Don Lancaster's

Tech Musings

May, 1996

The intent and meaning of the term *power factor correction* sure has changed a lot lately. This appears to be causing a lot of help line confusion. Let's see if we can't straighten some of this out.

Back to the basics…

Power Factor: Then and Now

An electronic *component* is *passive* when there's zero net energy input from anywhere other than its input leads. A component is *linear* if it does not change in any manner with time. Also, in any linear component, the stimulus must be proportional to the response. Kick it twice as hard and it should "ouch" twice as loud.

There are only three possible *ideal* passive linear electronic components. All real components are made up of lumped or distributed combinations of these three.

The first component is the *resistor*. A resistor converts current into heat or light energy, following a *power = volts x amps* equation. Since there is zero energy storage, there is no way your current can get behind or ahead of the voltage. Current and voltage are said to be *in phase*.

When a fixed frequency sinewave voltage is applied, a sinewave current will result. This current follows the voltage per Ohm's law.

The second component is known as the *inductor*. An inductor is often a coiled conductor. With or without a field-intensifying core. An inductor *temporarily* will convert current into energy storage in a *magnetic field*.

The voltage-current rule for any inductor states that…

$$e = L\Delta i/\Delta t$$

This tells us that the voltage across an inductor is proportional to its size times the *rate of change* of a current through it. As your current increases, the magnetic field energy will go up and vice versa.

A pure inductor does *not* "waste" energy. It simply *stores* energy in its internal magnetic field.

When a voltage gets applied to an inductor, its current will slowly build up. Thus, current will be "behind" the voltage in an inductor.

If you apply a voltage sinewave, you should see a current *cosine* wave which is precisely one quarter cycle behind. Since there are 360 degrees of phase in one full cycle, we say that the inductor current *lags* in phase by exactly 90 degrees.

The third ideal component is called the *capacitor*. A capacitor is often a pair of conducting plates separated by air or another insulator.

A capacitor *temporarily* converts voltage into energy storage in some *electric field*. The current-voltage rule for a capacitor states that…

$$i = C\Delta v/\Delta t$$

…telling us that the current into a capacitor is proportional to its size times the *rate of change* of voltage across it. As the voltage goes up, the electric field energy goes up and vice versa. Reversing the voltage reverses the sense of the field energy.

As with the inductor, an ideal cap does *not* waste any energy. It stores that energy in its electric field.

If a current is sent to a capacitor, its voltage will slowly build up. The current will usually be ahead of the voltage in a capacitor.

Which has to mean that the voltage will usually be behind the current. If you apply a voltage sinewave, you'll get a current *negative cosine* that is precisely one quarter cycle *ahead*. Since there are 360 degrees of phase in one full cycle, we can say that the

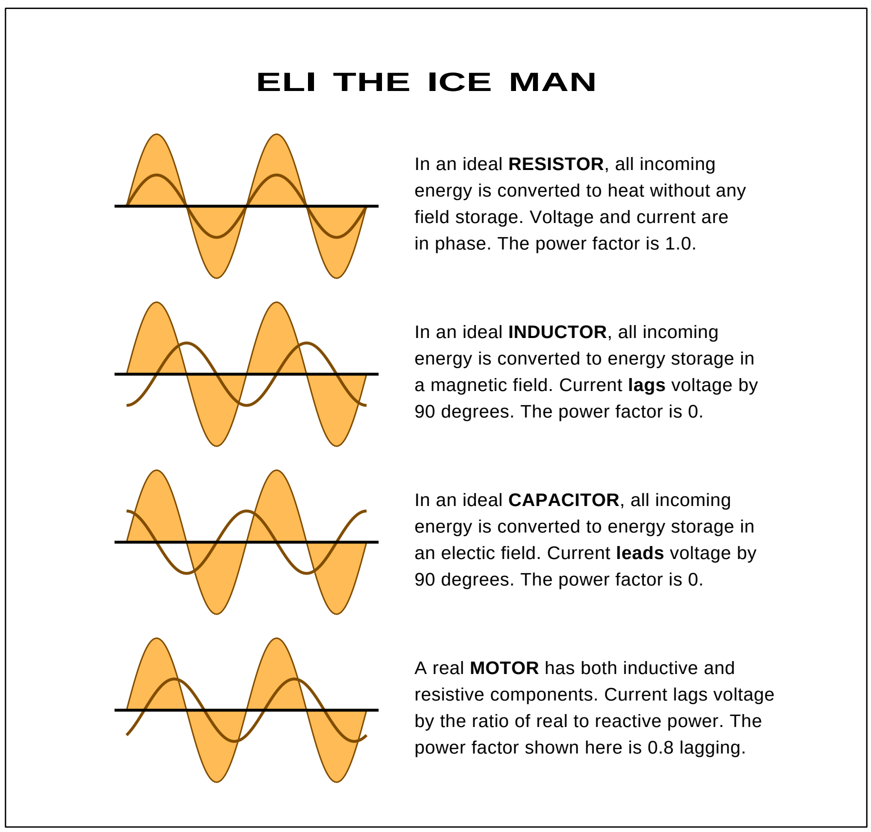

Fig. 1 – THE POWER FACTOR of a circuit is the ratio of the real to reactive input power. Power factor is expressed as the cosine of the phase angle between the voltage and current. A classic power factor correction involves aligning the input fundamental frequency voltage and current.

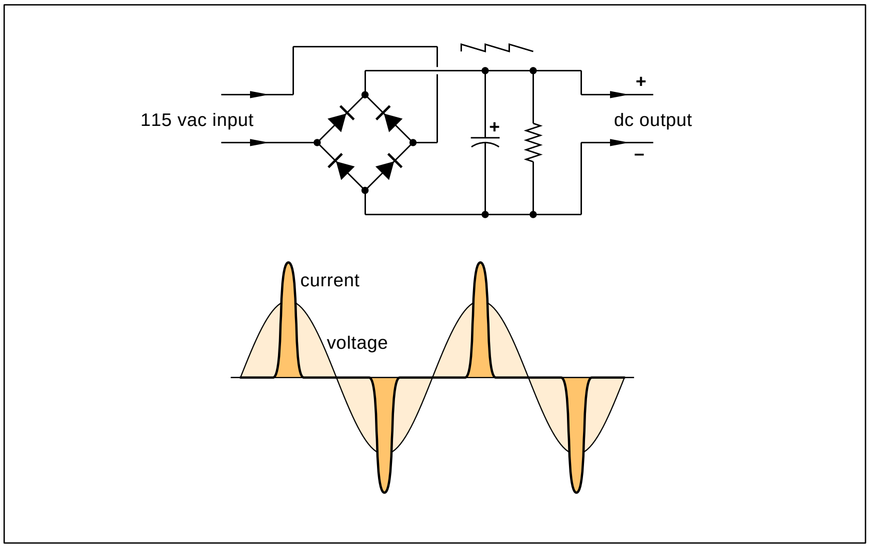

Fig. 2 – A TYPICAL LINE OPERATED POWER SUPPLY draws its current in very large, very narrow, and high harmonic mid-cycle pulses. Modern power factor correction involves both minimizing these harmonics ~and~ getting the input fundamental frequency voltage and current in phase.

current *leads* by 90 degrees.

There's an easy and ancient way to remember all this: Good old *ELI the ICE* man. The *E* voltage is ahead of the *I* current in the *L* inductor. The *I* current is ahead of the *E* voltage in the *C* capacitor.

Ideal components do not occur in the real world. Because an insulator, conductor, or semiconductor above absolute zero *will* have resistance and unavoidable conversion of current into heat. Any conductor that routes between two separate points in space *will* have inductance and unavoidable magnetic field energy storage. And any two conductors separated by an insulator *will* have capacitance and unavoidable electric field storage.

I have summarized these lead-lag rules in figure one.

Enter the Power Company– Stage Left

The power company only charges you for the energy you actually *use*. Generating light, burning it as heat, converting it to a mechanical motion (which ultimately becomes heat), or by otherwise never returning it. On the other hand, the energy you store in an inductor gets returned early on in the next cycle. As does any energy you might store in any capacitor.

We can define *real* power as the energy you actually use. The *reactive* power is energy that swaps back and forth between you and your utility company, temporarily getting stored in electric or magnetic fields.

The classic *power factor* is defined as the ratio of your real to reactive energy. Specifically, it is the *cosine* of the *phase angle* of your current waveform compared to the voltage.

A purely resistive load would have a power factor of 1.0 or unity. Any load which stores as much magnetic energy in an inductor as gets actually used would lag by 45 degrees or have a power factor of 0.707 *lagging*. A load which retains as much electric energy in a capacitor as gets actually used would lead by 45 degrees or have a power factor of 0.707 *leading*.

Uh, the power factor of any ideal inductor or capacitor is zero. Why? Because the trig cosine of +90 or -90 degrees is precisely zero.

Why should the power utility care how much reactive power you use? After all, you're going to give it right back a few milliseconds later.

The problem is that line *current* is required *both* for real and reactive power. The *extra* current consumed by all your reactive loads still causes utility losses in the resistance of their lines. It also demands higher currents in all the generators and transformers and such. The utility's costs go up, yet they have sold no more.

Now, most of your home loads will be resistive (such as a light bulb). Or partially inductive (such as a motor). Capacitive loads (such as an EL night light) are quite rare in normal home or industrial use. Thus, you are likely to have a lagging power factor.

The power company applies *power factor compensation* to clean up their own act. They might comp out their reactive power by hanging capacitors on poles every now and then. Or by purposely overdriving a synchronous generator to intentionally produce a *leading* power factor.

But note that hanging capacitors on one line end to comp inductors on the other does not fix much, because the reactive current *between* the two still contributes to huge transformer and line losses. Thus, *a utility cannot "fix" a customer's power factor*.

Utilities do punish large industrial electricity users if their power factor is too low. Their bill goes up when their power factor goes down. This encourages an industry to do its own

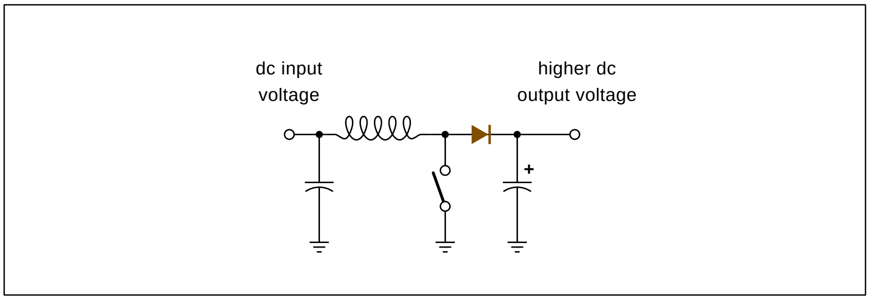

Fig. 3 – A "BOOST" SWITCHING REGULATOR CIRCUIT is normally used for stepping up dc voltages. Repeatedly closing the switch ramps up the current. Opening it transfers the stepped-up voltage to the load. The same idea can be used for power factor correction ~if~ you input a full wave rectified waveform and ~if~ you use very fancy switch duty cycles and rep rates. The tricky part involves drawing more average current mid-cycle and less near the edges. Special pf corrector chips ease this task.

power factor correction. Again with capacitors or overdriven generators.

So, the classic definition of *power factor correction* was taking steps to reduce longer distance fundamental frequency reactive energy transfers. Getting the fundamental frequency voltage and current waveforms back in phase with each other.

The Modern Problem

All of which is ancient electrical engineering. But lately, things went nonlinear. Electronic circuits started needing lots of rectifiers for internal dc power. The loads were no longer time invariant.

Figure two shows us the current waveform of a typical capacitor input full wave rectifier. For most of each half cycle, *zero* power is drawn. It is only very near the *peak* of each half cycle that the diodes switch on and draw a humongous and very narrow slug of current.

The utility has to provide this peak current. In spite of the fact that they are doing *absolutely nothing useful* for the rest of the cycle.

Well, the *fundamental frequency* voltage and current are still in phase with each other. At first glance, there appears to be no need for any classic power factor correction.

But my, oh my, the harmonics. As we have seen before, narrow pulses consist of a fundamental frequency and lots of harmonics. Mostly odd, some even. *Fourier* series and all.

Besides having to provide ten or twenty times the peak fundamental current capability, there's bunches of harmonics overloading the utility's transformers and such.

Ordinary home electronics is bad enough. But we've now got lighting ballasts and industrial motor controls adding to the mess. Something has to be done to minimize these harmonics and outrageous current slugs.

The trick is to do what you have to. Such that your drawn current gets back to looking at least roughly like an in-phase fundamental frequency sinewave. And that is what modern power factor correction is really all about. Harmonic stomping.

So, the definition for "new" power factor correction is making all of the current drawn to be in phase with the fundamental voltage *while* having as little harmonic energy as possible.

One way to handle this waveform improvement is with a *preregulator*. You still use a full wave rectifier, but you only *lightly* filter it with a small capacitor. The diodes now conduct over nearly the full cycle. You next take this changing full wave rectified waveshape and then *step it up* to a fixed and higher dc voltage. Say 200 volts. You can do this with a special regulator that involves a *power factor correction* integrated circuit.

Now for the tricky part: Not only do you have to step your voltage up differently in different parts of *each* half cycle, but you also want to draw *less* current with *large* stepups. And *more* current with *small* stepups!

The reason for all this is that you will want the *average* of your drawn current to look pretty much like a fundamental and in-phase sinewave. Thus, early in your half cycle, you'll want low currents but high voltage stepups.

A quarter way into the half cycle, you should want to be drawing more current but providing for less voltage stepup. And midway at the half cycle peak, you'll want lots of current but only a minimal stepup.

Figure three shows us a switching circuit known as a *boost regulator*. You briefly close your switch. The current in the inductor starts at zero and begins ramping up. Open the switch. Because of good old $\Delta i/\Delta t$, you can not immediately change the current through an inductor.

The current through the inductor will be the same immediately before and immediately after you open the switch. The diode now conducts and the inductor delivers its current into the output capacitor and load.

The inductor's current should now start dropping, caused by the draw of any resistive load. Close the switch again to ramp up your current. Open the switch to transfer energy to the load. The inductor's current will be roughly constant but has a slight high frequency triangular ripple.

Your typical switching frequencies these days go from 20 kiloHertz on upwards. As you vary the *duty cycle*, or the percentage of time the switch is on, you'll vary the output voltage. Feedback can hold the output voltage to any voltage you like.

Well, any voltage *above* the input supply that is. If you never close the switch, your input voltage appears at the output. Thus, a boost converter is just that–a method for controllably *increasing* an input voltage.

To convert a boost regulator into a power factor corrector, we have to get sneaky with our switch timing. At mid waveform, we will want a *short* on-time for a limited step up. But we will also want a *high frequency* for maximum current.

NON-EXCLUSIVE DOMAIN –

Simply contact your service provider and ask for a name. There is usually no extra charge. Your domain will be in form *servprov.com/yourname* Others can still freely use *yourname*, and your full address *will* have to change when and if you switch service providers.

EXCLUSIVE DOMAIN –

First, *http://internic.net* and select their *whois query form* to find out if your intended name is still available. To find out if *yourname.com* is available, enter *whois yourname.com* This will tell you who *yourname.com* is. Or that the name *might* still be available for registration.

Second, email *mailserv@rs.internic.net* and request a domain registration form. Fill in the form and crop the instructions with your word processor. Then return it to *hostmaster@internic.net*.

There is a $100 registration fee for the first two years, then $50 per year afterwards. Your exclusive domain name will be in form *yourname.com* Registration *must* be done online. The process usually takes a few days.

Finally, go to your service provider and request a "pass through" or "direct" access service. An extra monthly premium may be charged.

Fig. 4 – ROUTES TOWARDS your own Internet domain name.

SOME INTERNET RESOURCES

Boardwatch 8500 W Bowles Ave #210 Littleton CO 80123 (303) 973-6038	**Internet Market Report** 5841 Edison Place Carlsbad CA 92008 (619) 438-8100	**NetGuide** 600 Community Drive Manhasset Ny 11030 (516) 562-5000	**WEBsmith** Po Box 55549 Seattle WA 98155 (206) 782-7733
InformationWeek PO Box 1093 Skokie IL 60076 (516) 562-5000	**Internet World** 20 Ketchum Street Westport CT 06880 (203) 341-2872	**Network Solutions** 505 Hunter Park Drive Herndon VA 22020 (703) 742-4777	**WEB Week** 20 Ketchum Street Westport CT 06880 (708) 564-1385
Inter@ctive Week 100 Q Roosevelt Blvd # 508 Garden City, NY 11530 (516) 229-3700	**The Net** 1350 Old Bayshore #210 Burlingame CA 94010 (415) 696-1688	**WEB Techniques** 600 Harrison Street San Francisco CA 94107 (303) 661-1885	**Wired** 544 2nd St 3rd Fl San Francisco CA 94107 (415) 904-0664

Near the waveform zeros, we will want a *long* on time for a *large* step up. But we'll also need a much *lower frequency* to do the stepups not as often for lower current.

Thus, some really fancy footwork is required to continuously change *both* the step up ratio and the drawn current. All the while adjusting for a changing load current or a drifting supply voltage. But all you are doing is continuously changing the rep rate and the pulse width in a magic way.

Note that the small input filter cap provides an averaging energy storage for these high frequency variations. All that the utility has to give us is a clean fundamental frequency current sinewave. At unity power factor.

Three primary sources for power factor correction chips include *Micro Linear*, *SGS* and *Unitrode*. Free ap notes are available.

The trade magazines here include *Power Quality* and the *EPRI Journal*.

Your Own Web Page

How do you get your own private Internet address for email? How can you start your own web page?

The Internet location addresses are specified by a *domain*. To get on the net, you'll need access to a domain. *URL* domain addresses are a group of characters separated by periods. An "@" is used to isolate internal email addresses.

Thus a *bowseretta@woof.com.us* may be a complete email address.

The *.us* is the country. This can be eliminated for US addresses. But a *.uk* stands for England, and so on. The second domain level is usually a *.com* (if a for-profit company), *.org* (if a non-profit organization), *.gov* (if government), *.edu* (university), or a *.net* (for another network).

Here, *woof* is the *service provider*. That is someplace where a computer runs continuously to send and receive net contents for you.

You hire a local service provider at $18.50 per month from the ads out of your local paper. Or get limited free access from your long distance phone service. Or subscribe to a commercial online service. Such as *Compuserve*, *GEnie*, or *AOL* at $3 per hour.

Or, you can become your very own service provider. While dedicating your own computers and modems to full high speed access duty (hundreds of dollars per month plus big bucks in equipment and skills).

And *bowseretta* is the woofer who is actually subscribing to the Internet access. Should Bowseretta go and start up her own kennel, her internal accounts might get separated by…

http://www.woof.com/rover

Should some version of automated processor be used, it might have an email ddress of…

server@woof.com

NEED HELP?

Phone or write all your US Tech Musings questions to:

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Synergetics
Box 809-EN
Thatcher, AZ, 85552
(520) 428-4073

US email: don@tinaja.com
Web page: www.tinaja.com

My own Internet email address is don@tinaja.com and my website is *www.tinaja.com*.

You have two choices for internet addresses: *Unregistered* names can be anything that you and your access service can agree on. They are also usually free. But there is nothing to stop someone else on the net using the same name.

Registered names are exclusively available for your use. Your service provider will offer a *pass thru* name for an additional fee. Ferinstance, if Bowseretta registers, she can become *Bowseretta.com*. Pass-thru's give you a shorter address.

To find out if a registered name may be available, you get on the Net and go to *www.internic.net*. Select their *whois query form*.

To actually register a name, click on the *new domain registration* link. A form and detailed instructions will be emailed back to you. Fill in and crop your form. Return your form to *hostmaster@internic.net* Use the words *New Domain* as the *Subject*.

The cost is $100 for the first two years. Then $50 per year afterward.

Typical registration takes a day or two. The billing is by mail or online. Domain registration is by email only.

Details in figure four.

Internic is also *Network Solutions*. I have shown their address in this month's *Internet Resources* sidebar. Along with a few of the Internet hard copy magazines.

Magnetic Levitation

Everyone from physics students to perpetual motion machine fans have been fascinated by that ability of like-pole magnets to repel each other.

NAMES AND NUMBERS

American Science & Surplus 3605 Howard St Skokie IL 60076 (708) 982-0870	**Physics Teacher** 5112 Berwyn Road College Park MD 20740 (301) 345-4200
Beyond Electronics 213 Harding Way East Galion OH 44833 (800) 747-2861	**Power Quality** 2742 Eastman Ave #33-34 Ventura CA 93003 (805) 650-7070
Bunting Magnetics 500 S spencer Avenue Newton KS 67114 (316) 284-2020	**Probe Master** 215 Denny Way El Cajon CA 92020 (800) 772-1519
Commonwealth Trading Co 1685 E Park Place Blvd Stone Mountain GA 30087 (770) 469-7292	**SGS-Thomson** 1000 E Bell Rd Phoenix AZ 85022 (602) 867-6259
Edmund Scientific 101 E Gloucester Pike Barrington NJ 08007 (609) 573-6250	**Small Parts** PO Box 4650 Miami Lakes FL 33014 (305) 557-8222
EPRI Journal PO Box 10412 Palo Alto CA 94303 (415) 855-2000	**Synergetics** Box 809 Thatcher AZ 85552 (520) 428-4073
Eriez Magnetics PO Box 10608 Erie PA 16514 (814) 833-9881	**Talking Electronics** 626 S Euclid Street Anaheim CA 92802 (714) 533-4252
Fujitsu 3545 N First St San Jose CA 95134 (800) 642-7616	**Test Probes Inc** 9178 Brown Deer Road San Diego CA 92121 (619) 552-2090
Littelfuse 800 E Northwest Hwy Des Plaines IL 60016 (708) 824-0400	**Thomson Industries** 2 Channel Drive Port Washington NY 11050 (800) 554-8466
Magnet Source 607 S Gilbert Castle Rock CO 80104 (800) 525-3536	**UFO** Box 119A Kingston NM 88042 (505) 895-5608
Micro Linear 2092 Concourse Dr San Jose CA 95131 (408) 433-5200	**Unitrode** 580 Pleasant St Watertown MA 02172 (617) 926-0404
Oak Ridge Natl Labs PO Box 2008 MS-6087 Oak Ridge TN 37831 (423) 574-4281	**Walker Scientific** Rockdale St Worcester MA 01606 (800) 962-4638

Slide two or more ring magnets onto a wooden dowel and all of the upper magnets will mysteriously "float" in air. Provided that the like poles of each magnet face each other. North to north or south to south. The effect seemingly exhibits "antigravity".

Actually, the vertical forces cancel at a height where your upward mag repulsive forces exactly balances the downward gravitational pull.

Unfortunately, you can't take the stick away because there is no lateral stability. And, of course, there is no free lunch here. The energy needed to place two magnets in any position where they can repel each other will *always* exceed any recovered energy.

Similar magnetic repulsion effects are often used in "frictionless" mag bearings and in maglev trains.

The *Levitron* is a fascinating new combination science toy, magic trick, and *Golly Gee Mister Science* party mind-blower. The Levitron uses the angular momentum of a spinning top to stabilize the magnetic repulsion of a pair of ring magnets. The spinning top literally floats in air for two or more minutes at a time.

Eerily locked yet somehow alive in a fixed position in space an inch or two above a table.

No, there are no batteries. Nor any electricity or other energy source of any kind. Beyond that initial kinetic energy imparted as momentum. And no, it is not an illusion. You can wrap your hand totally around the floating top. You can even "capture" the top inside a glass and then actually put a lid on the glass!

Top operation is more than a little tricky. You'll need lots of patience to master the technique. You first place a plastic sheet above your magnetic base and *carefully* locate the center magnetic null point. Then, with your elbow held *very* high, you give the top a sharp spin.

Next, you *slowly* raise the leveled plastic sheet until the top *just barely* launches itself upwards.

Remove the sheet, and the top does its antigravity bit. At least until the air resistance slows the top below a stability limit.

The exact mass of the top is *very* critical, so there are some weighted washers and O-rings you can add or remove. If the top leaps up, it is too light. If it never floats at all, then it is a tad too heavy.

The magnetic base also has to be on a solid surface and *exactly* level. A pair of wedges are provided. If the floating top leaves to the east, you *raise* the east side of the base. Use one wedge for east-west; the other for north-south.

All in all, the effect is well worth the time and effort to master it.

One Levitron source is *UFO*. Short for Mike Sherlock's *Unlimited Fun Options*. $44.95 for the Levitron plus a well-done 24 minute video.

Do not attempt to use the Levitron without carefully watching the entire video first! More Levitron theory is in the April 1995 *Physics Teacher*.

An Antigravity Contest

Alas, the Levitron is not very user friendly. It has only a strictly limited stability range. A bare *minimum* of two to three hours of solid practice is required to master its operation. This, of course, is also true for most real magic tricks. Once mastered, though, you levitate nearly every time.

And you'll be the only one at the party that can get the beast to work at all. Particularly when you add such misdirecting hogwash as "Well, you have to wear an orange shirt."

The Levitron is not at all suitable for smaller children. Owing to all the small edible parts and the frustration involved in mastering it.

For this month's contest, show me some modifications to the Levitron which will make it friendlier.

A second base *above* the top might help, but this would hurt the illusion. Or we could include some sort of an active electronic feedback network.

Could you gimbal the magnets to automatically level? How can you do this at very low cost?

How can that magnetic "stability well" be increased? It's been pretty much proven that two ring magnets producing inverse square repulsive fields can not be forced inherently stable. At least not without serious outside help. But can some tricks be pulled to improve the size, shape, and depth of the stability well? Possibly a lot of tiny magnets arranged in a ring but slightly tilted inward?

Why is it necessary to recalibrate the top's mass? Does the temperature *really* make that much difference? Why? Can calibration be done with a real time base adjustment?

Another possibility: If you capture the top inside a covered glass, could there be some way to *reduce* the air pressure in the glass? Even a vacuum of only one-fifth atmospheric might let the top float for a half an hour or more. Could something like a spray bottle pump help here?

To experiment on your own, tops and low cost magnets are available from *Edmund Scientific*. Or else from *American Science & Surplus*. O-rings and washers are available from *Small Parts*. Industrial magnet sources are *Bunting*, *Eriez*, and *Magnet Source*. Big time magnetic instrumentation is offered by *Walker Scientific*.

As usual, there'll be copies of my *Incredible Secret Money Machine II* book going to the best dozen entries, along with an all expense paid (FOB Thatcher, AZ) *tinaja quest* for two going to the very best of all.

Be sure to send all of your *written* entries to me here at my *Synergetics* and not to **Electronics Now** editorial.

Snailmail only please.

New Tech Lit

From *Fujitsu* a fat new data book about *Wireless Communications and Power Management*. From *Micrel*, a *Designing PCMCIA Power Control* ap manual and data book.

From *Analog Devices*, free design software on the TMP01 *Temperature Controller*. An *Electronic Designer's Guide* is available from *Littelfuse*.

Two economical alternate sources for oscilloscope test probes are *Probe Master* and *Test Probes Inc*.

Low cost bearings are available in the *Nyliner Plus Evaluation Kit* from *Thomson*. Details on a fresh *Gelcast* approach to low cost ceramics (both magnetic and otherwise) are offered from *Oak Ridge National Labs*. Used Santa Claus machines are in stock at *Commonwealth Trading*.

Several freebie samples of useful self-stick *Velcro* products are offered by *Levitt Industrial Textile*.

Power electronic modules suitable for large motor controls and such are offered at bargain prices by *Beyond Electronics*. Free catalogs.

Talking Electronics is a brand new international hobby magazine. This one appears to have lots of hands-on and low cost projects.

For all the fundamentals of digital integrated circuits, be sure to check out my *TTL Cookbook* and *CMOS Cookbook*. These are also available as a portion of my *Lancaster Classics Library*. From *Synergetics*.

I'm in the process of building up a web page at *http://www.tinaja.com*. I am calling it *The Guru's Lair*. It is still under construction, but you are certainly welcome to visit.

Eventually, it should hold rich text and fast globally searchable reprints for all of my columns and stories, a technical helpline area, links to other sites, a *Synergetics Consultant's Net* access, plus third party support for the Basic Stamp and similar goodies.

My site works best when you have both *Netscape Navigator Gold* and an *Adobe Acrobat Amber* reader.

Let's hear from you. ✦