Sunfire

WHITE PAPER

Conversational English transcribed
from a talk given by Bob Carver

SOME HISTORY

This amplifier had its beginning over fifteen years ago. After I sold Phase Linear, which I founded in the early 70's, and decided to start Carver Corporation, I wanted to come out with a new amplifier that would be light years ahead of anything currently available. I 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, 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 1 ohm 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.) I toiled over a year trying to make this into a reality but couldn't get it to work. And so, after a year of working until two in the morning, I finally gave up 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". I used that to start Carver Corporation.

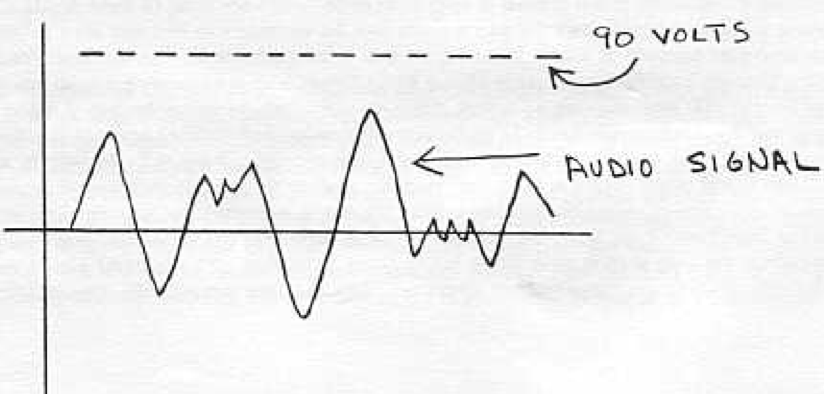
FAST FORWARD 13 YEARS

A little over two years ago, while still at Carver Corporation, I decided to have another go at it. I pulled out my notes from years ago, including the old patent; this time I succeeded and succeeded *in spades*. The resulting amplifier was able to deliver massive power and humongous current, it could operate down to 1 ohm and it didn't get hot. In short, it fulfilled the original dreams I had years ago. I called that amplifier the Lightstar and on December 17, 1992 I turned over the design to my engineering department for packaging (having completed about 95% of the work) and went on a sabbatical with the intention of final tweaking and voicing when I got back. Upon my return, I had a falling out with Carver Corporation and early last year left Carver to form Sunfire Corporation. At first it was Zeus Audio, named after my puppy, but I received a letter from an attorney who said, "No, you can't name it Zeus because we represent an amplifier company and we have names like Hercules, Aphrodite, Apollo, and Zeus." I renamed the company Silvermane and promptly got a letter from another attorney who wrote, "No, I represent the Marvel Comics Group and we have a Superhero called Silvermane." Silvermane was out. Enter Sunfire.

SUNFIRE - HOW IT WORKS

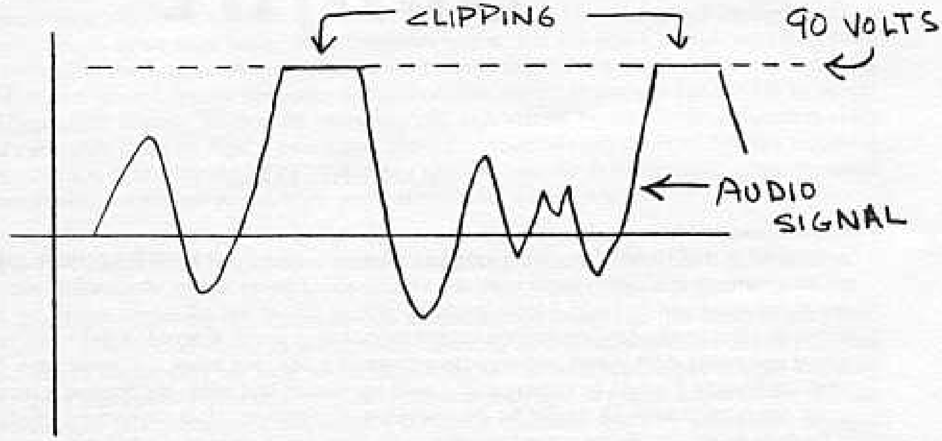
In order to understand how the Sunfire amplifier works, it would be helpful to review a conventional amplifier and illustrate some of the very difficult engineering problems associated with powerful and very high current amplifiers. As you know, a conventional amplifier has a power supply and for a 300 watt amplifier the power supply voltage is approximately 90 volts. That 90 volts is parked way up in the sky at 90 volts above ground zero. 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:



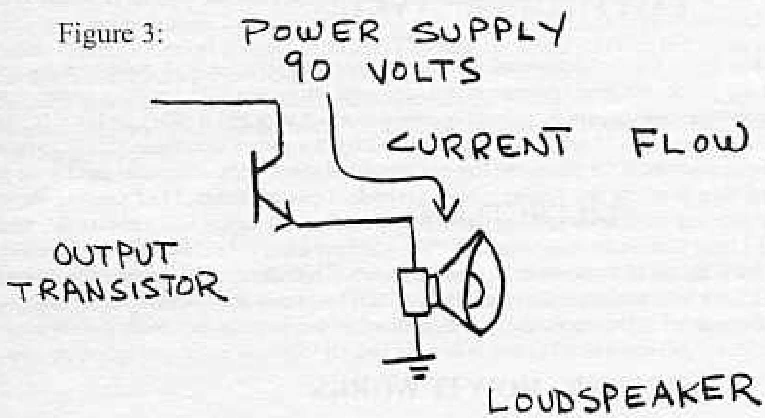
Of course, if the audio signal is required to be greater than the 90 volt power supply, the amplifier will clip as illustrated in Figure 2.

Figure 2:



Now, 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:

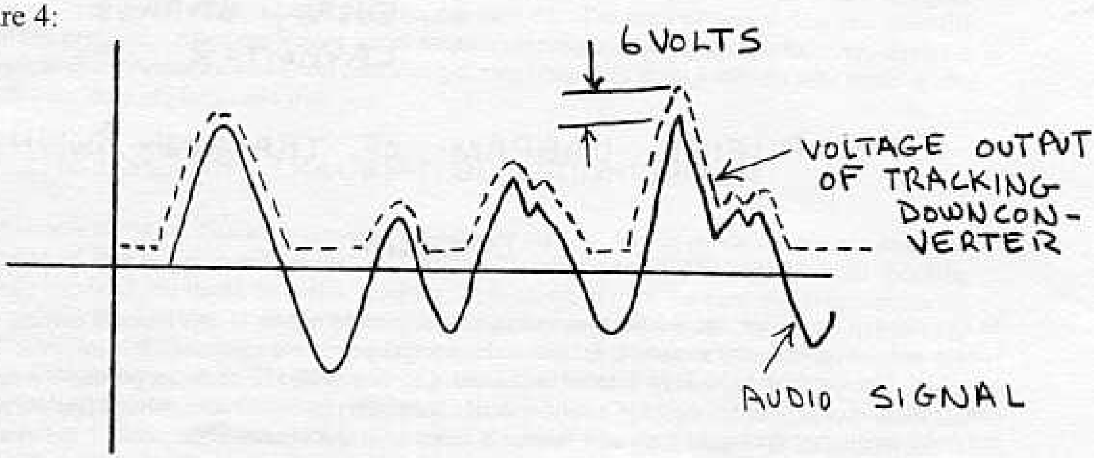


As an example, assume the output voltage at the loudspeaker is 30 volts and 10 amperes of current are flowing. The current starts at the power supply and flows through the transistors; as it goes through the transistors it makes them get hot. How hot? The measure of hotness is power; voltage times amperage. 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 and must be gotten rid of. Hence, the transistors are mounted on a large heat sink; the heat is transferred to the heat sink and ultimately to the atmosphere. Now, 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, 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 necessary to allow the amplifier to deliver the power. *However, a problem that is very insidious exists!* The problem is this. The output transistors that amplifier designers use are big 20 ampere output transistors. I use them, they are used in small amplifiers and large amplifiers. They are used in high end amplifiers and even used in most of the big receivers these days. It's a standard part in our industry. It's the big Motorola, Toshiba, the Sanyo or Sony equivalent. This transistor 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. Not very much current. 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. Remember, they are *not* good for 20 amperes, they are really only good for a small portion of that, especially when driving low impedance loads. *Consequently, a designer has to parallel many, many output transistors.* He or she must mount these transistors on huge heat sinks, and, because the amplifier is not very efficient, it must have a huge power supply. 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. To this day, solutions are still being sought, for example, Nelson Pass uses the sliding biasing circuit, Krell uses a four-tiered switchable dynamic biasing circuit. Engineers and designers forever fret over whether they're going to bias their amplifiers Class A or Class AB or use a sliding bias scheme. Big problem. Still, amplifiers that can deliver these awesome and majestic currents do exist, but to get there you have to reach up to the big Mark Levinson's, Thresholds, the big Jeff Roland's, even the massive Krell's. Those amplifiers can deliver the performance, but they are very expensive - starting at about $8,000. There is a better way.

THE TRACKING DOWNCONVERTER

In the Sunfire amplifier, that 90 volt power supply voltage that I mentioned earlier is removed from being parked 90 volts above ground and is brought down and parked at only 6 volts above ground. The 90 volts no longer exists. Then, at any moment in time, regardless of what the output of the amplifier is, that 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 lies the beauty of the Tracking Downconverter. Now, consider the previous 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. 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.

Figure 4:



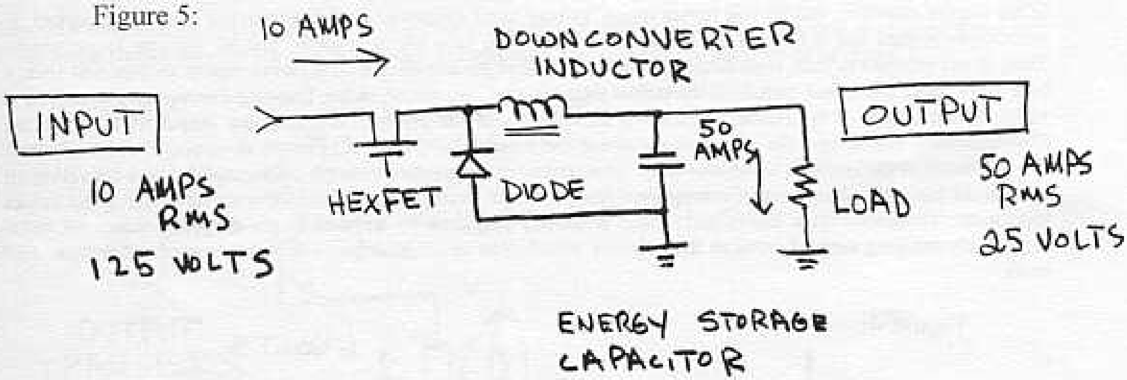
Ten times less --- an order of magnitude less. It's so little power that the amplifier does not have a heat sink, it doesn't need one. There is not a heat sink to be seen in this amplifier, yet it can deliver well over 2,000 watts into 1 ohm. And because of its increased efficiency, the power supply 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 200 watt limit). In the Sunfire, 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 the Sunfire I used 12 output transistors per channel, each capable of 20 amperes; that represents a 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. That's what is required to have an amplifier with the performance of a $10,000 machine.

THE UNCANNY TRACKING DOWNCONVERTER AND A TRULY REMARKABLE FACT

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. It's 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 say "load invariant". Have you ever lusted for a $7,000 - $20,000 Mark Levinson, Threshold, Roland, Krell or Boulder amplifier?

Figure 5:



SIMPLIFIED DIAGRAM OF TRACKING DOWNCONVERTER

LISTENING

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, the design is not yet complete. The amplifier needs to be listened to. 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. When I listen, I first use a female vocalist and make certain that she can be accurately located in an acoustic space between the speakers and in such a way that a believable halo of space surrounds her and she becomes palpably three dimensional. Also, I want her voice to be soft, musical, lyrical and have a great deal of believability. After the female voice, I listen to the male voice using baritones for the chestiness in the human male voice. When that part of the work is completed, I go to the symphony. I have in my head a template of what a symphony orchestra should sound like. I close my eyes and fit the sound of that symphony orchestra in my head, to the sound that my amplifier is making through the loudspeakers. In the case of the Sunfire, since human voice reproduction was so stunning, I found that the symphony orchestra locked in and I didn't have to do anything --- sort of like getting flesh tones correct on a color television receiver, all the other colors often lock in with very little effort. Getting the flesh tones correct is the most difficult process of designing a color set. But I digress. This effort was because I wanted a totally accurate amplifier.

CURRENT SOURCE - VOLTAGE SOURCE

At that point I had an amplifier that was tremendous --- lots of current, lots of voltage, incredible performance and then I added a unique feature. A choice of outputs --- voltage source output and current source output. Let me explain. 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 at least 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 sumptuous and lovely to listen to, is quite captivating and the main reason many people love vacuum tube amplifiers. Now, back to the Sunfire. Sunfire has 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 (current source) output characteristic. The choice of which to use is up to you. If you wish a solid state kind of sound, use the voltage source output terminals. If you want the vacuum tube sound, use the current source output terminals. Or, and this is the best part, you can biwire your speakers. Use the voltage source to the woofer and wire the current source to the upper range of the system. That way you have the tight slam impact bass that a solid state amplifier can deliver and you have the glow to the midrange, the sumptuous sound stage, and soft, delicately detailed highs that current source amplifiers typically deliver, i.e., vacuum tube amplifiers. The best of both worlds. Again, when wired that way, you have tight bass, a beautiful sound stage, a sumptuous high end and a very believable sense of layered depth to the sound stage that is simply not available from a solid state amplifier. (At least from normal output impedance solid state amplifiers.)

SUNFIRE 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 --- except for the meter pilot lamp, it's fully solid state.

THE UNCANNY 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, always above it a constant 6 volts. 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 humongous #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

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, the Sunfire could deliver those huge currents all day long --- far longer than a few hundred microseconds.

Sunfire
PUTTING IT ALL TOGETHER

1) Full output current from each transistor is always available up to 20 amperes per transistor.

2) Massive output current is available even at low output impedances.

3) Heat sinks are not required.

4) Power continuously doubles down to below 1 ohm.

5) 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.

6) Only 12 output transistors are needed per channel for peak-to-peak current of 240 amps.

7) Bias current and idling current issues become irrelevant and non problematic.

8) The Tracking Downconverter multiplies current in the same ratio that the output voltage is reduced and it does so automatically by its intrinsic nature.

9) At high impedances, it delivers high voltage and high current. At low impedances or difficult impedances, it delivers even more current, delivering awesome and difficult to believe amounts.

10) When biwired, Sunfire delivers incredible bass whack and a huge three-dimensional sound stage with detail retrieval so stunning that you will often hear musicians *breathing*.

11) Costs far less than any other amplifier in the world that has Sunfire's performance. All because of science and the uncanny Tracking Downconverter.

MY PERSONAL BELIEF SYSTEM REGARDING AMPLIFIER DESIGN

My philosophy regarding amplifier design is embodied in this new Sunfire amplifier. The amplifier speaks for itself, but 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 rap 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. This is very easy to do. 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-linearities. In the past, this problem has given op amps a very bad name for use in audio circuits and, from my perspective, unnecessarily so. Yet, as you can see, 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 chose 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 or dynamic control circuits as in a prologic decoder and, of course, 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. Further, 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 and for the most part I consider to be a fad having essentially zero scientific substance. When you examine a circuit that I design 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 you will see in my circuit designs are the ones that I believe yield the best results and 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 basically in my opinion, a fad. Excellent results, of course, can be obtained in lower priced, lower powered amplifiers using mosfets.

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 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, I would never do otherwise. (Given the best of both devices currently available.)

PRECISION PARTS

My choice of using precision parts is based on my scientific view of the world. It's not based on myth or fads. For example, in my Sunfire, 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. 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.

# # #

Bob Carver
October, 1995