Sunfire amplifiers had their beginning over 25 years ago. After Bob Carver sold Phase Linear, which he founded in the early 1970's, and decided to start Carver Corporation, he wanted to come out with a new amplifier that would be light years ahead of anything available at that time. He began work on a signal tracking power supply. Successfully implemented, an amplifier that incorporated such a power supply would be able to deliver lots of power, would run stone cold and would be incredibly efficient. All of the input power would become output power, it would be able to deliver massive amounts of current and would drive almost any impedance down to 1Ω and below. It would have the potential of ultra-reliability because it would be running cold, would not require heat sinks, and because it would be so efficient the power supply could be much smaller for the equivalent output power – in a conventional amplifier only 20% to 30% of the input power actually appears at the output of the amplifier as usable audio power. The story obviously doesn't end there…

SUNFIRE – WHAT'S IN A NAME?

It wasn't the greatest of beginnings – Bob Carver toiled for more than a year trying to make this design into a reality but couldn't get it to work. And so after a year of working until two in the morning he temporarily admitted defeat, set the design aside, and instead developed a different power supply called the Magnetic Field power supply. That power supply and its power amplifier became the original Carver "Cube". This amp was used to start a small little audio company you may have heard of… Carver Corporation.

FAST FORWARD 13 YEARS

In 1992, while still at Carver Corporation, Bob decided to have another go at the amp design that had earlier escaped him. He pulled out his notes from years prior, including the old patent, and this time he succeeded… and succeeded in spades! The resulting amplifier was able to deliver massive power and enormous current; it could operate down to 1Ω and it didn't get hot. It did the impossible and fulfilled the dreams he had years ago. He dubbed that amplifier the *Lightstar*. On December 17, 1992 he turned over the design to the engineering department for packaging and went on sabbatical with the intention of final tweaking and voicing upon his return. The rest of the story is best left to the attorneys, but the end result was that Bob left the company he had founded years earlier and embarked on a new venture...

In 1993 a new Bob Carver "child" was born. At first it was Zeus Audio, named after his puppy (who sadly passed away in 2006), but Bob received a letter from an attorney who said, "No, you can't name it *Zeus* because we represent an amplifier company who owns names like Hercules, Aphrodite, Apollo, and Zeus." No problem (he thought), and renamed the company *Silvermane* (taken from the color of his puppy's coat). That promptly got him another letter from another attorney who wrote, "No, I represent the Marvel Comics Group and we have a Superhero called Silvermane." Silvermane was out, and in 1994 Sunfire was born…

CONVENTIONAL AMPLIFIERS

In order to understand how the Sunfire amplifier works, it is helpful to review a conventional amplifier and illustrate some of the very difficult engineering problems associated with powerful, and very high current amplifiers. As you know, a conventional amplifier has a power supply; and for a 300 watt amplifier the power supply voltage is approximately 90 volts. Those 90 volts are parked way up at 90 volts above ground. The audio signal varies under that voltage and as long as the amplitude of the audio signal remains below 90 volts, as illustrated in Figure 1, the amp will not clip or run out of power.

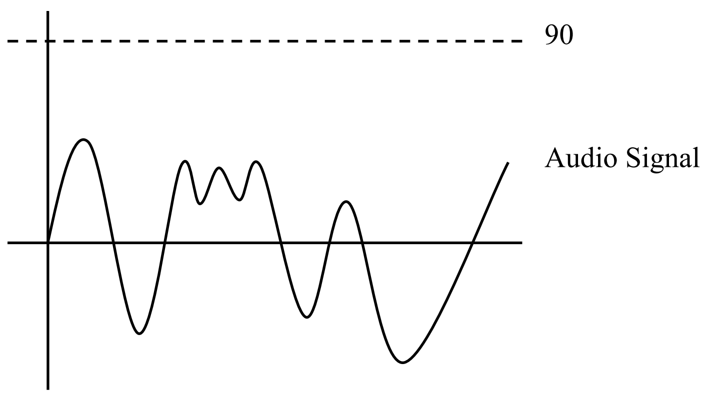

Figure 1

Of course, if the audio signal is required to be greater than the 90 volt power supply, the amplifier will clip as illustrated in Figure 2.

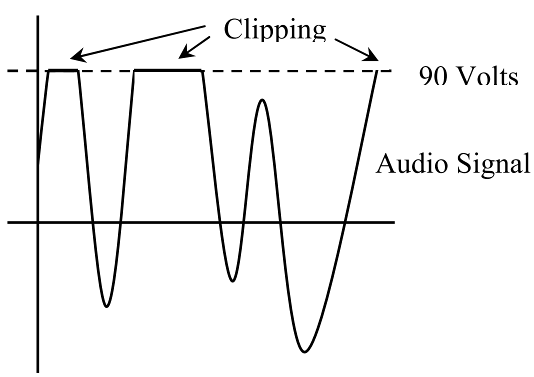

Figure 2

In a conventional amplifier, when the amplifier is delivering power to the loudspeaker load, the current flows out of the power supply, through the output transistor or transistors, and then into the load. Refer to Figure 3.

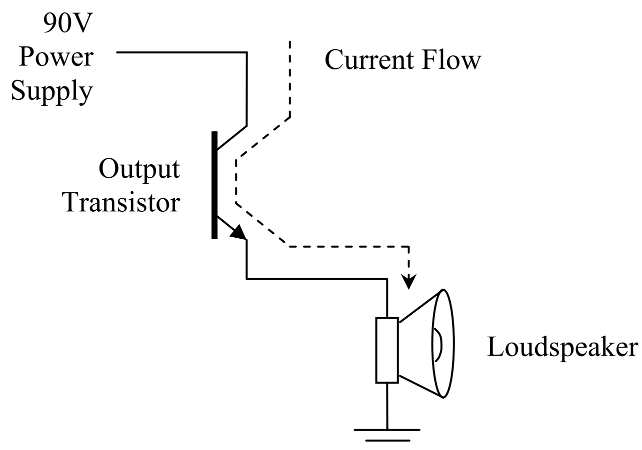

Figure 3:

As an example, assume the output voltage at the loudspeaker is 30 volts and 10 amperes of current are flowing. The current starts at the power supply and flows through the transistors; as it goes through the transistors it makes them get hot. How hot? The measure of hotness is power; voltage times amperage. Remember, there are 10 amperes flowing; and if there are 30 volts on the loudspeaker and there is a 90 volt power supply, that means there are 60 volts across the transistors. Again, the power is equal to volts times amps — 60 volts times 10 amps equals 600 watts! That is not the power going to the load, that's the power going into the transistors as heat that must be dissipated. Hence, the transistors are mounted on a large heat sink; the heat is transferred to the heat sink and ultimately to the air around the unit – ever notice how hot you're A/V cabinet gets?

Since the amplifier is only about 20% to 30% efficient, a lot more power has to go into the amplifier than comes out because 600 watts is going up in heat. Since it's inefficient, there must be lots of output transistors, lots of heat sink(s), and the power supply has to be much larger than would ordinarily be required in order to make up for all the power that's being wasted. Instead of a 30 pound power supply, it has to be 80 pounds. Well, so what? It's not difficult to add power supply and heat sink(s) necessary to allow the amplifier to deliver the power. However, an insidious problem exists – the output transistors that amplifier designers use are big 20 ampere output transistors. They are used in large, high end amplifiers and most of the big receivers these days. It is a standard part in the electronics industry that is rated at 20 amperes. However, it's only able to deliver 20 amperes if there are 10 volts or less across it. That's because it's a 200 watt part and can never dissipate more than 200 watts or its rating is exceeded. At 50 volts, for example, it can deliver only 4 amperes because 4 times 50 is 200. At 90 volts it can deliver only 2.2 amperes. Going back to the earlier example with 60 volts across it, it can deliver only 3.3 amperes. If a designer wants to have an amplifier that's able to deliver lots of current into very low impedance loads, to deliver current in an unvarying way, no matter how difficult the loudspeaker impedance, no matter what the phase angle, he or she must use many paralleled output transistors – lots and lots of them. In this case, they will not output the full 20 amperes, only a small portion of that, especially when driving low impedance loads. Consequently, a designer has to parallel many, many output transistors. These transistors arrays must be mounted on huge heat sinks to dissipate all the power wasted as heat. And to make matter worse, because the amplifier is not very efficient it must have a huge power supply – if you've ever "popped the hood" on an amplifier or receiver you've likely seen this in action. Since each transistor draws its own idling current, the amplifier tends to run hot when it is just sitting there at idle. Biasing issues become very severe problems and to this day other manufacturers are still searching for solutions. Engineers and designers forever fret over whether they're going to bias their amplifiers Class A, Class AB, or use a sliding bias scheme. Amplifiers that can deliver these awesome and majestic currents do exist, but to get there you would have to reach up to the ones that are very expensive – starting at about $8,000. There is a better way.

SUNFIRE'S TRACKING DOWNCONVERTER

In the Sunfire amplifier, that 90 volt power supply voltage that was mentioned earlier is no longer "parked" at 90 volts above ground. Instead it is brought down and parked at only 6 volts above ground; the 90 volt constant no longer exists! Then, at any moment in time, regardless of what the output of the amplifier is, the power supply voltage will always be 6 volts above the *output signal*. Let's read that again, because that was the breakthrough… "*At any moment in time, regardless of what the output of the amplifier is, the power supply voltage will always be 6 volts above the output signal*." If the output signal is zero, the output of the Tracking Downconverter will be 6 volts. If the output of the power amplifier is 30 volts, as in the previous example, the output of the Tracking Downconverter will be 36 volts. The voltage across the transistors remains a constant, unvarying 6 volts. Therein lays the beauty of the Tracking Downconverter. Now, consider the earlier "poor conventional amp" example. The amplifier was delivering 30 volts to the load and 10 amperes of current were flowing. That example resulted in 600 watts of power in the output transistors. Consider Figure 4 on the next page.

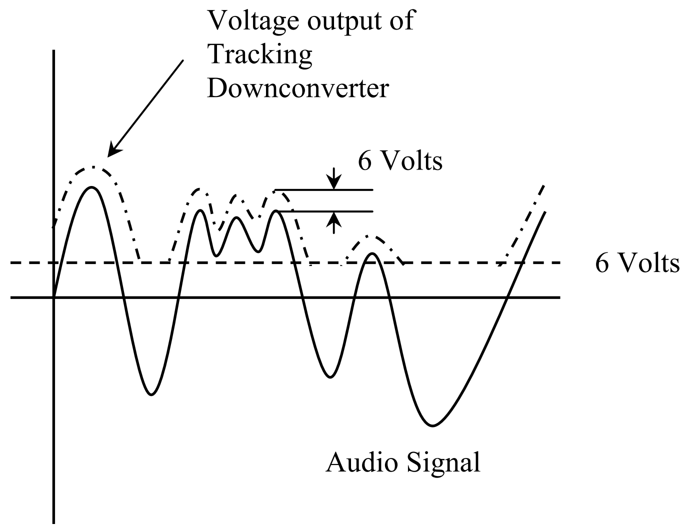

Figure 4

In the Sunfire amplifier, that same 10 amperes is not dropping across 60 volts. Instead, it's dropping across 6 volts so the power is only 6 volts times 10 amps — 60 watts wasted rather than 600 watts. *Ten times less* — that's an order of magnitude! It's so little power that the amplifier does not have a heat sink, it simply doesn't need one. There is not a heat sink to be seen in this amplifier, yet it can deliver well over 2,000 watts into 1Ω. And because of its increased efficiency, the power supply doesn't have to weigh 80 pounds. The power supply can be a reasonable 30 pounds.

But here's the best part – remember that a 20 ampere transistor can only deliver the full 20 amperes if there are 10 volts or less across it (because of its intrinsic 200 watt limit). In the Sunfire amplifier, since there are only 6 volts across the transistors at all times, the full output current of 20 amperes can be delivered from each output transistor instead of 2, 3 or 4 amperes as in a conventional amplifier. Because each output transistor can deliver its full 20 amperes, the amp can deliver lots and lots of current into low impedance loads. In modern Sunfire amplifers, 18 output transistors are used per channel, each capable of 20 amperes. That represents a potential peak to peak output current of over 240 amperes! And it can do so into vanishing low load impedances. That's a staggering amount of current, and what is required to have an amplifier with the performance of a $10,000 machine.

A remarkable feature of the Tracking Downconverter is its intrinsic and unique ability to transform high voltage and low current to low voltage and high current. For example, if the input power to the Downconverter is being delivered at a very high voltage, the output power can be delivered at a very high current. The transformation ratio; i.e., how much the current is increased is in the same proportion that the voltage is decreased. In the case of the Sunfire, the power supply voltage is 2 times 125 volts, approximately 250 volts. Therefore, if the input current is 10 amperes and the output voltage is 25 volts, corresponding to a difficult or low load impedance, the output current will be 100 amperes because 250 divided by 25 is 10. (The input current 10 amperes multiplied at the output by 10 for 100 amperes. A conventional amp could never do that, i.e. 10 amps in equals 10 amps out.) See Figure 5.

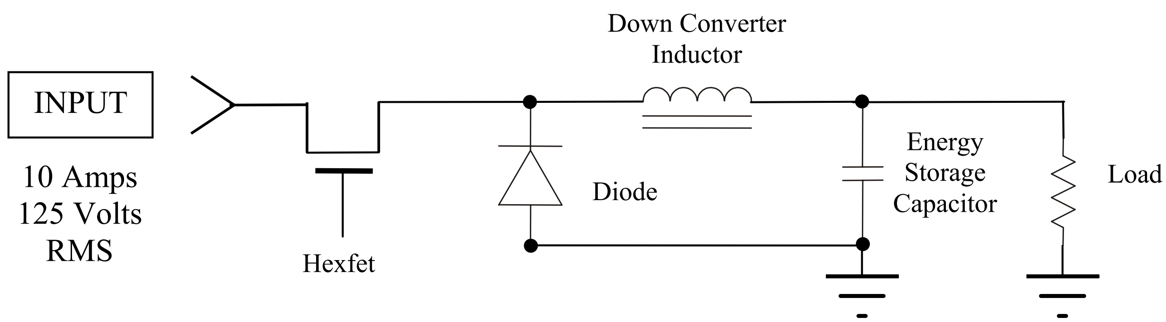

Figure 5

It is this remarkable property of a Tracking Downconverter that allows the amplifier to deliver tons of current into vanishing low load impedances. It is also the property that allows the amp to run cold, to have a smaller power supply than would conventionally be required, and to possess a very flat output voltage characteristic. Whenever the load impedance is halved, the power just continuously doubles. A scientist would call this "load invariant".

At that point in the design, the Sunfire was an amplifier that could deliver almost limitless current, almost limitless voltage and deliver both simultaneously for tremendous output power and runs cold. However, at this point in the design, its full benefits were not yet realized. The amplifier needed to be *listened to*.

TO HEAR IS TO FEEL

Listening to an amplifier in its design process is potentially the most time consuming, and is where the art of amplifier design enters the picture. Bob first used a female vocalist to make certain that she could be accurately located in an acoustic space between the speakers and in such a way that a believable halo of space surrounded her and she became palpably three dimensional. Also, her voice was soft, musical, lyrical and had a great deal of believability. After the female voice, he listened to the male voice using baritones to listen for the "chestiness" in the male voice.

When that part of the work was completed, he went to the symphony – in spirit at least. Since human voice reproduction was so stunning in his first listening tests, he found that the symphony orchestra locked in and there wasn't much tweaking needed — sort of like getting flesh tones correct on a color television, all the other colors often lock in with very little effort. At that point Sunfire had an amplifier that was tremendous. It had lots of current, lots of voltage, incredible performance, but there was still more to come.

CURRENT SOURCE – VOLTAGE SOURCE

A transistor is inherently a voltage source device; whenever an amplifier designer designs an amplifier with transistors, the result is a solid state amp that will typically have a very low output impedance approaching zero. A vacuum tube, on the other hand, is intrinsically a current source device. If an amplifier designer builds an amplifier out of vacuum tubes, he or she typically ends up with an amplifier that has a current source output characteristic, i.e., a higher output impedance. It's this high output impedance that is primarily responsible for 80% to 90% of what makes a vacuum tube amplifier sound like a vacuum tube amplifier – a glow to the midrange, a soft high end, typically a layered stage depth and often a sound stage that is wider than it would be with a solid state amplifier. This musical presentation is very pleasing and lovely to listen to, is quite captivating and the main reason many audiophiles love vacuum tube amplifiers. Bob took a step back, looked at the revolutionary amplifier he had designed, yet he wasn't quite satisfied. He still desired that glowing sound that tube amplifiers offered; and being the perfectionist he is, set out to design a circuit that would mimic it.

Enter a new twist – Sunfire amplifiers have two sets of output terminals on the back. One is a *voltage source* output with very low impedance. The other is a *current source* output with a higher impedance output characteristic. The choice of which to use is up to the listener. If you desire the tight response of a solid state amplifier, use the voltage source output terminals. If you want the warmth, airiness, and spatiality of a vacuum tube, use the current source output terminals. But here's the best part – you can use both at the same time to bi-wire your speakers! Connect the voltage source output to the woofer and the current source to the upper range of the system. That way you have the tight, impact bass that a solid state amplifier can deliver; *plus* a glowing midrange, sumptuous sound stage, soft yet delicately detailed highs, and a very believable sense of layered depth to the sound stage. This one-two punch is simply not available from a conventional solid state amplifier. With Sunfire you get the best of both worlds!

CIRCUIT DESCRIPTION – AMPLIFIER SECTION

The input stage is a low noise FET operational amplifier operated in a forced Class A single ended mode. The output of this stage drives balanced Class A level shifters and a balanced Class A voltage stage that swings the full rail of 250 volts peak to peak. The remainder of the current gain stages run full balanced with a constant VCE of 6 volts to the loudspeaker. It is heavily biased into the Class A region for small signals and Class AB region for large signals. Since the power dissipation in the output stages under simple quiescent bias conditions is 15 times less than a regular amplifier for the same output power, much more idle current can be used. The issue of how to bias this amplifier becomes moot – all but irrelevant. All of the biasing issues simply evaporate because of the 6 volts. Even though it has a vacuum tube output characteristic on the current source output terminals, there is not a vacuum tube inside at all – it's fully solid state.

CIRCUIT DESCRIPTION – TRACKING DOWNCONVERTER

Coming in from the outside world we find a conventional main power supply; a large power transformer and filter capacitors. The output of this power supply feeds the Tracking Downconverter. The output of the Tracking Downconverter is fully regulated and tracks the audio, receiving its input signal from the same signal that drives the main amplifier. Essentially, the Tracking Downconverter is another power amplifier because its output voltage is in synchronism with, and tracks the audio signal, constantly remaining 6 volts above it. The input to the Downconverter is a small signal Class A Motorola transistor. The output of this transistor drives a Texas Instrument PWM digital comparator. The output of the comparator drives a Hewlett Packard precision optocoupler which level shifts the digital control pulses to the gates of 12 International Rectifier Hexfets. The final output is smoothed into a continuously varying tracking voltage by the main energy storage Downconverter inductor wound with large gauge #12 wire on a low-loss, non-saturating, ferrite inductor. The final energy storage capacitor is a 6.8 microfarad low ESR unit and 12 dB of feedback is taken from this capacitor to the input stage. Finally, a Shotky free wheeling diode provides the energy return path for the Hexfet side of the Downconverter inductor.

SIDE BAR – AMPLIFIER TESTING

Many amplifier testers will operate an amplifier into an essentially dead short circuit and give it a pulse of 500 microseconds or 20 microseconds or even one-thousandth of a second and measure the output current. This test is only a parlor trick since the output current can be very large but since the load impedance is zero, and power is I squared R, no matter how large the current, the output power is zero. It is a parlor trick. The amplifier could never sustain those huge currents for more than a few hundred microseconds because if it did, the transistors would blow up. Take a conventional amplifier and do such a test with it and you can have incredibly high currents for a few hundred microseconds but not for long. The amplifier would blow up because for the high voltages that exist across the transistors during that moment in time, the transistors are rated for only a few amperes (not tens or hundreds of amperes). However, this test does tell the amplifier tester a lot about the protection circuits. A skilled tester can determine whether the amplifier has current limiters or power-fold back protection circuits or whether it doesn't have any protection circuits at all and relies on fuses alone. It does not tell anything about how much useful current the amplifier can deliver. A conventional amplifier may deliver 60 amperes or more for 100 microseconds but could not, under those conditions, ever deliver more than 8 amperes of current for longer than that. Not exactly a high current amplifier. Again, it tells us something about the action of the protection circuits, but not about the current capability of the amplifier. By comparison, Sunfire amplifiers can deliver those huge currents all day long – far longer than a few hundred microseconds.

PUTTING IT ALL TOGETHER – SUNFIRE AMPLIFIER BENEFITS

- Full output current from each transistor is always available up to 20 amperes per transistor
- Massive output current is available even at low output impedances
- Heat sinks are not required so cabinets remain cool without using troublesome fans
- Power continuously doubles down to below 1Ω
- Most of the input power goes to the load, therefore, the power supply can weigh 30 pounds instead of 80 pounds. The amplifier can supply humongous current, massive output power, tremendous voltage, runs cool, and is very efficient
- Only 18 output transistors are needed for peak-to-peak current of 240 amps
- Bias current and idling current issues become irrelevant and non problematic
- The Tracking Downconverter multiplies current in the same ratio that the output voltage is reduced and it does so automatically by its intrinsic nature
- At high impedances, it delivers high voltage and high current. At low impedances it delivers even more current, delivering awesome and difficult to believe amounts
- When bi-wired, Sunfire delivers incredible low frequency "punch" and a huge 3D sound stage with detail retrieval so stunning that you will often hear musicians breathing
- Costs far less than any other amplifier in the world that has Sunfire's performance. All because of science and the Tracking Downconverter

BOB CARVER'S COMMENTARY ON AMPLIFIER DESIGN

My philosophy regarding amplifier design is embodied in Sunfire products. While the amplifier speaks for itself, I would like to address some of the details.

INTEGRATED CIRCUIT OPERATIONAL AMPLIFIERS

In the past, monolithic integrated circuit operational amplifiers (op amps) have received a bad reputation for use in audio circuits and for good reason. My experience has been that if a sampling of op amps, all from the same manufacturer, and all the same number, are tested, one finds that about one in fifteen will exhibit some crossover notch distortion. The reason for this is that most op amps operate with a Class AB output stage but they do not have a control for adjusting the idling current. Since an op amp is subject to the same limitations that a big amplifier is, some of the units will exhibit large crossover notch distortion, most will exhibit none, and a few of them will actually run slightly warmer than intended. In high speed mass production the op amp idling current is set by the design of the circuit but it does not come with an adjustment to allow for variations in idling current.

This problem may be completely eliminated by operating op amps in what's known as forced Class A operation. All that is required is a current source or a simple pull up resistor installed at the output of the amplifier. This forces one transistor to be always off, and the other transistor to be continuously operating as a single-ended Class A output device. As long as the op amp is operated within the new current source limit, the output will be totally free of crossover notch distortion. The practical result is that any family of op amps can be used with absolute assurance that all of them, time after time again, will not have crossover non-linearity. In the past, this problem has given op amps a very bad name for use in audio circuits and, from my perspective, unnecessarily so. But as you can see, it's not without good reason.

In my designs, whenever I use an op amp, I always use a current source at its output. The choice of whether to use an op amp or to use discrete components is a matter of application. For example, for low distortion small signal requirements, an op amp is definitely the way to go. Normally, an op amp will have better power supply rejection and will be far more linear. In the case of FET input amplifiers, vanishing low offset voltages and great immunity to input rectification accrue. Slew rates can be as high as we please and distortion as low as we please depending on the choice of op amps. However, in other applications, for example, one with large signal swings, a discrete circuit is best when higher current is required than is normally available from integrated circuit op amps. In conclusion, for a small signal amplifier operating on plus and minus 15 volts, I would always choose a good op amp. I would never build a discrete one unless I had a very special application, i.e. high current or high voltage output.

DISCRETE CIRCUITS

I design with discrete circuits whenever I have complex feedback issues, or when I have complex signal processing issues in which control voltages must be developed for muting circuits, protection circuits, dynamic control circuits (such as those in a surround processor), and in the output stages and driver stages of high power, high current audio amplifiers.

CAPACITORS

I prefer to use film capacitors for coupling capacitors, and to use electrolytic and/or film capacitors in bypass applications. I prefer to use ceramic capacitors in high frequency feedback systems and for certain high frequency bypass applications. I use electrolytics for energy storage and will use an electrolytic capacitor as a coupling capacitor provided that under no condition is the voltage across the capacitor allowed to vary at all. This means that a very large coupling capacitor has to be used at the lowest frequency of interest and it must be approximately 100 times larger than normally required. Hence, an electrolytic can't be used in a filter circuit or critical timing circuit. In that case I would use either a film capacitor or a precision ceramic capacitor. Furthermore, I believe that ceramic capacitors are best for high frequency stabilization in feedback loops and the use of film capacitors in that application is something that relatively inexperienced designers do. For the most part, I consider this to be a fad having essentially zero scientific substance. If you examine a circuit I have designed, you will find a mixture of electrolytic capacitors, ceramic capacitors, tantalum capacitors, film capacitors, low ESR film capacitors, and high current capacitors depending on the particular application. Each type of capacitor has its advantages and disadvantages when used in any particular circuit. The choices that are presented in my circuit designs are the ones that I believe yield the best results and, of course, the best sound!

OUTPUT TRANSISTORS - BIPOLAR OR MOSFET

I believe that the output stage of a power amplifier is best served by designing and building it with bipolar transistors simply because bipolar transistors are more linear, can deliver more current, and will typically have better SOA (Safe Operating Area) specifications for simultaneous voltage and current when compared to an equivalent MOSFET. If a very high performing amplifier is desired, bipolar transistors are the exclusive way to go and you can see this by simply surveying the amplifiers on the market. All the very expensive, very high current, high performing amplifiers in the $8,000, $10,000, $15,000 price range use bipolar transistors. Not one is designed using MOSFETs. Bipolars are best in audio output stages. The use of MOSFETs in audio output stages, again, is in my opinion a fad.

MOSFETS OR HEXFETS (Brand name of International Rectifier MOSFETs)

I design high power clocking circuits using MOSFETs because that's where their advantage lies. If a device is going to be on or off, then a MOSFET is definitely the way to go because Safe Operating Area (SOA) considerations are not an issue, and their high speed and lack of storage time can yield incredible efficiencies. In those applications they are extremely rugged – far more rugged than bipolar transistors – just the opposite of when used as a linear output device, in which case bipolars are more rugged than MOSFETs. To summarize, I use bipolars for linear operation and MOSFETs in digital applications. Given the choice and if the best in both devices are available, I would never do otherwise.

PRECISION PARTS

My choice of using precision parts is based on my scientific view of the world. It is not based on myth or fads. For example, in Sunfire amplifiers, I use the fastest, lowest transition time, highest precision digital comparator on the face of the earth. That is a Hewlett Packard HCPL-2611 because the circuit performs best when using the best precision available. In the case of circuit performance, I ordinarily use 1% precision resistors because by using 1% resistors, assembly and manufacturing efficiencies are vastly increased because provisions for adjusting the circuit to come into specifications are not required. Each circuit works the same as the previous circuit time after time after time in a manufacturing environment.

FALSE BELIEFS

I think that false beliefs, especially in audio, have given rise to some really wild designs – for example, $25,000 nine watt audio amplifiers – yes, you read that right… 9 watt. You will never find me designing such equipment – I simply do not believe in it. However, I love to read about such designs and I love to think and talk about them. I'm overjoyed there are people in this world who do design amplifiers like that. It's part of what makes audio so much fun!

Sincerely,

Bob Carver

