Don Lancaster's

Hardware Hacker

June, 1993

Short haul telemetry
Max-min slope theory
SETI books & resources
Unique new optical link
Maximum power transfers

As I might have mentioned a time or two before, I am the sysop of *Guru's Lair* and do have bunches of reprints of my *Hardware Hacker*, *Ask the Guru*, *Blatant Opportunist*, *Resource Bin* and *LaserWriter Corner* columns.

We might start off with a pair of back-to-the-basics fundamentals…

Maximum Power Transfer

Say you're using an electrical or electronic generator. Say further it happens to provide a one ohm source impedance and is outputting a one volt signal. What is your "best" load resistance?

As figure one shows us, there is no "best" choice. Only compromises that depend entirely on exactly what you are trying to do.

If you make your load resistance fairly high, you'll get high efficiency and good regulation. *But you will be unable to get the maximum possible power from your generator*. Your ac power utility is an example where the generator impedance is made as low as possible to minimize all the source and transmission losses.

If you make your load resistance *equal* to your source resistance, you should extract the maximum possible power from your generator. But the efficiency will be a mere *fifty* percent and your regulation will be poor.

Video and rf transmission lines get important areas where you want to precisely match load to the source. Besides delivering maximum power, you'll also minimize reflections and standing waves. Other areas where "make load = source" are important are the older power audio amplifiers driving speakers, car batteries when cold cranking, and solar cells trying to deliver as much power to the load as possible.

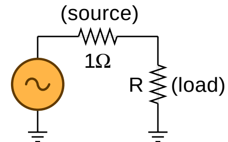
You also have the choice of using a very low load resistance. Which will give you a horrible efficiency and a terrible regulation. It also will only deliver a tiny fraction of the possible generator power. But there are a very few lower level uses where you want your generator to look and act like a *current source*.

For instance, a current source load for a transistor amplifier can offer an enormously high voltage gain. These unusual apps sometimes justify the low power and bad efficiency.

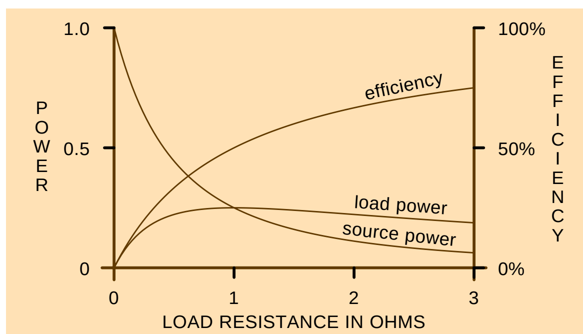
Do note what this maximum power transfer curve is telling us: *You can deliver the most power to a load by throwing half of the generated power away in your source!*

The max power transfer curve is surprisingly broad. Double or halve

(A) Typical generator and normalized load. Varying load resistor R changes the total delivered power…



(B) Maximum power transfer takes place whenever the source resistance matches the load resistance…



(C) How to prove the maximum power transfer theorem…

Borrow these two rules from differential calculus…

$$d(uv) = vdu + udv$$

$$d(u^n du) = nu^{n-1}du$$

The voltage across the load will be…

$$V_L = R/(1 + R)$$

The load power E^2/R will simplify to…

$$P_L = R/(1 + R)^2$$

Take the derivative and set it equal to zero…

$$(1 + R)^{-2} - 2(1 + R)^{-3} = 0$$

And simplify to…

$$(1 + R) - 2 = 0$$

Which solves as R = 1.

Fig. 1 – THE MAXIMUM POWER TRANSFORM THEOREM tells us that you deliver the most possible power to a load only when you purposely burn up half of the generated power in your source. Here are some key details.

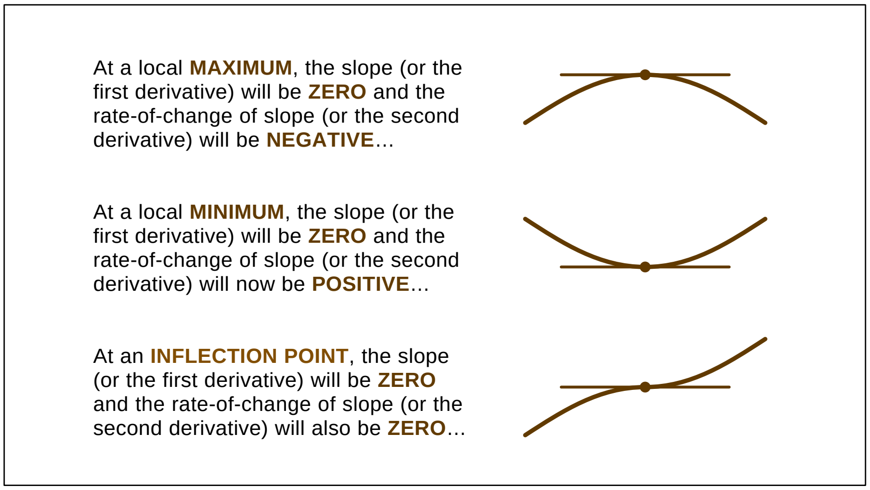


Fig. 2 – MAX-MIN THEORY is a branch of differential calculus that lets you quickly and easily find a maximum or a minimum of any reasonable curve.

your load and your power that gets delivered only drops by about twelve percent or so. Thus, an exact match sometimes isn't all that important for maximum power transfer. A precise match just might be needed for other reasons, though. Such as to eliminate standing waves and reflections.

If you are going to mismatch, it usually pays to do so on the high side. This way your overall efficiency will be better, even if the delivered power drops a tad.

Let's look at several examples of how a bad source-to-load mismatch can severely do you in. In figure two, let's take a piezo striker and see what we can get out of it. Let's assume the striker has a source impedance of ten megohms and outputs a peak of 1600 volts. We will also disable the spark gap to prevent breakdown.

Into an open circuit, we get *zero* power. For maximum possible power, we'll use a ten meg load, matching source to load. Half the voltage will appear across the load, and our power will end up as 640 milliwatts. Per the usual $P = E^2/R$ rule.

Which is over half a watt, so we should be able to light a lamp with it, right? Wrong. As 2-B shows us, a flashlight bulb offers a resistance of about ten ohms. With a ten ohm load and a ten meg source, you can only deliver 256 *nano*watts!

Your efficiency is essentially *zero*. Ergo, no light.

Can you do better? Substituting a neon lamp for a flashlight bulb would help bunches. Instead, you can place a transformer with a 1000:1 turns ratio between the striker and the bulb, as shown in 2-C. A 1000:1 turns ratio gives you a 1,000,000:1 impedance ratio. Your bulb now "looks" like a ten meg load to the source. And you should get nearly the full maximum power flashing the lamp.

Remember, of course, that all piezo devices are ac only generators.

Most small impedance mismatches between source and load are not that big a deal. But bad ones (especially with high value sources driving low value loads) will severely do you in.

Several columns back, we found several good reasons why any piezo power production hacks were likely to end up a bad scene. Some of you helpline callers pointed out there is an even more fundamental gotcha.

Most power generators are either *E-field machines* or *H-field machines*. An H-field machine uses a changing *magnetic field* to induce *current* into a *conductor*. An E-field machine will use a changing *electric field* to induce a *voltage* across an *insulator*.

All E-field machines are inherently high impedance devices. *The power density of all known E-field machines is extremely low*. E-field machines tend to force you to the inefficient extreme left of the maximum power transfer curve of figure one. Precisely where you don't wanna be.

The curent state of the art in both materials science and high vacuum techniques simply will not allow us to construct any economical high power E-field machine.

As far as I know, there *never* has been *any* E-field machine anywhere *ever* produce commercial "nickel per kilowatt-hour" ac power. I'll give you an *Incredible Secret Money Machine* if you can prove me wrong on this.

And while any piezo generator is obviously an E-field machine, it is only a "fair to middlin" one at its very best. Sigh...

Finding Maximums and Minimums

There's a number of fairly obvious ways you could verify that maximum power transfer curve of figure one. Being lazy, I just told the incredibly superb general purpose PostScript computer language to plot it for me. As we have seen before, PostScript is now the ultimate hacker's language.

Or, you could go into the lab and use a wattmeter and a variable load resistor. Which should give you the same curve, again with its maximum value matching your source.

Let's try using some math instead. There's this ugly rumor going around that electrical circuits will obey math rules. And that you can predict what they will do simply by looking at the underlying math.

In the figure one circuit, we have a voltage divider which attenuates our one volt input by...

$$e_{out} = R/(1 + R)$$

Your output power should be this voltage squared divided by the load resistance. Which simplifies to...

$$P_{out} = R/(1 + R)^2$$

You or a computer can then plot this curve for different values of R to generate the max power curve.

By the way, this stunt of using one volt generators with one ohm source impedances is called *normalization*. If you can ever analyze something using easy numbers instead of hard ones, it will usually pay to do so. Anything that can be scaled can also be normalized. Much more on this in my *Active Filter Cookbook*.

But there is a much better way to find your maximum power transfer point. There is a math process called *max-min theory* that easily lets you find maximum or minimum points for

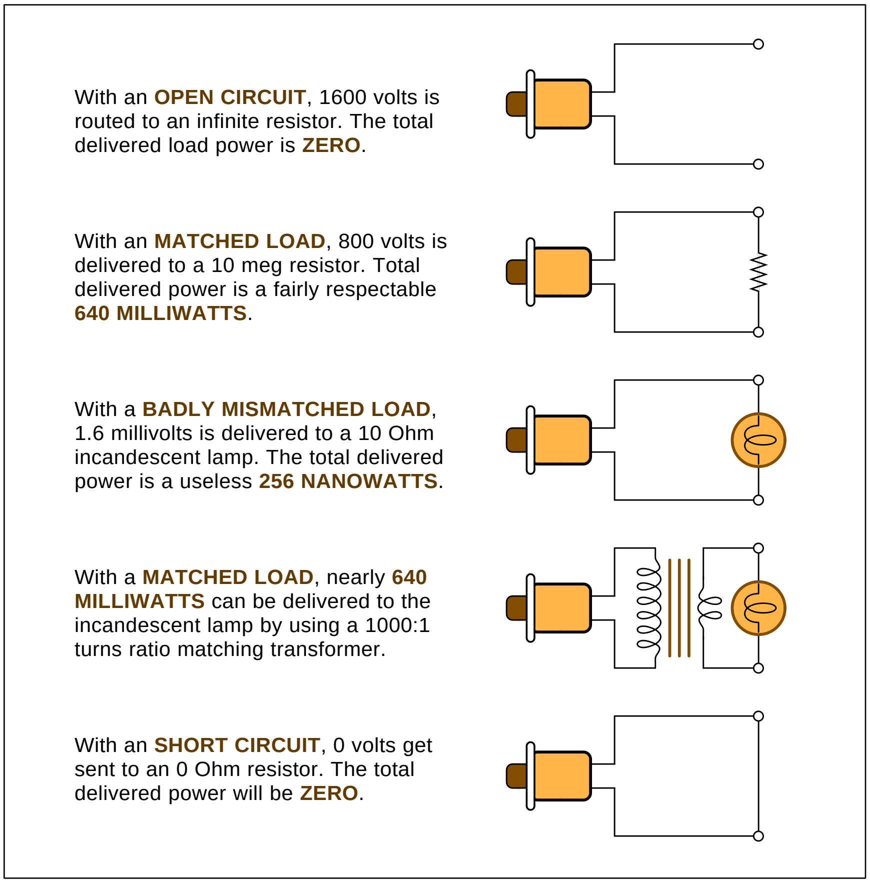


Fig. 3 – GROSSLY MISMATCHING your source and load impedances can severely reduce your total available delivered power. Here are examples that try to use a piezo striker as a power generator.

any reasonable curve. Figure three shows you the key secret.

Any reasonable curve will also have a *slope*. A slope is simply the "steepness" or the "rise over run" of any tiny portion of the curve. One crude way to find the slope of any point on a curve is to take a point just before and one just beyond and create a tiny triangle out of it. The rise/run (or *tangent*) of the triangle will equal the slope of your curve.

As figure three shows us, there are only *three* possible cases where you can get a zero slope on a curve. These happen only at a *local maximum*, at a *local minimum* or, more rarely, at an *inflection point*. And that's all there is to max-min theory.

Just find the math expression for the slope of your curve. Set it to zero and solve it. All solutions will be a max, a min, or an inflection point.

How can you tell which is which? Often, it will be completely obvious. If not, you'll go one step further and find the *slope of the slope*. If you are at a local maximum (3A), the rate of change of slope will be *negative*. At a minimum, (3B), the rate of change of slope will be *positive*. And if you are now at an inflection point, the rate of change of slope will be *zero*.

Your "correct" and "exact" way to determine the slope for any curve is known as *finding the derivative* and this whole field is called *differential calculus*. You could find a full set of rules in any university level Calculus 101 text. A good listing also appears in the *Mathematical Tables* from the *Handbook of Chemistry and Physics*.

I've shown how you use max-min theory to prove the maximum power transfer theorem in figure one. Sure enough, the maximum is *exactly* at a load impedance which matches the source. Taking most derivatives is quite simple. For instance, a parabola $y = x^2$ has a slope anywhere of 2x.

SETI RESOURCES

Associations:

Amateur Radio Astronomers
247 North Linden Street
Massapequa NY 11758
(516) 798-8459

Planetary Society
65 North Catalina Avenue
Pasadena California 91106
(818) 793-5100

Pacific Astronomical Society
390 Ashton Avenue
San Francisco, Califronia 94112
(415) 337-1100

SETI Institute
2035 Landings Drive
Mountain View California 94043
(415) 961-6633

Publications:

Edward Ashpole, *Search for Extraterrestrial Intelligence*, Blandford, 1989.
Issac Asimov, *Asimov's Biogaphical Encyclopedia*, Doubleday,1972.
John Billingham, *Life in the Universe*, MIT Press 1981.
Howard Blum, *Out There*, Simon & Schuster 1990.
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A.G. Cameron, *Interstellar Communications*, W. Benjamin, 1963.
Nathan Cohen, *Gravity Lens*, John Wiley, 1988.
Frank Drake *Intelligent Life in Space*, MacMillian 1962.
Frank Drake, *Is Anyone Out There?* Delacorte Press, 1992.
Robert Forward, *Dragon Egg*, Ballantine 1980.
Donald Goldsmith, *Quest for Extraterrestrial Life*, University Science, 1980.
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James Gunn, *The Listeners*, New York: Charles Scribners Sons, 1972.
J.S. Hey, *The Evolution of Radio Astronomy*, Neal Watson, 1973
John Lilly, *Man and Dolphin*, Doubleday 1961.
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Cyril Ponnamperuma, *Interstellar Communications*, Houghton Mifflin, 1974.
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Iosif Shklovsky, *Intelligent Life in the Universe*, Holden-Day, 1966.
Walter Sullivan, *Search for Intelligent Life on Other Worlds*, McGraw-Hill, 1964.
David Swift, *SETI Pioneers*, University of Arizona Press, 1990.
Frank White, *The SETI Factor*, Walker, 1990.

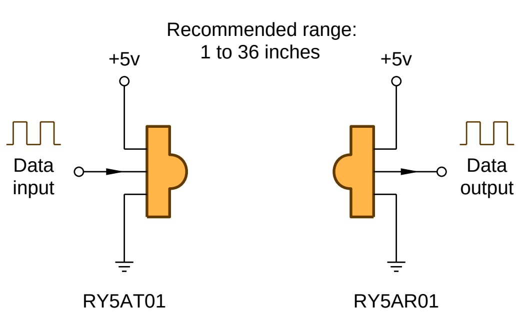

Fig. 4 – NEW SHARP OPTO CHIPS offer all sorts of new possibilities for wireless communication, safety isolation, and short haul telemetry. The 500 kHz pulse modulation ignores ambient light and TV/VCR remotes.

Good old $u^n du$ and friends.

Advanced math can be neat stuff. And very valuable, too.

SETI Resources

NASA has recently started a new and very aggressive SETI (search for extraterrestrial intelligence) program. In the first few hours of operation, more frequencies have been observed in more ways than have in the *entire* history of *all* previous ET watching.

One prominent researcher in SETI is Frank Drake. He is famous for the "Drake Equation" which accurately predicts the number of intelligent civilizations and unintelligent senators that are likely to be lurking in the universe at any given time. Frank has recently authored a new and highly readable book titled *Is Anybody Out There?* and published by *Delacorte*.

So, I thought it might be a good time to do a resource sidebar on SETI. I've included several associations and a listing of the better books.

Besides the three groups Frank mentioned in his book, I've added the *Amateur Radio Astronomers* who also publish a *Radio Observer* newsletter. But note that their main focus is on radio astronomy fundamentals. And that they do distance themselves from ET watching and the UFO crowd.

For several reasons, I strongly feel that the odds for an imminent SETI contact are quite high. As openers, our signal detection, processing, and computing abilities have skyrocketed in the last several years. And should continue to do so.

Shortly after World War II, our sun suddenly turned into a radio star.

Captain Video, *Roller Derby*, and *Kukla, Fran, & Ollie* became our first goodwill ambassadors to outer space. These signals are now 45 light years away from us, and have now swept out nearly a third of a million *cubic light years* of space.

Within this humongous volume are several hundred "probable" candidate star systems. Our own signals are easily detectable at this range with our present state of the electronic art. In another 45 years, *eight times* more volume will be swept out with eight times more candidate star systems now watching *Your Hit Parade*.

At a further signal strength drop of less than six decibels!

We are now in transition between calling hundreds of candidate star systems to annoying thousands more.

On the other hand, I personally feel that looking for obviously modulated narrow SETI signals in the expected "water hole" frequency band might not be the swiftest way to go. If Earth is an even remotely typical example, all the *unintentional* radiated signals swamp those *intentional* ones by at least a zillion to one.

And we have recently discovered spread spectrum communications. If you really want to punch any signal through very high noise over great distances, spread spectrum seems a very good way to go. The chances are that you could step up to multiple dimensions of spectrum spreading.

Using, say, frequency, time, and some sort of a trellis modulation type of overlay.

Perhaps a "multi-level marketing scheme" in which the unswift could pick up that something was coming down, the fairly bright could receive useful info, and the superintelligent could grab the full set of plans. This surely would beat sending out prime numbers forever.

The signals may be there but we just might not be smart enough to recognize them just yet. Perhaps the fundamental question to ask is "What spreading and modulation scheme would give us the most bang for the buck?" And then start looking for something similar heading our way.

Let's have your thoughts on this.

New Opto Chips

Infrared data communications has recently become much simpler thanks to a pair of *Sharp* circuits. Figure one shows details.

These devices look like a transistor with a built-in lens. Their RY5AT01 transmitter outputs a burst of 500 kHz modulated infrared square waves if fed a logic one. And outputs nothing with a logic zero. This is a form of modulation that's called *Amplitude Shift Keying*.

The RY5AR01 receiver accepts an infrared signal and converts it back into digital logic levels. An internal digital filter rejects most interfering signals or noise.

The modulation scheme largely ignores ambient light. Signals from most interfering TV or VCR remotes are also strongly rejected. Data rates up to 19,200 baud are supported. The beamwidth is a somewhat narrow ten degrees, and the recommended range is 1 to 36 inches.

Obvious hacker uses include safety isolation, data comm, handicapped aides, virtual reality, robotics, and for wireless mice.

Because of the narrow beamwidth, the two devices must point *directly* at each other at all times. While there is good rejection to ambient light and many random IR signals, there is no selective coding. Which means that you will have to strictly isolate each optical linkup from any potentially interfering neighbors. This turns into an especially sticky problem in full duplex (two-way) data comm.

Sadly, Sharp's $10 intro price for these is in the "What are they on, and where can we get some of it?" range. These will be superb products when they drop to sixty cents each.

Short Haul Telemetry

There are all sorts of emerging new uses for shorter range wireless data communication. I'd like to apply the generic term *short haul telemetry* for any newer method that tries to send information a few inches or a few feet without any wires.

We've seen one possible need in a previous column and in my ongoing *Hardware Hacker* BOD reprints.

An *Isopod* is a tennis-ball shaped beastie that you glomp onto an ac power wire. The isopod automatically measures and transmits the current to a nearby receiver. This can greatly simplify home energy management. No rewiring, no electricians, and no code hassles need be involved.

Another new need is for a wireless pulse rate sensor for use on a bicycle computer. And there are thousands more. How about an "optical mouse" that senses where you are *looking*? Or new ways to get data onto or off of a rotating shaft or moving vehicle. Or ground-loop-free alternatives to data communications?

But why don't you tell me instead? For this month's contest, either (A) show me a use for the RY5AT01 and the RY5AR01, or else (B) dream up a brand new application for short haul telemetry.

There will be dozens of the usual *Incredible Secret Money Machine II* book prizes awarded, along with an all-expense paid (FOB Thatcher, AZ) *tinaja quest* going to the best of all.

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Cerac Inc
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Milwaukee, WI 53201
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Delacorte Press
666 Fifth Avenue
New York, NY 10103
(212) 765-6500

GEnie
401 N Washington Street
Rockville, MD 20850
(800) 638-9636

Gerber Scientific
83 Gerber Road
South Windsor, CT 06074
(203) 644-1551

NASA
Langley Research Center
Hampton, VA 23665
(804) 865-3281

NEC
401 Ellis Street
Mountain View, CA 94039
(800) 632-3531

Radio Observer
7605 Deland Avenue
Ft Pierce, FL 34951
(407) 464-2118

RF Design
6300 S Syracuse Way, S650
Englewood, CO 80111
(303) 220-0600

Sharp
5700 NW Pacific Rim Blvd.
Camas, WA 98607
(206) 834-2500

Signetics/Philips
811 E Arques Avenue
Sunnyvale, CA 94088
(800) 227-1817

Synergetics
Box 809
Thatcher, AZ 85552
(602) 428-4073

Wired
544 Second Street
San Francisco, CA 94107
(415) 904-0664

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NEED HELP?

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New Tech Lit

From *Signetics*, a new and thick *Desktop Video Data Handbook* chock full of A/D, D/A and DSP chips. Also included are their genlocking video encoders.

From *NEC* a large packet of data sheets on *Infrared Control ICs*. Yes, these definitely include the fancy new teachable versions.

RF Design is a trade journal which covers radio communications in the VHF and UHF range. Lots of ads for specialized chips and components here. And *Wired* is a brand new mag out of Multimedia Gulch that is quite interesting but hard to describe. The stories so far have included ones on cellular hacking and virtual reality.

Plotter codes appear in the *Plot Data Format Reference Book* from *Gerber*. This includes photoplotter and vinyl sign cutter info.

From *Cerac*, a freebie pocket size periodical chart of the elements.

For the fundaments of most digital integrated circuits, be sure to check into copies of my *TTL Cookbook* and *CMOS Cookbook*. Both are available per my nearby *Synergetics* ad.

Most of those items I've mentioned do appear in our *Names & Numbers* or *SETI Resources* sidebars. Be sure to check here first before calling our technical helpline.

Let's hear from you.✥