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Specifying General Purpose Amplifiers in High Frequency Applications

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Here is useful information for understanding the technology, performance and other parameters that must be considered when selecting general purpose gain block amplifiers

Wideband general purpose amplifiers (GPAs), also known as “gain blocks,” are invaluable components for controlling signal levels in RF and microwave circuits and systems, such as receivers and transmitters. In receivers, a GPA can boost received signals prior to reaching the demodulator. In transmitters, a GPA can provide the necessary gain to boost the signal to the correct level at the inputs of a power amplifier. GPAs are also useful as buffers to provide a known impedance or isolation between two components, such as a local oscillator (LO) and a mixer.

GPAs are also employed in fiber optic systems for laser drivers and customer premise equipment (CPE) RF boosters. They are available with wide frequency ranges—300 to 3,000 MHz and greater—that are suitable for multiple applications, such as wireless communications, medical, cable-television (CATV) and wireless local area network (WLAN) systems. Some typical GPA applications are shown in Figures 1, 2 and 3.

This article provides an overview of these devices and the key specifications to compare when specifying these amplifiers for RF, microwave and optical applications.

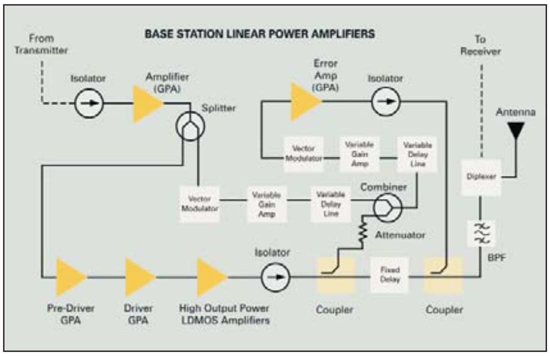

Figure 1 · Applications for general purpose amplifiers in a typical base station power amplifier.

A Broad Range of Applications

GPAs can be specified for many different frequency bands and performance characteristics (Figure 4). They tend to be small-signal, broadband devices, usually with either a single-stage common emitter, common source, or Darlington configuration. Most GPAs are matched to 50 ohms at input and output ports, with on-chip impedance matching and resistive feedback elements to determine usable bandwidth and reduce the number of external components required. The size of each device and its bias requirements (supply voltage and current consumption) determine its output power capabilities.

Current GPA specifiers are faced with products fabricated with numerous different semiconductor technologies based on both gallium arsenide (GaAs) and silicon processes. Low-power GPAs are commonly based on heterojunction field-effect-transistor (HFET) or heterojunction-bipolar-transistor (HBT) structures. The former is commonly based on GaAs, while the latter can be fabricated with GaAs or silicon, including InGaP and SiGe materials. Both HFETs and HBTs provide extremely good linearity at reasonable efficiency and cost, although HFETs tend to offer superior noise-figure performance. HFETs can be used

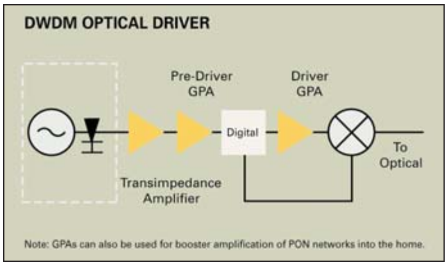

Figure 2 · Optical driver applications for GPAs.

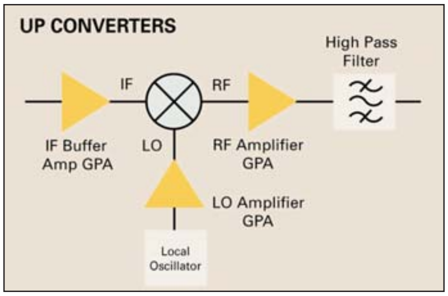

Figure 3 · GPA applications in upconverter circuits.

for higher power levels than most HBTs, although HBTs are capable of high gain from a single low positive voltage supply. Table 1 offers a comparison of different GaAs-based technologies, including enhancement-mode pseudomorphic high-electron-mobility-transistor (pHEMT) devices capable of running on a single positive voltage supply.

Comparing GPAs

Low- and medium-power GPAs are generally compared on the basis of several key performance parameters, including gain, bandwidth, output power at 1 dB gain compression (the output power level at which the gain drops by 1 dB), noise figure, linearity and efficiency. "Low power" is defined here as output power levels to 1 W (+30 dBm) while "medium power" is defined by output power levels from 1 to 30 W (+30 to almost +45 dBm).

A GPA's small-signal gain is generally a function of frequency, with gain gradually rolling off at higher frequencies. Since GPAs are designed for numerous applications over a wide frequency range, the gain may vary over the full range by 6 dB or more. However, when considering a GPA for a particular application, it is important to refer to the required gain flatness over the band of interest, such as 1,800 to 1,900 MHz, rather than the full-band gain flatness. Since GPAs are available with input and output ports matched to 50 ohms, they can be cascaded when higher gain levels are needed, although each additional gain stage adds to the total power consumption.

Standard GPAs generally exhibit gain levels between 15 and 20 dB and a variety of output-power options, specified as the output power at 1 dB compression. In some applications, it may be acceptable to run a GPA at its compression point. Other applications may require that the GPA be "backed off" or operated below compression in order to ensure linear operation. Since a GPA's output power correlates directly to the amount of power consumed, specifiers should consider output power requirements in concert with the efficiency of a given amplifier.

A GPA's efficiency is defined as a ratio of the generated RF power to the consumed DC power. Ideally, an amplifier that draws 1 W of DC power would provide 1 W of output power, or efficiency of 100%, but that is never the case. In practical terms, an amplifier that requires a supply of 200 mA and +5 VDC and generates 200 mW output has efficiency of 20%. Of course, higher efficiency means less power consumed, but at a penalty in linearity.

The Importance of Linearity

Achieving linearity in a GPA often involves a tradeoff in efficiency. Under Class A conditions, an amplifier's active devices remain powered during all phases of an input signal. While Class A operation provides excellent linearity with minimal distortion, it also suffers the highest power consumption of amplifier operating modes. Some power can be conserved by keeping amplified signal levels low, or by allowing a certain amount of distortion. Under Class AB conditions, for example, an amplifier's active devices are turned off during part of the input signal's cycle, saving power during that time but introducing distortion caused by the switching of the active devices. Further savings in power are possible

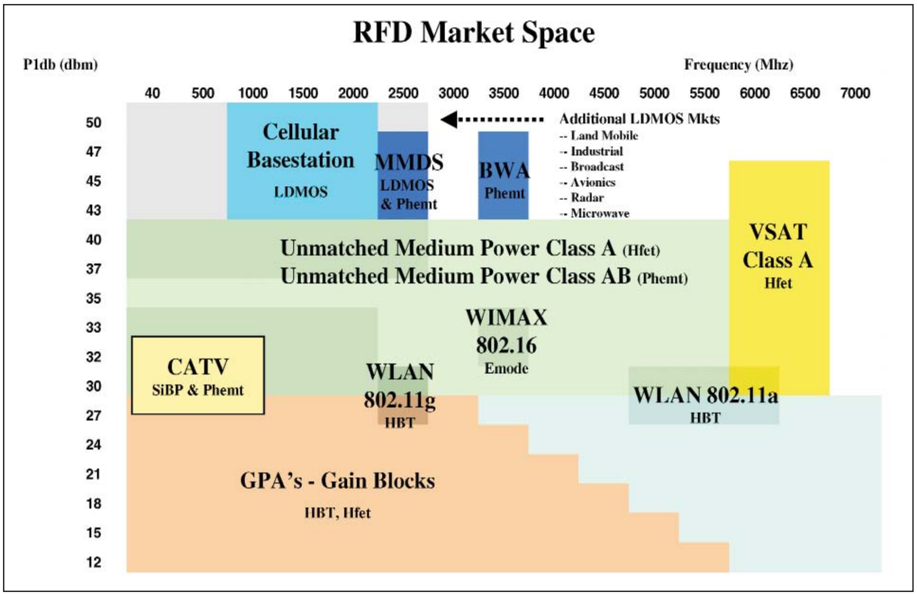

Figure 4 · Commercial gain blocks or GPAs can be specified for wide operating-frequency ranges and numerous different output-power and linearity levels.

GaAs technology	Class A linearity (IMD/IP3)	Class AB linearity (ACP/IMD)	Power-added efficiency	Maximum operating frequency	Noise Figure	Power Supply	Applications
HFET (12 V)	Excellent	Good	Good	8 GHz matched	Excellent	Dual	Drivers high IP3, monotonic IMD
pHEMT (12 V)	Good	Excellent	Excellent	8 GHz matched	Excellent	Dual	PA output socket, LNA, CPE output
pHEMT (26 V)	N A	Excellent	Excellent	3.5 GHz matched	NA	Dual	PA output socket
Emode (5 V)	Good	Excellent	Excellent	6 GHz	Excellent	Single	GPA, LNA, predriver, CPE output
InGaP HBT (5 V)	Excellent	Good	Good	6 GHz	Fair	Single	GPA, predriver, CPE output

Table 1 · A comparison of GaAs gain block technologies.

with Class B and Class C operating modes, in which the "on" times of an amplifier's active devices are further minimized, although the tradeoff is increased distortion. Because most GPAs are intended for applications requiring good linearity, they tend to be biased for Class A operation.

A GPA's linearity is generally judged by its ability to amplify multiple tones with minimum intermodulation distortion (IMD). The third-order intercept point, which defines the level of two input tones required to produce a third-order output signal at the same level, is a measure of this capability. In the case of a GPA, the third-order intercept point is referenced to the output. This specification, which actually represents an imaginary output level, can be many times the level of a GPA's compressed output-power level. For example, it is not unusual for a GPA with output power at 1 dB compression of 0.25 W (+24 dBm) to be characterized for a third-order intercept point of 8 W (+39 dBm) or more.

For applications in which a wide signal dynamic range must be processed, the third-order intercept point represents the upper limit of the dynamic range, while the GPA's noise figure represents the lower limit of the dynamic range. The residual noise that the amplifier introduces to a system is more critical in receiver applications (in which signal sensitivity will be impacted by an increase in noise) than in transmitter applications. Applications calling for the widest dynamic range require GPAs with both high third-order intercept point and low noise figure.

For simplicity, many GPAs are designed for single, positive voltage-supply operation. Typical supply voltages range from +5 to +10 VDC, although some amplifiers can run on supplies of +3.3 VDC and less. Matching a GPA's voltage supply requirements to a particular application can ensure achieving the efficiency and linearity performance levels expected for that device.

Packaging and Mounting

Most GPA suppliers promise high reliability for their devices. Reliability is often judged by a figure of merit known as mean time to failure (MTTF), with higher numbers indicating better reliability. In general, a device designed to dissipate heat efficiently and operate at lower semiconductor junction temperatures will outlast a device running at higher temperatures. Devices designed for low thermal resistance will maintain low junction temperatures (+125ºC or less) and high reliability. Achieving low thermal resistance is a function of many factors, including die-attach materials and methods, package materials and even the size of the die. In general, from a reliability point of view, larger die and lower power density are desirable. However, these factors drive up device cost and may have an impact on electrical performance.

The three primary die attach methods are eutectic, solder and conductive epoxy. Eutectic is generally considered better but imposes certain constraints on die and package processing. Conductive epoxy is generally the simplest die-attach method, but it can yield slightly degraded thermal and electrical performance. Conductive epoxy is the least stiff of the mounting methods and may offer reliability advantages in the presence of printed-circuit-board (PCB) flexure (adjusting to flexure with less stress on the device die). Most GPA die are stiff and can crack under certain mechanically- or thermally-induced PCB flexure conditions. Damage to the gain block can usually be prevented by "pinning" the PCB to the system heat sink with a few screws in the immediate area of the gain block, preventing PCB movement or flexure that can damage the GPA.

GPA die are commonly mounted on metal (such as copper) heat spreaders, which form the bottom of the device package. The heat spreader can then be attached to a heat sink to create a clear thermal path for optimum dissipation of device-generated heat. Although surface-mount techniques now support much of the world's low-cost electronics manufacturing, these methods do not always lend themselves to optimum thermal management, since directly mounting a GPA on a PCB can create a path of high thermal resistance. The PCB thermal resistance can be lowered through use of a thermal via array under the gain block, but this adds cost to the system.

Some plastic package materials have a built-in temperature limit that is independent of MTTF considerations. It may be related to the temperature limit of the plastic mold compound used, or it may be imposed by metal interface (e.g., gold wire bond on aluminum bond pad) issues. Conventional SOT-89 packages are limited to a junction temperature of +150ºC. However, recently developed packages with more advanced materials can handle junction temperatures to +175ºC or even as high as +200ºC, on a par with more expensive ceramic packages.

Of course, with increased reliability comes increased cost, and most commercial applications do not require the long-term durability of a military-grade or space-qualified GPA, especially for an application such as a cellular telephone, with a limited expected operating life. The tradeoff between reliability and cost should be considered when matching a GPA to a particular application.

In addition to these basic parameters, some applications may require scrutiny of a GPA's peak or saturated output-power capability rather than simply its output power at 1 dB compression. This is usually the case in a system with high peak-to-average power ratio, such as in code-division-multiple-access (CDMA) cellular systems. Another consideration when specifying a GPA is its video or instantaneous bandwidth, especially for applications requiring amplification of complex or wideband modulation. Insufficient video bandwidth will cause distortion of wideband-modulated signals and inevitably loss of transmitted information. Typically, video bandwidth is determined from a two-tone test in which the spacing of the tones is increased in search of the point where the IMD increases significantly.

Gain blocks are often available with additional special features, such as multiple amplifier stages and switching capability within a single package for multimode, multiband applications. In some cases, power detectors and temperature-compensation circuitry may be included to maintain level gain with frequency and temperature.

Conclusion

Briefly, GPAs are indispensable solutions for a broad array of RF receiver and transmitter applications, ranging from CATV systems to virtually every type of wireless communication system. By understanding the different types of devices available, plus their environmental and performance characteristics, designers can more easily choose the proper device for a specific application.

Author Information

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Technical and product information can be found at www.freescale.com/rf.