

Trying on RF Amplifiers Get the Right Fit

Amplifiers continue to occupy greater board area, consume more power and have higher costs. The task of selecting the right amplifier for a specific application is more critical than ever.

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As wireless standards keep evolving, RF system designers are faced with continuous challenges to reduce cost and size and to improve the overall performance of their systems. Techniques that were “rocket science” 20 years ago are now implemented in a single \$1 (US) ASIC. Other analog and RF components used in the



transceiver, especially amplifiers, consume more power, occupy a greater board area and have higher costs. Increasingly, amplifiers dominate the cost and overall system specifications making the selection of the right amplifier for a particular application more critical than ever.

With the variety of choices offered by amplifier suppliers, many RF system design engineers find the amplifier selection process can be long and frustrating. This article hopes to shed light on some of the important parameters to consider first in the selection process.

What are the top five parameters to consider when choosing an amplifier? A complete list of amplifier parameters and specifications can be very long and intimidating. The five parameters discussed below are the first and most critical. Answer these completely before digging into the other details.

1. Frequency:

First, the engineer needs to get into the right mindset of what is optimal or practical within a certain frequency band. Mimix Broadband offers amplifiers from few MHz to beyond 50 GHz. What is considered industry standard for one frequency band can

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be considered either inadequate or overkill at another frequency band. Two of the main frequency determining factors are package parasitic effects and process technology.

For example, surface mount packages have been practical at frequencies up to 6 GHz for many years now. But only recently, thanks to the QFN and 0.15um pHEMT process, have true surface mount, reasonable-cost power amplifiers appeared at 35 GHz. The XP1031-QK is a 35 GHz MMIC power amplifier whose design necessarily incorporates the parasitic package effects. It is suitable for high volume, standard flow PCB assembly — quite a departure from the expensive chip and wire hybrid assemblies of just yesterday.

Let's consider an example of how process technology enters the decision tree. Silicon LDMOS is a rugged, high power, high voltage, low cost process. These devices can deliver more than 100 W of power at lower frequencies but they only perform (today) up to about 4 GHz. If you need a few watts at 5.8 GHz, GaAs HFET and HEMT devices are a better choice.

Another frequency related consideration is simultaneous bandwidth. Broad bandwidth complicates the task of meeting all the requirements in one shot. Broadband matching is only possible when a device has an inherent moderate and well behaved return loss. For example: 2.5 and 3.5 GHz WiMAX applications require at least 200 MHz bandwidth. There are many power amplifiers that can be narrowband matched (perhaps with some difficulty) at 2.5 or 2.7 GHz, but there are only few process recipes that meet all the requirements across the band.

2. Voltage:

Amplifiers operate over a wide range of voltages depending on the design, architecture, and process technology used in the semiconductor die fabrication. GaAs pHEMT, GaAs MESFET and GaAs HFET devices generally require positive and negative voltages whereas HBT devices require only positive voltage. Lack of a negative supply in a system though should not prevent RF system designers from considering and taking advantage of the low noise figure and superior linear performance of GaAs process FET devices. Design tricks like self bias or zero gate voltage (I_{dss}) can eliminate the need for a negative voltage. The CFS0303-SB low noise pHEMT amplifier achieves noise figures of less than 0.5 dB and OIP3 greater than +32 dBm when operated in a self-biased, single supply mode.

InGaP HBT Darlington-pair gain blocks, like the CGB7000 series, are loved by every RF engineer thanks to their broadband performance, excellent linearity, inherent stability, low cost and ease of use. Unfortunately, the design architecture and process technology are not suitable for battery operated applications where only a 3.3 V (or less) supply is available — these parts need more voltage.

Remember too that voltage, power, and impedance are not separable. $P \sim (V^2 / 2R)$ If you try to build a 100 W PA with a 1 V supply, you end up with a practically impossible matching task. Similarly, you don't need +12 V for a low current, low IP3, LNA. Harmonizing process technology, RF requirements, and available system voltages will give the best efficiency, ease of design, and highest performance.

3. Linearity:

Linearity has always been a key worry for the RF designer and it is getting tougher every day. The spectrum is more busy than ever, spectral efficiency $\#151$ bits/Hertz $\#151$ is at Shannon's limit, and don't forget the huge number of unintentional emitters like computers. Users expect wireless devices that give "wired" quality of service in every location and environment. Linearity requirements break down into two general categories according to whether we're talking about the transmit chain or the receive chain, and each has specific problems.

On the receive side high linearity allows a system to operate in a crowded environment with large dynamic range. A base station for example may "see" hundreds of users which range in



power and distance from nail-driving at the tower base to a whisper on the horizon. Linearity preserves each of those individual signals as they flow from the antenna to the receive demodulator. Third order intercept point (IP3) is typically the figure of merit when it comes to measuring the linear performance of an amplifier in this context.

On the transmit side, linearity ensures that the modulator and RF output waveforms look the same, and that a given transmitter doesn't unduly interfere with adjacent channel neighbors. The latest wireless standards like WiBro and WiMAX feature complex OFDM multi-carrier modulation schemes. OFDM typically uses a hundred or more equally spaced carriers, each with their own amplitude/phase constellation. Third order intercept is an important gating specification in these contexts, but each market has specific measures that better describe their unique operation and performance requirements.

OFDM systems specify Error Vector Magnitude (EVM) and Peak-to-Average Ratio (PAR). Wired and fiber cable TV systems spec Composite Triple Beat (CTB) and Composite Second Order (CSO). CDMA systems talk in terms of Adjacent Channel Power Ratio (ACPR). These measures describe how well the transmitter delivers the correct amplitude and phase to the channel and the amplifier generated spurious energy levels dumped in your neighbor's channels.

Distortion generally increases with output power so linear amplifiers operate in back-off mode, that is at an average power level well below compression. Typical linear modulation back-off ranges from 3 to 10 dB. Pay special attention to both an amplifier's absolute output power level, and the usable power (back-off) level that satisfies the needs of a given signal format.

Consider a 1 W WiMAX outdoor CPE with an EVM less than 2.5%. WiMAX uses OFDM with peak to average ratios ranging between 6 and 12 dB. In order to achieve better than 2.5% EVM, the output power amplifier needs to operate at 6 to 9dB back-off from its 1 dB gain compression point (P1dB). Putting this together, the selected power amplifier needs to be capable of delivering at least 6 W of peak power. The exact back-off figure varies according to the amplifier's inherent process linearity. Be sure to specify or verify average power, EVM, modulation type, and PAR when working with an amplifier vendor. P1dB and IP3 only provide a rough, order-of-magnitude estimate. The CHV2710-QJ has a P1dB of 5 W but is capable of 29 dBm of linear power (EVM

MESFET and HFET devices like the CMM6xxx series achieve high linearity with a low 2 dB noise figure. This combination makes these devices ideal for wireless receive chains or as drivers in linear transmitters and CATV applications.

4. Efficiency:

Whether it is a portable device, satellite radio, cable setup box or even a base station there has been growing emphasis on power efficiency. In the case of the WiMAX outdoor unit discussed earlier, amplifier efficiency is related to the amount of back-off. Less back-off means a lower P1dB and lower DC power. A good indicator of efficient linear operation is the spread between the P1dB and OIP3 specifications. Most semiconductor processes yield amplifiers with about a 10 dB delta. A good MESFET amplifier though, like the CMM6004, can hit almost 20 dB. That is a huge increase in linearity with the same DC power. Less DC power brings other important benefits like lower unit temperature, smaller power supplies, and better reliability.

Operating point strategies like Class AB operation can deliver better efficiency but create unacceptable distortion levels. Digital pre-distortion and feed forward techniques can correct a somewhat non-linear amplifier, but at the price of significant cost and complexity. Thanks to DSPs and ASSPs, the tipping point on this trade-off is trending downward. But the trade also depends on what is most precious to the application. Power efficiency at any cost may be the right answer for a satellite application, whereas cost alone may be most important for a consumer wireless access point. A rule-of-thumb for many applications today is that linearization schemes start to be attractive at the 5 to 10 W average power levels.

5. Reliability:

Size and cost demand physically smaller amplifiers while their linear waveforms call for higher power. It's getting hot in here! Designers need to pay close attention to thermal resistance and reliability.

Mean Time to Failure (MTTF) is dependent on the die temperature, and die

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temperature is set by the dissipated power and the combined die/package thermal resistance. Smaller die means more power over less area and higher thermal resistance. Manufacturers combat these realities by careful transistor spacing, metal via holes, and a thin die. Together this spreads the heat and moves it faster to the package paddle or leads. But a thermally efficient device doesn't guarantee success. The system designer must provide an efficient thermal path to carry that heat away from the package, and ultimately to the ambient environment. PCB metal area, well located plated thru via holes, and a conductive thermal path to the outside world ensure that the design achieves the expected reliability.

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