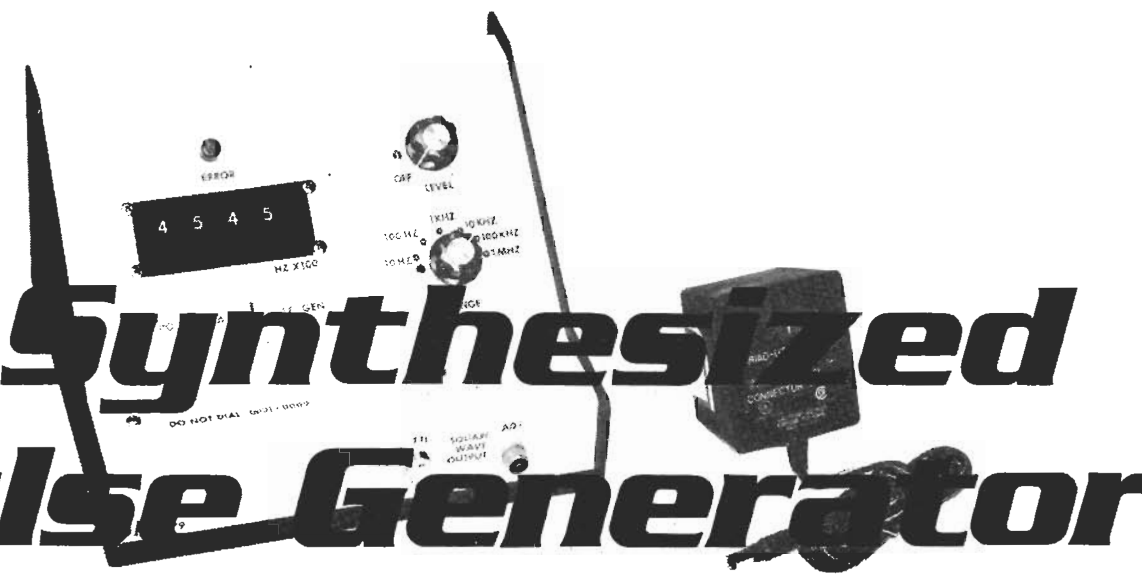
Synthesized Pulse Generator



This synthesized pulse generator has a range of from 1/100 Hz to 1.000 MHz. Use it for working with logic circuits—or with analog devices well into the HF range.

GARY McCLELLAN

ONE OF THE HANDIEST PIECES OF ELECtronic equipment you can have is a good signal generator. But one particular area that has been neglected is pulse generators for driving logic circuitry.

The Programma 1 will change that. Now you can build and test digital circuits without expensive clock circuitry, pulse generators, or other sources. The Programma 1 marries the frequency stability of a synthesizer with a logic-level output. And, when you are not using it to run your breadboard logic-circuits, you can use it as a regular signal generator.

This design has many exciting features. The output frequency is programmed via four BCD (*B*inary *C*oded *D*ecimal) front-panel switches. There are a total of 9990 possible frequency combinations available, with each one offering crystal-controlled accuracy. Also included in the Programma 1 is a multi-stage frequency divider that extends the frequency range even farther! In fact, you can readily generate signals from 0.01 Hz to 1.0000 MHz. The accuracy of any of these frequencies is within ± 0.005%, if the generator is accurately calibrated. As far as the output voltages are concerned, you have your choice of standard TTL/CMOS output, or an adjustable 0 to 5-volt output. This is ideal for general purposes like running logic circuits, or for use as an audio signal generator. And, since its frequency range extends into the RF spectrum, the Programma 1 is also useful for AM radio alignment. Still other features include drive capability for one TTL load, and an ERROR lamp that tells you that the frequency selected is correct. This lamp is helpful as a diagnostic device, should troubleshooting become necessary.

There's more

Not to be overlooked is the design of this instrument. Thanks to the latest CMOS circuitry, it uses just ten IC's. Contrast that number with the seventeen IC's that are normally required in a comparable TTL system. Besides a reduced IC count, you get CMOS advantages like low power consumption, absence of drift-causing heat, and a less noisy signal. Also, the construction has been simplified to one small, single-sided PC board, that you can easily make or buy. Not to be neglected, the other parts have been kept to a minimum by careful engineering, to make buying them easier. In fact, great care has been taken to insure that all parts for this project are readily available. You can expect to be able to assemble the Programma 1 in just a few evenings, thanks to its simplified circuitry and good parts-availability.

For the future

With "smart" test equipment on the horizon, or instruments that interface with computers, this project will become more useful. By replacing the programming switches with appropriate IC buffers, the Programma 1 may be controlled by a microprocessor, automatically generating the frequencies required. This technique is being used in industry for testing, and even alignment, of finished equipment. It's a big money saver, and you'll be hearing a lot more about automatic testing. The Programma 1 has this automatic test-capability built in right now, ready for the future—someday you'll appreciate that!

Theory of operation

Figure 1 shows a block diagram of the pulse generator, so refer to it for details as you read the circuit description. Although the diagram has been stripped down to just the basics, the actual circuitry isn't much more complex. In fact, you are going to read about one of the simplest frequency synthesizers ever designed.

Why a synthesizer?

You may be wondering why a synthesizer has been used in this project, and even, for that matter, what it is. Basically, a frequency synthesizer is a circuit that takes a single frequency from a quartz crystal, and uses it to generate many others, each with the accuracy and stability of the crystal. In the Programma 1, a single color-TV crystal is used to generate 9990 different frequencies. In other words, you replace 9990 crystals with *one* single-crystal frequency synthesizer. (Now you know why they are found in CB radios, and

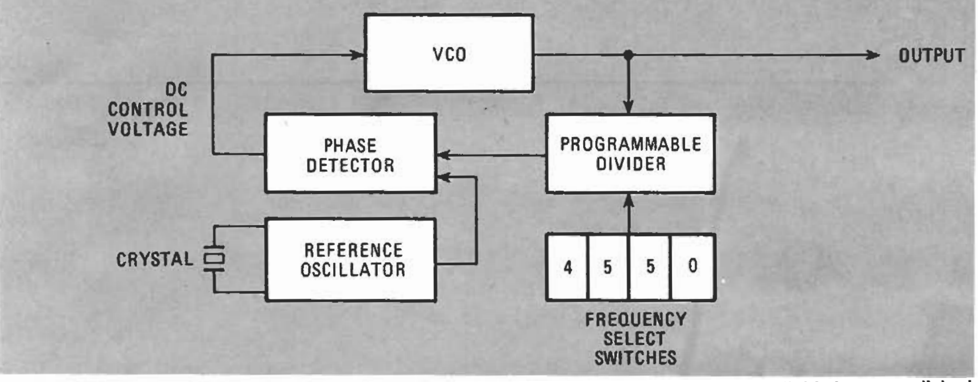


FIG. 1—BASIC FREQUENCY SYNTHESIZER, showing the four major sections. All this is accomplished by only three IC's!

other places where lots of crystals once were used.) Through frequency synthesis you gain accuracy and save money.

As you can see from Fig. 1, the synthesizer consists of four basic parts. The first is the VCO (*V*oltage *C*ontrolled *O*scillator. It simply generates a signal whose frequency can be varied by changing a DC control voltage. In this project, the VCO frequency can be swept from 1 kHz to 1 MHz.

The next section is the *reference oscillator*. It provides a stable, fixed reference-frequency. In the Programma 1, a single IC, combined with a 3.579545-MHz color-TV crystal, does the job. Next, a *programmable divider* takes over, dividing the VCO frequency. The exact divisor is selected by the front-panel switches. In this design, another IC performs the entire task, and can divide the VCO signal by up to 10,000.

The final section is the *phase detector*. It compares the signal from the reference oscillator with the signal from the programmable divider. In operation, the phase detector outputs a DC voltage comparable to the difference of the two signals. The greater the difference, the greater the DC output is. On the other hand, if the two input signals are the same frequency, the DC output doesn't change. Since the DC voltage drives the VCO, it can now adjust the frequency until the signals on the phase detector input are the same. The result is a VCO output-frequency equal to the product of the *divisor of the programmable divider* and the *reference oscillator* frequency. In this project, the VCO and phase detector sections are all included inside one easy-to-obtain IC. That takes care of the basics.

Refer to the schematic diagram in Fig. 2 for the circuit details. The programmable divider is IC1, whose divisor is selected by the front panel switches. It is a single LSI IC, and it costs less, works better, and is easier to use than any other divider scheme. A unique feature of this circuit is that setting the switches to 0000 results in a divisor of 10,000. That saves the cost of an extra switch. The phase detector and the VCO are in IC2. The divider input of the phase detector is pin 3, and the reference oscillator input is pin 14. The output is pin 13. It drives resistors R19 and R20, and capacitor C6, forming a network known as a *loop filter*. Basically, this filter does nothing more than clean up the VCO control voltage. Other phase-detector circuitry includes transistor Q1, which connects a LED to the error-detecting circuitry in IC2. If something goes wrong with the circuitry, and the frequency is off, the LED will light.

The VCO portion of IC2 is simple and straightforward. The DC control voltage is applied to pin 9. Resistor R17 and capacitor C1 set the maximum operating frequency of the VCO. The squarewave output signal appears on pin 4, ready for use elsewhere. The reference oscillator circuit consists of IC3, and it contains all the devices required to excite TV crystal XTAL1 and to produce a 100-Hz reference signal. The balance of the circuitry on this board consists of five decade-dividers, IC4—IC8, that simply divide down the output signal, giving a symmetrical waveform. Since the outputs of these IC's are all at CMOS levels, with a 10-volt swing, buffer IC9 has been included to convert the voltages to TTL-compatable values.

The power requirements of this circuit are provided by IC10 and Zener diode D1. These components provide a well-regulated 10 volts for the synthesizer, and 5 volts for IC9, which is used to drive 5-volt TTL devices. Power to the PC board is supplied by a 14-volt surplus battery charger. Not much current is required (about 10 mA DC), so the entire unit can be battery-powered if desired.

Construction

Now that you know how the Programma 1 works, let's put one together. One important reminder is in order if you are considering breadboarding the project—the output signal will be noisy unless you are careful. Like most other frequency synthesizers, this one has a high loop-sensitivity, and is suceptible to noise pickup. So if you wish to get a high-quality signal from this project, be sure to use a PC board. If desired, you can buy one, together with assembly instructions and troubleshooting hints, from the supplier indicated in the parts list. Or you can "roll your own" using Fig. 3.

Another important reminder concerns the quality of the parts you use. It shouldn't be necessary to remind you to use top-quality components, but if the urge to use cheap substitutes is overpowering, you may wind up with problems. Generally, the quality of the output signal will suffer, and frequent servicing may be required. Play it safe, and save time and money in the long

PARTS LIST

All resistors ¼ watt, 5% unless otherwise noted.

R1-R16, R19—100,000 ohms
R17, R18—10,000 ohms
R20, R22, R23—2,200 ohms
R21—22 megohms
R24—47 ohms
R25—10,000 ohms linear taper pot (carbon) with SPST switch

Capacitors
C1—47 pF mica
C2, C8—0.1 µF disc
C3, C9—33 pF mica
C4—10 pF mica
C5—6 to 20 pF trimmer (E.F. Johnson 275-0320-005 or equivalent)
C6—4.7 µF, 16 volts, tantalum
C7, C10—10 µF, 16 volts, tantalum
C11—220 µF, 25 volts, electrolytic

Semiconductors
D1—5.1-volt, 1-watt Zener diode (1N4733 or equivalent)
D2, D3—1N4148 or 1N914
Q1—2N3906
IC1—CD4059AE CMOS divider (RCA)
IC2—CD4046 CMOS PLL (RCA)
IC3—MM5369EST CMOS oscillator (National)
IC4-IC8—MM74C90N CMOS counter (National)
IC9—CD4050 CMOS hex buffer (RCA)
IC10—MC78L05 5-volt regulator (Motorola)
LED1—.200-inch discrete LED
S1-S4—BCD thumbwheel or lever-type switches (C&K 332110000, EECO 1800 Series, or equivalent)
S5—6-position, single-pole rotary switch
S6—SPST switch (mounted on R25)
XTAL1—color-TV crystal, 3.579545 MHz, 32 pF parallel-resonant, HC-33 case
J1—jack to match connector from power source used
J2—RCA-type jack
J3—BNC connector

Miscellaneous: PC board, 14-volt DC power supply or battery eliminator, one 8-pin IC socket, five 14-pin IC sockets, two 16-pin IC sockets, one 24-pin IC socket, enclosure, knobs, solder, ribbon cable, etc.

PC boards are available. Order part SCG-1. Price, postpaid in USA, $10.00; California residents add 6% tax. Foreign orders please add $3.00 for shipping and handling. Order from: Technico Services, Box 20HC Orangehurst, Fullerton, CA 92633.

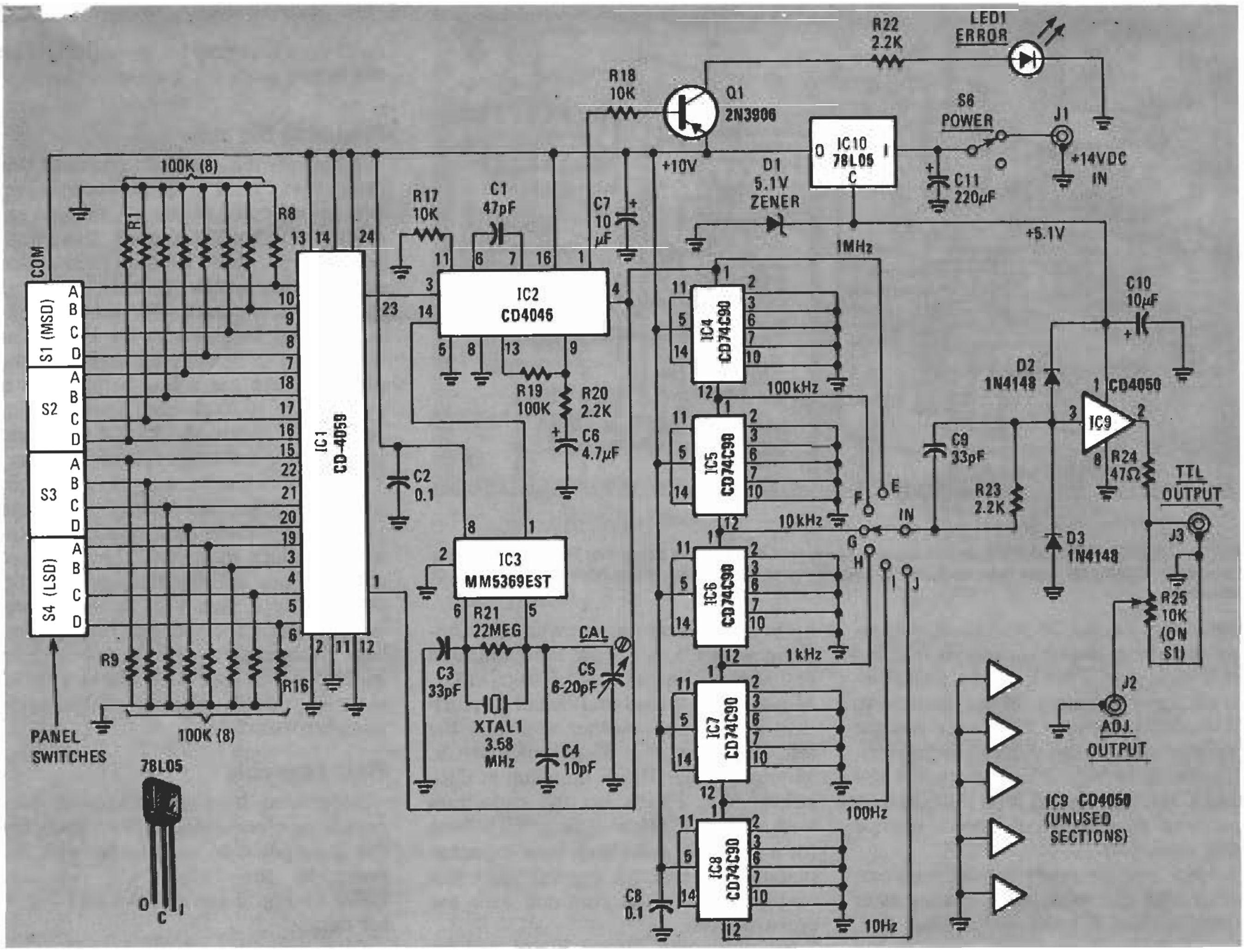


FIG. 2—PROGRAMMA 1 has a frequency range of from 0.01 Hz to 1.000 MHz. BCD panel-mount switches are used for exact selection of pulse frequency.

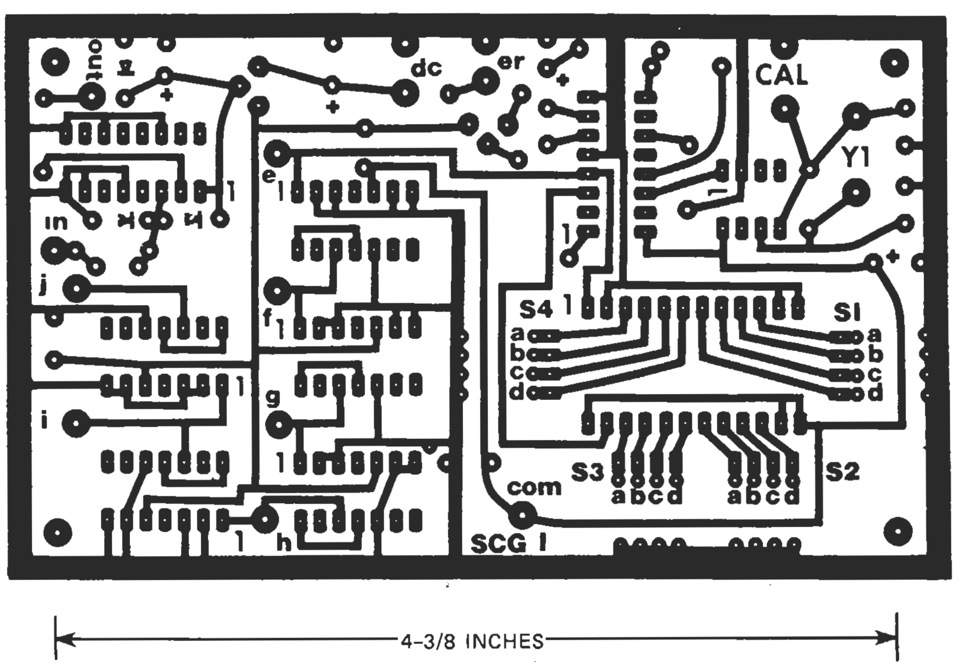


FIG. 3—FOIL PATTERN for the Programma 1. See parts list for supplier if you prefer not to make your own PC board.

run by using top-quality parts. This is especially important with respect to the IC's and the capacitors. Although the need for quality IC's is obvious, the capacitors should be the type (e.g. mica or tantalum) and value specified. This will insure the best possible signal stability and purity at a small additional cost.

Refer to Fig 4 as you install the parts on the PC board. A good place to start is with the IC sockets. Begin by installing a 24-pin socket at IC1, then an 8-pin unit at IC3. Check to be sure all pins are soldered in place on the sockets—

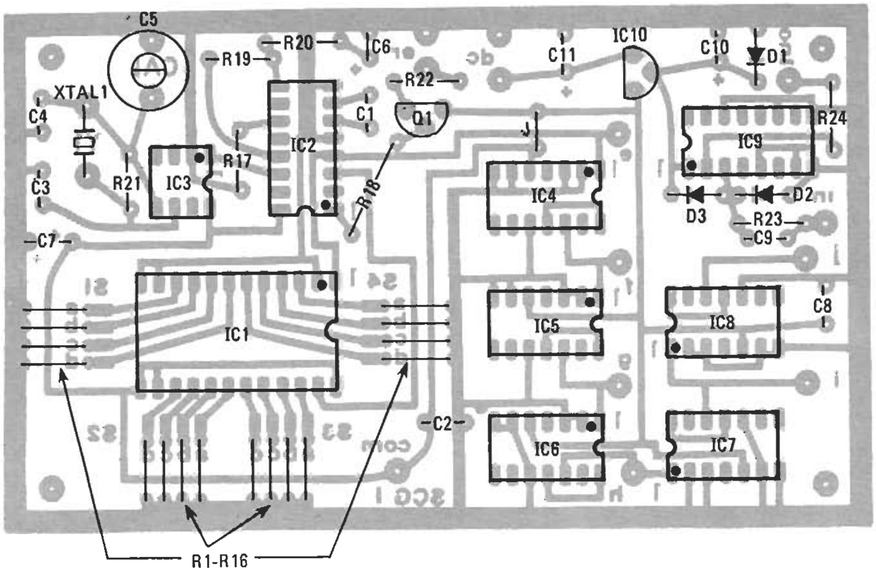


FIG. 4—OBSERVE POLARITIES shown in parts-placement diagram. Be aware that 78L05 pinouts may be shown differently from manufacturer to manufacturer. Orientation given here is correct for all versions.

especially on the 24-pin one. Continue by installing 16-pin sockets at IC2 and IC9 locations. Finish up the socket installation by adding 14-pin sockets to IC4—IC8 locations. This board has one jumper wire, which you can insert next. Locate it in Fig. 3 first (between IC4 and C11), then install it on the board. A piece of bare wire cut from a resistor will work fine.

Now you are ready for the resistors. Start with the 100K units, placing 16 of them around IC1 (R1-R16). After that, install R21, 22 megohms, next to the IC3 socket. Then mount a 10K resistor on either side of IC2. Note that, while the leads of R17 are simply bent and inserted in the board, R18's leads must be left longer (about ¼-inch) to cover the distance between the holes. Next, install 2.2K resistors at R20 and R22, and a 100K resistor at R19. Move over to the other edge of the board and mount a 47-ohm resistor at R24. And finish up with R23, 2.2K. Be careful not to confuse the location with that for D3, just below it!

The diodes are next, and the installation will go quickly. Be careful to install them correctly, and double-check against Fig. 3 afterwards. Start with D1, a 1N4733 5.1-volt Zener diode, and then install 1N4148 diodes at D2 and D3. That's it.

The next step is to install the capacitors. You can start with C7, 10 μF. Orient it as shown in Fig. 3. Then install a 33 pF mica capacitor at C3, and a 10 pF mica capacitor at C4. The trimmer is next, so examine C5 and note that the ground terminal is probably marked in some way. If there's no arrow or paint dot, then trace out the pin that attaches to the adjustment screw. Install it so the ground terminal faces the edge of the board. If the trimmer is reversed, the project will work, but will be tough to calibrate due to capacitance added by your hand on the screwdriver! Continue with C6, a 4.7 μF tantalum, and just above it install a 47 pF mica at C1. Move up the board and install a 0.1 μF disc at C2, and another at C8, at the left. Then install a 33 pF mica at C9. Mount another 10 μF tantalum at C10, below IC9. Finish up the capacitors with a 220 μF electrolytic at C11. Stop for a moment, and check your capacitor installation. Correct any mistakes you may find and then continue with the construction.

By now your circuit board will be nearly complete and will look like the one in Fig. 5. There are just a few parts to go, so let's finish up the board. Mount crystal XTAL1 first, pressing the case down firmly against the board before soldering the leads. Then install IC10, a 78L05 regulator next to C11. *(Note: The 78L05 pinout given by some manufacturers may differ from that shown here. To the best of our knowledge, our pinout holds true for all versions of the 78L05*—Editor).

Finish up with the IC's, starting with IC1. Note that the foil side of the board and Fig. 4 indicate the orientation of each IC. Use them to guide you. After the IC's are installed, check the board

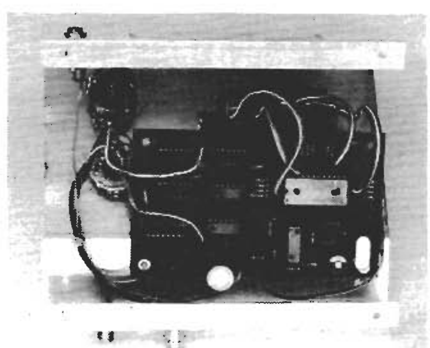


FIG. 5—FRONT-PANEL SWITCHES are connected to PC board by ribbon cable. Note power jack, J1, at back of enclosure (upper left).

over very carefully for errors. Then set the board aside for a while.

Preparing the case

Although the original version of this project was built in an old meter case, you are welcome to use any suitable enclosure. It should be metal, though, to prevent radiation of stray signals that can interfere with your tests. As far as the layout is concerned, you can exercise your judgment in the matter, or duplicate the box layout shown in the photos. Here are a few helpful tips if you decide to "roll your own:" First, be sure to locate the ERROR LED and FREQUENCY switches close together. This is important because they are used together. Also, the output jacks and LEVEL pot should be located close together. In fact, they should be positioned closer to one another than they are on the prototype (see Fig. 7), since long leads degrade the shape of the signal at high frequencies. All signal-carrying leads, for that matter should be kept as short as possible. The rest of this part is straightforward.

Final assembly

After you have the enclosure prepared, you're almost done. Probably the best place to start is to wire the board to the FREQUENCY switches. Refer to Fig. 2 (schematic) and Fig. 6 for details.

Start by wiring all the common pins of the switches together with a piece of bus wire. Then attach a short piece of stranded wire to it. This is the "COM" lead to the circuit board. Next, you can wire the switches themselves, starting with S1. Note that S1 is the MSD (*M*ost *S*ignificant *D*igit), and that it is the switch section on the far left of the panel as you view it from the front Use short pieces of four-conductor ribbon cable for the connections. You can attach the ends of the switches first. In fact, it might be a good idea to solder a length of cable to each switch first, and then to the circuit board later. This is easier if you have mounted the switches in the box already.

After the wires are attached to the switches, connect the cable from S1 to the holes on the board. Note that some BCD switches are coded "1 2 4 8" and that corresponds with the "A B C D" marked on the board. In the same manner, wire the remaining switches. Switch S4 will be the section on the right when viewed from the front. Finally, connect the "COM" wire, and you are through with S1—S4.

Now for switch S5. Prepare a short length of six-conductor ribbon cable and connect one end to the fixed contacts of S5. Then attach a single piece of wire to the wiper terminal. Connect the other ends of the ribbon-cable wires

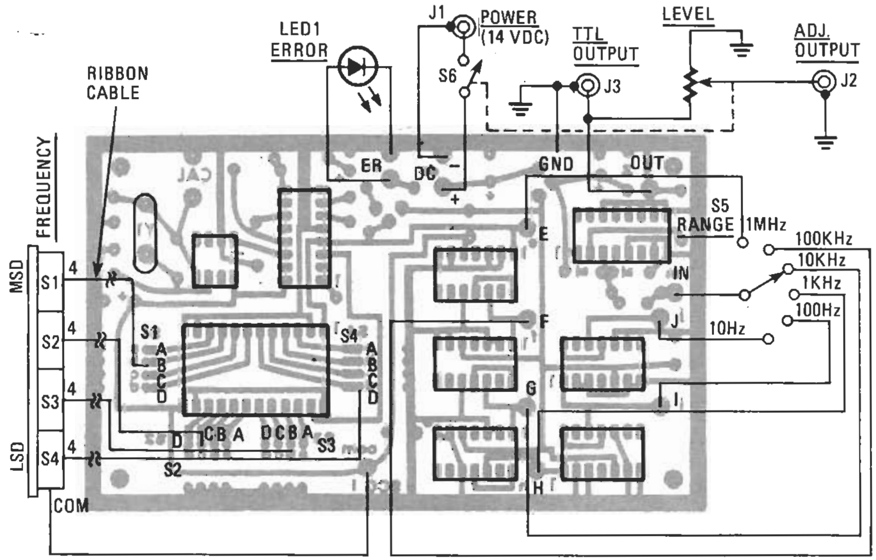


FIG. 6—CONNECTION OF OFF-THE-BOARD components. Resistor R25 is a part of the on/off switch, S6. All leads should be kept as short as possible to avoid difficulties at high frequencies.

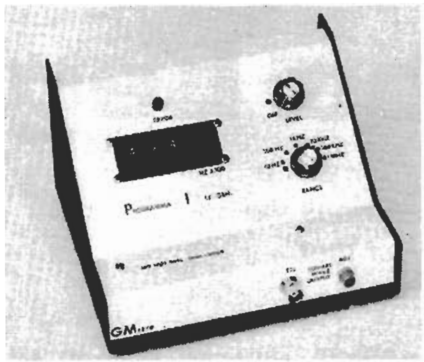


FIG. 7—THIS LAYOUT works well, but is not ideal. Output jacks and "level" pot should be located closer to one another to keep leads short.

to the "E" through "J" outputs, and the single wire from the wiper to "IN," This wiring is shown in more detail in Fig. 6. Next, the LED may be installed. Finally, wire up pot R25, the output connectors, and the power leads. Don't forget to run a short wire from the circuit-board ground foil to the box. A good place for this is at the "minus" terminal of C11 (220 μF). Wire up the POWER jack, J1 (on the back of the box) and you are finished.

Calibration

Although this project should work reasonably well without any calibration, you might want to make a simple adjustment for the best frequency accuracy. To do this you'll need an accurate frequency counter and an ×10 oscilloscope probe. Supply 14 volts DC to J1, then rotate the LEVEL pot to turn on the power. At this point there's no need to set any of the switches on the project. Connect the probe to the counter, and clip its ground lead to the pulse generator. Then, carefully touch the probe to pin 7 of the MM5369EST (IC3). You should get a reading of 3,579,5×× (-=variable) Hz. Adjust the trimmer so that you get exactly 3,579,545 Hz and you are all set. Disconnect the counter and you can close up the box.

Operation

Operating the Programma 1 is a snap! Simply set the frequency you want on the thumbwheel switches, and watch the ERROR LED. It will blink about four or five times, then go out. When it does, you are locked on frequency. Switch S5 selects the frequency you get out. For example, on the 1 MHz range, you'll get an output from about 900 Hz to exactly 1.000 MHz. Switch to the 100-kHz range and you'll get a tenth of that or 90 Hz to 100 kHz. The rest of the ranges work in the same manner. If you would like an adjustable output instead of the TTL-level signal from J3, simply use J2, and adjust the LEVEL control for the voltage you want. There's nothing to using this project!

Here are a few tips to help you get the most out of your project. First, due to the design of VCO and divider circuits, switch positions from 0001 through 0009 will be inoperative. The ERROR light will come on as a reminder that these numbers are invalid. Note that the setting of 0000 is OK; in fact it will give you 1.000 MHz, but watch those other settings. As far as the output signal is concerned, it is a constant-amplitude squarewave with a 50% duty cycle. However, if you start to load it down, the amplitude will change. Also, the waveform quality will tend to deteriorate as the frequency goes up. So, for best results when you are interested in waveform quality, use a very light load, and watch out for the effects of coaxial cables at the higher frequencies. Finally, some degradation of the squarewave will be noted at the adjustable output (J1) at high frequencies. This is normal where a simple pot-attenuator is used.

Some uses for the Programma 1

There are a great many uses for this pulse generator. Although it was designed for operating digital circuits, it does well in other areas, too. Here are a few things that can be done with it: checking TTL divider circuits, decimal-counting uses (why not make a timer?), general logic-troubleshooting, and much more.

In the analog area, it can be used for amplifier squarewave-testing, electronic music (it generates a wild glide tone!), AM radio alignment, and more. How about using it as a short-wave radio marker-generator? (The harmonics go well into the HF spectrum.) Or as a programmable sinewave generator? (Active filtering can change the squarewave to a sinewave.) There are numerous uses for the Programma 1. How many can you think up? **R-E**

SYNTHESIZED PULSE GENERATOR

Here's a tip for readers who built the Synthesized Pulse Generator described in the October, 1980 issue of *Radio-Electronics*. Changing capacitor C6 from 4.7 μF to 1.0 μF may result in better performance, as some CD4046 IC's produce slight jitter using the old value. That will allow the project to give the premium performance that it was designed for, regardless of IC manufacturer.
GARY McCLELLAN

3.5
4
4.5
5
6
7
8
9
10