Differential TWGs

Another variation on the triangle-wave generator (TWG) is to make the generator loop differential, as shown below. This is a simplified circuit of the Exar 2206 FG IC.

Diagram

Description automatically generated

In this circuit, the timing capacitor, C , is not grounded but is suspended differentially between current-source switches. To maintain an accurate waveform, the diff-amp following the loop must be able to reconstruct the two waveform fragments into a continuous (“glitch-free) waveform. A differential TWG was also used, with higher performance, in the HP3314A.

Autosymmetric FG

The fuller benefit of differential waveform generation was realized in the Tek FG506 prototype (never introduced as a product), shown schematized below. The difference in value of the two timing capacitors is corrected by sensing the sum of the differential waveforms and amplifying it as differential error. The –IT current source is then driven by the error to keep the waveforms symmetrical.

This auto-symmetry scheme is able to maintain symmetry over four decades of frequency sweep, a feat that is essentially infeasible with previous schemes. Asymmetry is a major cause of sine distortion and a sine sweep over four decades was featured in the FG506.

Diagram

Description automatically generated

The block diagram, shown below, of the FG506 illustrates what is involved in a sweeping FG with autosymmetry.

Diagram

Description automatically generated

An additional flourish, shown below, is the generation of an exponential sweep frequency (by the “sweep gen” block) so that by sweeping an audio amplifier or other device under test with a four-decade sine-wave (10 Hz to 100 kHz), a Bode magnitude plot can be presented on an oscilloscope screen by observing the sine amplitude across the screen. Exponential sweep causes the horizontal ‘scope axis to be displayed as a logarithmic axis. Nowadays, with microcontrollers, this simple technique is still applicable because FG frequencies often exceed maximum μC interrupt rates.

Diagram, schematic

Description automatically generated

The voltage-controlled frequency (VCF) input to the triangle-wave generator, vF , is an integrated current pulse, IF of fixed duration τ < T , where T = 1/f . Hence a fixed charge is dumped into CF when the one-shot (MMV) is triggered each cycle of the TWG output. Consequently, vF increments by ΔvF each cycle;

Diagram

Description automatically generated

The rate of change in vF (t ) over an interval of Δt is

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For many cycles, n , during the frequency sweep, the rate can be approximated by a derivative;

Text

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The TWG output frequency, f , depends on vF by scale factor, KF , and

Text

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Then combining equations,

Text

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This first-order differential equation has the solution,

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and frequency is thus swept exponentially:

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Description automatically generated

In a μC-based FG, the same basic principle can be used to simplify software generation of the exponential by avoiding calculation of the exponential function. Instead it results from incremental function generation. At low FG frequencies, for each FG cycle the μC is interrupted and vF is incremented by an amount that determines frequency sweep rate. FG frequencies can easily exceed what even a fast μC can process and the FG frequency is instead input into a μC counter by which frequency can be measured and vF controlled. During sweeping, the counter is set to overflow every N cycles, causing an interrupt in which ΔvF is applied. N depends on the low and high frequency limits of the sweep. For wideband sweeps, however, the analog circuit remains feasible and perhaps preferred, to keep what in the μC is N = 1 so that the low frequencies are swept through in a shorter time. A low frequency of 1 Hz can result in a sweep lasting seconds.

Additional FG Functions

Sine Shaper

Besides the basic TWG loop which outputs triangle- and square-waves, a sine-wave is part of the FG repertoire of functions. As in the above FG circuits, a diode-resistor network was used early in FG history as a piecewise-linear function shaper. One of several clamping circuits per shaper is shown below.

A picture containing text, weathervane

Description automatically generated

Usually three or four of these circuits are paralleled and use a common output resistance, placed between the shunt Ro of the segments and ground. By adjusting breakpoints with R and slopes with Ro , total harmonic distortion (THD) can typically be reduced at audio frequencies to around 0.1 %.

By using translinear circuits, this can be reduced further and kept lower at higher frequencies. Translinear circuits are based on the matching of BJT b-e junctions and the ability to generate power-series functions using them. For instance, a three-term Taylor-series expansion of the sine function for two quadrants is implemented by the circuit shown below. The emitter-coupled BJT pair current sources are ratios from the coefficients of the sine series.

Diagram, schematic

Description automatically generated

An improved and simplified four-quadrant sine generator is shown below. It is driven by a differential triangle-wave current and the output is a differential sine-wave. Art Metz developed it and Tektronix holds an expired patent on it.

Diagram, schematic

Description automatically generated

THD values of well under 0.1 % can be achieved with this circuit.

Control of Amplitude, Frequency, Symmetry, and Gating

Because of the versatility of FG circuitry, it is possible to give the user control of several waveform parameters. In addition to the voltage-controlled frequency (VCF) input, a multiplier provides amplitude control for amplitude modulation of the waveforms. The two timing-current sources allow for independent control of each half of the cycle. Symmetry can be varied in some FGs by an input voltage, but in many, the waveform selection function provides some fixed symmetries – usually 10 % and 90 % values that result in ramps, reverse ramps, and pulses. Sines with asymmetric half-cycles are also a fallout of the FG circuits though they are seldom offered as user selections; they are of dubious utility as waveforms though they do occur in some digital phase modulation techniques.

What can be of use is the gating of waveforms by an external voltage input. The waveform is turned on and off. Of greater utility is the phased gating of FG waveforms. The Tek FG501 has a control whereby the starting phase can be adjusted. In another variation, N cycles can be synchronously gated and counted for N -cycle burst generation.

Presentation of the output can vary depending on the power amplifier that drives it. A 50 Ω output resistance is standard. Amplitude can range from 5 V for fast generators to +/- 20 V for versatile ones. Output offset control adds versatility. A FG differs from a PG in that amplitude and offset must be varied interactively for setting desired high and low pulse or peak and valley levels. However, there is no reason that amplitude processing in Fgs need be any different than in PGs.

TWG WITH OPAMP



