Experiment with WWVB

Details on various 60-kHz reception techniques that can make your superclock self-resetting and always accurate. These are strictly experimental systems, described for advanced electronics buffs only

by DON LANCASTER

THERE ARE AT LEAST THREE REASONABLE ways to make your Superclock (**Radio-Electronics**, July and August 1972) or any other parallel-load clock self-resetting and always accurate. One is to use National Bureau of Standards stations WWV and WWVH. A second is the television timing system, which is still experimental. A final way is with WWVB, a 60-kHz station of the National Bureau of Standards broadcasting from Fort Collins, Colorado. WWVB broadcasts a continuous time code 24 hours a day. The code is in Greenwich Mean time, but this is easily converted to local time with the Time Zone conversion chip in the Superclock. The performance of WWVB varies across the country, being best in the mountain states and poorest far east, far south, and in noisy industrial or high thunderstorm areas. Depending on your area, you might get reliable reception with a very simple system, or you might not get good enough results to reliably run a clock even with the most exotic techniques. We'll try to show you how to build up several receivers, ranging from the simple to the complex, along with a suitable decoder. What we *won't* do is guarantee results—but with our circuits and subsystems as a start, maybe you can avoid all the pitfalls and mistakes we made along the way.

Even if you can't get continuous coverage, a late night update can usually be used to keep your clock accurate, with the crystal timebase filling in between updates.

The systems we'll talk about were tested in Phoenix, Arizona, where the simplest system worked very well and in San Antonio, Texas, where the more complicated system gave acceptable performance in the middle of a high industrial noise and high topical storm area. Your reception job will be extremely difficult east of the Mississippi, but NBS coverage of the entire US by WWVB is termed "adequate" and maybe you'd just like to try this exciting project.

About WWVB

You can find out about all of the NBS services by getting a copy of *NBS Frequency and Time Broadcast Services*, NBS Special Publication #236 for 25¢ from The Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Stock Number 0303-0866. Or, you can subscribe to the *NBS Time and Frequency Services Bulletin*, a monthly publication that gives day-to-day operating details of the various stations, announces upcoming changes, and so on.

WWVB transmits a continuous 60-kHz carrier 24 hours a day, except for occasional Tuesday maintenance schedules. The transmitter is located in Fort Collins, Colorado and the transmitted power is 13,000 watts. Field strength contours for the United States are shown in Fig. 1. Except for the code modulation we'll tell you about in a minute, the signal is all carrier—there are no voice announcements, no tics, geoalerts, or anything else. At the beginning of each second, the carrier suddenly drops 10 decibels in amplitude, giving the impression of "half value" on a peak-to-peak scope display. The signal stays low for a portion of the second and then goes high again, dropping on the next second.

One bit of an elaborate time code is presented each second by the *duration* of the low part of the code. If the signal stays low for 0.2 second, you have a "0." If it stays low for 0.5 second, you have a "1." If it stays low for 0.8 second, you have a "P" or framing pulse. These pulses are shown in Fig. 2, along with the complete code.

The code repeats every minute. It starts out with two "P" pulses in a row identifying the start of a minute. Next comes the "10 minutes" information, followed by the "minutes," and another P pulse at ten sec-

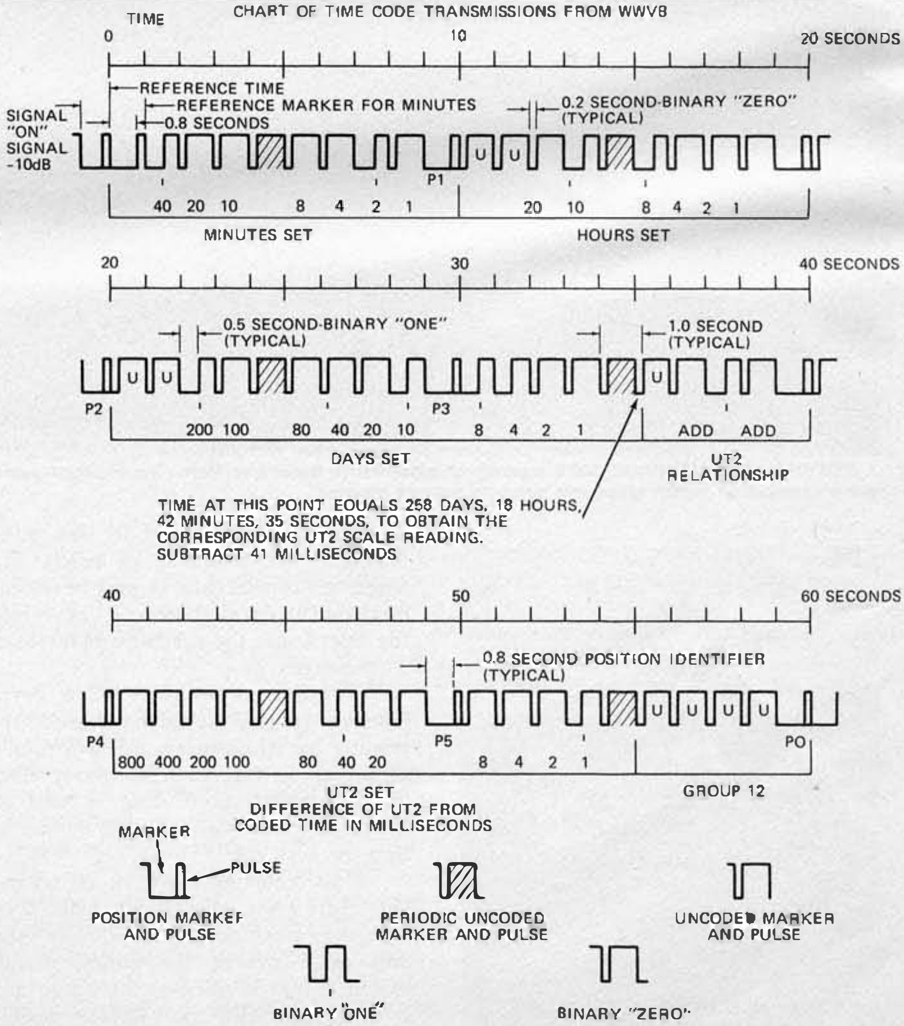


FIG. 2—PULSES AND TIME CODE broadcast by WWVB on 60 kHz from Ft. Collins, Colo.

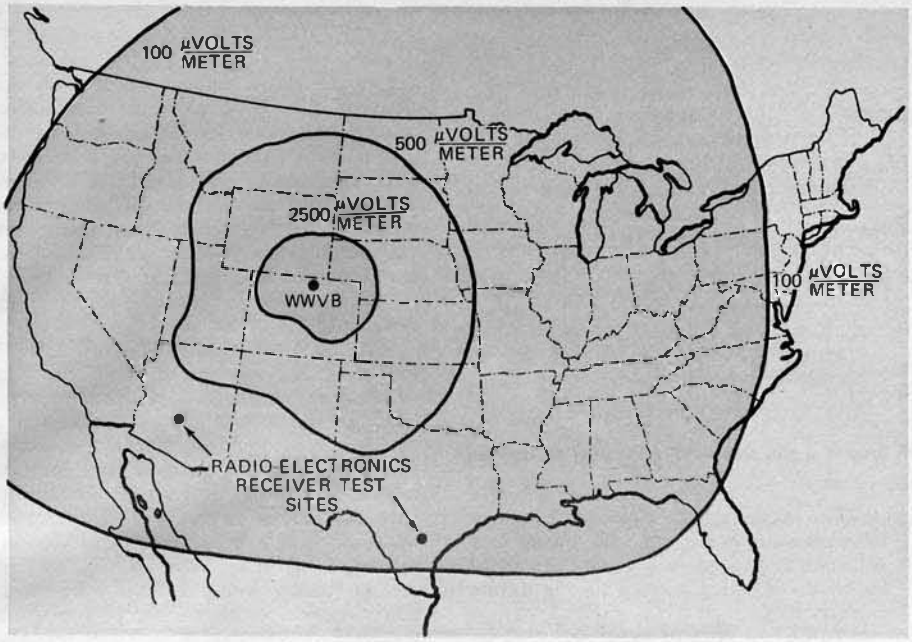
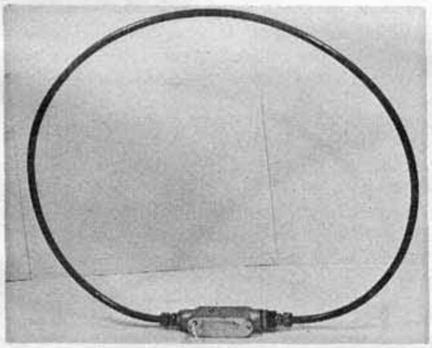


FIG. 1—SIGNAL STRENGTH of WWVB broadcast over the continental U.S.

onds. This is followed by the "ten hours" information, and the "hours" information, ending up with a P pulse at 20 seconds. Beyond 20 seconds, the code goes on to give you the day in the form of a number from 1 to 365 or 1 to 366, and some "fine grain" time information we won't be using.

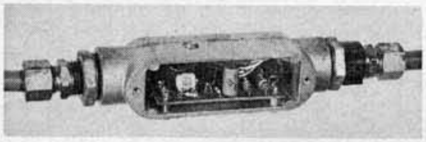
The code repeats once each minute, updating the information for that minute. Since it takes at least 10 seconds to get out the minutes information, the code runs 10 seconds late. To beat this, you preload a "10" into your seconds counter at the time you update the minutes information. The time-zone chip in the Superclock automatically takes care of the 2400 hour GMT to local time conversion.



TRADITIONAL LOOP ANTENNA. Note insulating section on shield.

So, to get from WWVB to a Superclock update, we need a 60-kHz *receiver* that picks up the signal and converts it to a reliable string of "1"s and "0"s. Then we need a *decoder* that converts the "1"s and "0"s into a proper format and decides when the Superclock is to be updated. The decoder is easy and reliable—the problem is the receiver.

WWVB is completely free from fading and keeps a remarkably stable output, except for a short diurnal variation for a few minutes at local dusk and dawn. The low frequency allows very accurate timing information with the whole world behaving as a waveguide to bring the signal to you without any of the problems common to the shorter wavelengths. There's almost always enough signal. The problem is that WWVB is an AM system at low frequency and there is substantial terrestrial and man-made noise, particularly near thunderstorms and in industrial areas. So we have to start with a stable, narrow-band receiver. If we are lucky, that's all we'll need. If not, we'll have to go to some more exotic reception techniques.



WWVB PREAMP is in the loop antenna. It should be completely shielded.

Building a preamp

Regardless of what you do with your receiver, a good preamp is absolutely essential. The one we'll tell you about is simple and cheap—but has been the result of many hours of painful testing and lessons learned the hard way.

Before you do anything, if you could beg, borrow, or steal five minutes of time on a real, high-quality, military field strength receiver (*Singer, Empire Devices,* etc.) with a low-frequency plug-in, you can get a fair idea of how hard the signal will be to receive. Use a vertical antenna, a location above all local metal, and try it an hour after dusk. Tune to 60 kHz and watch the S meter. If there's any hope at all, you should get a fairly strong signal on the meter with a distinctive once-each-second sudden drop in amplitude. You should be able to read the code except for occasional noise pulses, and the background level should drop below the minimum signal as you tune off frequency.

A shielded loop antenna is essential for the preamp. It's shown in Fig. 3 along with the complete preamp schematic of Fig. 4. Start with 6 feet of copper tubing, insert a piece of 12-conductor surplus shielded cable, and bend it into a loop. Terminate it in a conduit housing that's big enough to hold the preamp. Be sure to use a plastic fitting on one end to keep from getting a shorted turn on your shield. These are available in many hardware and electrical supply stores and are intended for shockproofing electric hot water heaters. The shield must be double (the cable plus the tubing) and has to be this thick because of the skin effect at 60 kHz requiring considerable shield thickness. The final form of the loop will be slightly over 2 feet in diameter.

The loop is completed by wiring the conductors together to form a 12-turn loop and then soldering the shield and tubing at one end only. Tune this coil to 60 kHz with high-quality polystyrene capacitors or the much more expensive silver micas. Any other capacitor type is unsuitable. The coil Q should be around 25 to 40. More will cause temperature and tuning problems, less will let in too much noise.

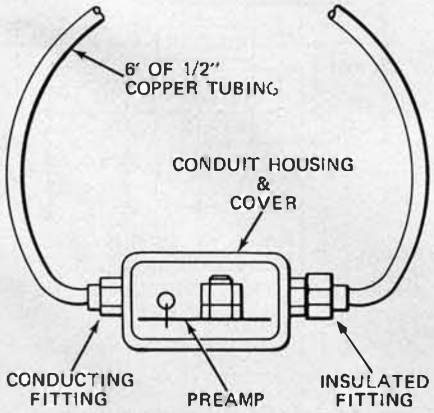


FIG. 3—SHIELDED-LOOP ANTENNA for receiving WWVB broadcasts.

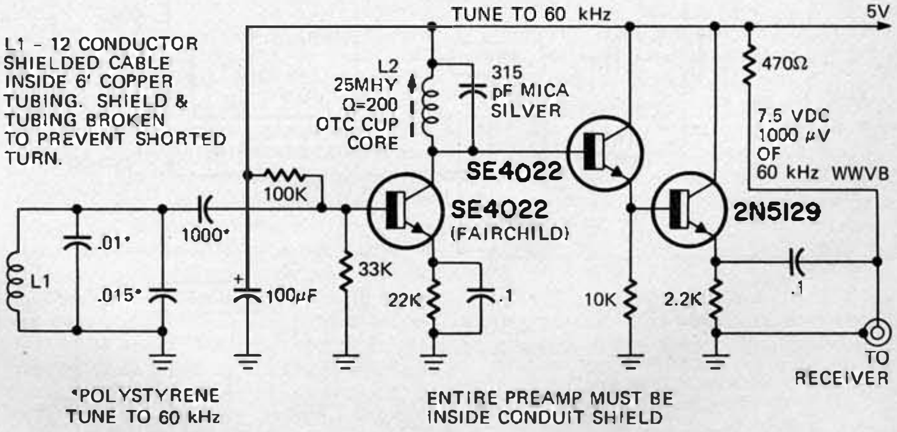


FIG. 4—PREAMP SCHEMATIC. Three-transistor circuit is easy to build and inexpensive. Total cost is about $8.

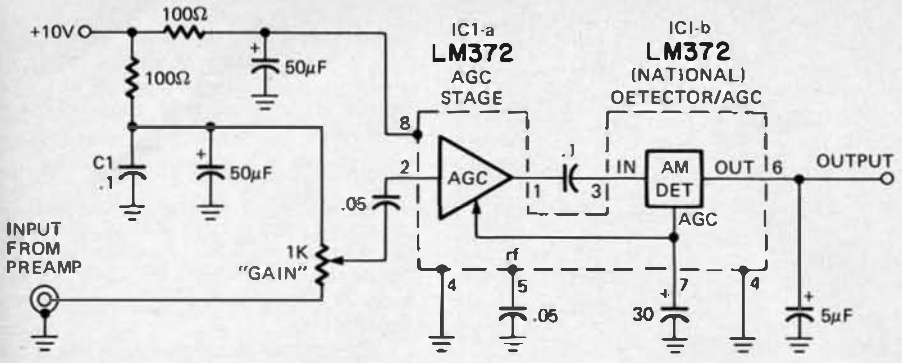


FIG. 5—A SIMPLE WWVB RECEIVER can be built around a National LM372 IC. Just follow this basic schematic.

If you're real lucky, you'll have around 0.5 μV to play with. So, you'll need a very high gain, extremely low-noise preamp. Use the transistor called out or another one designed specifically for low-noise, high-gain operation. This one runs a gain of around 1200 with a 0.5 dB noise figure at a 75-μA *collector* current. A shielded, temperature compensated, variable cup core is used for the collector load, tuned with a silver mica capacitor. One suitable cup is the #448-07-25 mHy.

Costs around $4 from *Caddell Burns Mfg. Co.*, 40 East 2nd Street, Mineola, N.Y. 11501. A special #2103 tuning tool is $1 extra. The Q of this tank should be over 200 for proper noise reduction. Thus, the coil, the tuning capacitor, and any loading all get into the act. A Darlington emitter follower, using a superbeta transistor driving a plain one superimposes the signal onto the B+ line so you can drive 30-50 feet of shielded single-conductor cable. You power the preamp from a 9- or 10-volt supply. A 470-ohm dropping resistor and capacitor to demultiplex the other end. The supply line must be thoroughly bypassed to prevent any stray signals from getting into your receiver.

The output signal level should be over 100 microvolts in a poor area and up to 4 millivolts in a good one, getting the signal up big enough that we can handle it with ordinary IC's.

To use the preamp, get it above all local metal and point it towards Fort Collins, Colorado, or so the hole in the loop is pointing 90° *away* from Fort Collins. This is the optimum signal position, although turning it slightly from this might reject some directional local interference.

Hook up some supply power and look at the output with a sensitive 100-μV audio voltmeter, or add some raw gain and look at the output of your amplifier with a vom. Unless you can get a reasonably legible, if somewhat noisy, signal, there's no point in going any further. Try reading the code. Unless the preamp can get you at least a recognizable signal, there's no hope for anything further down the line. Both the loop and the tank cup core should be tuned for maximum amplitude. Try rotating the loop 90° and see how far out of the noise the minimum signal is.

At this point, you should have a good idea of how rough the reception job will be. If it looks like you could arc weld with the signal—fine, a simple receiver is all you need. If the signal is barely identifiable, some more exotic techniques will do the job. If it's not there, either you don't have a working preamp, it's daytime of an alternate Tuesday, or else the job is hopeless. Above all, don't go beyond this point until you are confident you can get results. Total cost this far should be under $8.

A simple receiver

A National Semiconductors LM372 makes a dandy receiver. The IC has two sections—an initial agc stage which you can capacitor couple to a high-gain stage and a detector. You should get several tenths of a volt of detected output signal, and you can monitor the output with a vom. Be sure to have data sheets on this and all the other transistors and IC's on hand when you are working with them. Also, if you attempt preamp tuning with the LM372 attached, don't forget to defeat the agc or you won't see your tuning peak. If you can get reliable results with this simple system, all you have to do is add a suitable comparator on the output to get 1's and 0's and then go straight to your decoder. The simplified receiver is shown in Fig. 5.

Some advanced techniques

At this point in the game, you either have a good signal, a marginal one or a worthless one. If it's good, you're done at low cost. If it's a little marginal, maybe some of the tricks we'll show you will help. Which ones you want to use depends on what you want to spend in the way of time and effort and how close you are to reliable operation. Here's a rundown of suggestions:

TECHNIQUE No. 1—*Clip the impulse noise.* Much of the interference will be caused by high-amplitude, high-energy spikes of short duty cycle many times the signal amplitude. If you can clip these off at twice the normal signal level, they won't contribute nearly as much to problems later

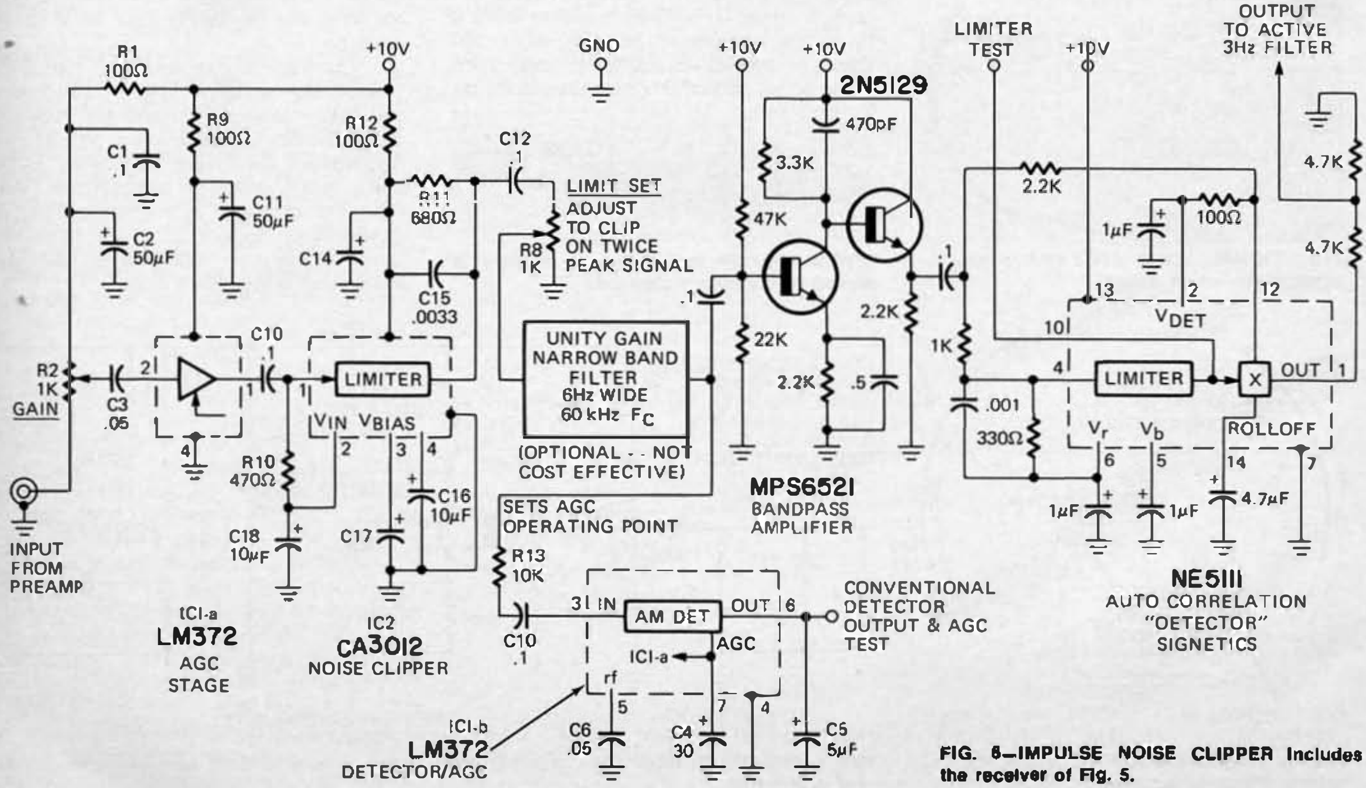


FIG. 6—IMPULSE NOISE CLIPPER includes the receiver of Fig. 5.

in the circuit. The limiter has to be inside the agc loop, and the inside gain has to be adjusted so that limiting takes place at twice the normal signal level over the normal operating agc range. Once set properly, the agc will accommodate a reasonably wide range of signal levels without the clipping level moving around too much. It's absolutely essential that you limit the noise *before* further filtering or detection, for the impulse noise gets wider and lower with further processing. Thus you want to remove as much of the noise energy as soon as possible in the circuit. Fig. 6 shows an experimental circuit that includes the limiter with some of the other advanced techniques. The circuit includes the basic receiver and is used with the preamp.

TECHNIQUE No. 2—*Watch how you reduce the bandwidth.* The way in which you end up with a final narrow-band detected signal can make a drastic difference. The effective noise bandwidth at the preamp with a Q of 200 is 60,000/200 or about 300 hertz. We need a final "video" bandwidth of around 3 hertz. Here's some facts of life on how we can pick up signal to noise ratio while we decrease bandwidth:

1. If you do your filtering *after* detection, you will only improve the signal-to-noise ratio by $\sqrt{100}$ or a factor of 10. This is how the simple receiver of Fig. 5 does the job.
2. If you do your filtering *before* detection, you will improve the signal-to-noise ratio by a factor of 50 which is slightly better than seven times or 7 power dB better than the basic receiver.
3. If you don't detect, but instead you multiply (autocorrelate) the signal with a limited version of itself and then filter, you also gain 7 times or 7 power dB over the basic receiver. The filtering is now much cheaper, but the circuit more complex.
4. If you don't detect, but instead multiply the input signal (cross correlate) by a signal that looks like WWVB is supposed to and derived from an ultra narrow band phase-lock loop, you can do three power decibels or twice as good as in 2. or 3. The ultimate improvement is then 10 times or ten power decibels better than the simple receiver.

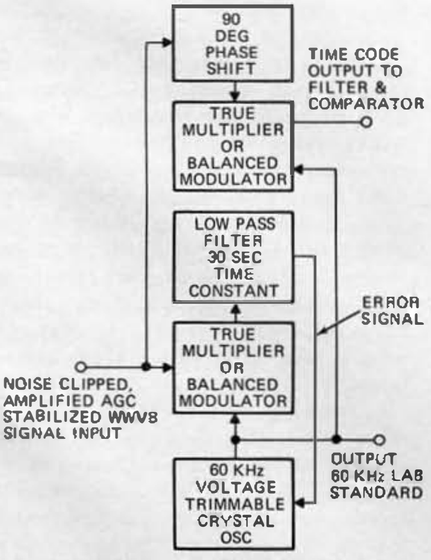


FIG. 7—VARACTOR-TRIMMED CRYSTAL oscillator improves noise 3 dB.

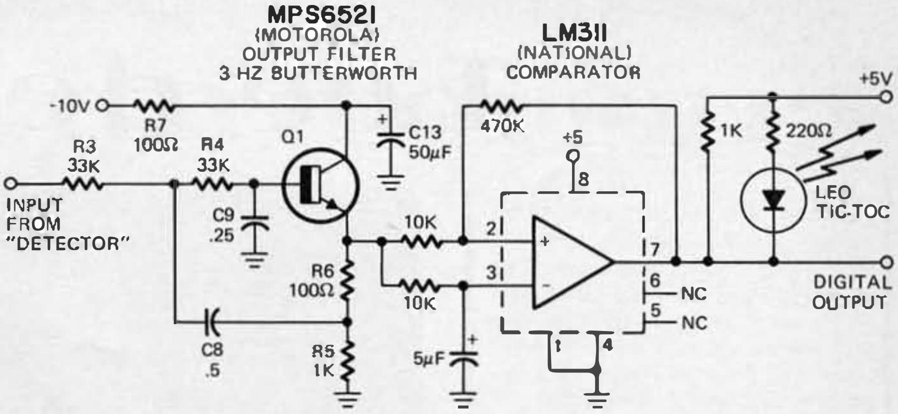


FIG. 8--LOW-PASS FILTER is used to filter the output. Gives a dB or two of additional improvement.

By the way, the final "worst case" signal to noise ratio must be at least 14 dB for error free code reception.

We already went route I with the simple receiver of Fig. 5. For 2, all we need is a nice 6-Hz wide, temperature-stable, accurate 60,000 hertz filter. Lots of luck. We tried a bunch of very expensive ones, including quartz resonators, magnetostrictive stacks and ultrasonic filters. All of these worked but were too expensive. You might try several preamp circuits cascaded; this will reduce the signal bandwidth somewhat but probably won't be cost effective and could cause oscillation and shielding problems. 60-kHz crystals have too *high* a Q, even if you let air into the can to damp them, although a pair of crystals properly stagger tuned probably would work. Again, it's not cost effective.

For 3, use the limiter/multiplier, shown in Fig. 6, and you'll get good results. This IC is under $3. Make absolutely certain the limiter output is a noise-free square wave. Incidentally, this output also makes a reasonable precision frequency reference for lab work if it is hard limited.

This multiplication technique is *not* detection. It translates the signal down to dc, and a filter following it acts just like a narrow band filter in the rf. Since both sidebands fold over, a 3 Hertz low pass output filter does the same job a 6 Hertz Bandpass RF one would.

For 4, you have to ask whether another 3 dB is really worth all that effort. Anyway, a block diagram is shown in Fig. 7. First you build a varactor-trimmed crystal oscillator that runs within a few hertz of 60,000 Hertz. You build a phase detector and an integrator with a half-minute time constant, and critical loop damping. Full details are in *Phaselock Techniques* by Floyd Gardner, published by John Wiley. Master the book before you start.

The theory of the phase lock loop says that you are reconstructing a replica of WWVB that averages out all the noise. When you multiply (cross correlate) this signal against the regular received WWVB, the signal you want gets translated down to dc. Noise that happens to be out of phase (in quadrature) with the signal gets cancelled, while other noise gets reduced in proportion to its phase angle. The average statistical reduction of the noise is 3 dB, or 0.707. It probably isn't worth it, although you get an ultra-accurate, ultra-stable lab standard in the bargain. Note that IC phase lock loops are hopelessly inadequate for this job where the stability has to be measured in drift rates of cycles per minute.

EXPERIMENTAL SUPER-LOOPSTICK is shown less shield. Rods are 5¼-inch long, Figure of merit is around 2. Resonating capacitor is around 235 pF.

TECHNIQUE No. 3—*Filter the output sharply.* If we only need 3 Hz bandwidth to get the signal we want, anything else beyond 3 Hz is noise. If your filter falls off slow, you pick up extra noise. So, use a second order low-pass like the one in Fig. 8. It only buys you a decibel or so of improvement, but it's simple and cheap. Fig. 8 also shows a comparator that converts the analog code to digital logic levels.

Once again we've just run out of space and cannot complete this article till next month. In the September issue we will present details of an improved receiver and a decoding circuit including two more schematics.

PC BOARDS

Replicas of the PC boards for the Preamp (Fig. 4) and the Flywheel (Fig. 9) are available free from

SOUTHWEST TECHNICAL PRODUCTS
219 WEST RHAPSODY
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