Don Lancaster's

Tech Musings

August, 1995

"All channels" FM transmitter
Electronic filter fundamentals
Switched capacitor ic resources
Narrow tunable bandpass circuit
More on active noise cancellation

Let's start off with our usual reminders that I try to run a no-charge technical helpline at (520) 428-4073, as per that *Need Help?* box below. Please note my recent area code change.

Your best calling times are 8-5 on weekdays, Mountain Standard Time. Funding constraints strictly limit this service to U.S. callers only.

I am also the sysop for the *GEnie* PSRT RoundTable and have a similar helpline service there. With reprints of most of my columns.

Besides being a library forum for Shawn Carlson's *Society for Amateur Scientists*, Steve Hansen's *Bell Jar* vacuum newsletter, Steve Robert's *Nomadness Notes*, Jim Fitzsimons' *Math Wonders*, and others.

We've now got 1300+ files in our library. Most of them not available elsewhere. You will also find info on wavelets, the Basic Stamps, patents, BOD, GhostScript, and Acrobat.

I am often asked to give out free Internet services. Or free email. Or free books. Or free coconut anchovy pizzas. But the askee never seems to get around to explaining exactly how this would be funded.

Although you might use Internet's SYNERGTICS@GENIE.GEIS.COM to send questions you want answered on PSRT or in future columns. Or to ask for catalogs or place orders. Private email responses are billable at my personal consulting rates. Making *GEnie* ridiculously cheaper. A typical PSRT reprint download costs you 21 cents. *GEnie* also newly provides full Internet access.

An "all channels" FM Transmitter?

I've had several helpline requests for this one. As a paging override for a factory or plant cable system. Or as a "please buy this house" realtor's message. One which gets received on an FM tuner set to *any* station. No matter which. I could also see several emergency vehicle traffic clearing aps for this as well.

Uh, I don't yet have a plug-and-go answer. But I do have a fairly simple paper design that *might* work. One that uses more of that *Fourier Series* we have been looking at.

Any decent FM receiver offers the *capture effect*. When two competing signals are being received, and if one of them is even slightly larger, then *only* your stronger signal shows up as output audio. Interference free. The capture effect happens because of the receiver's limiter circuitry.

So, we're off to a good start. When your nearby signal is stronger than a distant one, then your signal and *only* your signal gets received.

We looked at stereo broadcasters a few times in past columns. See both HACK22.PDF and HACK52.PDF on PSRT and in the reprints.

Your usual starting point was that *Rohm* BA1404 stereo chip. We have seen how the BA1404 makes a dandy low cost stereo multiplexer but is a terrible transmitter. Frequency drift and tuning accuracy slashes range or outright stops reception on digitally synthesized receivers.

Especially with car radios.

The one- or two-channel solution is to use the BA1404 to drive a crystal stabilized FM transmitter. But high quality linearly frequency modulating of a crystal oscillator is more than a little bit tricky. A lab full of obscure test equipment is needed before you can even think about it. Plus lots of math and years of experience.

We've seen schematics on how the *Pioneer* CD-FM-1 or the *Sony* XA7A auto CD adaptors give you an off-the-shelf design solution.

But the real problem here is not to transmit on a single channel, but to create *identical* signals on *all* the FM channels at once. Those FM channels run from 88.1through 107.9 MHz, with an 0.2 MHz channel spacing.

Figures one and two show us how the Fourier Series "comb transmitter" approach might handle this for us. A square wave has a fundamental plus 1/3 the third harmonic, 1/5 of the fifth harmonic, and so on. So, start with a single channel transmitter using one of those CD car adaptors. Divide this down to precisely 100 kHz, making sure your final stage is an ultra high speed divider having a risetime better than two nanoseconds.

At this point, we have got an FM square wave with lots of harmonics.

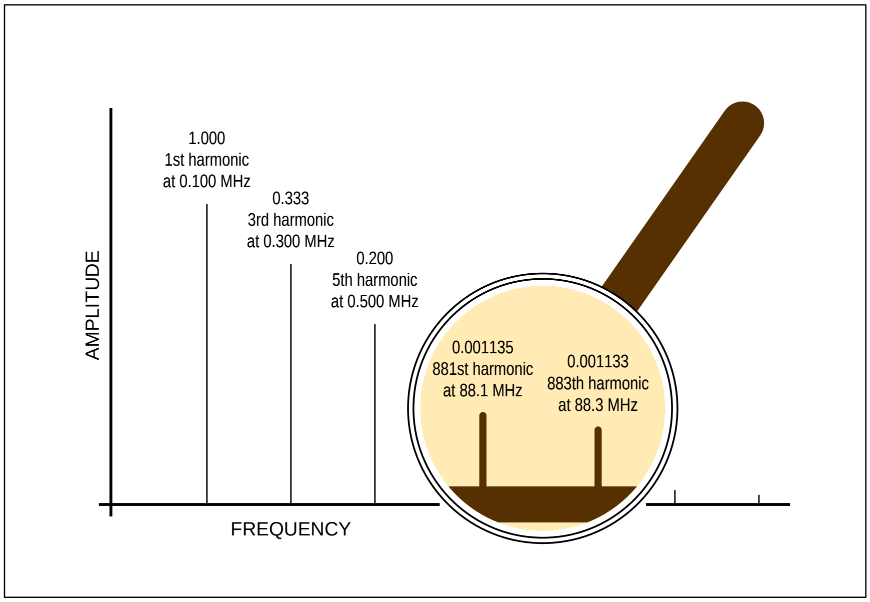

Fig. 1 – A FAST RISE 100 kHZ SQUARE WAVE has harmonics well into the FM band. The harmonics match existing FM station channels.

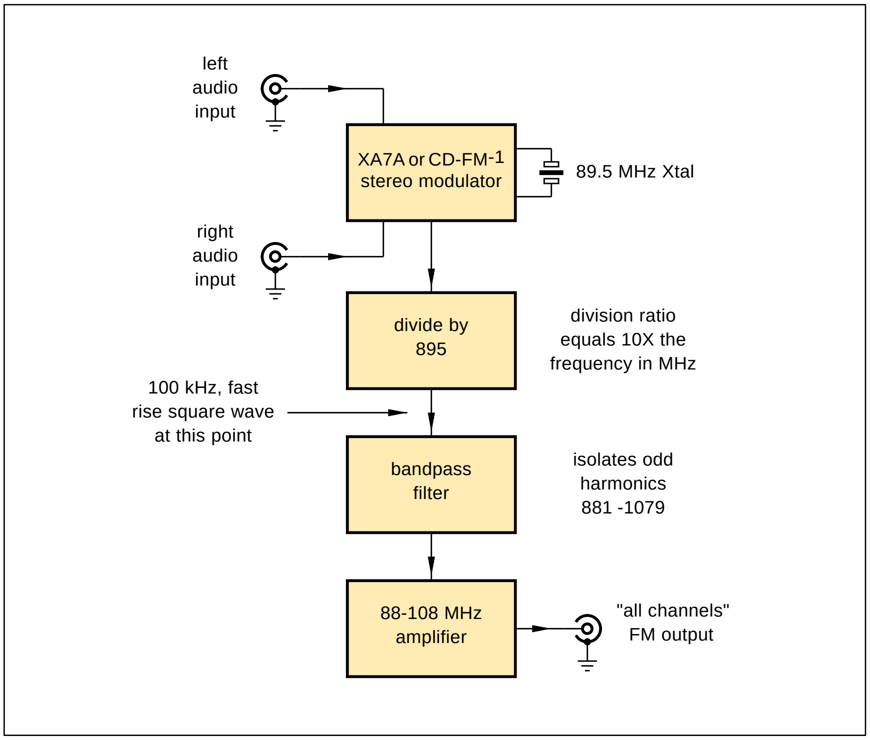

Fig. 2 – ONE POSSIBLE SCHEME for an "all channels" FM generator.

Ferinstance, you'll have around two millivolts or so of 881st harmonic at, of all places 88.1 MHz.

And, surprise, surprise, you have also got an 883 harmonic up at 88.3 MHz, and an 885th harmonic at 88.5 MHz. Up to the 1079th harmonic at, wonder of wonders, 107.9 MHz.

Yeah, the high end "stations" will be a tad weaker than those lower end ones. By around 20 percent or two decibels. Or, from the center of the band, plus or minus one percent, or one decibel either way.

So, add some gain and a bandpass filter to build up an all channel FM broadcaster. Those dollar MAR chips from *Mini-circuits Labs* should work just fine for predrivers.

To be sure, you'd have problems getting this one to behave in the real world. Wide dynamic range would be needed. And thorough shielding.

To prevent instabilities, you might want to mill each stage out of a block of solid aluminum. Or, at the very least, use stripline and double ground planes all the way around.

There's also some very restrictive FCC regs on this sort of thing. And transmitting unwanted messages to anyone ever is a definite no-no. But neither of these should be a problem on any private cable system.

One solution to a "buy my house" ap is to use several ultra low power curbside sites. Or perhaps go to some sort of a "lossy line" *leaky cable* that acts as a distributed antenna.

Filter Fundamentals

An electronic *filter* can be defined as a frequency selective network. A filter gets used to emphasize wanted info while rejecting noise.

Low pass filters sustain the lower frequencies but obstruct higher ones. One example for a *low pass* filter is the treble control on any hi fi. Noise reducing capacitors to ground on a power supply line are also low pass filters. Often called *bypasses*.

Bandpass filters select mid range frequencies while rejecting the higher and lower ones. The tuning dial on a radio, ferinstance. Audio *equalizers* are made from overlapping bandpass filter circuits. Each of which can be independently adjusted.

High pass filters will block lower frequencies but emphasize the higher ones. That bass control on a hi fi is one example of a high pass filter. By adjusting its *cutoff frequency*, you can selectively de-emphasize any of the lower musical notes.

Actually, there is no such thing as an electronic high pass filter. One of these would also be able to transmit microwaves, heat, light, and cosmic rays as well. The *frequency response* of any electronic circuit usually sets an upper limit. Making all high pass filters into band pass ones.

Similarly, a true low pass filter has to respond down to dc. Including any circuit bias or offsets. Audio lowpass filters add a large *coupling capacitor* to block out dc. And thus become a bandpass filter in the process.

Other more specialized filter types include *band stop* filters that reject a range of frequencies, the *notch* filters that are just a very narrow band stop filter, and *delay networks* that adjust phasing at chosen frequencies.

There are several popular ways to build a filter. *Classic* filters use fixed inductors and capacitors.

Transmission line filters are just the UHF or microwave equivalent of classic L-C filters. The big difference is that the inductance and capacitance is *distributed*, rather than *lumped*.

Active Filters use combinations of resistors and capacitors and opamps instead. Advantages include low cost, gain, and easy tuning.

Mechanical filters use the physical resonance of a crystal, some ceramic resonator, or magnetostrictive rods. *Surface Wave* filters use constructive and destructive interference of sonic waves on a piezoelectric surface.

The *Switched Capacitor* filters are a hybrid analog and digital scheme. More on this shortly.

Finally, *Digital* filters will treat the filter problem as a group of numbers. Using *digital signal processing*, FFT transforms, or even wavelets.

The *order* of any filter determines how strong or how powerful it is. For instance, a *first order* lowpass filter should, at best, fall off at six decibels per octave. And cutting its response in half as you double frequency.

A second order lowpass filter can respond at 12 decibels per octave. A filter of order eight drops down at a rate of 48 decibels per octave.

This gets real tricky on bandpass designs. For instance, a second order bandpass filter might drop off rather steeply just outside its passband, but its ultimate high- or low-frequency falloff will be six db per octave.

The initial falloff rate is set by the Q of your filter. Which, for a second order section ends up as the inverse of the bandwidth.

The *style* of a filter gets set by the underlying math used to determine its response. Filters using *Bessel* math give you the flattest time delay but a really poor amplitude response.

Butterworth filters will give you the flattest passband amplitude.

Chebycheff filters give you faster amplitude dropoffs, but at the price of lumpy passband ripple.

Elliptic filters will add one or more notches just into the stopband. Which give the steepest possible falloff, but far poorer ultimate rejection.

Actually, these strange names are part of a *continuium* of possible filter responses. To an active filter, all you have is a stack of cascaded first and second order sections. Each one has a *cutoff frequency* and a *damping*. By suitably changing these values, you can create any filter from Bessel on up through Elliptic.

In general, you can't do nearly as much with a filter as you'd like to. Increasing the order adds cost, noise, linearity, dynamic range, shielding, losses, tuning, stability, and response problems. Besides totally trashing the transients and time delays.

One real nasty here is called *group delay*. Ferinstance, if the modem tone frequency for a one has a different group delay than the zero tone freq, then you'll get times when you get a one, a zero, *neither*, or *both*.

In general, digital filters let you do much more far better. Ferinstance, a filter having a "brick wall" or "reject everything" response is impossible with analog designs, but easily done digitally. Group delay is also much more easily dealt with. So are elegant new *constant phase* designs.

Sadly, digitial filters are currently restricted to big amplitudes and low frequencies. Or to non real-time uses. And they do have their own set of problems. Not the least of which is *aliasing*, or generating nasty in-band artifacts from out-of-band signals. And *windowing*, which is properly dealing with the start and end of your digital number sequences.

By using wavelets or fast Fourier transforms, you can rapidly find the full spectrum of a waveform. Analog filters instead must be *slowly swept*.

In fact, you can shortly expect a revolution in radio receivers. Start at the front end, downconvert, and then digitize. From there, do *everything* digitally. Even *including* your station selections! Several tech notes on this are offered by *Harris Semiconductor* and *Analog Devices*.

You'll find much more on filtering in my *Active Filter Cookbook*. Now in its brand new second edition and *seventeenth* printing. See my nearby *Synergetics* ad for availability.

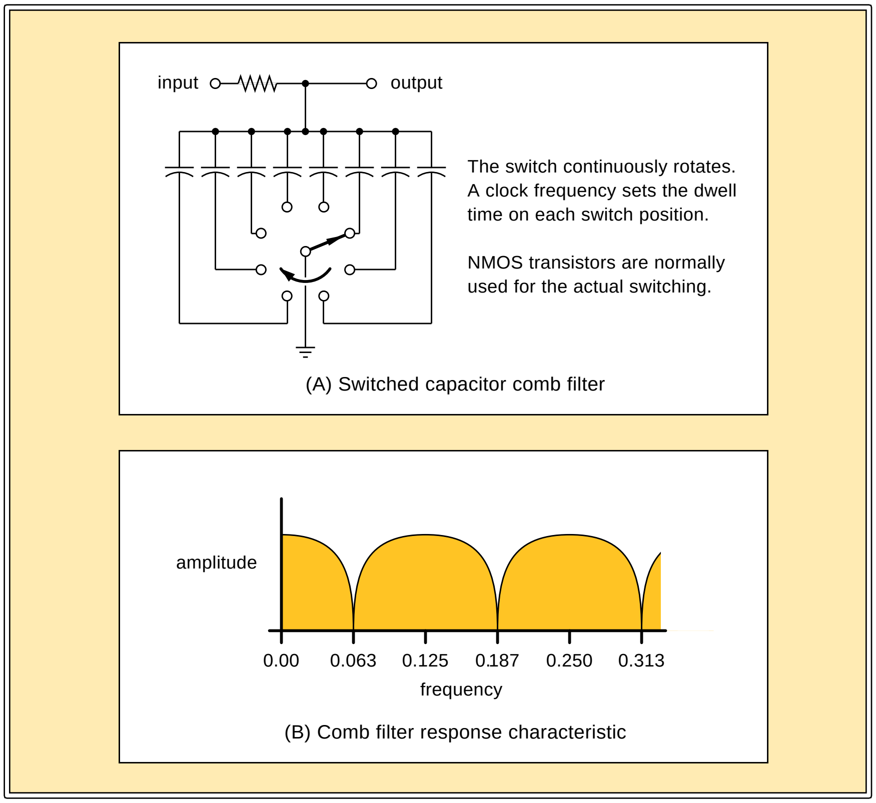

Fig. 3 – A COMB FILTER BUILT UP by using switched capacitor techniques. Lowpass, bandpass, and highpass versions are also possible.

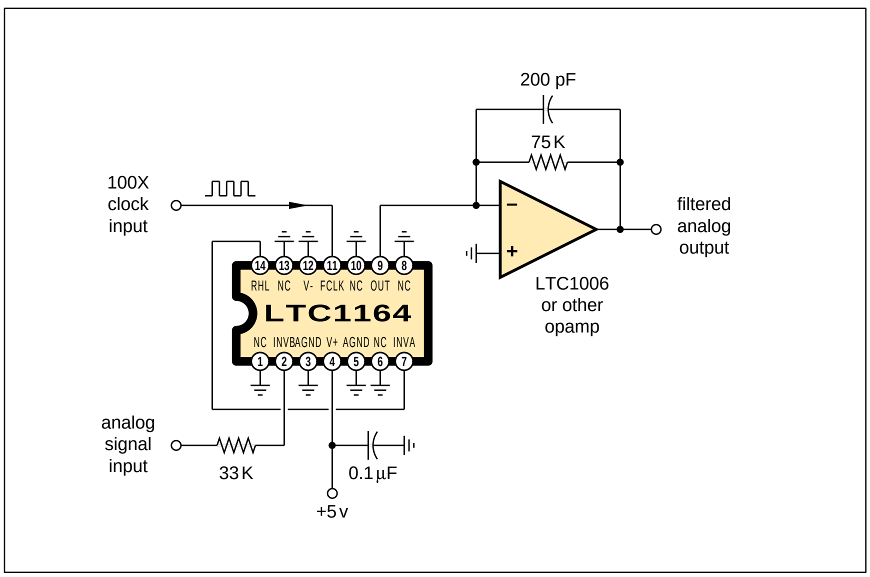

Fig. 4 – AN ULTRA SELECTIVE switched capacitor bandpass filter. The center frequency can be tuned by adjusting the digital 100X clock.

SWITCHED CAPACITOR FILTER RESOURCES

Analog Devices
PO Box 9106
Norwood MA 02062
(617) 329-4700

Burr-Brown
6730 S Tucson Blvd
Tucson AZ 85706
(602) 746-1111

Cermetek
1308 Borregas Ave
Sunnyvale CA 94088
(408) 752-5000

Crystal Semiconductor
PO Box 17847
Austin TX 78744
(800) 888-5016

Datel
11 Cabot Blvd
Mansfield MA 02048
(508) 339-3000

EGG/Reticon
345 Potero Ave
Sunnyvale CA 94086
(408) 738-4266

Exar Corp
PO Box 49007
San Jose CA 95161
(408) 732-7970

Linear Technology
1630 McCarthy Blvd
Milpitas CA 95035
(408) 432-1900

Maxim
120 San Gabriel Dr
Sunnyvale CA 94086
(800) 998-8800

National Semiconductor
2900 Semiconductor Rd
Santa Clara CA 95052
(800) 272-9959

SGS-Thomson
1000 E Bell Rd
Phoenix AZ 85022
(602) 867-6259

Texas Instruments
PO Box 809066
Dallas TX 75380
(800) 336-5236

Switched Capacitor Filters

There's an interesting hybrid filter scheme which uses both analog and digital technology. This is known as a *switched capacitor* filter.

The basic idea is shown in figures three and four.

Your switch goes round and round at some *clock rate* that is a multiple of your desired center freq. Now, for a given switch position, there's only *one* capacitor in the circuit. This cap should either increase or decrease its charge per that *difference* between itself and the input signal. Each cap thus retains a *sample* of your recent previous input history.

Now for the neat part: At dc or very low frequencies, the capacitors will pretty much track the input. As the frequency increases, the caps may charge or discharge.

At a frequency of exactly *one-half* the one-trip-around rate, any cap will charge on one pass and discharge on the next, giving a *zero* output.

At a frequency of precisely the one-trip-around rate, any capacitor charges identically on each pass and gives you a *maximum* output.

This simple example forms a *comb* filter. The first null frequency will be determined by the switching rate and the number of caps. In this example, your first null frequency is at 1/16th the data rate. Comb filters can get used to reject a fundamental and *all* of its harmonics. One major comb filter use is separating NTSC color from brightness.

Somewhat different combinations of resistors, switches, and caps could build high quality lowpass, highpass, bandpass, or bandstop responses.

Switching is normally handled by CMOS analog switches. Much more on using and understanding analog switches in HACK75.PDF and in my classic *CMOS Cookbook*.

Advantages of switched cap filters include precise tuning. Over a wide frequency range. Plus lower cost and small size. Because everything gets done on the silicon chip, there is no need for any external caps.

Dozens of switched capacitor filter chips are now available from several sources. Some approaching a dollar each. Our resource sidebar for this month shows you several of the main suppliers involved.

Of these, check into *Maxim* and *Linear Technology* first. Lots of free samples from *Maxim*.

Sadly, there have been quite a few false starts involving these switched capacitor filters. Early versions had excessive noise floors, caused by the transient feedthrough of the clock.

This happens because of the gate to source capacitance in any CMOS device. The *dynamic range* is set at the low end by the noise floor, and at the high end by clipping, distortion, or other nonlinearities.

Today, these glitch and noise floor problems have been minimized. Still, though, switched capacitor filters are *strictly* limited to larger signals. They are not at all suited for microvolt size inputs. Typical devices are limited to ultrasonic or lower frequencies.

But they sure are a useful tool.

A Narrow Bandpass Filter

There is this interesting new LTC 1164-8 chip from *Linear Technology*. This device creates an easily tunable and ultra narrow eighth order Elliptic bandpass filter. The bandwidth is one percent of the center frequency.

Cost is around $24 in singles.

Figure four shows us details. The chip goes ahead of an op-amp in such a way that your generated noise floor is independent of your gain. With a single 5 volt supply, your current is around two mils and the maximum center frequency is 4 kHz. The input clocking frequency is 100 times your center frequency. Output noise is half a millivolt. The stopband attenuation is fifty decibels or so.

Careful ground plane shielding is required. Be certain to carefully read the LTC1164 data sheet.

Gain is adjusted by changing the input resistor. Note that the *smaller* your resistor, the *higher* your gain. A gain of 1000 is possible, but you will get best dynamics at unity gain.

To use the circuit, set your gain by

NEED HELP?

Phone or write all your US Tech Musings questions to:

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Web page: *www.tinaja.com*

NAMES AND NUMBERS

Active Sound & Vib Control
8858 Blue Sea Drive
Columbia MD 21046
(410) 381-9359

Bell Jar
35 Windsor Drive
Amherst NH 03031
(603) 429-0948

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

Harris Semiconductor
Box 883
Melbourne FL 32902
(407) 724-7000

IC Card Systems & Design
6151 Powers Ferry Road NW
Atlanta GA 30339
(404) 955-2500

Mini-Circuits
PO Box 350166
Brooklyn NY 11235
(718) 934-4500

Nomadness Report
PO Box 2185
El Segundo CA 90245
(310) 322-1655

Pioneer
Box 1720
Long Beach CA 90801
(213) 835-6177

Quatech
662 Wolf Ledges Parkway
Akron OH 44311
(800) 553-1170

Radio World
5827 Columbia Pky #310
Falls Church VA 22041
(703) 998-7600

Roberts Hydraulics
311 North Morgan Street
Chicago IL 60607
(312) 829-1365

Rohm Corporation
Box 19681-631
Irvine CA 92713
(615) 641-2020

Special Shapes
PO Box 7487
Romeoville IL 60446
(708) 759-1970

Society Amateur Scientists
1549 El Prado
San Diego, CA 92101
(800) 873-8767

Sony
9 West 57th St 43rd Fl
New York NY 10019
(212) 371-5800

Sycard Technology
1180-F Miraloma Way
Sunnyvale CA 94086
(408) 749-0130

picking the input resistor, apply an input signal you want filtered, and a 100X square wave clock derived from any old TTL or CMOS source.

For quick and dirty experiments, simply use one sixth of a 74HC14, a variable resistor, and a cap to make a square wave clock source.

One obvious use I've got for this chip: Checking real-world harmonic performance of the magic sinewaves we looked at a few columns ago.

But one major warning over *any* narrow band filter: *If your signal is rapidly changing, most of it will be missed!* This happens because that high Q of the filter takes a long time to build up a useful result.

Sorta the same as whapping a large pendulum with a hammer. Nothing much happens with one ping. Its only when hundreds of well timed pings occur that oscillation starts.

Thus, narrow band filters must be very accurate. And very *slowly* tuned. And they will only work with very *slowly changing* signals.

Uh, the data sheet doesn't mention it, but I suspect the LTC1164 also responds to the second and higher harmonics of your center frequency as well. This is called *aliasing*. Some external prefiltering thus appears to be a real good idea.

This device seems ideal for a lot of telecomm and mid-range audio aps. Especially for vibration studies and harmonic analysis. But, for ultra low frequencies (such as seismography or brainwave research), digital FFT or wavelet techniques are the *only* way to go these days.

Two Contests

Let's have us a pair of contests this month. Either (A) Add to our dialog on "all channels" FM schemes, or (B) Show me an unusual new use for an ultra narrow, switched cap bandpass filter. There'll be a dozen or so of my *Incredible Secret Money Machine II* books going to the better entries. Plus an all-expense-paid (FOB Thatcher, AZ) *tinaja quest* for two going to the very best of all.

Please send your *written* entries to me here at *Synergetics*, rather than to **Electronics Now** editorial.

New Tech Lit

An update on those active noise cancellation topics we looked into several columns back: I've uploaded a tutorial and resource directory as NOISCNCL.TXT. There's also a new *Active Sound and Vibration Control News*. Free sample copies.

More on FM radio RBDS services: There is now an Internet forum up at *http://pcbf1-131e.util.ch/~uer/rdsh000.htm*. As always, *Radio World* is the best place to get RBDS info. Hundreds of stations now provide RBDS services. Ranging from song & singer, traffic & weather, coupon promotions, on up to GPS nav corrections.

Those new plug-in cards for laptop computers are also known as PCMIA cards. One trade journal that zeros in on these is the *IC Card Systems & Design*. A pricey source for books on the PCMIA standard is *Sycard*. One source of cards is *Quatech*.

Bargain hydraulics are offered by *Roberts*. Unusual modelmaking parts are available at *Special Shapes*.

The magic sinewave stuff that we looked at a column or three ago has now been improved and upgraded as MAGICSIN.PDF. I've got actual chips and working hardware. Co-developer packages are newly available for this emerging opportunity.

For most small scale startups most of the time, patents are certain to end up as a net loss of your time, energy, money, and sanity. Find out why in my *Case Against Patents* resource package. That also shows you tested and proven real-world alternatives.

Our usual reminder that most of the resources mentioned appear in the *Names & Numbers* or that *Switched Capacitor Filter Resources* sidebar.

Let's hear from you. ✥