HOMELAB PROJECT

Self-calibrating Frequency Meter

No alignment necessary

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In the May & June issue of ElektorLabs Magazine we described a 10-MHz reference frequency source that uses the signals from GPS satellites to provide an extremely accurate reference frequency. The author has designed a self-calibrating frequency counter based on that circuit.

Features

- Self-calibrating with GPS signal
- Input frequency range 5 Hz to 80 MHz
- Input signal amplitude 0.2 to 30 V
- Resolution 6, 7 or 8 digits
- Accuracy (after locking) ±1 count pulse

There are various ways to measure signal frequencies. They all have one thing in common: they require a stable and precisely known reference frequency. A suitable reference frequency source was described in the May& June 2018 issue of *ElektorLabs Magazine* [1]. Here we use it as the basis for a full-fledged frequency counter with self-calibration capability.

A brief history

The 10-MHz reference frequency generator uses a precise 20-MHz voltage controlled temperature compensated crystal oscillator (VCTCXO) that is locked to the 1 pps output signal from a GPS receiver module. Under ideal conditions, the output signal has an accuracy of 1 part in 10^{10}. A commercial reference frequency generator with comparable accuracy is a lot more expensive than our DIY version.

Reciprocal measurement

The easiest (and conventional) way to measure signal frequency is to count the number of cycles of the input signal during a precisely defined 1-second time window. The uncertainty with this measurement method is ±1 digit. That corresponds to an error of ±1 Hz, which is of course unacceptable for measurement of low frequencies.

Another measurement method became popular with the advent of microcontrollers: reciprocal frequency measurement. With this method, the input signal defines a time window with a duration that depends on the desired accuracy. Two counters run during the gate time of this window. The first counts the number of cycles of the input signal, while the second counts the number of cycles of the reference signal. The frequency of the input signal can then be determined from:

$$frequency = \frac{input\ pulse\ count}{(reference\ pulse\ count) \times t_c}$$

Here t_c is the period of the reference frequency, which is equal to $1/f_{ref}$. Assuming a reference frequency of 10 MHz, the resolution of the frequency measurement is 6, 7 or 8 digits with a measurement window (gate time) of 0.1, 1 or 10 seconds, respectively.

Block diagram

The block diagram of the digital portion of the frequency counter is shown in **Figure 1**. The counter essentially consists of the gate timing logic and the two subsequent 32-bit counters, along with part of the microcontroller. The other blocks are responsible for generating the reference frequency. For more information about that, please consult the article in the May & June issue [1]. It's worth noting that with the exception of the VCTCXO (marked '20 MHz VCO' in the block diagram), everything shown on the block diagram is integrated into the microcontroller.

The maximum frequency that the microcontroller inputs can handle is 16 MHz, so the oscillator frequency is divided by 2 to obtain a 10-MHz signal. That is well within the specified capability of the microcontroller.

By the way, the microcontroller datasheet is not entirely clear on the maximum allowable frequency for the I/Os. Sometimes you think it is 16 MHz, and sometimes you think it is 20 MHz. That makes it anybody's guess. However, the author's prototype certainly did not have any problem with frequencies of 20 MHz or even higher, corresponding to 80 MHz or more at the input.

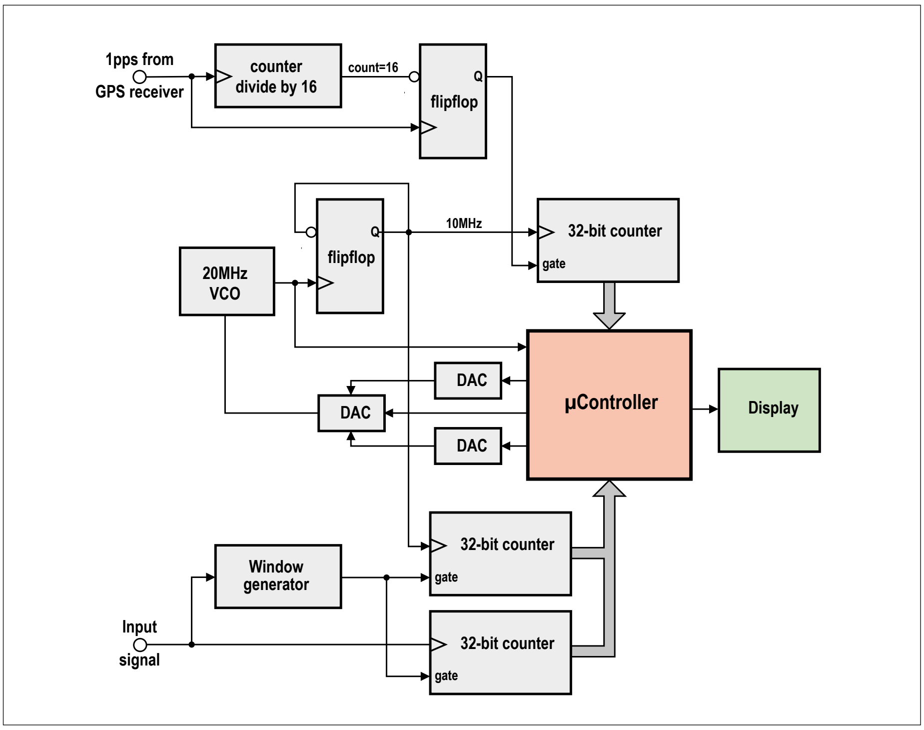

Figure 1. Block diagram of the frequency counter. Except for the display, everything shown here is located in the microcontroller.

Input amplifier

As we all know, digital circuits are only happy with digital signals, so the input signal has to be conditioned before it is applied to the microcontroller port. **Figure 2** shows the relevant part of the circuit (top half). The display module is also shown here in the bottom half, because that part of the circuit is located on the display board. You might wonder why it is on the display board. The answer is that the circuit needs to be as close as possible to the input connector, because long wire leads should always be avoided with high-frequency analogue signals.

The signal from the BNC connector J1 is limited by the dual diode D1 and buffered by the FET T1. This input circuit is required to obtain an input impedance of 1 MΩ and to avoid overloading due to high-amplitude input signals.

Transistors T2 and T3 provide enough gain to allows the comparator IC1 to convert the analogue signal into a respectable digital signal. The amplifier does not need to be especially linear, since all we actually need is the timing of the rising and falling edges. Counter IC2 divides the signal frequency by a factor of 4 to avoid confronting the microcontroller input with frequencies too high for it to handle. The frequency range of the input circuit, from the BNC input to the counter output, is at least 5 Hz to 80 MHz. The amplitude of the input signal should be between 0.2 V and 30 V.

The display used is a DOG type from Electronic Assembly with two rows of six-

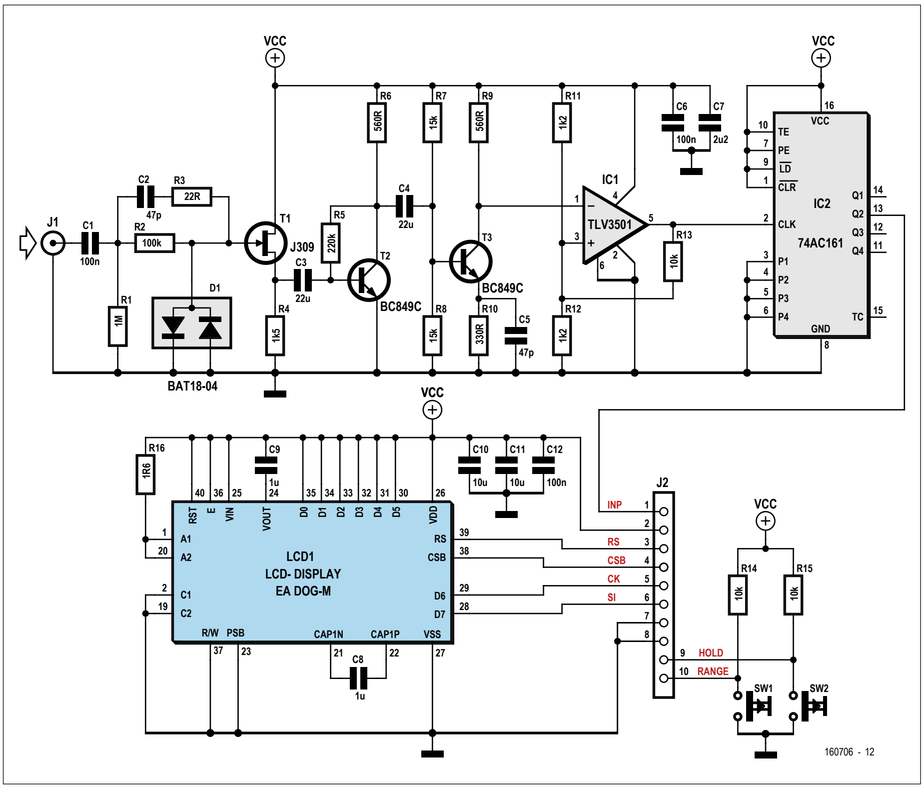

Figure 2. Schematic diagram of the input amplifier. It is shown on this diagram because it is located on the display board.

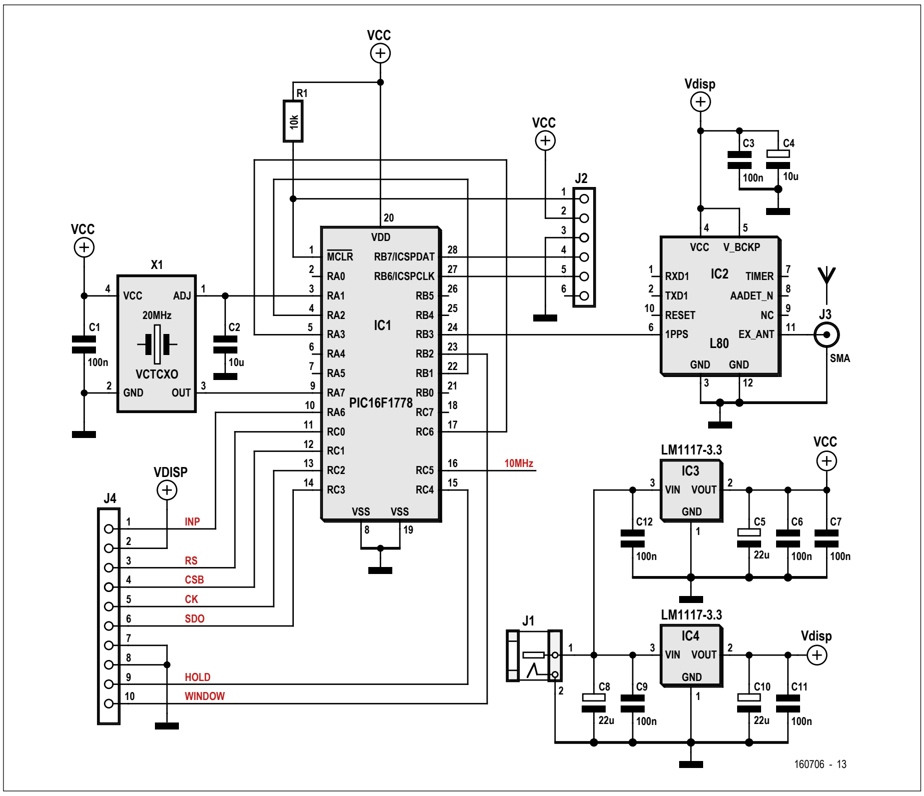

Figure 3. Schematic diagram of the microcontroller portion. There aren't many components, so the PCB is remarkably empty.

teen characters and white LED backlighting. The display is driven by the microcontroller over an SPI bus (connector J2).

Microcontroller portion

The microcontroller, the clock crystal and the GPS receiver are located on the main circuit board. The schematic diagram is shown in **Figure 3**. It is largely the same as the 10 MHz reference frequency project in the May & June issue. For more details, see the article in that issue. The only differences are:

- the two indicator LEDs are deleted (the microcontroller pins are needed for the SPI interface (J4);
- the buffered 10-MHz and 1-MHz outputs are also deleted because they are no longer necessary, but a 10-MHz signal is still available on the RC5 output of the microcontroller (pin 16);
- a second 3.3-V voltage regulator (IC4) has been added to provide the supply voltage for the display, the input amplifier and the GPS receiver. That way the VCTCXO and the microcontroller have their own power supply and the stability of the reference frequency is assured.

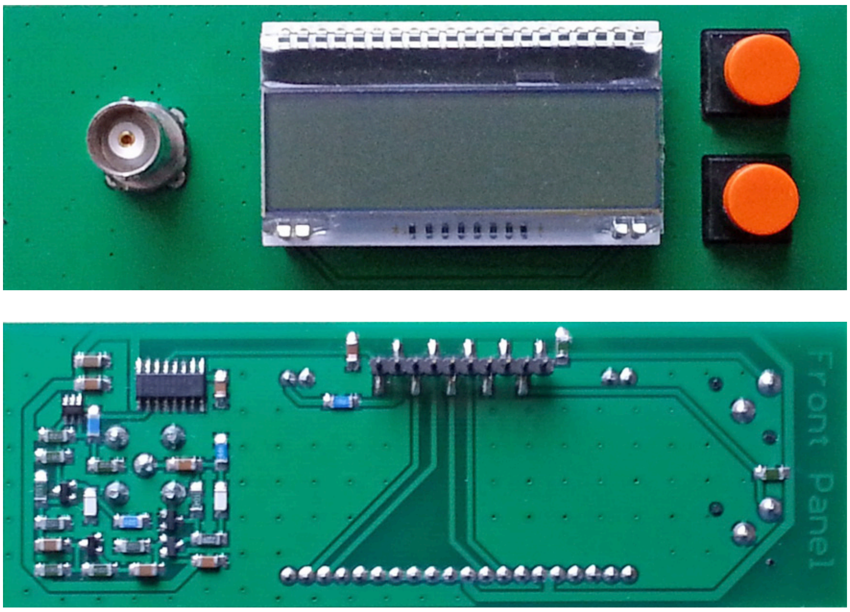

Figure 4. The display board with the input amplifier.

Connector J2 is intended for in-circuit programming of the microcontroller, and J4 provides the connection to the display board.

Construction

As previously mentioned, the input amplifier and the display are located on the display board. With the exception of the connectors and switches, which should preferably be leaded types because they are subject to physical stress, all components are SMDs. That keeps the overall package pleasantly compact (see **Figure 4**). It's a pity that for proper operation the GPS receiver has to be kept as far away from the oscillator as possible; otherwise it could have also been mounted on this circuit board.

Figure 5 shows the microcontroller board. It is very sparsely populated, but that is beneficial for the GPS receiver.

The boards are fitted in a Teko 011 case, with the original aluminium front and back panels replaced by acrylic sheets covered with aluminium-coloured self-adhesive film because the GPS receiver needs access to the outside world. The power source is a standard 5-V USB AC line adapter.

Figure 6 gives an impression of the author's prototype.

Firmware

The firmware residing in the microcontroller, which performs all the functions required for proper operation of the frequency counter, is written in assembly language because using a high-level language would have a number of serious disadvantages.

First of all, it would not be possible to control the timing of the various functions with sufficient accuracy, and secondly, it would take up more memory space. And the software would run slower – also

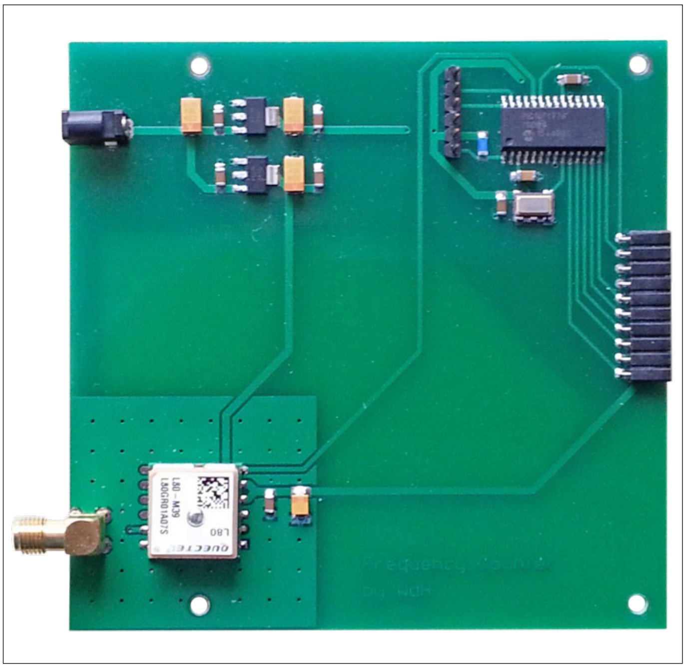

Figure 5. The microcontroller board.

Figure 6. The front and rear of the case.

Never calibrate again

a significant consideration. In particular, the multiplication and division operations that are necessary to calculate the frequency shown on the display are coded the way they need to be for this application. Multiplying the content of the 32-bit input counter by 10 and then dividing the result by the content of the second 32-bit counter takes less than 1 millisecond, including BCD conversion. All in all, the firmware in its present form occupies only 8% of the microcontroller memory. The firmware and the PCB layouts can be downloaded free of charge from the project page for this article [2].

Use

The frequency counter is easy to use. The duration of the measurement window (the gate period during which pulses are counted) can be selected with the Time button. That determines the resolution of the measurement (see **Figures 7a,b,c**). The selected window time is indicated by the number of dots in the bottom line of the display.

The small symbol at the left end of the top line appears for about 200 ms when a measurement has been completed and the display is updated (**Figures 7a and 7c**). The Hold button freezes the reading on the display (Figure 7d). Note that this only stops updating of the display; the counter keeps on making measurements.

The symbol at the left end of the bottom row (**Figures 7d and 7e**) indicates that the VCTCXO is locked to the GPS signal. But even if this symbol is not shown, accurate measurement is still assured for a relatively long time. Once the frequency counter has been locked to the GPS signal, the D/A converter settings are stored in the non-volatile memory of the microcontroller as described in the article in the May/June issue. Each time the counter is powered up, these settings are read from the memory and the converters are configured accordingly.

Of course, the frequency of the VCTCXO will gradually change over time — that is a normal ageing process. But as long as the oscillator is locked to the GPS signal at more or less regular intervals, the latest calibration factors for the D/A converters are always stored in memory. This way the accuracy of the frequency counter is guaranteed to be ±1 clock pulse.

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Web Links

[1] www.elektormagazine.com/160595

[2] www.elektormagazine.com/180343-01

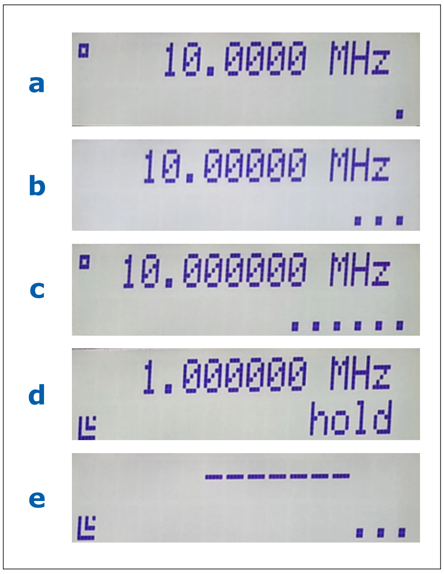

Figure 7. a: 0.1-s measurement window;
b: 1-s measurement window;
c: 10-s measurement window;
d: oscillator locked, readout frozen;
e: oscillator locked, no input signal.