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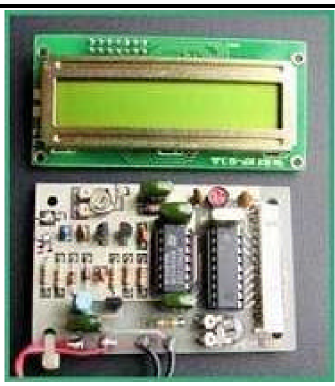
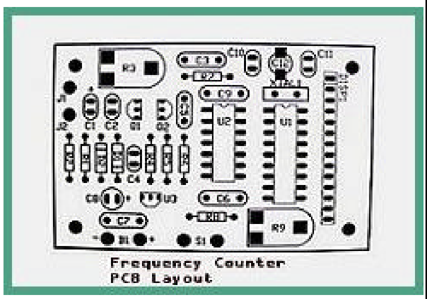
Pro-Kit

50MHZ Auto-Range Frequency Counter





Actual Size of PC Board is: 1-7/8" X 2-7/8"

Test equipment can really take a huge bite out of the experimenter's budget, and the more the current recession hits home, the more that craved collection of test gear seems to drift into dreamland of future days to come. A typical simple frequency counter can run anywhere between a hundred to several hundred dollars. Well, unplug your dream machine and plug in your soldering iron because the following article will show you a very inexpensive approach to a 7-digit 50MHz frequency counter using the new PIC16C5X series of microcontrollers, manufactured by Microchip. In addition to simplicity and low cost, this microcontroller makes possible an auto range, direct display feature that is not even available on some of the most expensive store bought models. That is, the frequency is displayed with the actual suitable suffix (Hz, KHz or MHz) with floating decimal point, instead of the old "number as an exponent" method. This makes for a substantial improvement in the readability of the frequency displayed. Also, the gate time automatically changes from 0.1 sec to 1 sec at the low end of the frequency range to allow measurements with a resolution down to 1 Hz. All this, using just a couple ICs and a couple transistors, linked to a display module.

About The Circuit

A schematic diagram is shown in figure 2. The signal being tested is coupled through C1 to the resistor network comprised of R1 and R2 which set the input impedance to greater than 1 megohms. C2 improves the signal gain at the higher frequencies, D1 and D2 clip those signals greater than 1Vp-p. The signal is applied to Q1 - an N-channel JFET configured as a common-source amplifier which is self-biased by source resistor R4. The output taken at Q1's drain is direct-coupled to the PNP transistor Q2, which is configured as a common-emitter amplifier and whose output is negatively fed back to the source of Q1 through collector resistor R5. This negative feedback helps to flatten the frequency response throughout the 50MHz bandwidth. The 500-ohm trimmer potentiometer (R3) sets the bias of both Q1 and Q2, decoupling capacitor (C4) further improves the gain at the higher frequencies. Note, that this input amplifying stage (Q1, Q2) is powered by 9 volts as apposed to 5 volts which powers the remaining part of the circuit. This allows for greater overall gain of the frequency counter's front-end. The sensitivity is about 100mVRMS from 100Hz to 2MHz, increasing to about 800mVRMS at 50MHz. Although this is slightly high at the upper range, it is sufficient to capture and read the frequency of most transmitters and/or digital oscillators, and allows for a simple and low cost circuit. The output of the Q1-Q2 amplifying stage is coupled through C5 to the schmitt trigger NAND gate (U2) which in turn converts the signal to a 5-volt square wave which can then be processed by the microcontroller. The voltage divider network consisting of R6 and R7 holds the input level of U2's pin 1 to the midway point between its high and low triggering thresholds. The function of the four NAND gates in U2 will be explained in a moment.

Microcontroller

The heart of the circuit is the microcontroller U1 (part no. PIC16C54) - an EPROM-based 8-bit CMOS microcontroller manufactured by Microchip. A pre-programmed chip can be obtained from the source mentioned in the parts list. This microcontroller has one 8-bit I/O port and one 4-bit I/O port whose pins are configured individually as either an input or output at different times during the execution of its program which is stored in 512 x 12 bits of internal EPROM. The chip also contains 32 x 8 bits of RAM used as general purpose registers in the execution of its program. An RTCC (Real Time Clock/Counter) input pin is available on the chip together with its own asynchronous ripple counter prescaler. The prescaler is completely independent of the microcontroller's operating speed and is what makes it possible to count the pulses of a signal being tested even though it may be at a much higher frequency then that of the microcontroller's clock. The clock is set by a 4MHz crystal (XTAL1), and trimmer capacitor (C12) is used for final calibration adjustments. The PIC16C5X series of microcontrollers' instruction time is equal to four clock pulses, so with a 4MHz clock, one instruction is executed every 1uS. This makes for ease in getting the exact gate times of 0.1 sec and 1 sec. The microcontroller starts the count of the test signal by driving bit-3 of port-A high which enables U2-a. Also this logic level is inverted by U2-d which is then applied to and disables U2-c (explained later). The output of U2-a passes through U2-b and is placed on the RTCC pin of the microcontroller. The internal prescaler assigned to the RTCC pin counts the pulses and automatically increments the RTCC's main register every time the prescaler reaches a full count of 256. The microcontroller's program is designed to watch the RTCC register and increment an additional register every time the RTCC register rolls over. So in effect you have three 8-bit registers to store the count, a maximum count being 16,777,215 or over 167 MHz when using a 0.1 sec gate. This is more then adequate for our 50 MHz counter. The programming loop that the microcontroller is in when performing this count function terminates after an exact predetermined time which is equal to the gate time (0.1 sec or 1 sec), then bit-3 of port-A is driven low preventing any additional input signal pulses from being applied to the RTCC pin. After accumulating the count for the duration of the gate time, the RTCC's prescaler holds the least significant 8 bits of that number. In order to retrieve this number the microcontroller has to toggle the RTCC pin externally while keeping a running count of the cycles required to force a rollover of the prescaler, which is detected by an increment of the main RTCC register. The actual number is then derived by using the two's compliment. As mentioned earlier, U2-c was disabled by the low from U2-d while the microcontroller was in the count mode. At the end of the gate time however, bit-3 of port-A was driven low. This low causes a high at the output of U2-d enabling U2-c. The microcontroller can then toggle bit-2 of port-A and that pulse will pass through U2-c and U2-b to the RTCC pin. The three 8-bit registers that hold the count - which represents the frequency of the signal in test (hint: with a 0.1 sec gate time, the frequency is found simply by moving the decimal point one place to the right) - must now be converted to a binary coded decimal in order to be displayed. This is done in a complex subroutine which stores the results in seven different 8-bit registers, one for each digit in decimal notation. The most significant four bits of each register is set to "0011", creating the actual ASCII equivalent of each decimal number, which can then be sent to the display module.

LCD Display Module

DISP1 is a 1-line, 16-character LCD display module which has its own built in controller designed to display both numbers and letters by receiving the standard ASCII code equivalent on its 8-bit port. Data, including the ASCII codes, are sent to the display via port-B of the microcontroller (U1). The first three bits of U1's port-A are used as control lines for the display (Data/Instruction, Read/Write and Enable). Writing a character to the display consists of first placing the 8-bit address (location for the character on the display) on port-B, setting the correct status on the control lines while strobing the enable line, then the actual ASCII character code is placed on port-B, while again strobing the enable line with the correct status on the control lines. U1 then changes port-B to an input, the status lines are set to read the busy flag from DISP1 and U1 strobes the enable line until the busy flag indicates DISP1's internal operation has finished writing the character to the screen. This all takes less than 100uS. Depending on the range of the count that was stored in U1's seven ASCII registers earlier, the count together with its appropriate suffix (Hz, KHz or MHz), with correct position of decimal point, are sent to the display module. U1 then jumps back to the beginning of the program and captures another frequency count.

Construction

Because of the high frequencies that may be subject for test by this project, it is recommended that you follow close layout procedures - especially concerning the input stage (Q1 and Q2). A pre-fabricated PC board is available from the source mentioned in the parts list, and is recommended. After obtaining all the necessary parts for construction, follow the parts placement diagram shown in figure 3, and start by mounting the IC sockets for U1 and U2. Be sure that you first determine the component side of the PC board which is labeled so. Next, mount the resistors and the two diodes, paying attention to the orientation of the diodes which is depicted in figure 3. The trimmer potentiometers (R3 and R9) can be soldered in next along with the trimmer capacitor (C12). Avoid excess heat being applied to the trim cap. Install the rest of the capacitors making note of the orientation of the polarized capacitors (C1 and C8). Mount the regulator (U3) and the transistors (Q1 and Q2) while also paying particular attention to their orientation as shown in the parts placement diagram. The crystal (XTAL1) should be mounted with a small gap between the bottom of its case and the PC board. There is a chance that the crystal's metal case could short the PC board's pads together if it were pushed all the way down onto the board when soldering. After soldering all components to the board, carefully check for cold solder joints (indicated by a dull blob of solder) and solder bridges between pads and/or traces. Re-solder any areas which appear suspect. Cut two pieces of 22-gauge, stranded, hookup wire about 6" long and twist together. Strip about 1/4" of the insulation from both ends, tin, and solder one end to the terminals labeled "S1" on the board. Solder the red lead from a battery clip to the "+" side of the terminal labeled "B1" and the black lead to the "-" side. For a test lead, use a piece of shielded cable such as Radio Shack's cat. no. 278-512. Strip about 1" of the outer insulation from the cable then separate the inner conductor from the braid. This can be easily done by sliding the braid down so that it forms a bulge at its base, then use a toothpick to separate the braid at the bulge wide enough to reach in (with the toothpick) and pull the center conductor out of the hole. The braid can then be twisted together and tinned. Strip 1/4" of the insulation from the center conductor, tin it, then solder it to the terminal labeled "J1". Solder the shield to the terminal labeled "J2". Tie a knot in the test lead about 4" from the board to be used as a strain relief. Strip 3-4" of the outer insulation from the opposite end of the shielded cable and use the same method as above to separate the center conductor from the braid. There are a number of different clips which can be soldered to the end of your test lead available at Radio Shack. The author used an alligator clip on the shield, and a micro-hook clip on the center conductor. Use a piece of 14-conductor ribbon cable to connect the display module (DISP1) to the PC board. A 25-conductor ribbon cable which is available from Radio Shack (cat. no. 278-772) or a 36-conductor (cat. no. 278-774) will work fine, simply peel off enough of the wires to make the cable 14 conductors. Use a razor blade to separate the conductors at each end of the cable by a length of about one inch. Strip about 1/4" of insulation from each conductor, tin, and begin soldering to the PC board and to display module. Pin 1 on the PC board is indicated by a rectangular pad as opposed to an oval one. Be sure to match this pad with the pad labeled "1" on the display module. The size of the PC board and the location of the mounting holes are such that it will mount directly into a 3" x 4" x 2" plastic enclosure available from Digi-Key (cat. no. SR232G-ND), but it is not required that you use this enclosure. Any box will do, provided it has the space for the PC board, display, battery and any part of the switch (S1) which protrudes into the enclosure. Avoid using metal stand-offs. They could short traces on the underneath side of the board too - by way of the screw - the ground plane on the top of the board. Cut a rectangular hole in the top of the enclosure for the display to show through and a hole below this for the toggle switch. Label the enclosure using dry-transfer lettering (available from office supply stores) then spray with clear enamel spray paint for protection. Give the enamel plenty of time to dry, then mount and hook up the toggle switch. The display should be mounted to the underneath side of the enclosure positioned so that all characters will show through the rectangular hole in the case. (Note: at its upright position, the ribbon cable will be at the top of the display module.) The author used RTV silicon adhesive to hold the display in place which will not crack with any flexing of the plastic enclosure the way epoxy will. Finish by cutting a slot in the back of the bottom half of the enclosure for the test lead to exit, and mount the PC board in the enclosure.

Testing

Before installing the IC chips, plug in a fresh 9-volt alkaline battery, turn on S1, and check for 5-volts at pins 4 and 14 of U1, and pin 14 of U2 (a good place to clip your volt meter's negative probe is to the shield of the test lead). If there is no voltage at these points try the opposite position of S1. If still no voltage check the orientation of the regulator (U3) and capacitor C8. If the voltage is less than 4.5 volts and U3 begins to heat up, remove power and check for a short (such as a solder bridge) somewhere on the board (top or bottom). Once power has been verified, it is time to set bias control (R3). Hold the positive probe f your volt meter to the side of R5 closest to the regulator (U3) and adjust R3 for a reading close to 5 volts. Be careful not to short R5's lead to the surrounding ground plane with your prob. If you are unable to adjust R3 for a voltage reading between 4 & 6 volts, check the orientation of Q1 and Q2, and for solder bridges on these components. Disconnect the battery, then carefully plug U1 and U2 into their sockets making sure that their tabs are pointing in the right direction as shown in the parts placement diagram. A very common mistake when using IC sockets, is that one of the IC pins will bend up inside and underneath the chip when being installed. The insertion force required to seat the IC chip in its socket is sufficient enough to mask any feel of this occurring, and it is very difficult to detect this error later without close examination. The best way to avoid this is to push the IC chip half way into its socket, then check all pins before you finish seating the chip. Start with trim pot (R9) turned all the way in the clockwise position, re-install the battery and turn on S1. Without a test signal being injected, the display should briefly show ".00 KHz", then automatically switch ranges and read "Hz". Adjust R9 if necessary to change the contrast of the display to your liking. If "Hz" does not appear, check both ends of the ribbon cable for solder bridges, and check for correctly installed ICs.

Calibration

The resolution of the frequency counter depends on the gate speed and will be 1Hz with a 1 sec gate, and 10Hz with a 0.1 sec gate. Hook your frequency counter's test lead to a stable reference source of a known frequency (the higher in frequency the better). The output of a calibrated PLL synthesized transmitter (CB or Ham radio) is a good starting place if no other source exists. Note however, that the accuracy of your counter will be proportional to that of your calibration signal. Your counter should display the frequency (within a small percentage) of your calibration signal. If your frequency counter initially jumps up to some number only to return to 0Hz, your test signal is not large enough in amplitude to trigger the NAND gate (U2). Obtain a stable reading on the display, then use a nonmetallic screwdriver and adjust the trimcap (C12) to tweak the displayed frequency to that of your calibration signal. Note, if the frequency displayed on your frequency counter is more then a few percent lower then your known calibration signal, chances are the amplitude of your calibration signal is at or close to the minimum triggering threshold, and low frequencies (60Hz for example) riding on the test lead are forcing that signal below triggering level during part of the gate time, resulting in a lower then true count. Increase the amplitude of your calibration signal if this occurs. When you are satisfied with your calibration, assemble the two halves of the enclosure together and you're ready to use your frequency counter.

Parts List

Resistors (All are 1/4-watt, 10%, unless otherwise specified)

R1 - 100,000 ohm
R2, **R6** - 1 megohm
R3 - 500 ohm, trimmer, potentiometer
R4 - 100 ohm
R5 - 300 ohm
R7 - 820,000 ohm
R8 - 47,000 ohm
R9 - 10,000 ohm, trimmer, potentiometer

Capacitors

C1 - 1.5 uF, 16-WVDC, tantalum
C2 - 47 pF, ceramic disc
C3, C6, C7, C9 - 0.1 uF, Mylar
C4 - 470 pF, ceramic disc
C5 - .047 uF, ceramic disc
C8 - 10 uF, 35-WVDC, electrolytic
C10 - 22 pF, ceramic disc
C11 - 10 pF, ceramic disc
C12 - 4-20 pF, trimmer, capacitor

Semiconductors

U1 - PIC16C54-XT/P (pre-programmed) 8-bit microcontroller (Microchip)
U2 - 74HC132, schmitt trigger, quad, 2-input, NAND gate
U3 - 78L05, low power 5-volt regulator
Q1 - MPF102, N-channel, VHF, field-effect transistor
Q2 - 2N4403, general-purpose PNP silicon transistor
D1, D2 - 1N4148, general-purpose silicon diode

Other components

DISP1 - 16x1 character LCD module (Optrex DMC16117 or equivalent)
XTAL1 - 4 MHz crystal
S1 - SPST toggle switch

Miscellaneous:

Enclosure, PC board, IC sockets, 9-volt alkaline battery, battery clip, ribbon cable, shielded cable, alligator clips, hook-up wire, solder, hardware, silicon adhesive, etc.

Ordering Separate Parts:

The following items are available from: CallSaver Corporation
931 W. Main St. Bridgeport, WV. 26330
304-842-2472
Email: callsaver@iolinc.net
Web: www.Invent-Electronics.com

- ✍ An Etched and drilled PC board (WTCNT-B), $10.00
- ✍ All board mounting components including pre-programmed PIC16C54 (WTCNT-C), $19.50
- ✍ LCD display module (DISP16X1), $18.50
- ✍ A pre-programmed PIC16C54 only (PIC-CNT), $15.00

All orders must include an additional $4.50 for shipping and handling. Shipping costs may vary depending on your State or location