Project 166

A laboratory standard function and pulse generator

Part 1

Here is another of our laboratory standard test equipment projects. This function and pulse generator covers the range from 1 Hz to 1 MHz, generates sine, square, triangle ramp and pulse waveforms. It features digital readout and six output voltage ranges, from 10 V down to 30 mV peak-to-peak. It has positive- and negative-going pulse outputs and the pulse width can be set from one second to 100 ns in seven ranges. In addition, it can be swept by an external sweep generator (to come . . .).

David Tilbrook

APART FROM a good multimeter and a variable, protected power supply or two, every electronics workshop worthy of the title, and every electronics enthusiast of serious intent, *needs* a function generator of some sort with performance adequate for the various tasks the operator is likely to engage in.

Now, that's a pretty vague specification. These days, the 'various tasks' one can tackle might range from amplifier system performance checks to the design and construction of a microprocessor system. At some stage of the task being tackled, a signal source of some description will be a necessity, like as not. I had to set some sort of performance specification when setting out the initial requirements of this project and cast around for a good starting point.

The best starting point I could find was right under my nose: the Wavetek function and pulse generator we've had in the lab here at ETI for some years. Now, Wavetek is to function generators what Tektronix is to oscilloscopes, so I figured our generator was a fair place to start the process.

Our model 166 Wavetek covers 0.0001 Hz to 50 MHz. It has sine, triangle, ramp, square and pulse outputs (TTL level, positive- and negative-going). The function output can be varied from 0 to 30 V peak-to-peak (open-circuit, 15 Vp-p into 50 ohms). The output dc offset can be varied over ±10 V open circuit, ±5 V into 50 ohms. The frequency can be swept over a 1000:1 range, log. or linear. The output can be amplitude modulated and the waveforms can be triggered. On sinewave output, the distortion is less than 0.5% between 10 Hz and 100 kHz, rising outside those limits. The triangle linearity is greater than 99% between 0.005 Hz and 100 kHz.

The pulse output can be triggered, double-triggered, gated or swept. The pulse period is variable between 20 ns and 10 000 seconds while the pulse width is variable between 10 ns and 100 ms in seven ranges. The transition time is variable, too, from 7 ns to 50 ms in seven ranges. The amplitude, dc offset and frequency stability in linear mode (to 500 kHz) is ±0.05% over 10 minutes, ±0.25% over 24 hours.

They are the main performance parameters of the Wavetek 166. It has a circular frequency-setting dial with calibration markings around the skirt. The dial frequency also indicates the start frequency of a sweep range. It has served us extremely well to date. However, quite a few of the performance functions and features have not been needed.

The next question I posed was, what functions and features of the Wavetek could be done without or would not be required by the serious enthusiast or general electronics workshop?

For a start, the frequency range is probably far too wide. I settled on 1 Hz as being a practical lower limit after considerable discussion among staff and associates. This is low enough for a great many *slow* digital operations and in linear applications is good for checking loudspeaker drivers for 'poling', etc. The upper limit, I knew, would be somewhat dictated by the sort of technology I would be restricted to using, given the restraints of component availability and cost. Without looking at the latter too closely, I thought an upper frequency range of 1 MHz was a desirable goal.

GENERAL SPECIFICATIONS — ETI-166 FUNCTION/PULSE GENERATOR

Function outputs	sine triangle square sawtooth
Frequency range	1 Hz to 1 MHz in seven ranges (square to 100 kHz only)
Pulse outputs	positive going } TTL level with pullup to 5 V negative going } (repetition rate set by frequency control, 1 Hz to 1 MHz)
Pulse width range	1 sec. to 100 ns in seven ranges
Frequency display	3½-digit, 1 Hz gate time, 1.000 Hz to 1.000 MHz
Sinewave distortion	typically less than 2% THD; diode shaped
External sweep input	sweeps generator over one-decade range; 1 V peak
Output voltage ranges	10 V, 3 V, 1 V, 300 mV, 100 mV, 30 mV (peak-to-peak)

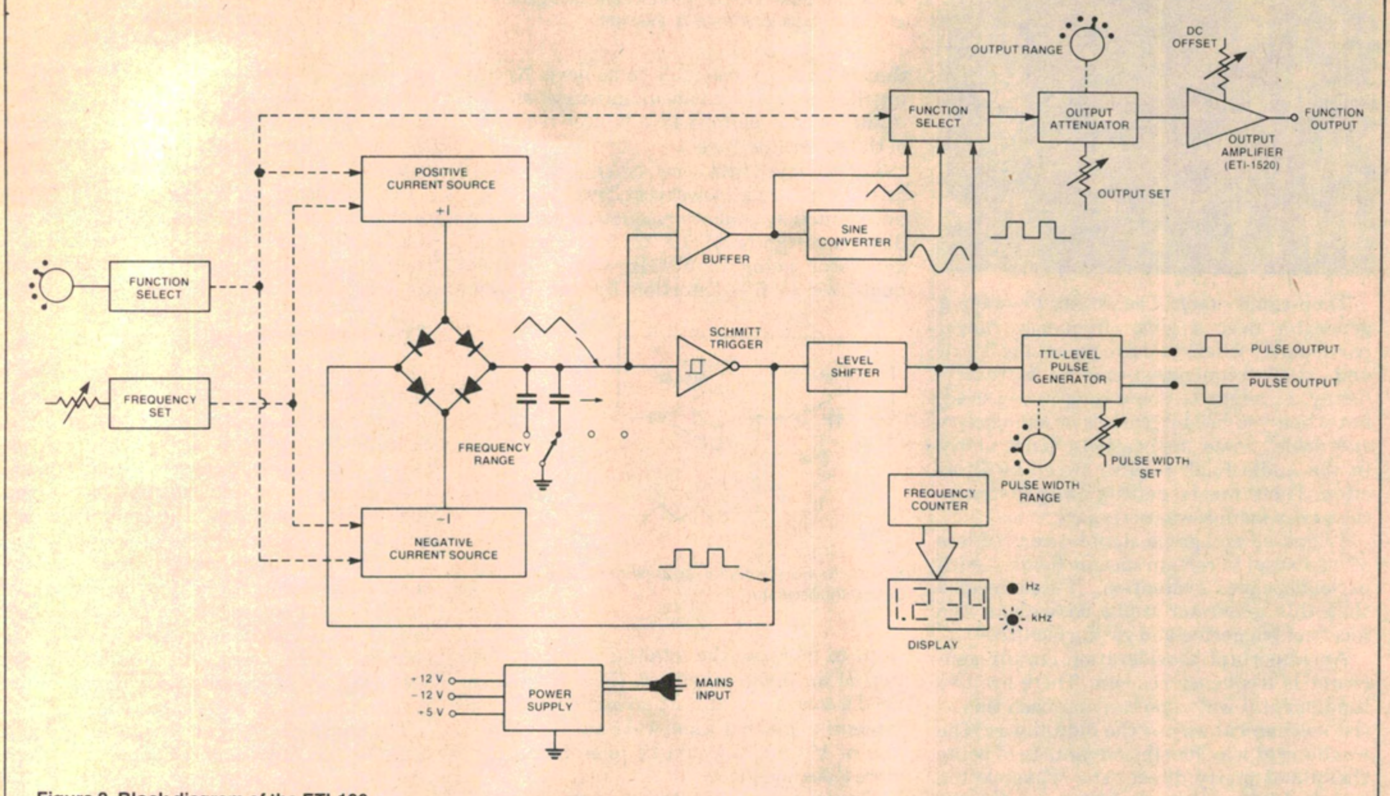


Figure 2. Block diagram of the ETI-166.

Two constant-current sources, **+I** and **−I**, are at the heart of the main oscillator. A diode 'steering' network, **diodes A-B-C-D**, allows **+I** to charge the integrating capacitor and **−I** to discharge it. The frequency range switch selects the integrating capacitor required. The oscillator works like this: let's assume the **Schmitt trigger** output is high (+ve) to start with. Diode D will be reverse-biased and diode C will be forward-biased, reverse-biasing diode B. Diode A is forward-biased and thus the integrating capacitor will be charged by **+I**.

The voltage on the capacitor will rise linearly until it reaches the upper threshold of the Schmitt trigger. The Schmitt's output will then swing negative, reverse-biasing diode C and forward-biasing diode D. This reverse-biases diode A, and diode B will thus be forward-biased, allowing **−I** (a current **sink**) to discharge the capacitor.

The voltage on the capacitor will fall linearly until it reaches the lower threshold of the Schmitt trigger, whose output will then revert to the high state, commencing the process once again.

As the diagram shows, the capacitor voltage is a triangular wave, while the Schmitt trigger output is a square wave.

By varying the actual current sourced and sunk from **+I** and **−I**, the oscillator frequency can be varied. Thus, voltage or current control of the frequency can be incorporated and the **frequency set** control is a potentiometer. To produce a sawtooth wave, the charge and discharge currents have to be different.

For a **ramp-up** wave, the integrating capacitor is discharged quickly by increasing the current sunk by **−I**. For a **ramp-down** wave, the capacitor charge current supplied by **+I** is increased.

This is achieved by the **function select** control.

The capacitor voltage signal is buffered and the triangle/sawtooth wave passed to the **function select** module. To produce a **sinewave**, the buffered triangle wave is passed to a **sine converter**, whose output passes to the **function select module**.

The Schmitt trigger output is passed to a **level shifter** so that the square wave signal swings between 0 V and the +ve supply rail. The **frequency counter** takes its input from this point, as does the TTL-level **pulse generator module**. The latter produces complementary pulse outputs with very fast rise and fall times. This employs a TTL monostable multivibrator, a switch selecting appropriate capacitors for the **pulse width range** and a pot. providing **pulse width set**.

The output of the function select module passes to the **output amplifier** via an **attenuator**. The output amp. includes a **dc offset** adjustment that can be varied with a pot.

Sweep-generation circuitry has not been included in the ETI-166, simply because we couldn't fit it in a reasonably-sized off-the-shelf case! Apart from that, we realised that a stand-alone sweep generator could be used with many of the commercially available signal generators so would be suitable as a project in its own right.

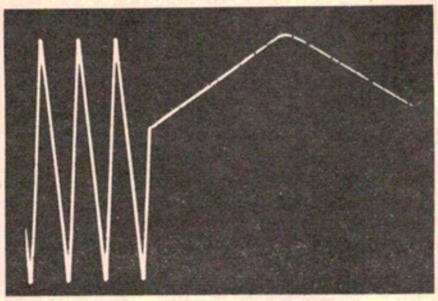
Constructionally, the ETI-166 has been divided into logical modules — the main generator, the frequency counter and display and the output amplifier. The latter has been dubbed Project 1520 and appears elsewhere in this issue. The other modules will appear in following issues.

What about the function outputs? They were obvious: sine, triangle, square, and ramp-up/ramp-down. The pulse outputs were a little trickier. The general consensus was that it would be desirable to set the pulse width over a wide range and that variable transmission time was rarely required. As TTL level outputs with resistive pull-up suit both CMOS and TTL circuitry, TTL level outputs only were settled on. Complementary outputs (negative- and positive-going pulses) were considered to be desirable.

The function output level, and the desirability of dc offset adjustment, came in for much discussion. Should the generator be capable of driving a 50 ohm load at some tens of volts peak-to-peak, or was some other arrangement tolerable and easier to achieve? A search through the data books and a little quick experimentation soon settled the question. The former was certainly possible and considered generally desirable.

The goal was to get a maximum output level of 10 Vp-p into 50 ohms (20 Vp-p open circuit) right across the frequency range — a tall order, because the output stage is required to deliver around a quarter of a watt. In addition, it would need to have a bandwidth of at least five times or more than the frequency range of the generator to accommodate the harmonics that go to make up the non-sinusoidal functions.

The ability to vary the output range between zero and a defined maximum is desirable. The Wavetek has an 'output attenuator' variable in 20 dB steps, but from experience we had found the intervals too great on many occasions so I settled on having 10 dB steps for the output attenuator on this generator. As the dc offset facility had come in handy — particularly when working with digital circuitry — provision had to be made for that, too. Much digital work is done with high-level signals, while much audio work is done with low- and high-level signals, ranging from millivolts to volts. The output attenuator has to cope with those requirements. ▶



◀ **A real smoothie.** Output of the triangle wave generator at 1 MHz; expanded trace on the right.

Then came *sweep.* The ability to sweep a generator over a given frequency range, particularly where you can preset the 'start' and 'stop' frequencies, can be extremely handy. It might be something rarely used, but when you need it, there's *no satisfactory substitute.* Some applications, particularly in the audio field, require sweep facilities often. There was no getting away from it — the sweep facility was necessary.

Triggered and gated signals are used less often, except in certain specific fields — such as loudspeaker evaluation. It was decided that this generator could do without the nicety of triggering and gating facilities.

An important consideration on any generator is frequency readout. There are two fundamental ways one can approach this — the mechanical way or the digital way. The mechanical way has the advantage of being cheap and pretty direct. The Wavetek 166 has a calibrated skirt on the frequency knob. That's fine, except in those (increasingly numerous) applications where you need to know the frequency to, say, 1 Hz in 1 kHz. Out with the digital counter! That's all right, except where you need to use the counter for other things while you're using the generator.

I opted for digital frequency display. This gave me an additional option — the ability to use a 10-turn potentiometer in place of a conventional pot. for the frequency setting control. You don't have to, but the possibility is there.

The basic functions and features settled on turned out to be:

- 1Hz to 1 MHz frequency range
- sine, triangle, square, sawtooth (ramp-up and ramp-down) and pulse outputs
- TTL level positive- and negative-going pulse outputs with variable width
- sweep facility
- output voltage range from millivolts to at least 10 V
- dc offset provision
- digital frequency display.

As the project was to be part of the 'lab-standard' series, I next had to define 'lab-standard' with regard to function generators.

The definition

This proved a difficult task as there are conflicts between *desirable* performance and *reasonably achievable* performance. It's like saying a desirable goal for a jogger would be to jog up Mount Everest and back, but it's one that is hardly reasonable to achieve. Keeping that in mind, I set about putting numbers to the various performance figures required of the generator project.

An obvious first one is sinewave distortion. Wavetek's lower cost, lower performance function generators quote a sinewave distortion figure of 1% to 500 kHz for a generator going to 5 MHz. Other brands quote 2% to 5% distortion figures. If you want to measure the total harmonic distortion of an audio amplifier, then you really need a special low-distortion oscillator. Thus, it seems to me that a sinewave output distortion of 1% to 2% would be tolerable, if not more than adequate.

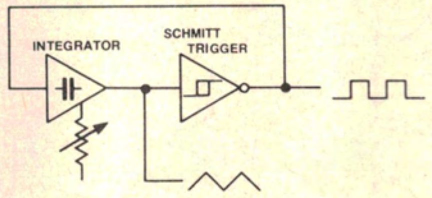


Figure 1. Fundamental arrangement of a function generator oscillator.

Triangle and sawtooth linearity should be at least 95%, preferably close to 99%, right across the frequency range.

Frequency readout is important. When messing around with audio filters, modems and the like, the ability to measure at least 1 Hz in 1 kHz is highly desirable. A simple 3½-digit counter will allow you to read 1 Hz in 2 kHz (for argument's sake . . .), which is quite sufficient in a huge variety of applications. If you want more accuracy than that, then it's time to dig out your six- or eight-digit counter!

The output attenuator, as stated earlier, needs to be able to provide signals down in the millivolt region on one hand, yet the maximum output level desirable was set at 10 Vp-p. Then there's the 10 dB steps. Well, all that's pretty simple. A six-range attenuator will give steps of 10 V, 3 V, 1 V, 300 mV, 100 mV and 30 mV. A pot. simply allows infinite variation over whatever maximum level range is set on the attenuator.

The pulse width range was not so difficult to define. From experience, pulses greater than one second wide are not often encountered or required, so that fixed a reasonable upper limit. Pulses around 100 nanoseconds wide are encountered more often, as well as a whole host in between. A vernier control would permit variation up to a set maximum pulse width. Thus, I made the pulse width ranges 100 ms-1 s, 10 ms-100 ms, 1 ms-10 ms, 100 us-1 ms, 10 us-100 us, 1 us-10 us and 100 ns-1 us.

For the sweep function, being able to sweep over a three-decade range (1000:1) is desirable, but problematical to achieve. I settled for being able to sweep the generator over any one-decade range.

We found the modulation facility of the lab. Wavetek was rarely used. That sort of thing's essential on an RF signal generator (. . . all right, all right — we'll get round to it), but of rare application in a function generator such as this. Hence, no modulator.

I decided that providing gating facilities on the function output was a specialised application. If you need it, then the ETI-124 Tone Burst Gate (Nov, '75) should suit most applications.

The technology

The fundamental circuit of a function generator is shown in Figure 1. This consists of an op-amp integrator followed by a Schmitt trigger with a feedback path between the Schmitt trigger's output and the integrator's input. Such a circuit is arranged such that, at power-on, the Schmitt trigger output goes hig and charges the integrator's capacitor. The integrator's output rises linearly until the Schmitt trigger's upper threshold is reached, where the output goes low. The integrator's capacitor then discharges linearly until the Schmitt trigger's lower threshold is reached, where the output reverts to the high state once again.

The variable resistor in the diagram is there to indicate that the integrator's charge and discharge rate can be varied (the rates will be the same), thus varying the oscillation frequency as the time taken to reach the Schmitt trigger's upper and lower threshold is varied.

To obtain a sinewave, the triangular wave output is rounded, or 'shaped', with a special circuit. Sawtooth waveforms are generated by having different charge and discharge times for the integrator. A 'ramp-up' waveform is generated by charging the integrator's capacitor slowly and discharging it quickly. A 'ramp-down' waveform is obtained by charging the capacitor quickly and discharging it slowly.

There are a number of special ICs available that provide the fundamental circuit blocks to make a function generator. The XR2206 and the 8038 are probably the most well-known ones. Unfortunately, neither meets most of the performance requirements set down earlier in this article. At best, the XR2206 will only get to 150 kHz and the waveform 'trueness' begins to fall off once it gets past about 20 kHz. It's a fine IC for non-critical applications, such as a low-cost 'knockabout' function generator. The 8038 is better — it will comfortably get to 500 kHz, but, again, waveform trueness is nothing wonderful well below that limit.

To meet the requirements set down earlier, I had to tackle the project in discrete 'blocks'. The block diagram in Figure 2 is the result. That is the overall block diagram of the ETI-166 Function/Pulse Generator.

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