Monolithic power amps provide diverse choices in circuit structures

Bill Travis, Senior Technical Editor

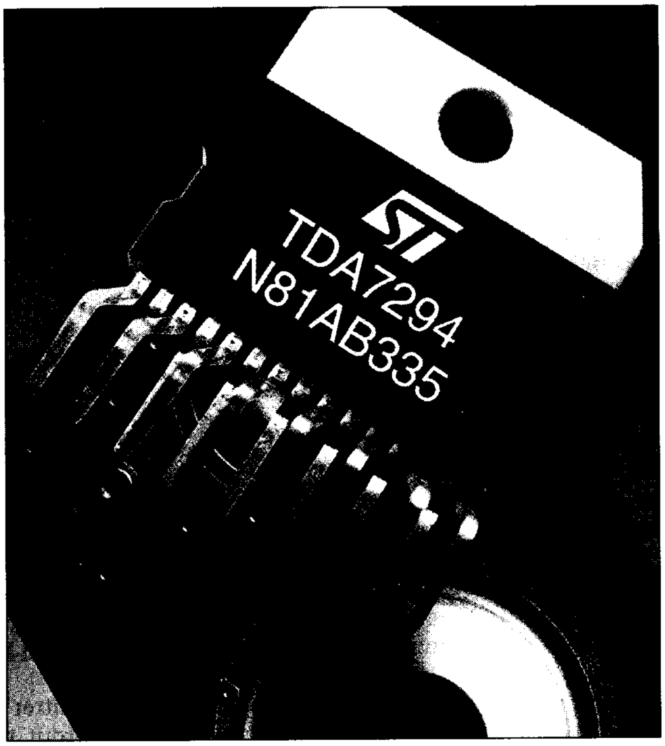
When choosing a power-amplifier IC, take time to carefully consider the input and output characteristics that suit your application.

In the midst of the flurry of multimillion-transistor digital ICs assailing the marketplace, it's easy to forget that a wide variety of loads demands a lot of volts, amps, and watts to drive them. Some examples are motors, actuators, vibration-cancellation systems, and, of course, loudspeakers. The representative sampling of monolithic power amplifiers in **Table 1** can provide that needed drive. However, you must choose among them prudently to ensure that both the input and output characteristics satisfy the needs of your application.

Of the two sets of characteristics, those of the output stage are probably the more crucial to the success of your design. The worst that can happen if you choose an amplifier with inappropriate input parameters are inaccuracies accruing from offset and drift and, perhaps, undue loading of the source because of too-low input impedance.

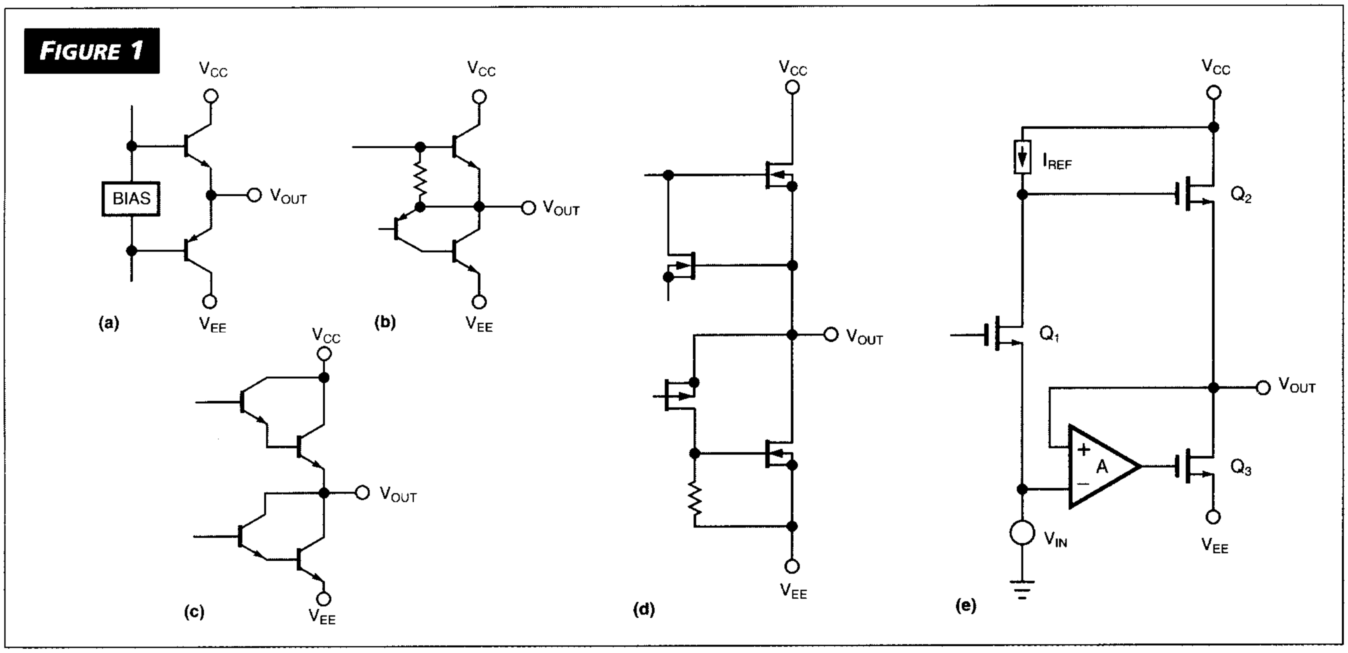
Far graver woes can result from the choice of an amplifier whose output structure doesn't match the needs of the load. These woes include premature thermal shutdown and outright destruction of the amplifier IC. A discussion of the various output structures in **Fig 1** may offer some insight into the appropriateness of the various amplifier types for your application.

Figs 1a, **b**, and **c** are simplified output structures



Hi-fi, high-power audio performance and complete output-stage protection characterize SGS-Thomson's TDA729x Series monolithic amplifiers.

FIGURE 1



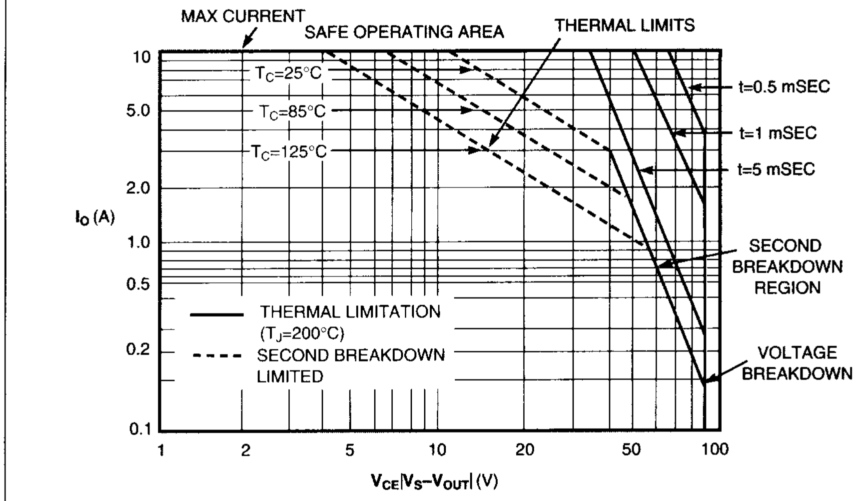
Bipolar output structures include full-complementary (a), quasi-complementary (b), and all-npn (c) types. The MOSFET structure in (d) suits high-voltage amplifiers; the structure in (e) suits low-distortion audio amplifiers.

that use bipolar power transistors. You're not likely to find the full-complementary topology in **Fig 1a** in monolithic amplifiers, because high-power pnp transistors are not very amenable to monolithic processing. More's the pity, because, as **Ref 1** explains, the full-complementary stage is easy to use. It offers symmetrical output impedance and low crossover distortion (assuming proper class-AB biasing).

The quasi-complementary stage in **Fig 1b** is amenable to IC processing and provides performance similar to that of the full-complementary topology. The two lower transistors in the circuit form a "composite-pnp" transistor. The drawback to this structure is the heavy local feedback in the lower transistor loop, which can lead to instability in the presence of inductive loads.

The all-npn output stage in **Fig 1c** is an early approach to fabricating monolithic power amplifiers. Its main disadvantage is the large difference in output impedances when sourcing and sinking current. The upper (sourcing) transistor is an emitter follower with inherently low output impedance. The lower (sinking) transistor operates in common-emitter mode with inherently high output impedance. Another disadvantage is the large difference in open-loop gain in sourcing and sinking modes.

FIGURE 2



When designing with bipolar amplifiers, you must be careful to keep the stress on the output transistors within the limits set by the safe-operating-area curves, especially in the solid-line region of second breakdown.

Beware of bipolar burnout

Bipolar power transistors are cursed with a negative temperature coefficient for V_{BE}, the base-emitter voltage required to yield a given collector current. So, unless a circuit designer incorporates compensation techniques into the output-stage drive circuitry, the power transistors are subject to thermal runaway. Power causes heating, heating causes V_{BE} reductions, and, with a given V_{BE} drive voltage, the transistor turns on even more fully. Without compensation precautions, this positive thermal feedback causes the transistor to self-destruct.

It's a tricky proposition to provide such V_{BE} compensation. A designer must strike a fine balance between two almost-conflicting criteria: maintaining adequate quiescent current to prevent crossover distortion and preventing thermal-runaway conditions.

An important consideration in matching bipolar output stages to the needs of a load is to respect the "safe operating area" (SOA) carefully. **Ref 2** gives a detailed explanation of how to use SOA curves for bipolar power transistors. **Fig 2** shows an SOA plot for a typical bipolar device. The maximum safe current is a function of V_{CE}.

At low values of V_{CE}, the transistor can deliver maximum current to the load. In this area of the SOA, the only worry is to avoid excessive currents that could overstress wire bonds or die metallization. As V_{CE} increases, the power dissipation increases to the point that self-heating raises the junction temperature to the maximum rated value (usually 200°C). Note that in this broken-line region, $V_{CE} \cdot I_C$ (power) is a constant.

As V_{CE} increases further, the safe output current decreases more rapidly. This area of the SOA plot is the *second breakdown* (also called secondary breakdown) region. Here, the transistor develops "hot spots" in regions of its

TABLE 1—REPRESENTATIVE INTEGRATED POWER AMPLIFIERS

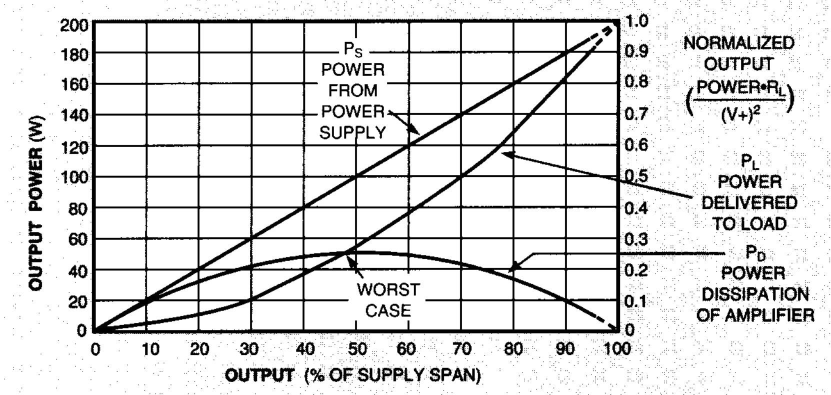
Company	Model	Type	Output structure	Supply span (V)	Output current	Package	Price	Comments
Apex Microtechnology Circle No. 321	PA43	Monolithic MOSFET	n-channel MOSFET	350	120 mA peak	Surface-mount, dual-inline	$13.60 (10,000)	40-V/μsec slew rate; 2-mA quiescent current.
	PA45	Monolithic MOSFET	n-channel MOSFET	150	5A continuous	8-pin TO-3	$17.90 (10,000)	Uses BeO substrate for 1.5°C/W maximum junction-to-case resistance.
	SA01	PWM (Class D)	Full-bridge (push-pull) p- and n-channel MOSFETs	100	20A continuous	10-pin hermetic power package	$250 (100)	Switches at 45 kHz; drives 2-kW load. Contains error amp for motor control.
Burr-Brown Circle No. 322	OPA544	Monolithic FET-input	Bipolar	70	2A continuous	5-pin TO-220	$6.95 (100)	Combines FET op amp with bipolar power-output stage.
	OPA2544	Monolithic FET-input (dual OPA544)	Bipolar	70	2A continuous	8-pin TO-3	$22.25 (100)	Combines FET op amp with bipolar power-output stage.
National Semiconductor Circle No. 324	LM1876TF	Dual bipolar monolithic	Bipolar	54	2.9A (limit)	15-pin isolated TO-220 style	$3.20 (1000)	Protection circuit automatically monitors SOA conditions. Provides 2×15W to 4Ω or 8Ω loads.
	LM4700TF	Bipolar monolithic	Bipolar	64	2.9A (limit)	11-pin isolated TO-220 style	$2.50 (1000)	Protection circuit automatically monitors SOA conditions. Provides 25W continuous to 8Ω load.
SGS-Thomson Circle No. 325	TDA7294	Monolithic BiCMOS DMOS	DMOS	100	10A peak	15-pin plastic Multiwatt	$5.10 (10,000)	Delivers 100W music power, 70W rms. Contains mute/standby functions.
	TDA7295	Monolithic BiCMOS DMOS	DMOS	80	10A peak	15-pin plastic Multiwatt	$4.10 (10,000)	Delivers 80W music power, 56W rms. Contains mute/standby functions.
	TDA7296	Monolithic BiCMOS DMOS	DMOS	70	10A peak	15-pin plastic Multiwatt	$3.75 (10,000)	Delivers 60W music power, 42W rms. Contains mute/standby functions.

geometry, points at which current flow concentrates. This condition leads to localized thermal runaway and, finally, device destruction. The final region of the SOA is the transistor's breakdown voltage.

Note the solid lines on the right side of the SOA plot in **Fig 2**. They indicate that you can exceed the second-breakdown limitations for short power pulses. Thanks to the thermal time constant of the silicon structure, such short-duration bursts of power don't give the transistor enough time to develop suicidal tendencies.

As **Ref 2** explains, you might be tempted to check for safe operation only at the point of maximum output voltage and current. But, this point may not be the most stressful. **Fig 3** is a plot of power dissipation as a function of the output voltage delivered to a resistive load. You can see that the worst-case dissipation for the amplifier occurs at 50% output voltage. You should use this condition to check for SOA compliance.

FIGURE 3



Maximum amplifier power dissipation occurs not at the maximum output voltages, but rather at the midpoint of the output-voltage span. Make note of this fact when you check for SOA compliance.

A short circuit to the negative rail is also a very stressful condition in the SOA. It forces the full power-supply voltage across the conducting transistor, and the current far exceeds the SOA limit. For this reason, amplifier designers incorporate thermal-shutdown circuitry in the ICs. For Burr-Brown's OPA544, for example, the short-circuit current is about 4A, and the safe SOA current is 1.5A. Thermal shutdown prevents device destruction.

Make note that the voltage in the horizontal axis of the SOA is not the amplifier's output voltage, but rather the voltage across the conducting transistor in the output stage. The vertical axis is the current delivered to the load. Also, be aware that capacitive or inductive loads can produce exceedingly stressful conditions in the output stage.

If a capacitive load is charged to the negative supply voltage and the output tries to go positive, the output instantaneously delivers maximum rated current at the full supply-voltage span. And, because an inductor acts as a current source, an analogous condition arises when the output tries to go negative.

National Semiconductor's bipolar-output parts (**Table 1**) incorporate a dynamic SOA-protection mechanism, called SPiKe, which stands for self-peak instantaneous Kelvin temperature-protection circuitry. National claims the circuitry makes the ICs nearly impervious to damage from instantaneous

TABLE 2—INTEGRATED-AMPLIFIER INPUT CHARACTERISTICS

Supplier	**Model**	**Maximum offset** (mV)	**Maximum offset drift** (µV/°C)	**Maximum input-bias current**	**Input noise**	**Minimum common-mode rejection ratio** (dB)
Apex Microtechnology **Circle No. 321**	PA43	30	130	200 pA	50 µV rms (typ) 10-kHz bandwidth 110 µV p-p (typ) 1 to 10 Hz	84
	PA45	10	50	100 pA	10 µV rms (typ) 10-kHz bandwidth	90
	SA0	10	No spec	5 µA	No spec	75
Burr-Brown **Circle No. 322**	OPA544/2544	5	10	100 pA	36 nV/√Hz (typ)	90
National Semiconductor **Circle No. 324**	LM4700/1876	15	No spec	0.5 µA	8 µV (max)	80
SGS-Thomson **Circle No. 325**	TDA7294/5/6	10	No spec	0.5 µA	5 µV (max) 20 Hz to 20 kHz	No spec

temperature peaks and overvoltage and overcurrent conditions.

Banish second breakdown

Advances in IC processing make it possible to fabricate monolithic high-performance MOSFET amplifiers, a product line that was once the domain of multichip-hybrid manufacturers. Two advantages MOSFET amplifiers enjoy are low quiescent current and the absence of second-breakdown thermal runaway. The surface-mountable Apex PA43, for example, works with a total supply span of 350V and consumes only 2-mA quiescent current.

SOA considerations are not as crucial for MOSFET structures as they are for bipolar outputs. MOSFET output stages have two limitations: the current-handling capability of the die metallization and the temperature of the MOSFETs. For user convenience, Apex does publish SOA curves for its devices. **Fig 4** shows the SOA curves for the PA43, which has an output structure similar to that of **Fig 1d**. Note, again, that you can exceed SOA limits for short power pulses.

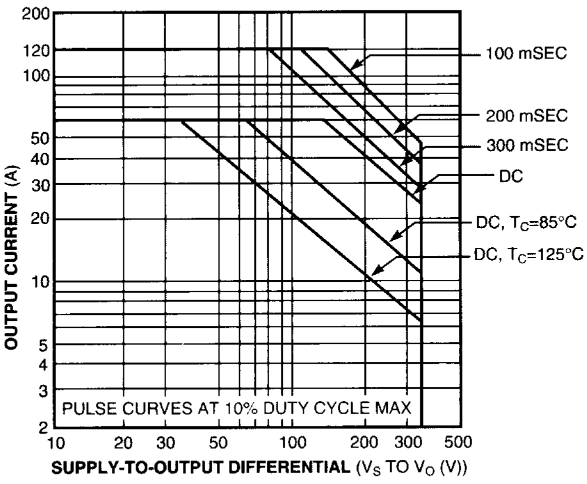
In **Table 1**, you can see that Apex's MOSFET amplifiers are high-voltage devices. High-voltage MOSFETs are much more amenable to IC processing than are bipolar transistors. These Apex amplifiers are general-purpose units, unlike the National and SGS-Thomson devices, which are characterized for audio applications. However, their application specificity doesn't prevent you from using them for other applications needing high-power drive.

The TDA729x Series from SGS-Thomson uses a mixed bipolar-CMOS-DMOS process to provide output-power levels from 60 to 100W to a loudspeaker. **Fig 1e** illustrates their output structure. SGS developed this novel architecture to ensure accurate control of quiescent current and to prevent crossover distortion. The quiescent current is a function of I_{REF} and the area ratio of Q_1 and Q_2, two adjacent DMOS transistors.

The local feedback afforded by the unity-gain block, A, in conjunction with the I_{REF}, Q_1 bias circuitry, prevents either transistor from cutting off completely. Complete cutoff would engender crossover distortion because of the relatively long recovery time of a cutoff MOSFET.

Like National, SGS employs a type of dynamic overload protection in the output stages of the TDA729x Series. Although the MOSFET output transistors are not subject to second breakdown, they are subject to destruction by overload. The protection circuitry senses the voltage and current—hence, power—in the output transistors and keeps the devices within SOA limits. It also uses a local temperature-sensing technique that dynamically controls the maximum dissipation.

FIGURE 4



The SOA plot for Apex's PA43 MOSFET amplifier takes account of die-metallization current limits and output-MOSFET temperature. Note the absence of the second-breakdown region inherent in bipolar structures.

Choose your input structure

In selecting a power-amplifier IC, you'll want to take a careful look at the devices' input characteristics. **Table 2** gives data-sheet parameters for the amplifiers listed in **Table 1**. Factors influencing your choice include source impedance, accuracy requirements, common-mode conditions, and noise performance.

The amplifiers from National Semi-

FOR FREE INFORMATION...

For free information on the power-amplifier products discussed in this article, circle the appropriate numbers on the postage-paid Information Retrieval Service card or use *EDN*'s Express Request service. When you contact any of the following manufacturers directly, please let them know you read about their products in *EDN*.

Apex Microtechnology
Tucson, AZ
(520) 690-8600
Circle No. 321

Burr-Brown Corp
Tucson, AZ
(520) 746-1111
Circle No. 322

Harris Semiconductor
Melbourne, FL
(800) 442-7747
Circle No. 323

National Semiconductor
Santa Clara, CA
(800) 272-9959
Circle No. 324

SGS-Thomson Microelectronics
Lincoln, MA
(617) 259-2543
Circle No. 325

VOTE...
Please also use the Information Retrieval Service card to rate this article (circle one):
High Interest 581
Medium Interest 582
Low Interest 583

Super Circle Number

For more information on the power-amplifier products available from all of the vendors listed in this box, you need only circle one number on the postage-paid reader service card. **Circle No. 326**

LOOKING AHEAD

Considering the power-amplifier ICs in this article, two trends begin to crystallize. First is the demise of multichip-hybrid amplifiers in the wake of the onslaught of high-performance monolithic devices. Gone are the halcyon days of such hybrid-amplifier makers as the late, lamented Teledyne Philbrick. After all, who wants to pay $200 for a hybrid amplifier when you can get a monolithic device with equivalent or better performance for $10?

The hybrids had their day because of the severe constraints monolithic ICs placed on analog-circuit designers. Back in the '80s, circuit-design wizards, such as the late Bob Widlar, learned how to live with, and even exploit, these former constraints. Widlar designed, for example, National Semiconductor's PA12, whose clever circuit topology made intelligent use of monolithic structures to provide thermal protection, emitter ballasting, and other useful bells and whistles. To put it succinctly, there is practically nothing an expensive hybrid can do that an inexpensive monolithic can't do.

The second trend centers around advances in processing technology, advances that made the amplifiers discussed in these pages possible. These advances will engender more and better power amplifiers in the future. A couple of examples are Burr-Brown's combining FET-input amplifiers with bipolar output stages and SGS-Thomson's use of a bipolar-CMOS-DMOS amalgam. These mixed-technology processes make it possible to enjoy the best of all worlds (depending on your application) in parameters such as input impedance, offset, and drift, as well as power consumption, output robustness, and available swing.

One final prediction: Bet on the emergence of more PWM-amplifier ICs like Apex's SA01; also, expect these types, too, to "go monolithic" as IC processing progresses. In this world of ever-increasing power frugality, the technical allure and marketing appeal of >90% efficiency is too great to resist.

conductor and SGS-Thomson use bipolar input stages. This fact is evident from the relatively high, 0.5-μA maximum input-bias currents. Therefore, you'd probably not select these types for applications having extremely high driving-source impedances. In **Table 2**, note that these amplifiers offer no offset-drift specs. As stated, they're designed principally as audio amplifiers, so drift is of relatively limited importance.

In judging whether the noise performance of an amplifier suits your application, you'll have to do some translation between the different style specs of the various amplifiers. For example, Burr-Brown's OPA544 specs 36 nV/√Hz typical, and the other amplifiers spec either wideband or limited-band rms or p-p voltage figures.

Maximum offset voltages range from the OPA544's 5 mV to the PA43's 30 mV. If the 30 mV seems high, remember that the PA43 is a 350V amplifier intended for applications such as telephone-ring generators, piezoelectric positioning, and electrostatic transducers and deflection circuits—applications in which offset is of little importance.

Monolithic amplifiers go digital

Just when we thought the amplifier-IC world was safe from the "fully on, fully off" mentality of digital technology, along comes Apex Microtechnology's SA01, a high-power device that occupies only 2 in.^{2} and delivers 2 kW to its load (**Ref 3**). This hybrid amplifier uses pulse-width modulation (PWM), or Class-D operation, to provide power amplification.

This device is a breakthrough in that such power levels were formerly available only from large "bricks" and chassis-mounted PWM amplifiers. The SA01 provides a full H-bridge (push-pull) output, effectively doubling the power available from a given single power supply.

Although this device's operating principle is not strictly "Boolean," you can consider it a digital circuit in the sense that its output stage only switches fully on and off and spends no time (except during transitions) in the linear region. The result is >90% efficiency, as opposed to the wasteful 50% inherent in linear amplifiers. The device is useful in applications such as brush-type motor control, magnetic coils for MRI systems, and vibration cancellation.

If the idea of rolling your own switching amplifiers appeals to you, read Jeff Sherman's *EDN* article (**Ref 4**), which shows how to use Harris Semiconductor's MOSFET-driver ICs to configure highly efficient, low-distortion amplifiers.

You now have available a variety of monolithic power amplifiers to fit almost any conceivable application. In selecting one, take care to match the input and output characteristics and limitations to the needs of your system. EDN

References

1. Apex Microtechnology, *Improve Your Analog Power*, Seminar III.

2. Trump, Bruce, *Power Amplifier Stress and Power Handling Limitations*, Burr-Brown Application Note AB-039.

3. Schweber, Bill, "First hybrid PWM amplifier requires just 2 in.^{2}," *EDN*, March 30, 1995, pg 9.

4. Sherman, Jeffrey, "Class D amplifiers provide high efficiency for audio systems," *EDN*, May 25, 1995, pg 103.

You can reach Senior Technical Editor Bill Travis at (617) 558-4471, fax (617) 558-4470 or via Internet at b.travis@cahners.com.