Application Briefs

Frequency Modulator

A FREQUENCY-MODULATED SINE-WAVE OSCILLATOR WITH TWO-PHASE OUTPUT USING IC MULTIPLIERS & OP AMPS

Low-cost high-performance complete-on-a-single-chip IC multipliers, such as the AD530,* make it feasible to build oscillators having two-phase sine wave output (i.e., $\sin\omega t$ and $\cos\omega t$), with frequency controllable by a voltage. The frequency may be varied over a wide range, depending on the dynamic range of the multiplier, for frequency-sweep applications, or it may be centred about a fixed frequency for highly-linear frequency modulation. If the slightly-regenerative damping and amplitude-control circuitry used for oscillators is replaced by slightly-degenerative damping, and an additive input signal is applied, the circuit becomes a variable-frequency tuned filter.

In the example to be discussed here, an IC multiplier is used because of its low cost. However, there is no inherent bar to the use of modular multipliers, such as Model 422, for increased bandwidth (to 5MHz), or Model 427, for increased low-frequency accuracy and resolution (0.1%), or even multiplying D/A converters, for digital control of frequency.†

HOW IT WORKS

These applications are all based on the analog scheme for solving a second-order differential equation, as shown in Figure 1. Damping is omitted for simplicity, but it is provided in the form of an additive feedback loop around either integrator, as will be seen in the practical example.

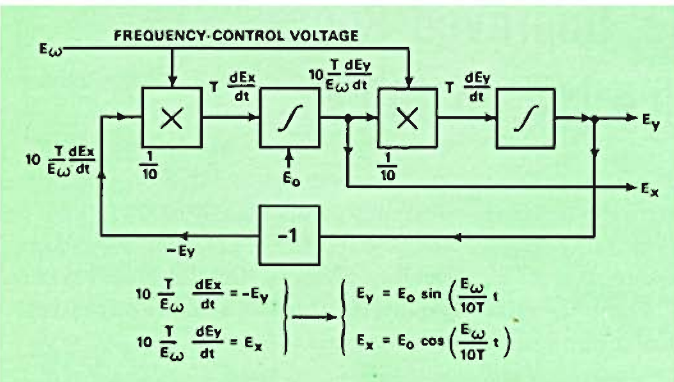


Figure 1. Block Diagram of Theoretical Controlled-Frequency Two-Phase Oscillator

If we assume that a voltage E_x occurs at the output of the first integrator and E_y occurs at the output of the second integrator, then the inputs are, respectively, TdE_x/dt and TdE_y/dt, where T is a dimensional constant. The integrators are preceded by multipliers, one of the inputs to which is the control voltage. E_ω. The other inputs to the multipliers must therefore be: $(10T/E_\omega)dEx/dt$ and $(10T/E_\omega)dE_y/dt$, where 10 is the dimensional constant of the multipliers ($e = e_1 e_2/10$). The loop is closed through a sign-inversion, and it therefore embodies the pair of differential equations shown in Figure 1, the solution to which is indicated for an initial condition E_o on the first integrator. It will be seen that the natural frequency is directly proportional to E_ω, for fixed values of same. Of course, if E_ω varies, the differential equations have time-varying coefficients, and the equation describing the solution is considerably more difficult to express (but the circuit will faithfully provide the correct response, however complicated the mathematical function it represents).

In practical designs, the important factors are: frequency scaling, amplitude establishment and maintenance, and damping. The frequency scale is determined, as shown in the equations by T, which is the integrators' characteristic time (=RC, for operational-amplifier integrators). For one-shot, or keyed oscillators, the amplitude is established by initial conditions, to which the integrators are reset after each run. For free-running oscillators, the amplitude builds up, with the aid of negative damping, until a limiting value is reached, at which point positive damping is applied to the peaks, and the amplitude stabilizes, with net zero damping. The essential elements are an amplitude reference and a nonlinear element to switch the damping (a zener diode can serve both purposes).

A PRACTICAL OSCILLATOR (WIDE RANGE)

The oscillator shown in Figure 2 delivers a 2-phase sine-wave output tuneable over a 10:1 frequency range by means of a dc control voltage. The output amplitude is stabilized by zener reference diodes at 7V rms, and maintained constant within 1 dB over the range of frequencies.

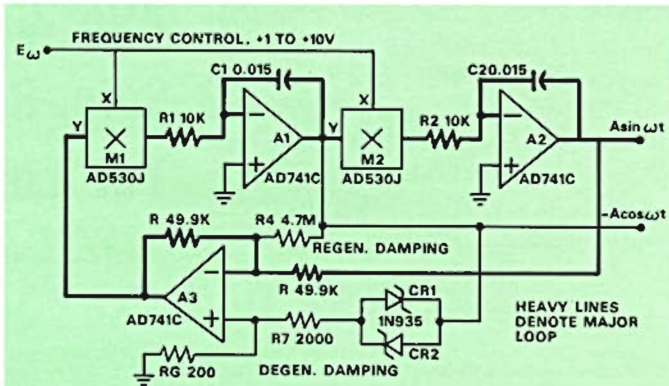


Figure 2. Practical Controlled-Frequency Two-Phase Oscillator

The oscillator system consists of two integrators, A1 and A2, and a unity-gain inverter, A3, which form a negative feedback loop. The effective time constants of the integrators are varied by a pair of multipliers, M1 and M2, which serve to (in effect) increase the conductance of R1 and R2 as the control voltage is increased, thus decreasing the time constant and increasing the natural frequency. Viewed in terms of gain and phase, at frequency $f_n = 1/(2\pi T)$, with $E_\omega = 10V$, both integrators have 90° phase lag and unity gain, the multipliers also have unity gain, and there are three sign inversions, all of which looks like a loop gain of $1\angle 0°$, at f_n (and only at f_n).

To assure sufficient regeneration to start and maintain oscillations, a small amount of positive feedback is fed from the output of A1 through R4 to the input of A3. This causes

*For information on the monolithic AD530 Multiplier-Divider-Squarer-Square Rooter, use reply card. Circle E13

†For information on other multipliers and multiplying D/A converters, use reply card. Circle E14

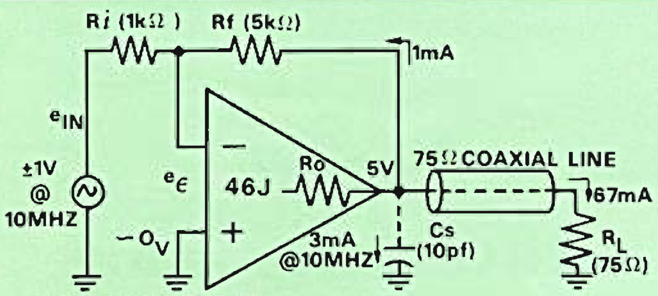
oscillations to build up until the zener diodes CR1 and/or CR2 begin to conduct at the tips of the waveform and produce increased negative feedback via the positive input of A3. The positive feedback must be kept small enough to provide buildup at a reasonable rate without requiring a large amount of negative feedback to keep the amplitude under control, since the zener diodes introduce some distortion. (Fortunately, this small distortion is integrated once in A1 and again in A2, so that the output of A2 is quite clean, and that of A1 is "oscilloscope-clean.")

With the values shown, the oscillator can be tuned from 100Hz to 1 kHz. Distortion at the cosine output was measured at 0.74% at 100Hz and 0.46% at 1 kHz. At the sine output, distortion was 0.64% at 100Hz and 0.18% at 1 kHz. Distortion at the lower end of the tuning range is somewhat affected by nonlinear "Y" feedthrough in the multipliers, and this feedthrough, plus temperature drift in the low-cost IC multiplier, places a limit on the useful tuning range.

It should be noted that, for negative values of E_ω, though the main loop still has the proper polarity to enable it to work undamped, the damping polarities are, unfortunately, reversed.

FREQUENCY-MODULATED OSCILLATOR

It's easy to modify this design to operate with frequency modulation about a fixed frequency. For example, to operate at 1 kHz, with ±10% frequency variation linearly controlled by E_ω (now ±10V), change R1 and R2 to 100kΩ, and add 10kΩ resistors between the output of A3 and the input of A1, and between the output of A1 and the input of A2.



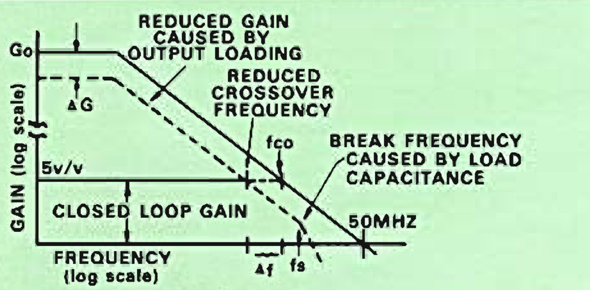
DESIGN REQUIREMENTS:

Output Current ($I_L + I_f + I_C$) ≅ 70mA — Gain-Bandwidth = 50MHz

Slew Rate ($2\pi f_{co} E_o$) = 314V/µs — f_{co} = 10MHz

Voltage Gain = 5V/V @ 10MHz (−3dB)

Figure 2. Line Driver Application



Gain Reduction (ΔG) = $G_o\left(\frac{R_o}{R_L + R_o}\right)$ — $f_s = 1/(2\pi C_s R_p)$

Bandwidth Reduction (Δf) = $f_{co}\left(\frac{R_o}{R_L + R_o}\right)$ — ($R_p = R_o \parallel R_f \parallel R_L$)

Figure 3. Effect of Output Impedance on Performance

Application Briefs

Notes on a Fast Op Amp

Model 46,* introduced in the last issue of *Dialogue,* is a wideband differential operational amplifier optimized for applications requiring exceptionally fast settling times (to 0.1% in 100ns, to 0.01% in 300ns), fast slew rates (1000V/µs), and high output currents (±100mA at ±10V). To obtain, measure, and make use of such performance is no trivial matter. The data sheet* outlines many of the salient considerations. Also, the literature is replete with articles on the meaning and measurement of settling time (e.g., Demrow in *Analog Dialogue,* Vol. 4, No. 1, Pease in the notes for the *EEE* L.I.C. Seminars, 1971).

In these columns, we offer a digest of two of the topics covered in the Model 46 technical data, with the hope that they will be found useful and inspire further study and application of fast op amps.

SETTLING TIME vs SIGNAL SWING

The curves in Figure 1, which represent the typical performance of Model 46, may be used to evaluate tradeoffs between settling time, error band, and step size. They can furnish approximate answers to such questions as: What is the largest output voltage step that can settle to within ±10mV in 70ns?

LINE-DRIVER APPLICATION

The combination of high power output and wide bandwidth make the Model 46 unusually suitable for transmitting high-frequency signals over data lines, usually at MHz rates. In these applications, the amplifier must provide substantial power gain at wide bandwidths, which places significant demands on amplifier slew rate and output current capability. A typical application is illustrated in Figure 2, which indicates the key amplifier requirements for driving a terminated 75-ohm coaxial line at 10MHz. The design hinges on the effect of the amplifier's output impedance on overall performance (Figure 3).

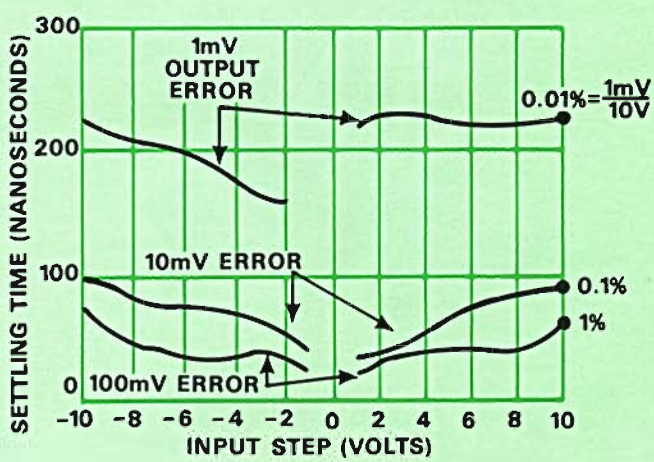


Figure 1. Model 46 Settling Time vs Input Step and Error Band (Unity-Gain Inverter)

*For complete data on Model 46 and its applications, use reply card. Circle E15

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