Don Lancaster's

Tech Musings

March, 1998

Most science students should quickly learn this essential rule: *An hour spent in the library is worth a month in the lab*. Same goes for engineers.

There's not much point in doing any personal labwork or any product development when someone else has long ago clearly created something much better. Or has found all of the hidden insider gotchas that are flat out gonna prevent you from getting where you think you are headed.

Let's look at a topic that starts off a lot more library than lab…

Understanding Quadrature

I've often been accused of heading off at right angles to everyone else. Turns out there often is a darn good reason for doing so.

Take a bicycle wheel. Tie a ribbon on its rim. Spin it on a north-south axis per figure one.

When viewed "axle-on" from the south, you will see the ribbon going round and round. Spending time east and west of the axle and time up and down from the axle.

When viewed from the west, you should see a ribbon bouncing up and down. Rapidly changing in mid path, but spending "dwell time" near its upper and lower travel limits.

The west-viewed waveform traced out by the ribbon is often called a *sinusoid* or simply a *sinewave*.

Now view the wheel from the top. You'll now see the ribbon bouncing back and forth, but this is different somehow. Yeah, this is still sort of a sinewave. Although this particular "sinewave" responds to the east and west ribbon motion rather than the up and down motions of the previous one. By itself, the shape does seem sinusoidal. But compared to the up and down viewing, we have a *cosine*.

Such a cosine wave will be *phase shifted* by precisely 90 degrees from its sinewave counterpart.

Note particularly that the side view *ignores* any and all back and forth ribbon motion, while your top view will ignore any and all up and down

ribbon motion. The info content on the one channel is invisible to that of the other!

The two waveforms are said to be either *orthogonal* or in *quadrature*. Quadrature waveforms do occur over and over again in electronics.

Ferinstance, your ribbon position could define a *vector* from your axle, expressed in *polar coordinates*. Our vector has a *length* and a *direction*. In a *math space*, your angle will be in degrees *counterclockwise from east*. Alternately, in a *geographical space*, the degrees are *clockwise from north*. Obviously, you should pick one or the other and stick with it.

Electronic stuff almost always uses math space degrees.

The west-view sinewave and the top-view cosine wave instead define your ribbon position with two *scalar* quantities, or a pair of *single* values. Often, quadrature measurements or waveforms can get used to *convert between a vector and its two scalar components*. Such separated parts are

said to be in *rectangular* or *Cartesian* coordinates.

Say you have a twenty inch bike wheel with a ten inch radius. Say the ribbon happens to slant +60 degrees in math space. The top viewed east to west or cosine component should be +5.0 inches, because the trig cosine of sixty degrees is 0.5000. The side viewed up-down or sine component will be +8.660 inches, because the trigonometric sine of sixty degrees is calculated as 0.8660.

Such trig values are easily found in math tables, in scientific calculators, and even slide rules. They also may be created by a series approximation algorithm or whatever.

The side or sine view is sometimes called the *real* or the I or the *inphase* component; the top or cosine view is sometimes called the *imaginary* or the Q or the *quadrature* component. The letter *j* is often used to denote an electronic imaginary axis. Seems that current had first dibs on the more obvious *i* variable.

the **QUADRATURE** channel will respond only to the back and forth ribbon motion.

the **IN-PHASE** channel will respond only to the up and down ribbon motion.
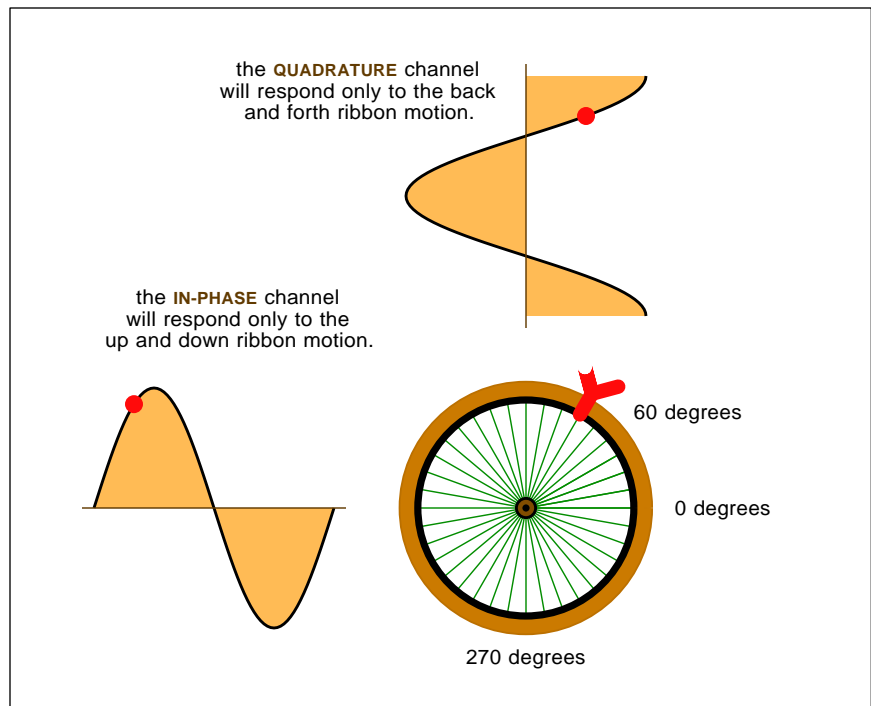
60 degrees

0 degrees

270 degrees

Fig. 1 – QUADRATURE WAVEFORMS are mechanically or electrically shifted by precisely 90 degrees from each other. They have many uses.
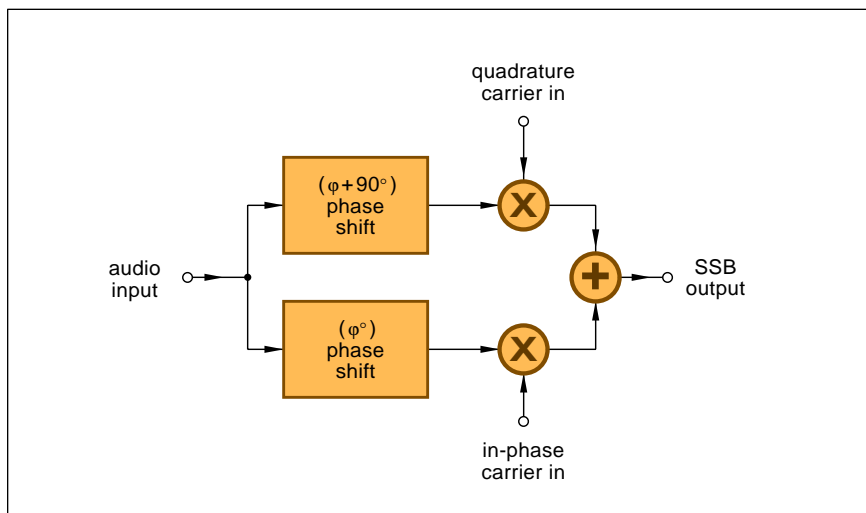
Fig. 2 – ONE POPULAR METHOD of single sideband generation uses a broadband audio quadrature phase shifter.

Neat Quadrature Tricks

One remarkable property is that all quadrature channels of information can be *independent* of each other. If you try multiplying any sine times a cosine over precisely one cycle, you will get a zero result.

This happens because your cross products change for each quadrant. Algebraic *signs* are both positive in quadrant I and are both negative in quadrant III. But they are opposites in quadrants II and IV.

Yet another group of remarkable properties is that the *slope* for any cosine is a quadrature sinewave! And the *slope* of a sinewave is a *negative* quadrature cosine wave. A different name for "slope" is the *derivative*.

Further, the *accumulated area* you should find under any sinewave is a quadrature cosine wave. And your accumulated area under the cosine wave is a negative quadrature cosine. Another name for "accumulated area" or any "area under the curve" is the mathematical *integral*. As with trig values, integrals and derivatives are found in books of math tables. Or can be generated by finding slopes or by adding up cumulative areas.

See any intro calculus book for all the gory details.

In fact, you could build a dandy oscillator simply by cascading two integrators and a sign changer. This "solves" the fundamental *differential equation* relating sines and cosines, and thus simply *has* to create them. Such an oscillator can simultaneously provide you with a pair of quadrature sine and cosine wave outputs.

A lossy variation on cascaded sine and cosine integrators is known as a *state variable active filter*. Which can offer you a stable high Q. One obscure use for these is *quadrature art* where psychedelic audio color patterns could get displayed on an oscilloscope or a computer screen. More details on state variable filters and quadrature art aps in my *Active Filter Cookbook*.

Although the sine values and the cosine values can end up completely independent of each other, together they should define a unique ribbon position or *phase* on the wheel. This suggests that we can place two totally different channels of information on a rotating vector or a similar *carrier*. Which lets us put twice as much stuff in a given bandwidth than we might have thought we could.

These channels might be called an "I" (for in phase) and the "Q" (for quadrature) channel. They become quite important in cellular comm and wireless modems. One older example of I and Q channel use is color tv where the chroma info is set by a pair of *color difference* values.

Generating Quadrature Signals

One really big use for quadrature signals can involve *single sideband communications*. Figure two shows us how a broadband quadrature phase shift network can be used to create SSB transmissions. For SSB gives us compelling advantages over earlier AM or *amplitude modulation*. In that only half your bandwidth is needed and no raw carrier power has to get
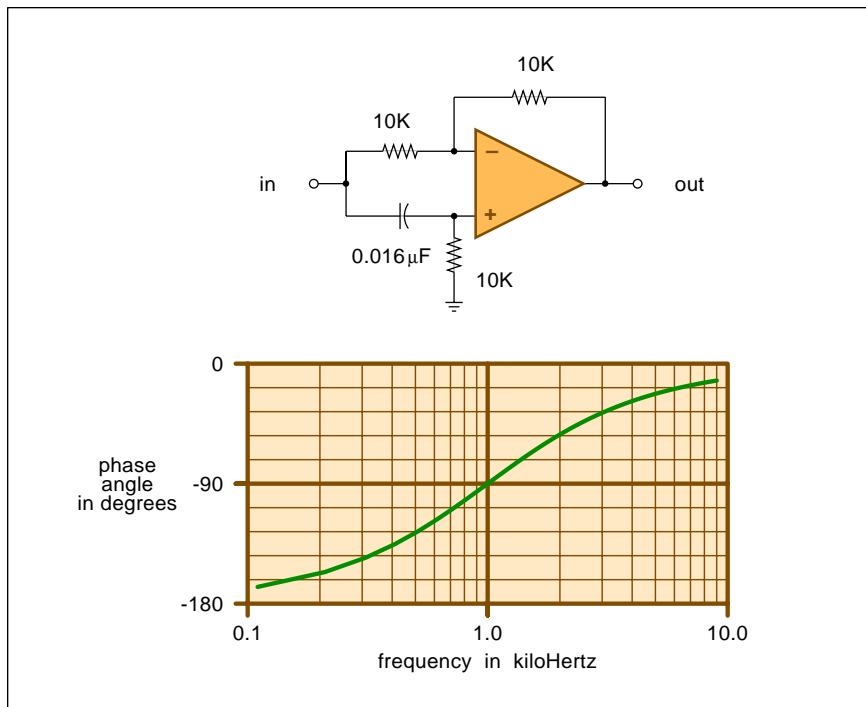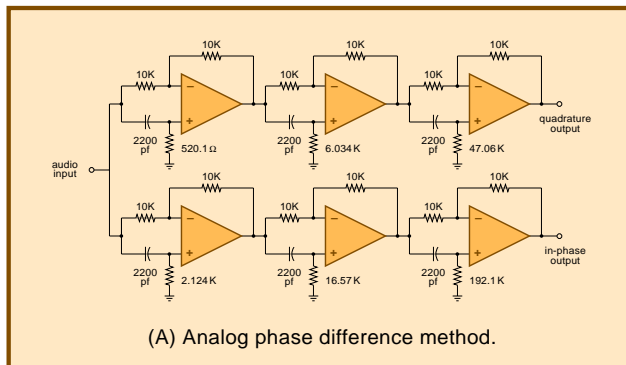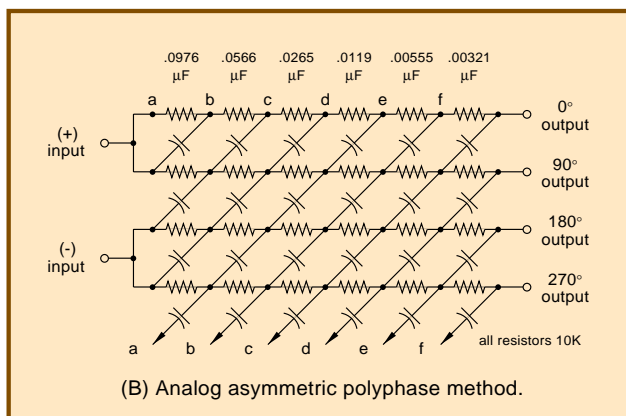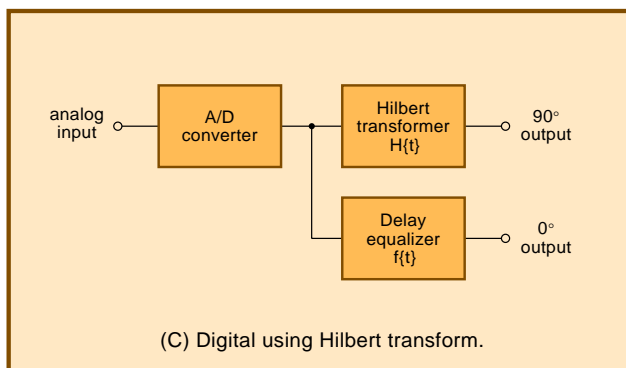

Fig. 3 – FIRST ORDER ALLPASS active filter can be used as an equalizer, cranking out phase as fast as some other circuit cranks it in.

(A) Analog phase difference method.

(B) Analog asymmetric polyphase method.

(C) Digital using Hilbert transform.

Fig. 4 – THREE APPROACHES to broadband quadrature phase shifting

transmitted or wasted.

Generating a quadrature signal at a single frequency is no big deal. We have seen that changing a physical point of view by 90 degrees does it. You also can simply stall or *delay* for a quarter cycle.

Ferinstance, a one kiloHertz audio sinewave has a time period of one millisecond. Any old *fixed* delay of a quarter millisecond should to it. At 100 MHz, a quarter wavelength or 90 degrees will be slightly over two feet.

Thus, the time delay from any short piece of coax or other line can get used as a single-frequency quadrature phase shifter. There even used to be *trombone lines* found in VHF phase shifting lab work.

For useful SSB or modem comm, though, you will need to quadrature delay a *band* of frequencies. Sadly, what was your 90 degree fixed delay phase shift at 1000 Hz becomes a 135 degree phase shift at 1500 Hertz and a 180 degree phase shift up at 2000

Hertz. Instead, you will want some *linear phase* system which advances phase exactly by 90 degrees as you advance your frequency.

Nearly any analog lowpass circuit using either capacitors or inductors inherently *has* to provide more delay than a linear phase. For the simple reason that capacitors and inductors are *causal*, meaning that they can "remember" what went on in the past but have no means of foretelling the future. Thus, higher frequency parts of waveforms tend to get further and further behind.

This is known as the *group delay problem*, and is it ever.

Ferinstance, if the ones of an older modem were at one frequency and the zeros were at another, with bad group delay in a filter, you will get times when you have a one, a zero, *neither*, or *both* at the output!

Obviously "neither" or "both" are highly ungood.

So, you'll have to get real fancy if you decide to build up a wideband quadrature network. In fact, it turns out there is no perfect way known to do so. Amplitude or phase lumps are certain. As is limited bandwidth.

But three useful approaches appear if you peek ahead to figure four. But first, let's pick up some details on a circuit we may find useful…

An Allpass Equalizer

To work around all of the inherent excess phase shifting problems with traditional inductors and capacitors, an *equalizer* can sometimes be used. An equalizer is simply a circuit that tries to crank out excess phase as fast as the problem circuit cranks it in.

A simple first order *allpass* section and its response appears in figure three. This circuit has the property that all reasonable frequencies will be passed with equal unity gain.

To analyze this circuit, note that the gain of the opamp will be -1 to an input on your left side of that left resistor on the inverting (-) input; and +2 to a signal applied directly to the non-inverting (+) input.

At the lowest of frequencies, the capacitor will seem nearly an open circuit, and the gain will be -1, for a phase *advance* of 180 degrees. At very high frequencies, the capacitor will be nearly a short circuit, and the

BROADBAND QUADRATURE RESOURCES

Albersheim and Shirley, **Computation Methods for Broad-Band 90 degree Phase Difference Networks,** IEEE Transactions on Circuit Theory, May 1969, page 180.

Bedrosian, S.D., **Normalized Design of 90 Degree Phase-Difference Networks**, IRE Transactions on Circuit Theory, June 1960, page 128.

Darlington, Sidney, **Realization of a Constant Phase Difference**, Bell System Technical Journal, January 1950, page 94.

Diethelm, Kai, **A Method for the Practical Evaluation of the Hilbert Transform**, www.informatik.uni-hildesheim.de

Gingell, M. J., **Single Sideband Modulation using Sequence Asymetric Polyphase Networks,** Electrical Communication, 1973 volume 48, nos 1 & 2, pp 21-25.

Hawker, Pat, **Technical Topics Scrapbook**, Radio Society of Great Britian, 1993.

Horowitz and Hill, **The Art of Electronics**, Cambridge University Press, 1989, page 5.16.

Jackson, Leland B., **Digital Filters and Signal Processing**, Kluwer Pub, 1989.

Lancaster, Don, **Active Filter Cookbook**, Synergetics Press, 1995.

Mikhael, Wasfy B, **Sequence Discriminators and their use in Frequency Division Multiplex**, IEEE Transactions on Circuits and Systems, February, 1979.

O'Meara, T.R., **The Synthesis of "Bandpass" Allpass Time Delay Networks with Graphical Approximation Techniques**. Hughes Research Laboratories Technical Reports #114 and #159, September 1960.

Orchard, **Synthesis of Wideband Two-Phase Networks**, Wireless Engineer, March 1950, page 72.

Saraga, W., **Design of Wide-Band Phase Splitting Networks**, Proceedings of the IRE, July 1950 page 754.

Schmidt, **Phase-Shift Network Analysis and Optimization**, QEX, April 1994.

Sekey, Andrew, **Digital Signal Processing**, IEEE Press, 1975.

Snyder, Richard V, **A new Broad-Band multiport Differential Phase Shift Network**, Proc IEEE, Aug 1971.

Winder, Steve, **Filter Design**, Newnes Publishing, 1997, Chapeter 9.

Yoshida, Tetsuo, **Polyphase Network Calculation using a Vector Analysis Method**, QEX, June 1995.

gain will be -1 + 2 = +1 for a phase shift of 0 degrees. Whenever your capacitive reactance matches your resistance, the combined phase shifts and gains on the op amp inputs will still give you a unity gain output, but at a phase advance of 90 degrees.

Thus, unlike any typical lowpass filter circuit, phase gets *retarded* as frequency increases. This retardation can be used to offset excess phase in whatever your new allpass equalizer is trying to equalize.

You can also have fancier *second order* equalizer circuits that let you crank phase in and out faster with more control. Higher order allpass networks are also possible, but they are usually done using cascades of first order and second order allpass sections grouped together.

Broadband Quadrature Networks

How can you generate a broadband quadrature phase shift?

Returning to figure four, our first scheme is called the *phase difference method*. In which you'll set up two cascaded chains of first order allpass circuits. One for I, one for Q.

By carefully specifying the phase advance of each circuit, you can get a 90 degree *differential* delay between the two channels over a chosen wide bandwidth. These differential delays typically can be +45 degrees and -45 degrees with respect to the input. The amplitude is reasonably smooth, but there will be lumps in the phase.

An original phase difference paper is by Bedrosian in the June 1960 *IRE Transactions on Circuit Theory*.

The second route uses the *phase sequence network*. The fixed array of resistors and capacitors gets driven off of a differential pair of audio

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NEED HELP?

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sources. And giving relative phases of 0, 90, 180, and 270 degrees.

This phase sequence method is covered in *The Art of Electronics*. One original phase sequence paper is by Gingel and published in *Electrical Communication*, v48-1.

Do note that these analog circuits only provide *differential* 90 degree phase shifting. Both output channels will inherently be "behind" the real world in-phase channel because a capacitor can causally react only to events that have already happened.

Digital filters do have a stunningly interesting property. They can look "forward" as well as "backward" in time. Simply by checking earlier or later taps in a time storage history. Thus, digital filters can be *noncausal* and hence "distortionless". It's quite easy to build a linear phase, sharp cutoff digital filter. We did look at these techniques in MUSE105.PDF through MUSE107.PDF

In fact, digital filters can easily do all sorts of things that are difficult or impossible with analog.

There is a piece of black magic math known as a *Hilbert Transform*.

NAMES AND NUMBERS

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San Jose CA 95110
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Atmel
2325 Orchard Pkwy
San Jose CA 95131
(408) 441-0311

Compu-Mart
899 Presidential #110
Richardson TX 75081
(972) 238-1133

Computer Reseller
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Manhasset NY 11030
(516) 562-5000

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Aurora CO 80015
(303) 690-2242

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Palo Alto CA 94303
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Which simply tells us "phase shift everything by ninety degrees." Figure 4C shows us the *Hilbert Transform digital filter* approach to broadband quadrature phase generation. While the phase can end up exact, there will be modest amplitude ripple in your needed approximations. One useful ploy is the *Ramez* algorithm.

Hilbert transforms can get built up with all the usual adders, delays, and DSP multipliers.

One useful digital filter book that includes Hilbert Transform info is Jackson's *Digital Filters and Signal Processing*.

I've gathered a few more detailed references on broadband quadrature networks together for you as this month's resouce sidebar. Loads of thanks to Winfield Hill and Rodger Rosenbaum for their inputs here.

HP's ScanJet 6100C

The nice developer people over at *Hewlett Packard* loaned me one of their new *ScanJet 6100C* scanners to play with. While I haven't had it long enough yet for a complete review, I am *very* impressed with what this beast can really do.

This is a premium and legal sized flatbed scanner that interfaces with a PC host through a fast SCSI interface. List price is $921 for either the PC or Mac version. Street prices should end up somewhere around the $620 range. Good pricing on HP products often shows up in *Computer Reseller* and *Comp-U-Mart* magazines.

This unit combines a fluorescent light with its CCD charge coupled device line sensor. Optical resolution is 600 DPI, with software deliverable resolutions ranging from 12 to 2550 DPI. Cropping is a snap and scaling can go from 3 to 400 percent.

Color or black and white is done in a wide variety of formats. Including a self-optimizing 10 bit gray and 24 bit full color. Fancy image processing options include dithering, filtering, thresholding, interpolation, a gamma adjustment, inversion, scaling, color correction, and mirroring.

There is even an optional 35 MM slide scanner accessory.

My main interest in a scanner is to capture all of my older books for my web site and CD-ROM publishing ventures. The HP scanner interfaces beautifully with *Acrobat Capture* for extraction of *both* the text *and* the layout. Bee is going bonkers over this machine, scanning all sorts of stuff for textile teaching, crafts, and

her co-op food newsletters.

There's also a copier mode that sure is handy. This works with your laser printer and gives you all sorts of size, quantity, quality, shading, and enlargement options. Compared to a "real" copier, the 6100C ends up somewhat slower using its highest quality mode. But normally makes for much better looking results.

This is a really great machine.

New Tech Lit

From *Texas Instruments*, CDROM platters on *Logic* and *1394 Solutions*.

From *AKM Semiconductor*, a new *Audio & Multimedia Data Book*. And from *Raychem*, the revised *Circuit Protection Databook*.

From *Atmel*, their new *AVR Risc Microcontroller* data book. Uh, when compared to the PIC, their *AVR* seems to me to be cheaper and faster, but a lot less elegant. Their instruction set is very much 6502 like, (yea, team) but typically should execute in single machine cycles. Even their smallest units include a fast multiplier and an analog comparator. Both external and internal interrupts are supported.

Landsat MSS image data is newly available on CD ROM by way of *Tom Oliver*. His prices start at $13 per CD. Broad coverage in several spectral bands is available. Amazingly cheap aerial photos with surprisingly high resolution are separately offered by several advertisers in *EOM*, short for *Earth Observer Monthly*.

Info on microwave and RF heating ideas at the *International Microwave Power Institute* at *www.impiweb.org*

Bunches of worthwhile books this month. Start with *Inside Intel*, which to me shows how enough arrogance and lots of lawyers can force clearly inferior technology into an industry dominance. I don't care for either the title or the really awful fonts in *Web Psychos, Stalkers, & Pranksters*. But the book nicely reveals solid info on hiding and unhiding web addresses and steps you can take towards your own web security. For guidance on where the web seems to be taking us, read *Growing Up Digital: The Rise of the Net Generation*. Check out my *www.tinaja.com/amlink01.html* for more details on these titles.

Finally, from *Lindsay*, his latest new-old book on *Popular Mechancics 1919 Shop Notes*. That hydraulic ram on page 2971 sure is a cute and "free" way to pump water uphill.

A great and free master industry wide electronic search service is now up at *www.questlink.com*

While not obvious, PostScript can elegantly (though not instantly) get tricked into painting with translucent ink! Plus "alpha" channel overlay effects. Blue screens, even. Further details are in ALPHADEM.PDF on my *www.tinaja.com*.

Info on new wireless developments appears in RESBN72.PDF, while the better and the more popular wireless books are listed for your review at *www.tinaja.com/amlink01.html*. And more secrets of web research newly appear in INFOPACK.PDF.

For the fundamentals of starting up your own tech venture, check into my *Incredible Secret Money Machine II*. From my nearby *Synergetics* ad. Our new full color catalog is now freshly available online.

A reminder that banner sponsors are welcomed for my *Guru's Lair* website. We've now "exceeded the speed of light" with way over 186,384 hits per month, and are fast sneaking up on "going to the moon" at 240,000. Total costs might end up under two cents per actual click through. Check *www.tinaja.com/advt01.html*. ◆

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