BY FRANKLIN J. MILLER

Building a Capacitance-Substitution Box

IF YOU WERE INTERESTED IN THE RESISTANCE SUBSTITUTION BOX WE DESCRIBED IN THE DECEMBER 1997 ISSUE, IT IS LIKELY THAT YOU HAVE BY NOW BUILT IT AND PUT IT TO WORK. THIS MONTH, WE WILL SHOW YOU ANOTHER USEFUL ACCESSORY for audio testing. It is a capacitance-substitution box, or C box; it is very similar to the R-box, and it too will help make your audio-testing chores easier.

A Capacitor-Substitution Box

Our C Box provides capacitance outputs from 10 pF to 11.1110 µF just by pushing the appropriate combination of buttons on the front panel. If you decide to build the box, be sure to use only precision components. Particularly, close capacitor tolerances are a must. Ideally, you need 1% components to make a very accurate box. Unfortunately, such tolerances are nearly impossible to find, and what is available is very expensive. To get around this problem, I purchased a large number of readily available 20% tolerance ceramic-disc capacitors. Then I measured them carefully with a capacitance bridge, and I selected sets of capacitors that came closest to the needed values. I also made sure that they all fell to the same side of the optimum value. I know that this is a time-consuming process, but it is the only practical way to get the precise values of capacitance you need if you decide to build the box without the benefit of the available kit (see the Parts List). The parts in my kit are selected in the fashion described, and all of the capacitors swing in the same direction so their actual values track.

A photograph of the finished unit is shown in Fig. 1. Just like the R-box, you select the value you want to use by simply punching in the capacitance value you need using the pushbutton pad. The selected value then appears across the terminals labeled CX at the top of the unit.

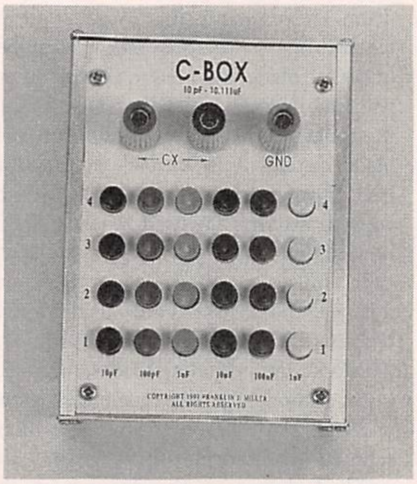


FIG. 1—HERE'S HOW THE C-BOX will look when finished. As you can see, the look is very similar to December's R-Box.

Note that the unit is labeled in nanofarads (nF) rather than the more familiar microfarads (µF). (Actually, outside of this country, capacitors are often marked in nanofarads rather than microfarads). To make the conversion, just move the decimal point three places to the left. For example, 562 nF is 0.562 µF.

Now, let's see how we would get the C Box to output that 562 nF. If you built or remember our R Box you have a head start, as the process is pretty much identical. First, you would push the 4 key and the 1 key in the row above 100 nF—that gives you 500 nF at the terminals. Then you would depress the 4 key in the 10-nF row and the 2 key in the same row. That adds 60 nF to the 500 nF. The switches stay down, and the selected value is available across the CX terminals. For the final 2 nF, push the 2 button in the 1-nF row. It is just that easy.

Putting It Together

The complete schematic for the substitution box is shown in Fig. 2. For easiest construction, a PC board is recommended and is provided elsewhere in this column. The parts-placement diagram for that board is shown in Fig. 3. As indicated there by the dotted lines, the capacitors are all mounted on the foil side of the board; that's done to make the entire assembly as compact as possible. The switches mount on the component side of the board in the usual manner.

Note that both the PC pattern and the schematic show DPDT switches, although only one section of each is used. Those switches are used because they are easier to find than latching SPDT pushbuttons; they are probably less expensive, too.

Construction is straightforward. All 24 switches mount right on the PC board. Make sure that you insert them so that they fit flat and tight against the board. This is important! If you do not get it right, the knobs will not fit properly through the top plate. Note: If you elect not to use the available kit, make sure you select an enclosure that is deep enough to accommodate the switches that you do use. The critical dimension here is the depth of the box; it should be deep enough so that when you mount the PC board inside, the switch buttons pro-

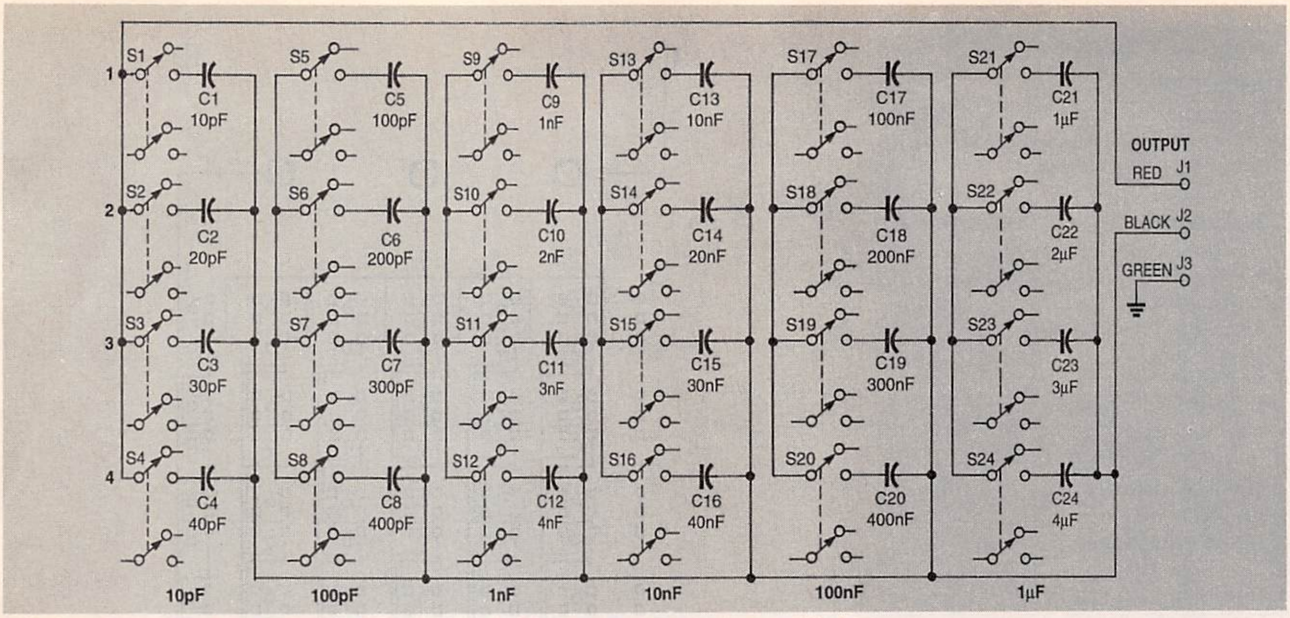


FIG. 2—AS YOU CAN SEE IN THIS SCHEMATIC, the C-Box circuit is simply a combination of capacitors and switches.

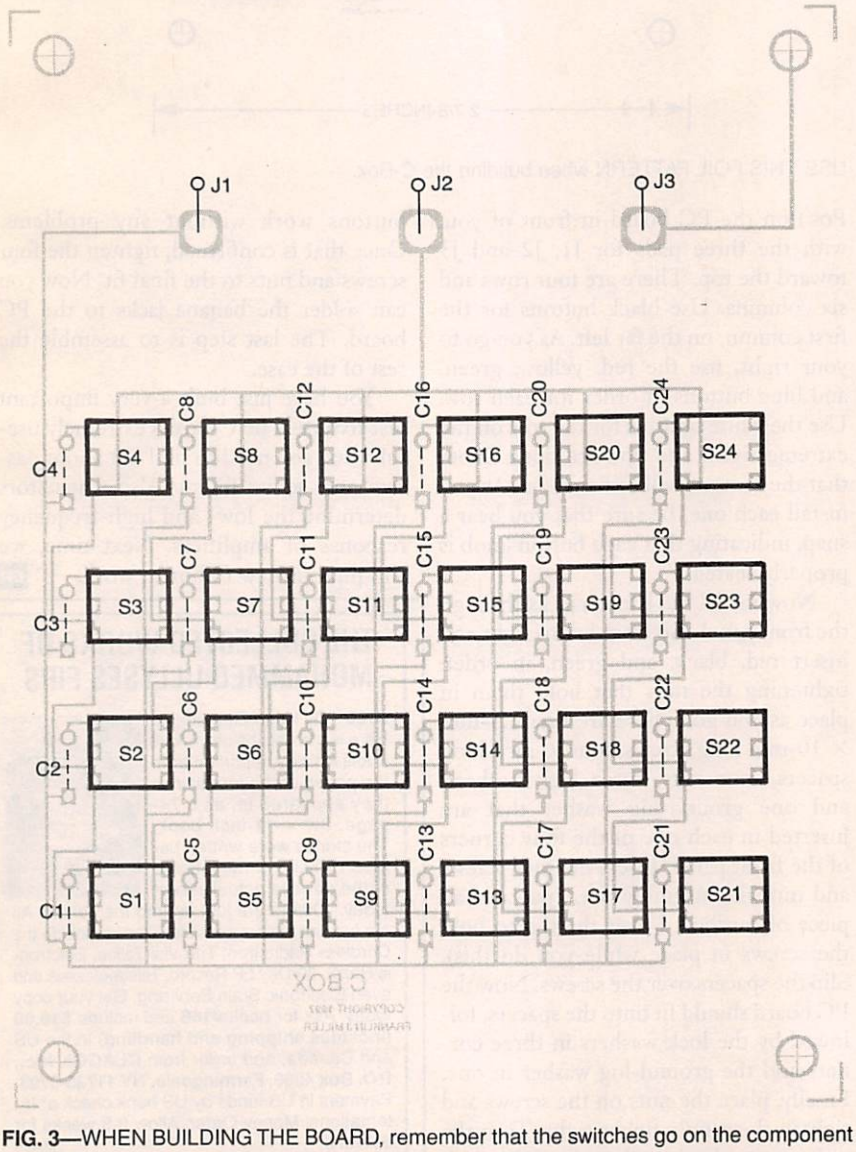


FIG. 3—WHEN BUILDING THE BOARD, remember that the switches go on the component side of the board, and the capacitors go on the foil side.

trude far enough through the top plate for you to attach the switch knobs. Once the switches are in place, mount the capacitors on the foil side of the board. Do not install J1–J3 at this time.

Once you have mounted all of the components (except J1–J3), carefully inspect the PC-board assembly for the usual construction errors. When you are satisfied all is well, put it aside for the time being.

The next step is to apply the front-panel overlay. If you choose to buy the kit, an overlay and pre-punched enclosure are provided. If you elect not to use the kit, you should create your own overlay. The appropriate markings can be seen in the photograph back in Fig. 1. If you want a drilling guide for the front panel, use the one for the R-Box, which was shown in Fig. 4 in the December 1997 issue. It is identical to the one for this unit. In fact, when we get around to building an inductance box (L Box) in a future issue, it too uses the same drilling pattern.

The overlay supplied with the kit has an adhesive backing. To ensure that it will adhere properly, you must make sure that the front panel is very clean. A small amount of acetone, which can be purchased at any paint store, will do the job nicely. It will remove any grease or dirt that might interfere with attaching the overlay. Since its vapors can be hazardous, make sure you are in a well-ventilated area when you work with acetone.

Now you need a small bottle of water with a spray attachment. It will allow you to move the overlay around for precise

PARTS LIST

CAPACITORS

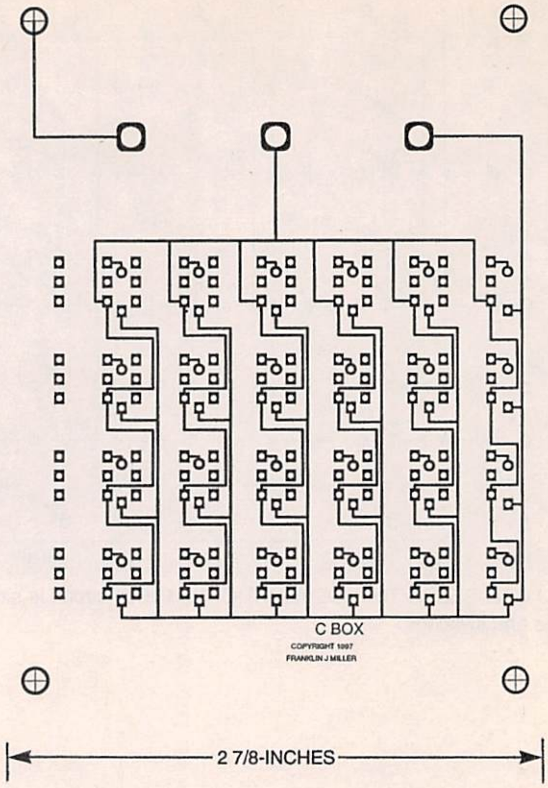
(All capacitors are 20%, 50-volt, ceramic disc, selected as described in the text to get the 1% values needed.)

C1—10-pF
C2—20-pF
C3—30-pF
C4—40-pF
C5—100-pF
C6—200-pF
C7—300-pF
C8—400-pF
C9—1-nF (0.001-µF)
C10—2-nF (0.002-µF)
C11—3-nF (0.003-µF)
C12—4-nF (0.004-µF)
C13—10-nF (0.01-µF)
C14—20-nF (0.02-µF)
C15—30-nF (0.03-µF)
C16—40-nF (0.04-µF)
C17—100-nF (0.1-µF)
C18—200-nF (0.2-µF)
C19—300-nF (0.3-µF)
C20—400-nF (0.4-µF)
C21—1-µF
C22—2-µF
C23—3-µF
C24—4-µF

ADDITIONAL PARTS AND MATERIALS

S1–S24—Pushbutton switch, DPDT, see text
J1—Banana jack, red
J2—Banana jack, black
J3—Banana jack, green
Switch knobs (four each black, red, yellow, green, blue, and white), enclosure (see text); PC board, top-panel overlay, hardware, wire, solder, etc.

Note: The following items are available from Franklin J. Miller, 2100 Ward Drive, Henderson, NV 89015. A complete kit, including pre-drilled aluminum case, front-panel label, pushbutton knobs, PC board and all other components, for $95.00 postpaid.



USE THIS FOIL PATTERN when building the C-Box.

placement. Place both the front panel and the overlay in front of you, with the three holes at the top. Remove the overlay backing and align the upper-left corner of both pieces. Once the label is aligned, gradually smooth the balance of the overlay down using the side of your hand. After this is done, use an orange stick (available in the beauty section of any supermarket) as a rolling device to get out all the bubbles. Let the front panel dry overnight to be sure all of the water has evaporated. Do not use heat! It will ruin the overlay material.

The next step is to put the knobs (supplied with the kit) on the switches. Position the PC board in front of you, with the three pads for J1, J2 and J3 toward the top. There are four rows and six columns. Use black buttons for the first column, on the far left. As you go to your right, use the red, yellow, green, and blue buttons in order for each row. Use the white buttons for the row on the extreme right, and you are done. Note that the buttons will just snap on. As you install each one, be sure that you hear a snap, indicating that each button knob is properly seated.

Now install the banana jacks through the front panel. Go from left to right and insert red, black, and green, in order, tightening the nuts that hold them in place as you go. There are four 2.5-mm × 10-mm long screws, four ⅛-inch long spacers, four nuts, three lock washers, and one ground-lug washer that are inserted in each one of the four corners of the front panel. Insert the four screws and turn the assembly over (put a small piece of cardboard over the top to hold the screws in place while you do this). Slip the spacers over the screws. Now the PC board should fit onto the spacers, followed by the lock washers in three corners and the ground-lug washer in one. Finally, place the nuts on the screws and tighten them only finger tight. Turn the unit over to be sure that all of the push buttons work without any problems. Once that is confirmed, tighten the four screws and nuts to the final fit. Now you can solder the banana jacks to the PC board. The last step is to assemble the rest of the case.

You have just built a very important test fixture. The C-box is extremely useful when you need to find out about passive and active filters. Also, capacitors determine the low- and high-frequency response of amplifiers. Next time, we will put our new C-box to work. EN

Capacitance-Substitution Box Error

There is an error in the "Audio Update" column in the February 1998 issue of **Electronics Now**. In the schematic for the capacitance-substitution box, only the first row of capacitors connects to one of the binding posts. The PCB layout is correct, and so is the parts-placement diagram. But if you trace through the schematic, you'll see that from the second row on, the capacitors do not connect to both binding posts when switched.

REN TESCHER
via e-mail

BY FRANKLIN J. MILLER
AUDIO EDITOR

Capacitance-Box Applications

NOW THAT YOU HAVE BUILT THE CAPACITANCE SUBSTITUTION BOX (C-BOX), YOU ARE READY TO START USING IT TO TEST ACTIVE AND PASSIVE CIRCUITS. TO GET YOU GOING, THIS MONTH I AM GOING TO PRESENT SOME EXAMPLES OF HOW you can put the box to work.

If you do any amount of circuit designing, you will find surely find the C-Box to be a handy test-bench accessory. That's because while any designer who knows what he is doing can use standard formulas to calculate any needed values, there is nothing like a real in-circuit trial to prove the theory.

Of course, using mathematics is certainly the right way to start the design process. But once the values have been calculated, it is important to build a working prototype of the new circuit. I have been fooled in the past, when something that I calculated did not work as planned. Test and measure is always a very good idea and good advice.

To illustrate what I consider to be the proper design procedure, let's consider the circuit shown in Fig. 1. The design equations we will be using are also shown in that figure.

The first thing we will be looking at is the effect changing a capacitor will have on the audio signal. Capacitor C1 is used to set the low-frequency point in the circuit. Take a look at Equation 1. It is the design formula used to determine frequency when the resistance and capacitance are known, and it is no doubt familiar to almost anyone who has studied even a little electronics math. The problem is that the equation is not in the most convenient form for our exercise as the unknown we are looking for is the capacitance. Fortunately, that is easy enough to fix; a little algebra allows us to rearrange the terms and gives us the formula shown in Equation 2. Since the lowest frequency of interest is 20 Hz and the impedance (resistance) is 100k, we can plug in those values to find that the capacitance needed to establish our -3-dB point is 79.57 nF.

Now let's see how this calculation works in the real world. Insert the C-Box in place of C1 and wire the rest of the circuit in the usual way. Set the C-Box to 79.57 nF. To do that, start with all of the buttons in the up position. Then depress the 4 button in the 10-nF column and then the 3 button in the same column. The next step would be to depress the 4, 3, and 2 buttons in the 1-nF column. Now push in the 4 and 1 buttons in the 100-pF column. For the final digit depress the 4 and 3 buttons in the 10-pF column. That should set the capacitance to 79.57 nF ± 1%.

Now, place a 20-Hz tone between C1 (the C-Box) and ground and measure the signal at the output of the first op-amp. If all is well, the output will be down 3 dB (the signal voltage will be reduced in half).

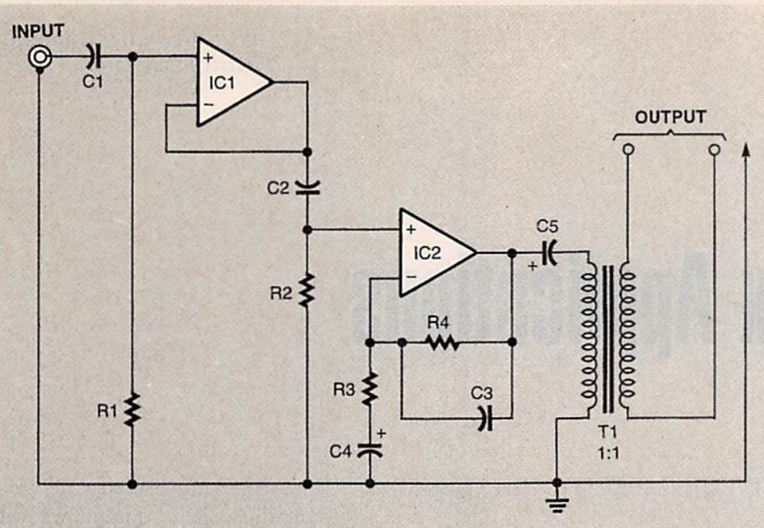
Now that we have confirmed that the real result matches the calculated one, let's try something different. Let's assume that we decide that the output should be flat at 20 Hz. That means that the -3-dB point must be moved to a lower frequency. The problem here is that we do not know what that frequency should be. But we can use the C-Box to easily solve this problem.

The same setup is used as above. If we look at the voltage output, we will see that it decreases as the value of capacitance increases. You can push the switches on the C-Box in and out and watch what happens at the meter. How close you get to a 0-dB loss is entirely up to you, the designer. I have found that replacing the 2 in the formula with a ¼ is a good way to start, though that is just my rule of thumb. If you do the calculation, to get a 0-dB loss you will come up with a value of 636.61 nF for C1. Of course, we cannot replace the C-Box with a capacitor of that exact value at a reasonable cost. The tolerance of the capacitor we do use will determine the exact value. For example, a 1-mF-electrolytic capacitor with a 20% tolerance will work well. Be sure to observe the proper polarity when installing the capacitor.

The High-Frequency End

The next capacitor to look at would be C3. It limits the high frequency of the op-amp system. The op-amp may be able to pass frequencies above 20 kHz, but there is little practical need for information above that frequency. As such, a good -3-dB point could be 30 kHz. Again use Equation 2 to solve for the needed value. Assuming a frequency of 30 kHz and a resistance for R4 of 100k, the answer is 53.05×10^{12}, or 53.05 pF. You cannot get that exact value with the C-Box. The closest value that you can get is 50 pF. Set up the C-Box for that value and test the circuit at the point where C5 connects to output of the IC2.

Next, set the audio oscillator to 30 kHz and put the level at +4 dBm. You should read a voltage of 1 dBm. Now look at the output when the frequency is set at 20 kHz. The voltage should be +4 dBm. If this is satisfactory, then you have



EQUATION 1: $$f = \frac{1}{2\pi RC}$$

EQUATION 2: $$C = \frac{1}{2\pi f R}$$

EQUATION 3: $$g = 1 + \frac{R3}{R4}$$

EQUATION 4: $$20\log(dB) = 1 + \frac{R3}{R4}$$

FIG. 1—HERE'S THE CIRCUIT WE'LL BE USING to demonstrate one of the best uses of the C-Box, which is to verify the capacitor values that are obtained using the standard design equations.

made a good choice. If not, you must use a lower value of capacitance. You might try designing for 40 kHz. Then the capacitance value will be 39.78 pF (use 40 pF). Continue to take readings and experiment with values until you are satisfied.

Setting The Low Frequency

The next capacitor in Fig. 1 that we need to look at is C4. It sets the low frequency of IC2. We will use Equation 2 again to calculate the value of the capacitor. But first we must calculate the value for resistor R3, which sets the gain of that op-amp. To do this we need to use Equation 3, or, if we already know the gain (specified in dBs), Equation 4. For this example, I selected a gain of 14 dB, and once again assumed a value of 100k for R4. That yields a resistance of 24,937 ohms for R3. For the sake of reality, use 24k. Plug that value into Equation 2, along with the frequency of 20 Hz, and your solution should be 331.5 nF.

Try that value in a real circuit and see how it works. Again, that is the -3-dB point. As resistance increases, the -3-dB point moves to a lower frequency. The exact value that you chose will depend on the use of the circuit. Use the C-Box to try different values and see what happens.

The final component that we will be dealing with in this circuit is C5, the output capacitor. That capacitor limits the low-frequency value. The only other factor that you do not know from Fig. 1 is the load impedance into which this circuit will work. Let us make two assumptions. First let's assume that the load impedance will be 600 ohms. Then let's look at a second load impedance at 10k. Again assuming a -3-dB point of 20 Hz, for the 600-ohm impedance the answer is 13.26 mF. As that value is out of the range of the C-Box, let's try 40 Hz instead of 20 Hz. That yields 6.63 mF, which can be set in the C-Box without any problems.

Now let's investigate an output impedance of 10k. Again use Equation 2 to solve for C. The answer is 795.7 nF. That value is easy for the C-Box. You might have noticed that the higher the impedance the lower the capacitor value. Knowing the load impedance with this capacitor is quite important. With this circuit you can investigate the effects of the capacitor on the frequency response. It will be a great learning experience for those of you that have not done this kind of work before. Practice makes perfect; experiment often and you will eventually be able to do this by instinct. EN

NEW PRODUCTS

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Computer & Monitor Maintenance, Inc.
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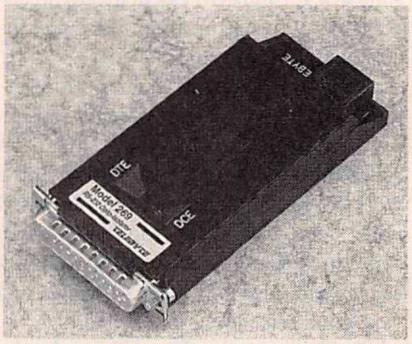
Norcross, GA 30092
Tel: 800-466-4411 or 770-662-5633
Fax: 770-840-8814
E-mail: cmm@america.net
Web: www.computermonitor.com/tv

Optoisolation Unit

The continual appearance of new government regulations worldwide causes havoc with equipment suppliers. IEC 601-1 invokes higher limits of isolation for electronic equipment used in medical environments. That requirement led to Telebyte's development of the Model 269, IEC-compliant, Optoisolator.

Designed for medical electrical equipment, the Model 269 is a compact RS-232 to RS-232 optoisolation module that withstands 4000 volts AC for one minute and provides that level of isolation for the TD (Transmit Data), RD (Receive Data), and ground RS-232 signals.



CIRCLE 23 ON FREE INFORMATION CARD

The primary RS-232 port is a DB-25 male connector, which may be configured via switch selection as a DTE or DCE device. The secondary port is configured in an RJ-12 six-position modular jack with pins 3, 4, and 5 being Transmit Data, Receive Data, and Isolated Ground, respectively.

Packaged in a plastic case that measures 2 by 4.1 by 0.75 inches, the Model 269 retails for $120.

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