a simple low-cost comb generator frequency calibrator

Produces pulses for test equipment calibration

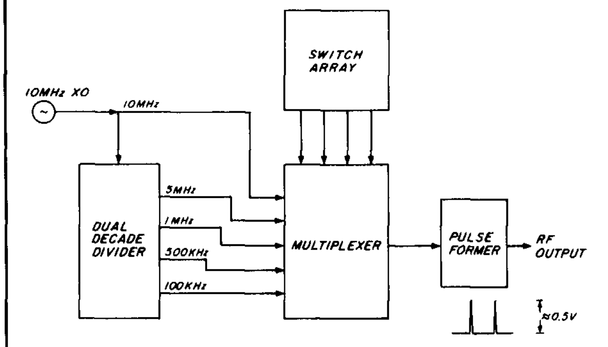

fig. 1. Block diagram of the comb generator. It is constructed on a 1.5 x 3.2-inch (3.8 by 8.1 cm) pc board.

Here's the construction and theory behind a simple digital comb generator* that produces accurate (crystal-controlled) pulses and can be used to calibrate a wide variety of test equipment. One possible application is the calibration of a spectrum analyzer (like the "Low-cost Spectrum Analyzer with Kilobuck Features," *ham radio*, September 1986, pages 82-90). It can also be used to align receivers, and to provide a stable comparison for calibrating various kinds of signal sources. A bandpass filter can be used to select any *tooth* of the comb to provide a single, pure signal.

A block diagram is shown in **fig. 1**. The heart of the generator is a crystal-controlled 10-MHz clock oscillator. Although a clock with moderate accuracy ($\pm$0.05 percent) is used in this model, more accurate oscillators are available in the same package style if you want higher stabilities. The oscillator's output is then divided down in frequency by a digital divider to a minimum frequency of 100 kHz. A multiplexer is used to select one of the signals from the divider chain or the 10-MHz signal. The multiplexer output drives the clock input of a high-speed CMOS D-type flip-flop, connected so that when a clock pulse is applied it tries to reset itself. This causes a narrow pulse about 6 nanoseconds wide to appear at its output. The repetition rate of this pulse train is the same as the applied input signal to the flip-flop, and when viewed in the frequency domain appears as a series of teeth separated in frequency by the repetition rate of the pulses. The schematic for the comb generator is shown in **fig. 2**; a parts list is provided.

The crystal oscillator, U3, can be purchased as a component in a DIP style package with a wide variety of specifications in terms of output levels and frequency accuracy. You'll need a part with either a CMOS or TTL compatible output for this application. The accuracy of the oscillator used in this comb generator is specified as $\pm$0.05 percent (about $\pm$72 kHz at 2 meters). Oscillator output is applied to both a frequency divider, U1, and one input of an eight-input multiplexer, U2. The frequency divider is a 74LS390 dual decade counter. It is hooked up so that its outputs furnish pulse repetition rates of 5, 1, 0.5, and 0.1 MHz simultaneously. All these outputs are then connected to the multiplexer inputs.

A quad DIP switch is used to select one of the five signals which appear at the output of the multiplexer, U2 (a 74LS151). DIP switch coding for the various output frequencies is shown in **table 1**. The multiplexer output is connected to the clock input of a high-speed CMOS D-type 74AC74 flip-flop, U4. The D input of the flip-flop is always wired high, so the flip-flop will set when the rising edge of a clock pulse occurs. The Q complement is wired to the flip-flop's reset pin; as

*It is called a comb generator because when its output is viewed in the frequency domain, as with a spectrum analyzer, the pattern resembles a comb.

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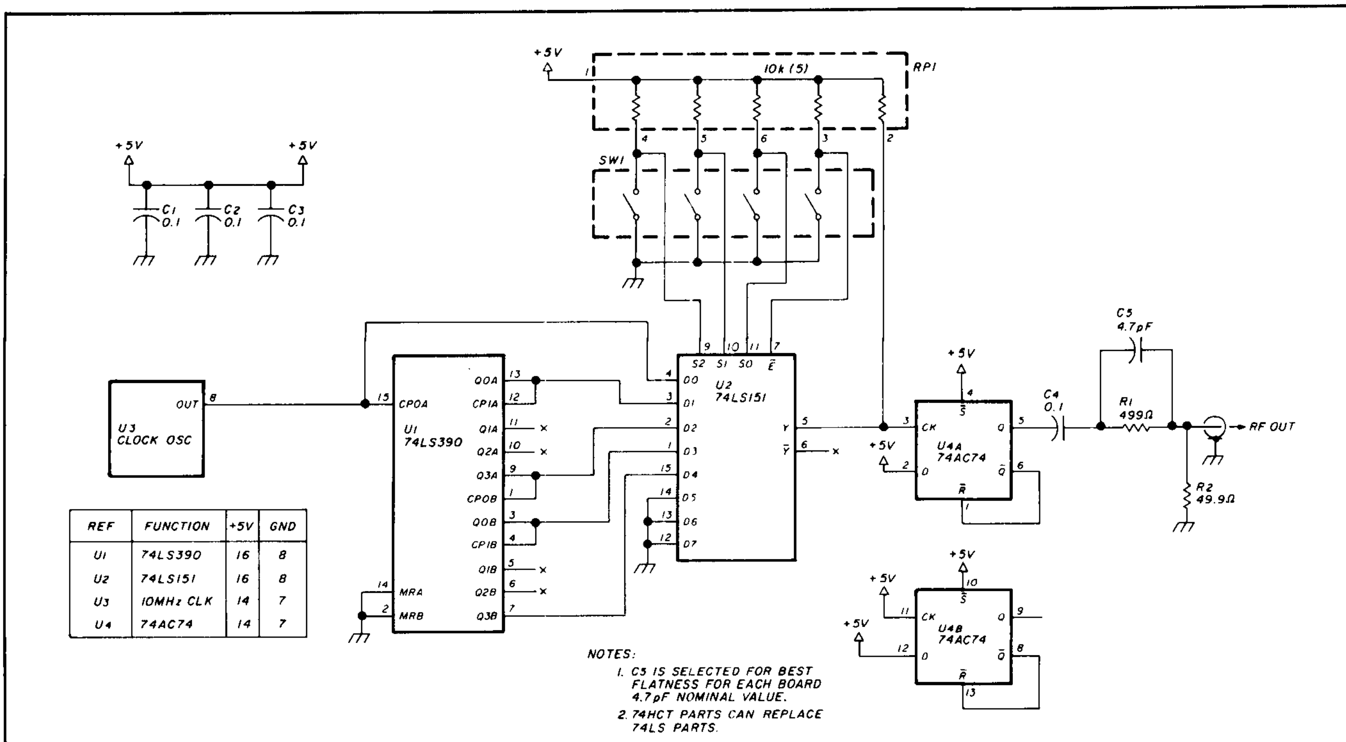

fig. 2. Detailed schematic of the comb generator. It uses four integrated circuits and a few other passive components.

Table 1. Output Frequency Coding

DIP Switch Code	Output Pulse Repetition Rate
0000	Output is disabled
0001	Output is disabled
0010	Output is disabled
0011	Output is disabled
0100	Output is disabled
0101	Output is disabled
0110	Output is disabled
0111	Output is disabled
1000	Output is disabled
1001	Output is disabled
1010	Output is disabled
1011	100-kHz rate
1100	500-kHz rate
1101	1-MHz rate
1110	5-MHz rate
1111	10-MHz rate

Ref. Desig.	Part Description	Manf'r	Qty.
C1	0.1 uF 50 V CK05 Capacitor	AVX	4
C2	0.1 uF 50 V CK05 Capacitor		—
C3	0.1 uF 50 V CK05 Capacitor		—
C4	0.1 uF 50 V CK05 Capacitor		—
C5	4.7 pF nominal value, CK05 Capacitor (Set at test)	AVX	1
J1	BNC PC Mount Jack	AMP	1
R1	499 ohm 1% 0.1 W resistor	Corning	1
R2	49.9 ohm 1% 0.1 W resistor	Corning	1
RP1	6 pin 5 resistor 10K ohm SIP	Bourns	1
SW1	4 position DIP switch	Grayhill	1
U1	74LS390N Dual Decade Counter	TI	1
U2	74LS151N Multiplexer	TI	1
U3	10 MHz Clock Oscillator	Dale	1
U4	74AC74PC Dual D Flip-flop	Fairchild	1
X1	Printed Circuit Board	LMCA	1

soon as the flip-flop is set (its output rises to 1), the complement output goes low, and the flip-flop is forced to reset. Its output is a narrow pulse whose width is limited only by the time delays through the internal logic of the flip-flop and the wiring delays associated with the pc board. This pulse, shown in **fig. 3**, is typically 6 nanoseconds wide.

This pulse train, when viewed in the frequency domain, looks like a comb (see footnote) as shown in **figs. 4** and **5** for a 10-MHz pulse repetition rate. **Figure 4** shows the output of the comb generator with a 10-MHz repetition rate from 0 to 100 MHz, while **fig. 5** shows the output spectrum of the same waveform from 0 to 1000 MHz. These figures show that the typical output is flat to within ± 1 dB from 0 to 100 MHz (careful adjustment of C5 can reduce the flatness to less than ± 0.6 dB) and that the comb generator is useful to above 1000 MHz.

The comb generator can be used as a very stable, pure tone generated by filtering one of the output teeth. The spectral purity of the 100-MHz tooth of the comb generator is seen in **fig. 6**, which shows the noise within a 1-kHz frequency span (with a 10-Hz resolution bandwidth). Note that the line-related sidebands are over 70 dB down.

Figures 7, 8, 9, and **10** show the output spectrum

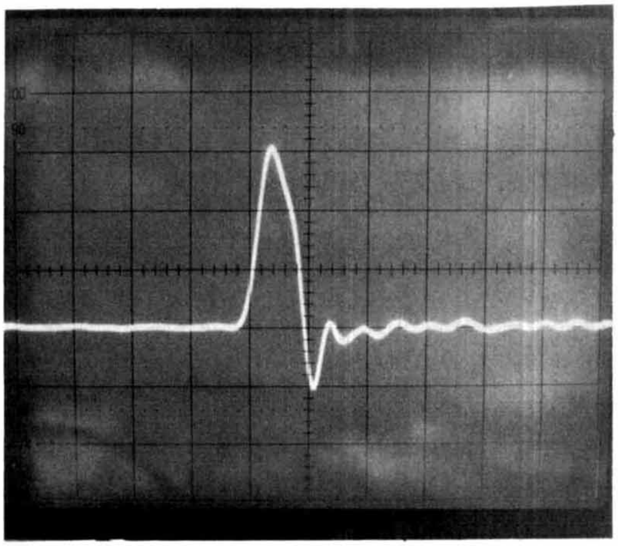

fig. 3. Output pulse of the comb generator. The horizontal scale is 10 nSec/div and the vertical scale is 0.2 V/div. The repetition rate of the pulses depends on the switch settings.

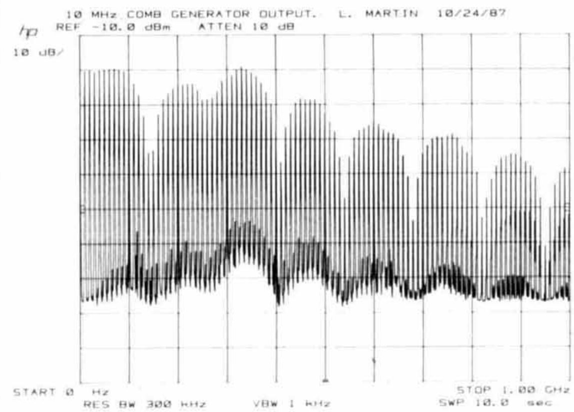

fig. 4. The output spectrum of the comb generator with a 10 MHz repetition rate. The vertical scale is 10 db/div and the horizontal scale is 10 MHz/div. The flatness of the generator is better than ± 1 dB.

for a 5-MHz repetition rate, a 1-MHz repetition rate, a 500-kHz repetition rate, and a 100-kHz repetition rate, respectively. Note that the amplitude of each tooth is reduced by the ratio of the repetition rates. This is because the energy in each pulse is spread into many more comb teeth, reducing the amplitude of each tooth when the repetition rate is reduced. **Figure 11** shows the output of the 100-kHz repetition rate signal over the 20 to 30-MHz frequency range and gives an indication of the flatness of the comb generator in the hf frequency bands.

The comb generator is constructed on a double-sided pc board with plated through holes. All compo-

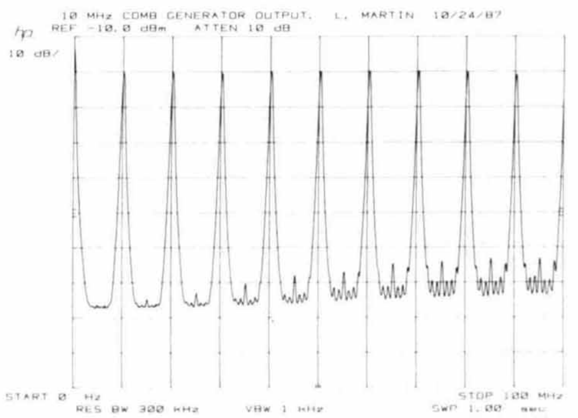

fig. 5. A broadband view of the comb generator output. The vertical scale is 10 dB/div and the horizontal scale is 100 MHz/div. This shows that the comb generator has useful outputs up into the low microwave range.

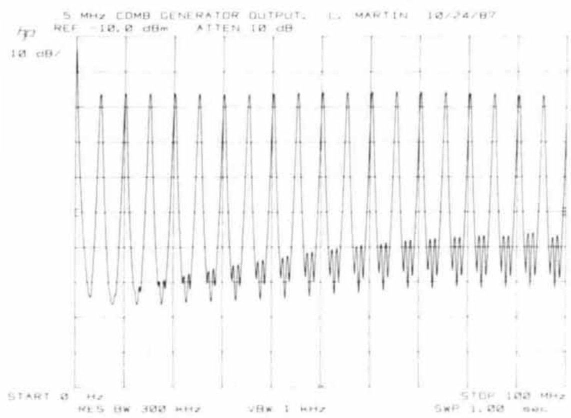

fig. 7. The output of the comb generator with a 5-MHz repetition rate. The horizontal scale is 10 MHz/div and the vertical scale is 10 dB/div.

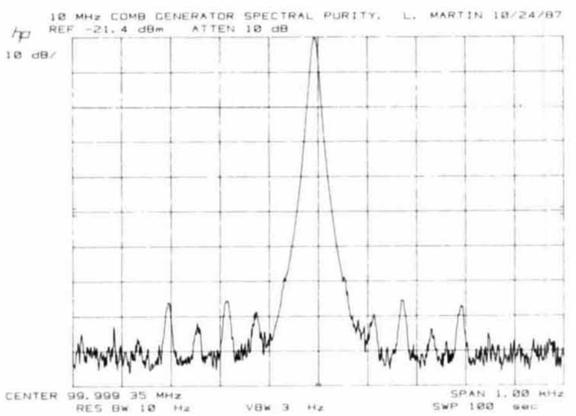

fig. 6. The close in spectral purity of the 100-MHz tooth of the comb generator when set to a 10 MHz-repetition rate. The horizontal scale is 100 Hz/div and the vertical is 10 dB/div. The spurious sidebands are multiples of 60 Hz.

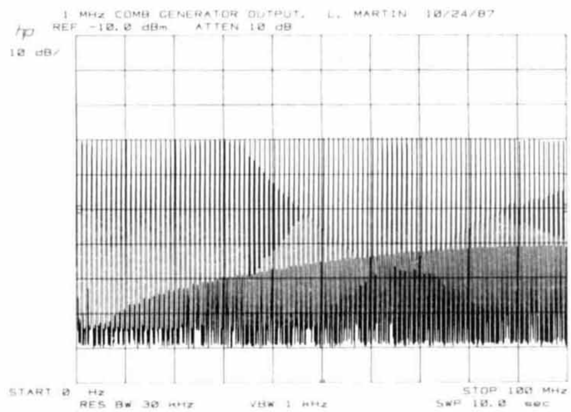

fig. 8. The output of the comb generator with a 1-MHz repetition rate. The horizontal scale is 10 MHz/div and the vertical is 10 dB/div. Note that the amplitudes of each of the teeth has decreased as their quantity has increased.

nents are soldered to the board without sockets to minimize component lead lengths and reduce any switching spikes which could upset the output pulse waveshape. The generator uses 65 mA from a + 5 volt supply.

A major use of the comb generator is calibration of test equipment — for example, a typical spectrum analyzer. The tunable oscillator in most rf spectrum analyzers is a varactor-tuned oscillator. This oscillator has an inherently nonlinear tuning curve, so when an unknown signal is measured, the analyzer must be calibrated to determine its frequency. The comb generator allows this calibration to be done efficiently.

First connect the unknown signal to the spectrum analyzer, set the analyzer to a wide frequency span (0 to 100 MHz), and note the position of the signal on the screen. Disconnect the signal and connect the comb generator to the spectrum analyzer. Set the comb repetition rate of the generator to 10 MHz, and count the number of comb teeth to the unknown signal to the nearest 10 MHz. Next, set the comb generator to 5 MHz and repeat the process; this sets the frequency of the unknown signal to 5 MHz. Then retune the analyzer so the unknown signal is on the screen and bracketed by two visible comb teeth (whose exact frequencies are known). Reconnect the unknown signal to the spectrum analyzer and note its new position. Repeat the above procedure, with

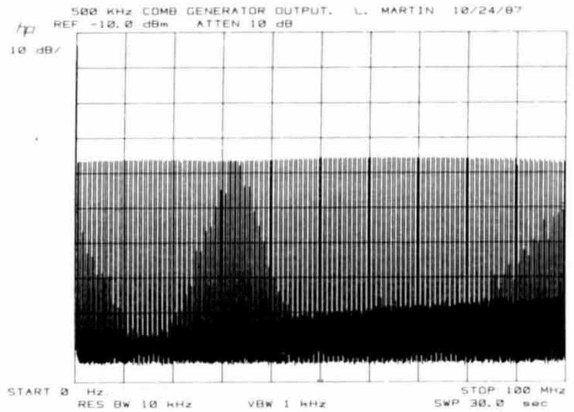

fig. 9. The output of the comb generator when set to a 500-kHz repetition rate. The vertical scale is 10 dB/div and the horizontal is 10 MHz/div.

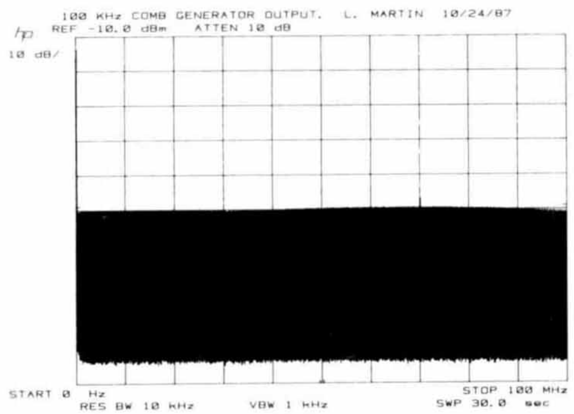

fig. 10. The output of the comb generator with a 100-kHz repetition rate. The vertical scale is 10 dB/div and the horizontal is 10 MHz/div.

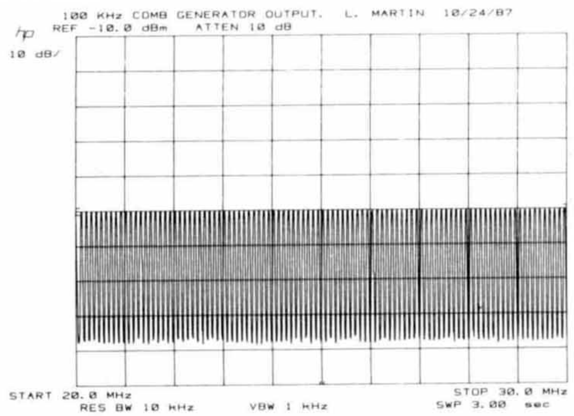

fig. 11. A closer look at the output of the comb generator with a 100-kHz repetition rate. The vertical scale is 10 dB/div and the horizontal scale is 1 MHz/div centered at 25 MHz.

smaller and smaller steps between the comb teeth, until the frequency of the unknown signal is estimated by interpolation between the nearest two 100-kHz comb teeth. You will be able to determine the frequency of the unknown signal to about 1 or 2 kHz resolution because most oscillators are relatively linear over very small tuning ranges. The absolute accuracy of the crystal oscillator sets the absolute accuracy to which the unknown frequency can be measured. The above accuracy specification means that a 100-MHz comb tooth will have an accuracy of 50 kHz — much poorer than the measurement capability of the newly calibrated spectrum analyzer.

Many low-cost receivers are not frequency synthesized. The comb generator can also be used to calibrate receiver dials in steps as fine as 100 kHz with an iterative procedure similar to that used for spectrum analyzer calibration.

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