Don Lancaster's

Tech Musings

June, 1999

EIS impedance spectroscopy
Sources for radiation detectors
New flexible current transducers
Gun camera mechanism bargains
Fundamentals of spectrum analysis

This month, we might look at an arcane new field known as EIS which just might lead to a few fascinating papers and lots of exciting opportunities. But before we do, perhaps we should once again go over…

Frequency and Spectra

Say you are in an orchard during a windstorm. You happen to notice that 240 apples per minute are falling on the average. From the dictionary def, we could say your *frequency* of apple falling is four apples per second. Or that your *time period* between apple fallings averages 0.25 seconds.

Electronic frequency has a rather more precise definition. But one that usually leads us to the same concept. Suppose you have a voltage on some terminal. Only *one* voltage is there at any given time. Even though that one voltage might be the sum of a few wanted signals mixed with unwanted distortion or noise.

You call the instantaneous voltage here a *phase*. And then can specially define *frequency* as being *the rate of change of phase.*

Often, the rate of change of phase will include identifiable components that look like one or more sinewaves. You can tell how large a sinewave is by its *amplitude*. And how fast it is going by its *frequency*.

The usual way to show this is…

$$e = A\sin(\omega t)$$

…where A is the peak amplitude of your sinewave and ω is its radian frequency. (Radian frequency comes about because there are 2π or 6.2830 radians that run around a sine-cosine circle. For instance, 60 Hertz has a radian frequency of 377.)

Things get further complicated if they are *changing*. It is convenient to separate out the *transient* and *steady state* conditions. Transients (such as when starting up) often may involve exponantials, while steady state tends towards sinewaves.

Frequencies of technical interest range as low as the few Hertz found in earthquakes and brainwaves. On up through audio, radio, microwaves, the exotic terahertz mystery band, to heat, light, ultraviolet, and on up to high energy particles.

The arrangement of all frequencies expected to be present is often called a *spectrum*. A spectrum is normally shown as a plot of amplitude versus frequency. An instrument to display a spectrum is often called, of all things, a *spectrum analyzer*.

The "old" techniques for building spectrum analyzers are to sweep a narrow band filter through all your frequencies of interest and see what comes out. Or to build up parallel banks of narrow band filters. Each of which displays a limited frequency range energy as its output.

Ordinary varactor tv tuners are one route to lower cost swept analog rf instruments. And the "thermometer" displays on audio equalizers give us a

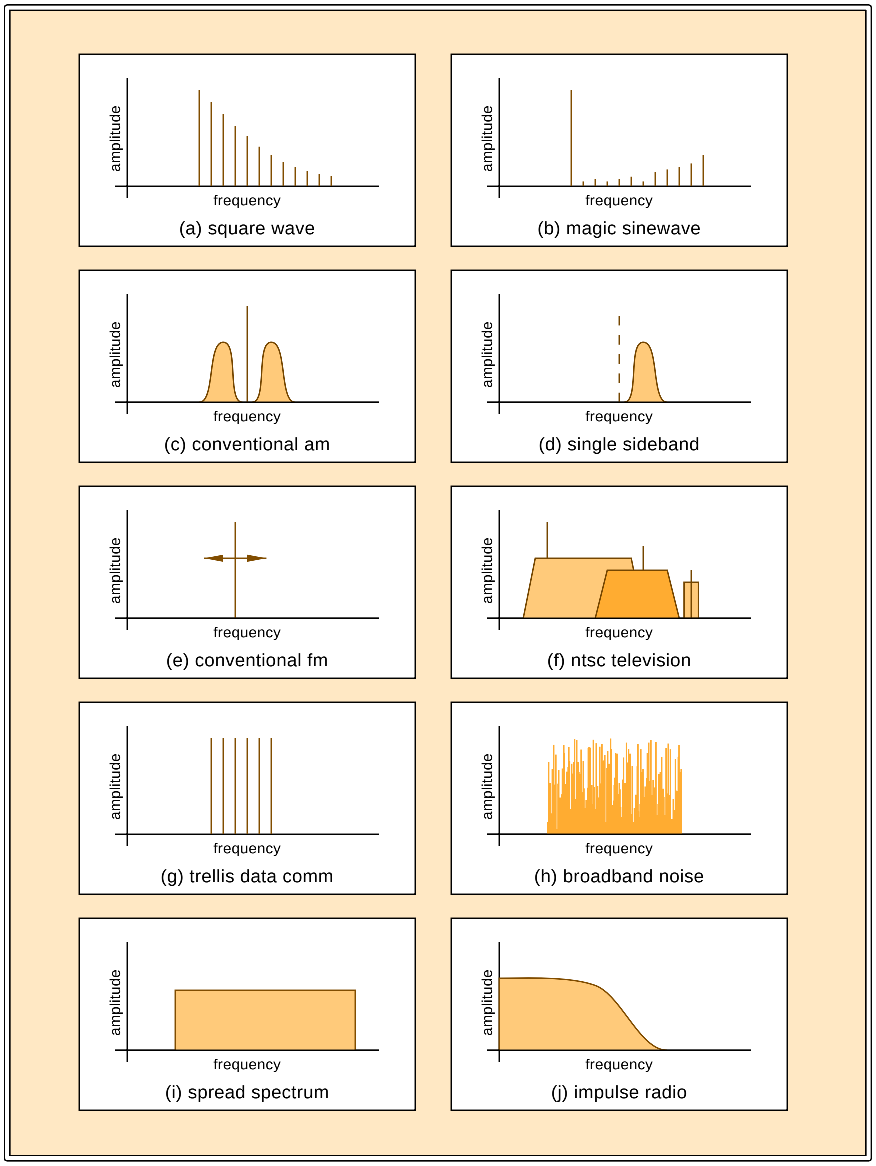

Fig. 1 – EXAMPLES OF FREQUENCY SPECTRA.

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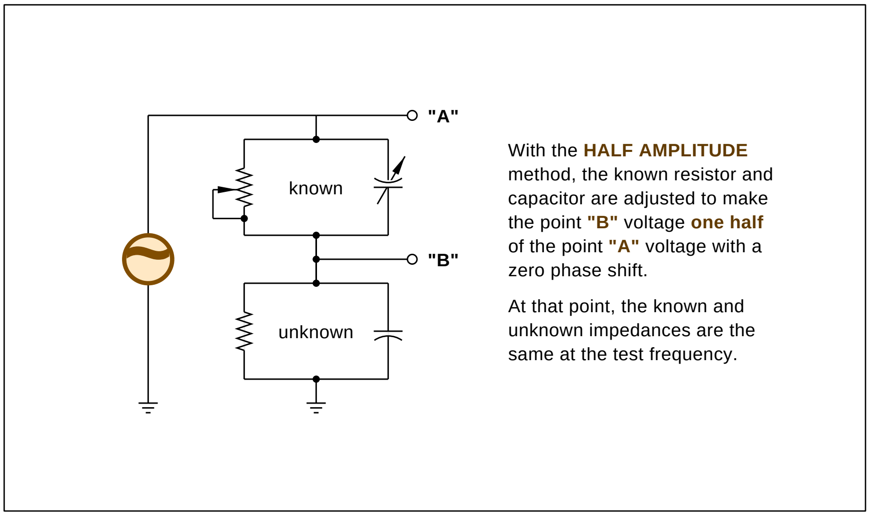

Fig. 2 – MEASURING IMPEDANCE at a single frequency.

useful example of the parallel filter method of spectrum analysis.

The "new" ways to build spectrum analyzers are much faster and more accurate. These operate by digitizing your time-versus-frequency info and then playing a few math games with the results. The usual techniques can involve that DFT, short for *Discrete Fourier Transform* or the FFT, short for the *Fast Fourier Transform*.

Both see wide use.

What does a spectrum look like? Figure one shows us some examples. The *square wave* of 1-A consists of a fundamental sinewave. Along with its diminishing odd harmonics of one third the third harmonic, one fifth the fifth, one seventh the seventh…

The *magic sinewave* of 1-B is an ultra-long sequence of digital ones and zeros that minimizes distortions of your low harmonics. Those higher ones get removed by load filtering.

That AM or *Amplitude Modulation* radio spectrum is shown in 1-C. We see that this consists of a continuous rf *carrier*, an *upper sideband*, and a *lower sideband*. AM is not efficient because the carrier conveys no useful information and the upper and lower sidebands are nearly identical.

That *single sideband* spectrum of 1-D transmits only your chosen upper or lower sideband of an AM signal. It is more efficient in both bandwidth and power. But elaborate techniques are needed at the receiver to mimic the needed carrier for detection.

A *frequency modulation* spectrum (1-E) results when some carrier's frequency gets moved back and forth. Rather than up and down in strength as in am. FM comm gives you strong noise reduction because signals can be hard limited. The math behind fm signals gets nasty and often involves *Bessell Function* beasties.

The *television* spectrum of 1-F is more complex. It is mainly AM, but the lower *vestigal* sideband is limited to lower frequencies. Which allows stronger amplitudes for fringe sync signals. Further, that sampled nature of tv scanning lets you stuff a second am *subcarrier* which holds your offset NTSC chrominance info. Plus a third narrow fm sound subcarrier.

A *trellis spectrum* is used for data communications. You might have six phases of six frequencies for a total of 64 transmitted states. Each state can efficiently represent up to six bits of transmitted data. As in figure 1-G.

The *noise spectra* of 1-H consists of random and changing signals over a broad band. This could be anything from undesirable interference to an intentional music effect.

A *spread spectrum* scheme appears in 1-I. Here, a signal is intentionally made much wider in bandwidth than needed. In the process, you'll pick up all sorts of nice security, multipath, and interference benefits.

Finally, in 1-J, we've got impulse comm. Which seems the ultimate in spread spectum. Where energy get splattered out over all possible lower frequencies. For superb interference reduction when used for micropower comm or measurement.

More on these topics appears in *www.tinaja.com/muse01.html* on my *Guru's Lair* website. Specific details on magic sinewaves are found in the *Magic Sinewaves* tech library here. Additional filtering details are in my *Active Filter Cookbook*. We recently looked at impulse comm, and a new website page on this is now in the works. *Spread Spectrum Scene* is a useful trade journal here.

Electrochemical Impedance Spectroscopy

EIS is pretty much the opposite of spectrum analysis. Instead of seeing what frequencies are present, you'll purposely apply test frequencies to determine useful properties of some ionic liquid.

At any given frequency, a liquid or

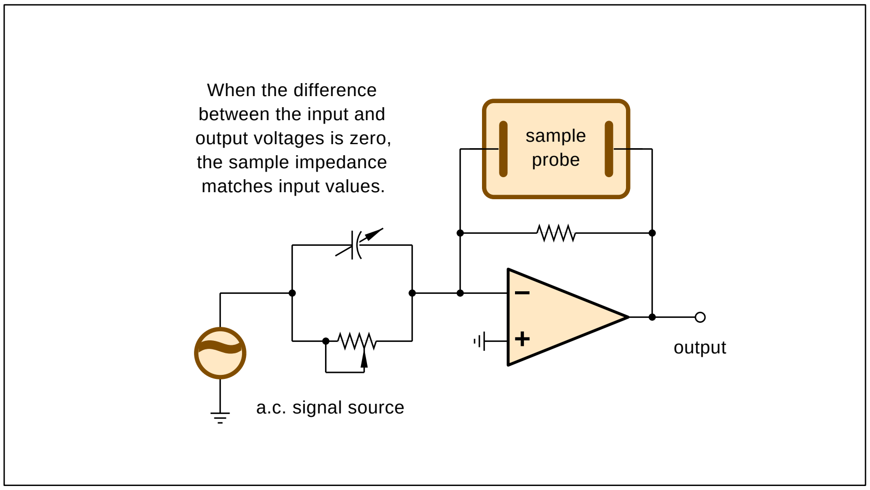

Fig.3 – AN IMPROVED METHOD of measuring impedance places EIS cell in the feedback path of an operational amplifier.

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another substance has a resistive loss plus a reactive storage. More often than not, the storage component will be capacitive rather than inductive.

The losses of a substance tend to go up sharply with frequency. While the overall impedance decreases.

Thus, EIS applies "by-frequency" measurement techniques to various electrochemical solids and liquids.

Important EIS uses include…

corrosion prevention
materials research
cancer therapy
paint development
concrete testing
battery monitoring

Finding an exact charge state and remaining lifetime for a battery can be extremely useful. In its spare time, EIS utterly demolishes the outrageous overunity claims of the hydrogen "pulse electrolysis" crowd.

Figure two shows us one general impedance measurement technique. Here, you'll apply a single frequency of a known amplitude through a variable resistor and capacitor. This goes into a sample of the measured substance. Your sample has to be of a fixed and known size, geometry, pressure, and working temperature.

You will then adjust your variable resistor and variable capacitor such that your terminal voltage *b* will be *one half* of the input voltage and that the phase shift is exactly zero. When your sample is inductive, you'll use an input inductor instead.

This same concept, of course, is how any 10X oscilloscope probe gets compensated. If the trimming cap is too small, the risetimes will be slow.

Too large and they overshoot.

There are many *bridge* variations of this circuit. These are often more concerned with finding component values, instead of determining how the values vary with frequency. With EIS, the frequency variations are not at all obvious.

In figure three, we instead place the sample in the feedback path of an operational amplifier. By stepping or sweeping input frequencies, an EIS curve of impedance versus frequency can get determined. A big advantage here is that lower impedance drive to your cell. Through suitable electrode design, nondestructive and real-time

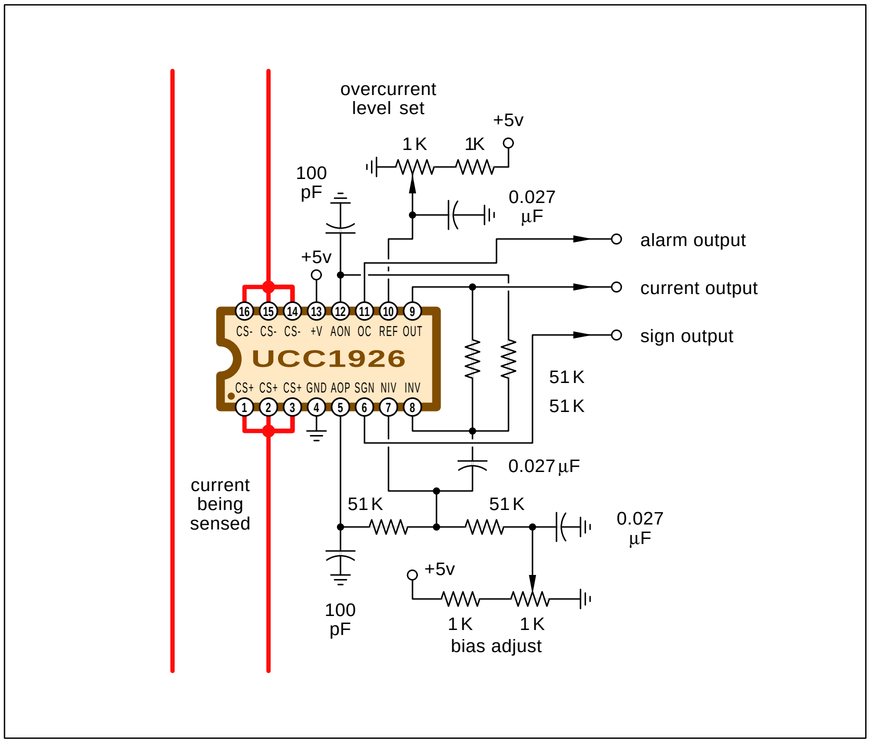

Fig. 4 – THIS NEW CURRENT SENSOR has an internal shunt that is useful to 20 Amperes. While ideal for ac power uses, the sensed frequencies can go as high as 40 MegaHertz with suitable circuit variations.

testing can easily be handled.

That feedback resistor is usually in the high meghoms. Its value is much higher than your normally expected EIS resistance and can get ignored or adjusted for. Circuit variations can simply measure the output amplitude and phase. Or might continuously force a null balance.

By very careful evaluation of the EIS impedance vesus frequency plot, your state of battery charge and life, the expected corrosion resistance of a coating, or even the status of a tumor treatment can be diagnosed.

EIS testing is both nondestructive and predictive. Test frequencies often go from tens of kiloHertz on down to those ultra low ones used for battery charge-discharge cycles.

A summary of some EIS resources appears in the sidebar. The European studies and instruments do appear to dominate this field. For more on EIS, enter "eis" and "electrochemical" in *www.hotbot.com* or into some other search engine. Or use the convenient buttons at my *www.tinaja.com*

Your three leading manufacturers are *Gamry Instruments*, *Solartron*, and *ACM Instruments*. Solartron has just announced a new model 1275 EIS instrument. Additional details are at *www.uniscan.co.uk/pr02.htm*.

A good introduction to EIS can be found at *www.bath.ac.uk/~chsacf/solartron/electro/html/int.htm* Topics here include electrode kinetics, mass transport, cyclic volt ammetry, and double layer effects.

A good book here is Macdonald's *Impedance Spectroscopy*.

See those *Electrochemical Society Proceedings* vol 95-21, 1995 page 103 for more tutorial material.

Several other useful texts might be Bard and Faulkner's *Electrochemical Methods*; or A.C. Fisher's *Electrode Dynamics*, Reiger's *Electrochemistry* or Delahays *Instrumentation Methods in Electrochemistry*. More details are at *www.tinaja.com/amlink01.html*

NASA report 94-2082 on their EIS corrosion studies is a typical paper. Copies are downloadible by emailing *corrosion@ksc.nasa.gov*

Or see *Electrochemical Impedance Spectroscopy (EIS) on Coatings* from *www.tno.nl/instit/kribc/ca-den_helder/caeis.html*

Use of EIS for electric car battery modeling appears at *www.rwth-aache*

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SOME EIS RESOURCES

RESEARCHERS & INSTRUMENT MANUFACTURERS –

ACM Instruments
125 Station Road
Clark Grange LA11 7NY UK
(44) 15395 59185

Northwestern ITI
1801 Maple Avenue
Evanston IL 60201
(847) 491-8165

Gamry Instruments
734 Louis Drive
Warminster PA 18974
(215) 682-9330

Solartron
Victoria Road Farnborough
Hampshire GU14 7PW UK
(1) 610-2645034

ISEA
Jagerstr 17/19
D-52066 Aachen GE
(49) 0-214-80-6920

TNO Tech Institute
1780 AB Den Helder
Netherlands
(31) 223-630867

Journals –

CA Selects: Analytical Electrochemistry
CA Selects: Electrochemical Reactions
Corrosion Science
Journal of Electroanalytical Chemistry
Journal of the Electrochemical Society
Journal of Solid State Electrochemistry
Surface Entineering and Applied Electrochemistry

Books –

Electrochemical Methods (Rossiter & Hamilton)
Electrochemical Methods (Bard & Faulkner)
Impedance Spectroscopy (Ross MacDonald)
New Instrumental Methods in Electrochemistry (Paul Delahay)

n.de/isea/Ww/texte/abstract/ka_vrla.html Very intriguing stuff.

A summer course on EIS and other electrochemical techniques is going to get offered by *minerva.acc.virginia.edu/~cese/taylor/eisshort.html*

Additional consulting on EIS and other technical topics is available by way of *www.tinaja.com/info01.html*

Some New Current Sensors

I still could use a few low cost and snap-on wireless ac current sensors. For this is the key towards intelligent home energy management. Details on this *isopod* concept can be found by a search on my web site. Karl Schmidt of *Transtronics* is working on a few interesting self-powered ac sensors that should solve at least part of this problem. Click through on his banner at *www.tinaja.com*

Meanwhile, there are lots of new ic current sensors. As usual, you'll go to *www.questlink.com* for a complete listing. That new UCC3926 circuit by *Unitrode* directly measures currents to twenty amperes by use of an internal 1.3 milliohm shunt resistor.

A transimpedance amplifier gives a sign output and differential current amplitudes. Bandwidth is an amazing 40 MegaHertz! A separate amplifier and alarm comparator is provided on the same chip. More details on this device are in figure four.

Supply voltage can vary from just under 5 to 12 volts. Current sensing can be on your high side, low side, or anywhere else between.

I've left the supply bypassing and some gain options off this simplified circuit, so do be certain to read your *Unitrode* data sheet and any ap notes before your actual use.

Another interesting but pricey new development is a new *flexible* current transducer. Instead of a clamp-around glomper, you've got this rope-shaped transducer which could get carefully worked around your individual wires in comfined spaces.

NEED HELP?

Phone or email all your US Tech Musings questions to:

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Web page: *www.tinaja.com*

An entire family of new *AmpFlex* flexible current probes is now being sold by *AEMC Instruments*. Their 30 models span from 0.5 to 30,000 amps and lengths of two to five feet.

Typical list prices are $300.

Amprobe sells an ACF-3000 This one gives you one millivolt per amp on their 300 amp range, and one tenth that on the 3000 amp range. Another example is the *Flexi-CT* model from *Reliable Power Meters*

More on home energy management at *Home Power Magazine*. Bargains in older snap-on ammeter probes are at *www.tinaja.com/barg01.html*

New Tech Lit

From *Advanced Linear Devices*, a data book on a group of electrically programmable analog devices. These replace trimpots and can ease system calibration. From *Simtek*, a new data book on non-volatile RAM.

From *Micrel*, the new MIC502 fan management chip. From *STM*, a one piece TDA7521 analog front end for use in CD applications.

A useful tutorial on gas discharge lamps is found at *www.intermarket.net/~don/dschlamp.html*

Jake Schwartz has a two CD set on *Hewlett Packard Calculating History* at $23. Bunches of other useful info on old calculators can be found in the *Calculator Collector* newsletter.

Experimental fuel cells are offered by *Bull Electrical*. A very expensive but definitive *Fuel Cells Bulletin* gets published by *Elsevier Science*.

Other featured trade journals for this month include *Computer Aided Engineering*, *IVR*, (as in *Interactive Voice Response*), and *Infostor*. The latter is a new tabloid on disk drives, data sharing, and archiving.

Surplus Record is a thick monthly list that has tens of thousands of used machine tools. Now in its 75th year.

Glass and mirror etching tools and supplies are stocked in depth by the folks at *Armour Products*.

One source for radiation detector sensors is *LND*. Who resell Geiger tubes, ionization chambers, counters, and neutron detectors.

Also try *Victoreen Instruments*.

One strange and wondrous book is David Lindsay's *Patent Files*. More up at *www.tinaja.com/amlink01.html* But for most individuals and smaller

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NAMES AND NUMBERS

Advanced Linear Devices
415 Tasman Dr
Sunnyvale CA 94089
(408) 747-1155

AEMC Instruments
99 Chauncy St
Boston MA 02111
(800) 343-1391

Amprobe
630 Merrick Rd
Lynbrook NY 11653
(516) 593-5600

Armour Products
PO Box 128
Wyckoff NJ 07481
(201) 847-0404

Bull Electrical
250 Portland Rd
Hove Sussex BN3 5QT UK
44 (0)1273 203500

The Calculator Collector
Intl Assn Calculator Collectors
14561 Livingston St
Tustin CA 92780

Computer Aided Engineering
1100 Superior Ave
Cleveland OH 44114
(216) 696-7000

Fuel Cell Bulletin
Box 945
New York NY 10159
(212) 633-7300

Home Power
PO Box 520
Ashland OR 97520
(916) 475-3179

InfoStor
98 Split Brood Rd
Nashua NH 03062
(603) 891-0123

IVR
12 West 21 Street
New York NY 10010
(212) 691-8215

LND
3230 Lawson Blvd
Oceanside NY 11572
(516) 678-6141

Reliable Power Meters
400 Blossom Hill Rd
Los Gatos CA 95032
(408) 358-5100

Jake Schwartz
135 Saxby Terrace
Cherry Hill NJ 08003
(609) 751-1310

Simtek
1465 Kelly Johnson Blvd
Colorado Springs CO
(800) 637-1667

Spread Spectrum Scene
PO Box 2199
El Granada CA 94018
(800) 524-9285

STMicroelectronics
55 Old Bedford Rd
Lincoln MA 01773
(781) 259-0300

Surplus Record
20 N Wacker Drive
Chicago IL 60606
(312) 372-9077

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

Transtronics
3209 W 9th St
Lawrence KS 66049
(785) 841-3089

Unitrode
7 Continental Blvd
Merrimack NH 03054
(603) 424-2410

Victoreen
6000 Cochran Rd
Cleveland OH 44139
(440) 248-9300

scale startups most of your time, any involvement with patents is virtually certain to end up as a monumentally dumb waste of time, energy, money, and sanity. Find out why in my *Case Against Patents* package. Available per by nearby *Synergetics* ad.

The latest surplus additions to my *www.tinaja.com/barg01.html* include a few 16 millimeter aerial gun movie cameras that are superbly rugged and fast. Besides being a collectible. Also some precision film platen robotics.

Detailed and custom solutions for most any tech question can be gotten at my *www.tinaja.com/info01* While longer term consulting can be found at *www.tinaja.com/consul01.html*

As usual, most of these mentioned items are in the *Names & Numbers* or in the *EIS Resources* sidebars. And a no-charge US voice helpline remains available per the nearby box. But do note catalogs are no longer mailed. Instead, you download them online at *www.tinaja.com/synlib01.html* or at *www.tinaja.com/barg01.html*.

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PostScript by Example	$32.50
Understanding PS Programming	$29.50
PostScript: A Visual Approach	$22.50
PostScript Program Design	$24.50
Thinking in PostScript	$22.50
LaserWriter Reference	$19.50
Type 1 Font Format	$16.50
Acrobat Reference	$24.50
Whole works (all PostScript)	$380.00
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