sitions.

The dynamic power measurements of the ST400II appear to show that the design is underbuilt. Construction quality of the unit appears to confirm this. The 20 kHz distortion figures are also high throughout the power band. For $105 dollars more the Rotel unit (see below) handily outperformed the Dynaco—in some cases by an order of magnitude! We thus cannot recommend this unit.

Hafler Series 9500 Transnova

Hafler, a division of Rockford Corporation, 648 River Street, Tempe, AZ 85281. Series 9500 stereo power amplifier, $1800.00. Tested sample on loan from manufacturer.

This is the only power amp in this survey to use a MOSFET output stage. Indeed, this is the only power amp in the survey to use FETs of any kind. (In truth, however, I do not know what devices are used by Mr. Yee in the UltrAmp). The Hafler marketing department has been pushing the MOSFETs-are-like-tubes angle in their advertising. This sullies the fine work of Jim Strickland, who is following in the path of Erno Borbely. Borbely was an early employee of Hafler (long before it was taken over by Rockford) and had a preference for MOSFETs for good scientific reasons (see above).

As stated above, the distortion characteristics of a MOSFET used as a source-follower output stage will be higher than those of a comparable bipolar stage. One way around this is to use the MOSFET in a common-source configuration. Headroom is also significantly improved with the common-source configuration. However, there are several problems with that approach. The most significant of these is the problem of biasing the devices. Traditional V_{BE} multiplier configurations cannot be used because the biasing loop now includes the power supplies. Any variation in the power supply now affects the output quiescent current. This problem has been attacked numerous times in CMOS integrated circuits. The solution usually involves the addition of a complete error amplifier around each output transistor. The error amp sets the quiescent current of the transistor and defines its gain. Assuming that each error amp sets the same current in both sides of the complementary pair (additional circuitry is often required to ensure this assumption is valid), the quiescent current of the output is set. Jim Strickland's solution to this problem is much simpler but far less obvious. His innovation is a dynamic power supply.

Here is how it works. Both sources of the complementary MOSFETs are connected to ground. The gates of the MOSFETs can now be biased and driven by the second stage in the standard manner. A stacked diode array in series with the collectors of the second-stage transistors sets the fixed voltage difference across the gate transistors, thus establishing the quiescent current. Now the drain of the *p*-channel output-stage MOSFET is connected to the positive supply rail and the drain of the *n*-channel MOSFET is connected to the negative supply rail. Think about this for a second—what happened to the positive output terminal of the amplifier? It's at the center tap of the power transformer! What happens in the amplifier is that as the output moves the transformer secondary, the full-wave rectifier moves and the power-supply filter capacitors move. The whole power supply follows the output signal! Clearly this amplifier cannot be described as direct-coupled.

With the bias problem solved, the next issue to deal with in a common-drain amplifier is the output stage's voltage gain. With three stages of voltage gain, there will be three high-frequency poles and lots of open-loop gain [Grebene 1984]. This is a recipe for an oscillator, not an amplifier. The solution used in the Hafler is to use a nested feedback loop in the output stage [Grebene 1984]. This loop is formed by a resistor between the output terminal and the gate of the output stage. This local shunt feedback loop stabilizes the output stage's transresistance [Gray and Meyer 1984]. Another problem with a common-drain output stage is that it has a very high output impedance [Grebene 1984]. This makes the gain of the stage and its high-frequency transfer characteristic highly dependent on the value of the amplifier's load. The aforementioned shunt feedback loop lowers the effective output impedance of the stage to help reduce this problem. The amplifier's name, Transnova, apparently is a reference to the output stage's transresistance property. The shunt feedback also reduces the input impedance of the output stage. Since the second gain stage has a high-impedance output, the voltage swing at the input to the output stage is limited. This allows the first and second stage to run on 24 V regulated rails. Power MOSFETs have large values of gate-to-source capacitance. When wired in a source-follower configuration this capacitance is bootstrapped, lowering its effective value. In the common-source configuration the capacitance is Miller-multiplied. This creates a difficult load for the second gain stage to drive.*

*Much of my statements (with supporting references) in this paragraph will be found to be in contradiction to a paper by Cherry [Cherry and Cambrell 1982]. In his paper a formal analysis of both common-emitter and emitter-follower amplifiers is undertaken. From mis mathematical analysis Cherry concludes that the stability of an amplifier with a common-emitter output stage should be very similar to that of an amplifier with an emitter-follower output stage when a load is attached. Other amplifier characteristics, including output resistance and distortion, are also claimed to be similar. This runs counter to my experiences, and I believe that Cherry's analysis may be flawed because of the simplification required to produce usable analytical results.

For example, the emitter-follower amplifier model used by Cherry does not include any predriver stages, causing a significant fraction of the load impedance to be reflected to the second gain stage. Another example is that the parasitic capacitor across the output device in the common-emitter amplifier is analyzed by replacing it with a Miller-multiplied capacitor at the input to the third stage. This capacitor also gives rise to a right half-plane zero [Gray and Meyer 1984], a further source of stability problems, but this zero is not considered in the Cherry paper. Cherry also claims that nested feedback around the third gain stage does not improve stability or enhance performance.

Professor Cherry is one of the seminal thinkers in audio, so he is not very likely to be wrong. I would therefore welcome any of our technical readers to comment on his paper.

The front end of the Series 9500 is more conventional than its output stage. Complementary differential pairs with JFETs form the first stage. The *n*-channel sources are connected to the *p*-channel sources through a resistor. Because the JFETs have a negative threshold (for the *n*-channel device), this arrangement self-biases the differential pairs. Unlike a constant-current biasing scheme, the current in the differential pair can increase when the differential pair is driven with a large differential current. This improves large-signal dynamic performance. A similar circuit was developed by Sansui [Takahashi and Tanaka 1984] using bipolar devices but is much more complex because the bipolar will not self-bias. The second stage is a complementary common-emitter stage. Both the first and second stage are cascoded with bipolar devices. There is a total of 19 transistors, including the quadruple paralleled output devices. Feedback is taken from the positive terminal of the amplifier (the transformer's center tap) back to the non-inverting differential-pair input, using the standard passive resistor divider. A 220 µF electrolytic cap is used in the ground return path of the main feedback loop (capacitor C_2 in Figure 6). It is bypassed with a small film cap. The amplifier's dominant pole is formed by a Miller capacitor around the second gain stage. Additional secondary compensation circuits are used throughout the amplifier. They are required keep the three-gain-stage topology stable.

A single huge transformer is used in the Series 9500. Each channel has its own secondary, which is connected in the dynamic configuration described above. The supplies are filtered with 20,000 µF capacitors, each paralleled with a 4.7 µF film capacitor. The first and second stages are driven by ±24 V regulated power supplies. The low power-supply rails can be used because the output stage has voltage gain. The regulated supply starts with a button-sized full-wave rectifier. 1000 µF capacitors filter the rectifier's output. LM317 and LM337 integrated rectifiers are used to generate the regulated rails. This supply is shared by both channels. I was somewhat surprised that separate regulators were not used for each channel. Owing to the more robust nature of MOSFETs, the only protection devices on the amplifier are the power-line fuse and fuses in the dynamic supply rails. A turn-on delay circuit prevents current flow in the differential pairs until the output stage has settled.

Construction quality of this amplifier is excellent. Thick sheet metal is held together with high-quality machine screws. Custom-designed heat sinks start at the side of the amplifier and then curve to the back. Double-sided circuit boards are stuffed with high-quality components. A large metal bar is placed across the inboard side of the output devices to ensure good mechanical contact with the heat sinks.

Given all the innovations in this amplifier, I was hoping to see static distortion numbers that would rival those of the Boulder 500AE, Bryston 4B, and Bob Cordell's MOSFET design. It turned out this was not going to occur. Into an 8-ohm load the 990 reaches a minimum THD-plus-noise level of -81 dB at 240 watts with a 1 kHz input. Into 4 ohms the minimum distortion level at the onset of clipping (400 watts) is -77 dB. At 0.55 watts the 20 kHz distortion curve reaches a minimum of -70 dB, then rises and plateaus, reaching -60 dB at clipping into 8 ohms. Into a 4-ohm load the 20 kHz distortion reaches a minimum level of -67 dB and rises to -57 dB at clipping. The origin of the relatively high 20 kHz distortion is unclear. It may arise from the dynamic power supply, or it could be an indication that the second stage is having trouble driving the capacitive load of the output stage. The 10 kHz square-wave response into a 6-ohm load with a capacitive component of -45° showed more than average overshoot and lots of ringing. Capacitive-load square-wave testing of an amplifier with an inductor in the output stage is not revealing of amplifier instability because the LC resonance dominates the amplifier's response. This amplifier does not have an inductor in the output stage, but the transformer is of course inductive. The value of this inductance and the value of the large bypass capacitors would not cause ringing at the rate observed in this test. As stated above, stability problems are more likely in a three-stage design.

The PowerCube system measured a dynamic output voltage of 55 V (378 watts) at 8 ohms. That represents 1.8 dB of dynamic headroom. The PowerCube showed that the maximum voltage output of the amplifier declined by 20% into 2 ohms for noninductive loads and by 45% into 1 ohm. The dynamic power into a 1-ohm resistive load measured 894 watts. Available output voltage increased into reactive loads; thus no stability problems were identified in the PowerCube tests. No *I-V* current limiter artifacts were observed because the Series 9500, like most MOSFET amps, does not require an *I-V* current limiter. Peak current output was 71 amps.

I wanted this amplifier to be recommendable, given all the innovative circuitry and good build quality for the money. The 20 kHz distortion and some evidence of lower stability margins into capacitive loads militate against such a recommendation. For only 1.7 dB more cash ($395, that is), the Bryston gives you 20 dB less 20 kHz distortion, the same level of construction, the same maximum power, and balanced inputs. I hope Jim Strickland can overcome the remaining design problems of his topology in the next generation of this product. In the meantime, does anybody out there want to produce a scaled-up version of Bob Cordell's state-of-the-art MOSFET power amplifier?

R.E. Designs LNPA 150

R.E. Designs, 43 Maple Avenue, Swampscott, MA 01907. LNPA 150 monoblock power amplifier, $2700.00 the pair. Tested sam-