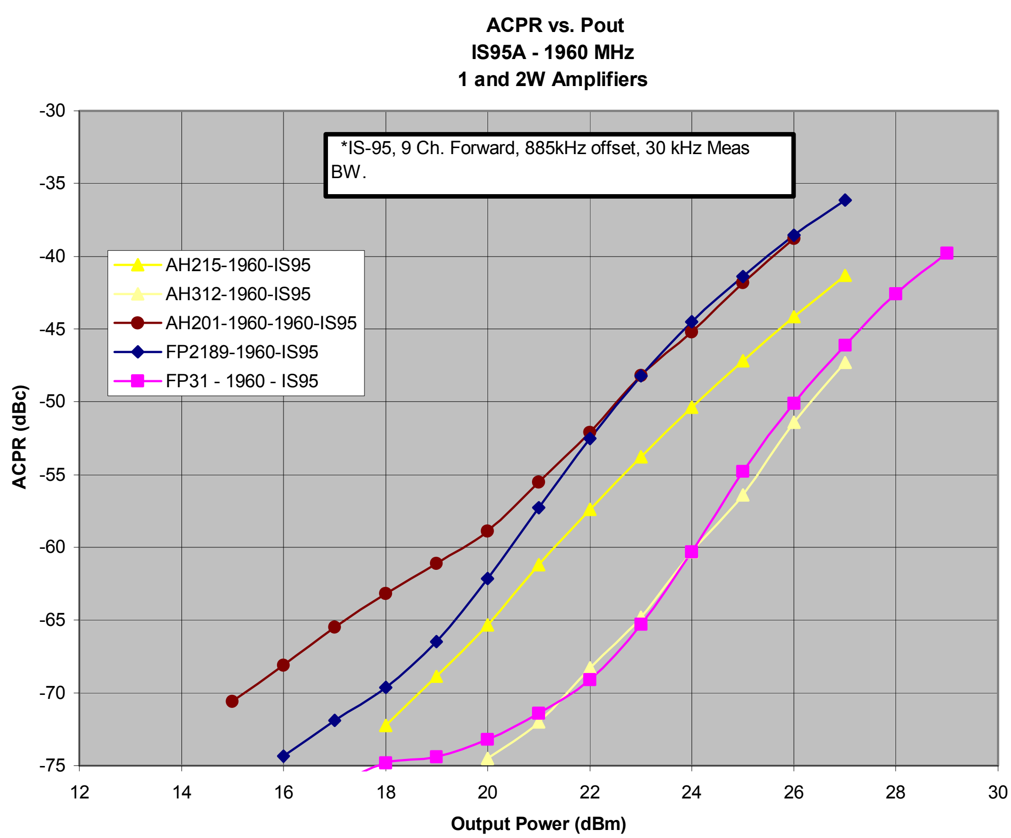

ACLR vs. PAE
WCDMA - 2140 MHz
0.5W Amplifiers
**3GPP W-CDMA, Test Model 1 + 64 DPCH, 5 MHz offset
ACLR (dBc)
PAE - Power Added Efficiency (%)
AH115-2140-WCDMA
FP1189-2140-WCDMA
AH102 - 2140-WCDMA
-30
-35
-40
-45
-50
-55
-60
-65
1
10
100

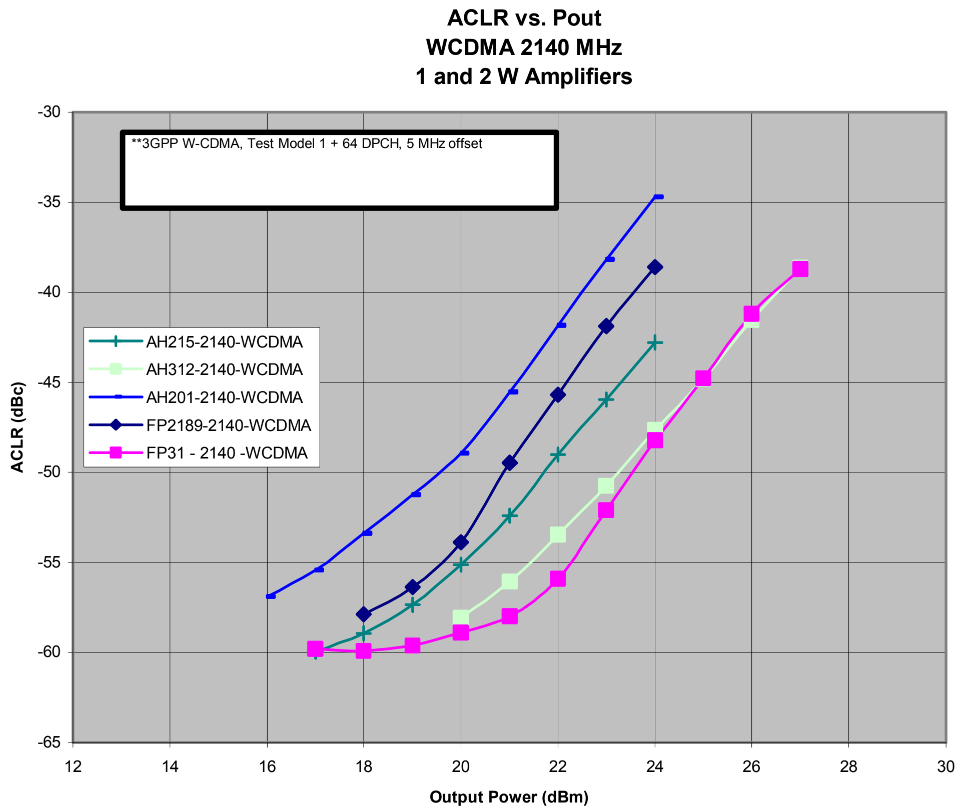
Each amplifier has unique advantages. The AH102 MESFET is a wideband device so it can be used across several different bands as compared to the FP1189 HFET and AH115 HBT, however it's power added efficiency is not as good. The FP1189 and AH115 are comparable in ACPR/ACLR performance but the FP1189 operates from a +8V supply and also requires a negative gate voltage as compared to the AH115 that operates from +5V.

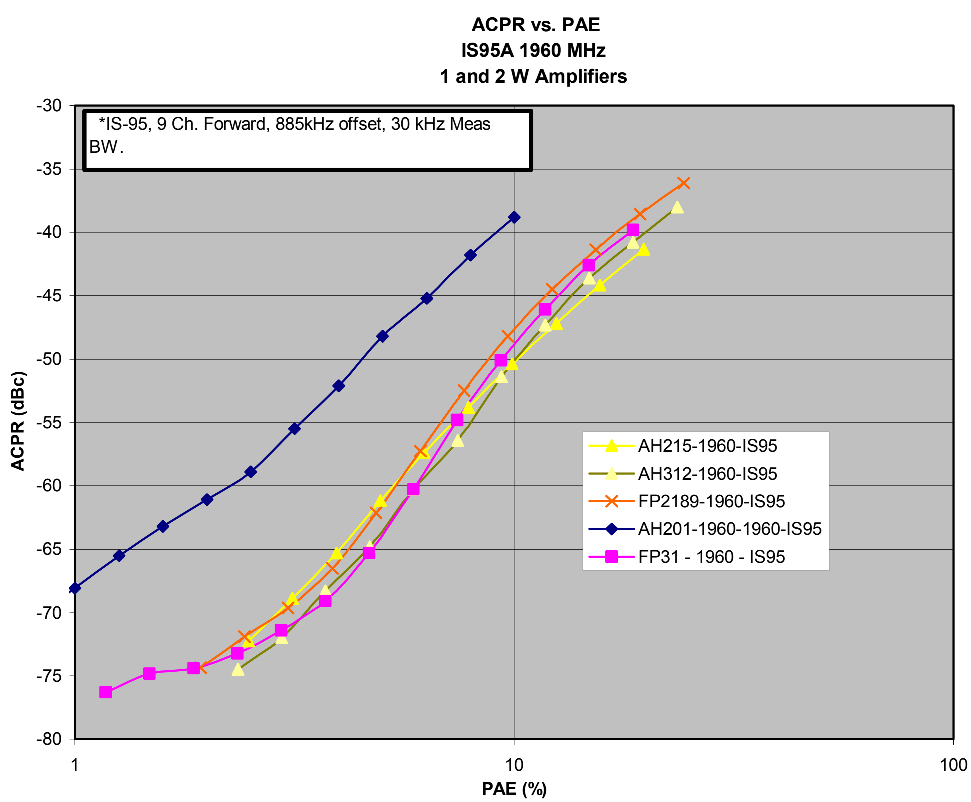
Comparison of 2W amplifiers

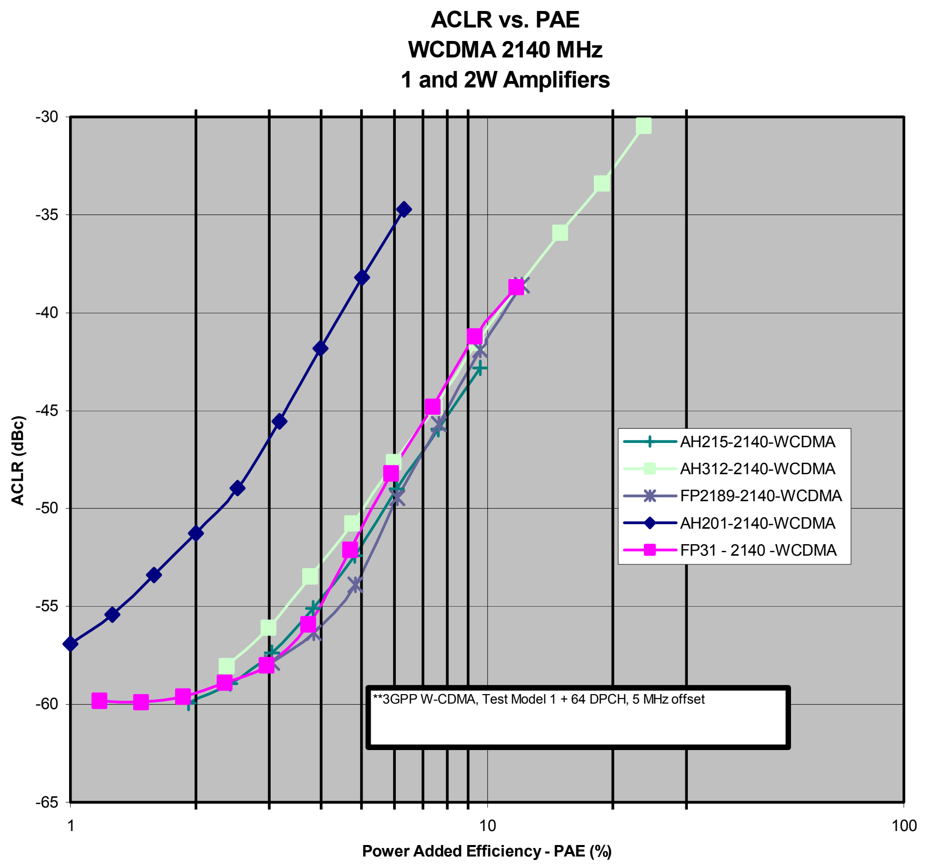
Model	Type	Gain, dB	P1dB, dBm	IP3, dBm	Bias	Pdiss, W	Amplifier Circuit Design	
							Amplifier Match	Effective RF bandwidth @ 2 GHz
AH201	MESFET	15	30	46 (10dBm/tone	11	3.9	Wideband	>300 MHz
FP2189	HFET	15.6	30.4	43.5 (15 dBm/tone)	8	2	Narrowband	60-100 MHz
AH215	HBT	12	32	46 (15 dBm/tone)	5	2.25	Narrowband	60-100 MHz
FP31	HFET	13.5	33.8	46.8 (18 dBm/tone)	+8V , -Vg	4	Narrowband	60
AH312	HBT	11	33.4	51 (17 dBm/tone)	+5	4	Narrowband	60

All data taken at 1960 MHz unless otherwise noted.




ACLR vs. Pout
WCDMA 2140 MHz
1 and 2 W Amplifiers
**3GPP W-CDMA, Test Model 1 + 64 DPCH, 5 MHz offset
AH215-2140-WCDMA
AH312-2140-WCDMA
AH201-2140-WCDMA
FP2189-2140-WCDMA
FP31 - 2140 -WCDMA
ACLR (dBc)
Output Power (dBm)
-30
-35
-40
-45
-50
-55
-60
-65
12
14
16
18
20
22
24
26
28
30


ACPR vs. PAE
IS95A 1960 MHz
1 and 2 W Amplifiers
*IS-95, 9 Ch. Forward, 885kHz offset, 30 kHz Meas BW.
AH215-1960-IS95
AH312-1960-IS95
FP2189-1960-IS95
AH201-1960-1960-IS95
FP31 - 1960 - IS95
ACPR (dBc)
PAE (%)
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
1
10
100



As is the case for the 0.5W amplifiers, the AH201 MESFET exhibits a wider band match but the ACPR/ACLR and power added efficiency of the FP2189/FP31 HFETs and AH215/AH312 HBTs are superior.

CONCLUSIONS

Many factors must be considered when selecting an RF amplifier for a CDMA/UMTS base-station transmitter. Traditional factors such as P1dB and IP3 are no longer adequate differentiators. The designer also needs to consider the amplifier's ACPR/ACLR, power efficiency, and required bandwidth/ease of matching to determine the best amplifier for a particular application. This article explains these tradeoffs and provides performance comparisons for various types of devices.

AUTHOR

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