THE PLL HAS NUMEROUS LIMITATIONS, INCLUDING LOW INPUT-SIGNAL SENSITIVITY AND CONTRADICTORY DESIGN REQUIREMENTS. THE SYNCHRONOUS OSCILLATOR DOESN'T SUFFER FROM THESE PROBLEMS AND HAS MANY POWERFUL PROPERTIES, INCLUDING THREE INTERNAL FILTERS AND A SELF-REGULATION PROPERTY.

Synchronous oscillator outperforms the PLL

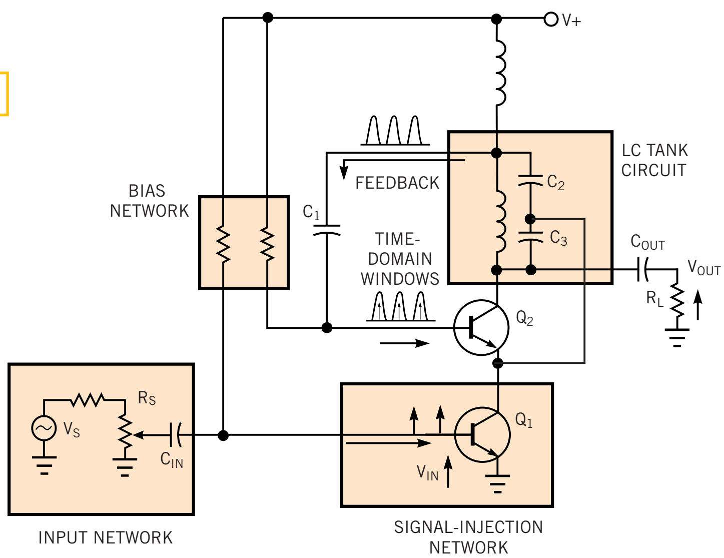
THE POPULARITY OF PLLs does nothing to reduce the basic shortcomings and limitations that accompany such networks. PLLs are susceptible to noise that external signals carry and can acquire lock only if the SNR is greater than 3 dB. The input-signal sensitivity of a PLL is also poor; the PLL cannot detect input signals lower than −25 dBm.

An alternative network, the synchronous oscillator (SO), has many advantages over the PLL. The SO works reliably when the SNR is as low as −40 dB, and the SO can detect signals as low as −100 dBm. The SO is a universal multifunction network that can synchronize, track, amplify, improve the SNR by as much as 70 dB, and modulate and divide by rational integer numbers, such as 3÷4 and 7÷8, in one step (**Figure 1**). With minor modifications, the SO in **Figure 1** can perform a variety of functions, including a PLL, clock and carrier recovery, a filter, an ADC, an audio/video-to-FM converter, a DAC, and an audio/video-to-direct-sequence-binary-phase-shift-keying/quadrature-phase-shift-keying converter.

The PLL has some particularly notable limitations. First, the loop filter must simultaneously satisfy the noise-rejection, tracking-range (same as data-bandwidth), and acquisition-time requirements. Unfortunately, the noise bandwidth and the tracking range are highly interdependent. Improving the noise rejection results in a reduced tracking range and an increased acquisition time. In other words, the product of the noise rejection and the tracking range is constant. Additionally, the acquisition time is highly dependent on the tracking range. The wider the tracking range, the faster the acquisition time. Any compromise between noise rejection and tracking range deteriorates the overall design.

Thus, the filter requirements for high noise rejection on one side and fast tracking and acquisition time on the other are contradictory. High noise rejection requires a narrow filter bandwidth, but a

Figure 1



The synchronous oscillator (SO) is a universal multifunction network that has many advantages over a PLL. Note the bursts in the feedback path.

TABLE 1–EXPERIMENTAL RESULTS

Parameter	PLL	SO
Maximum noise rejection (dB)	3	38
Minimum input-signal sensitivity (dBm)	–25	–100
Acquisition time	4 μsec	Less than 100 nsec

wide beta bandwidth and fast acquisition time require wide filter bandwidth. The loop filter simply cannot handle these contradictory requirements simultaneously. Designers can rarely meet all of the design requirements, and the result is a poor design after making the necessary compromises. Temporary solutions, such as widening the tracking range by sweeping the entire data bandwidth during acquisition, require additional equipment and introduce additional problems.

Another limitation of a PLL is its indirect synchronization process. The process is indirect because a PLL converts the synchronization signal to a dc signal through the phase detector and the integrating amplifier in the loop. This process causes errors and nonlinearities in the loop and in the voltage-to-frequency characteristics of the VCO. The phase detector and the loop filter are the main sources of delay, which can slow the acquisition.

SO TOPS A PLL

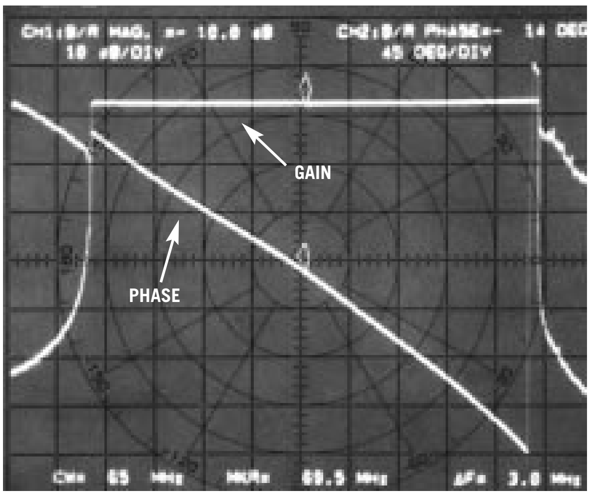
The SO has none of the PLL's limitations. The SO has three internal filters that work largely independently: the noise-rejection, or instantaneous, filter; the tracking-range, or data, filter; and the sampling filter. The summation of all noise-rejection filters generates the tracking-range filter. The sampling filter is a lowpass filter that results from the Class C operation of the oscillator; that is, the positive feedback is not continuous but occurs in bursts.

The SO operates like a spectrum analyzer. The noise-rejection filter corresponds to the resolution filter of the analyzer. The SO looks at any time to the instantaneous input frequency and its immediate surrounding frequencies to track the entire frequency spectrum. The SO can have a 200-Hz noise-rejection filter with a tracking range of several megahertz. The internal regeneration gain performs important functions. High regeneration gain implies high input-signal sensitivity, high noise rejection, and wide tracking range. The SO is also an energy-efficient network whereby the regeneration process provides energy to perform functions.

The SO has many powerful and unique functional properties. The internal regeneration gain and the input-signal sensitivity are inversely proportional to the input-signal level. This inverse relationship implies that the input-signal sensitivity and the regeneration gain go toward infinity as the input-signal level tends toward zero.

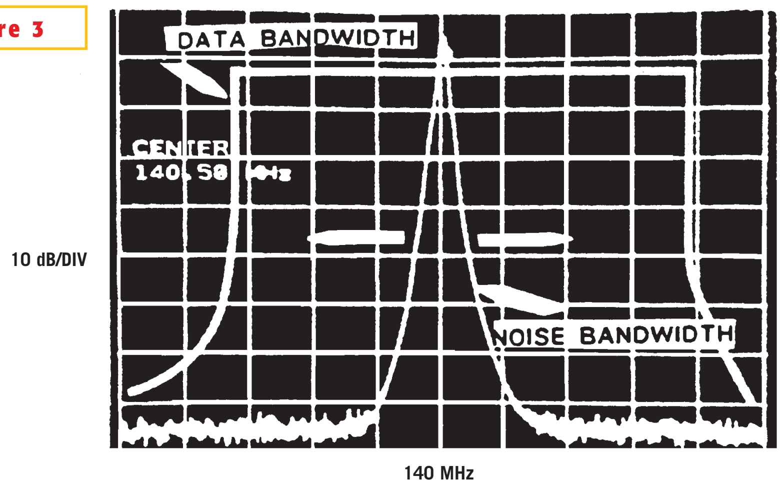
Still another powerful property of SOs

Figure 2



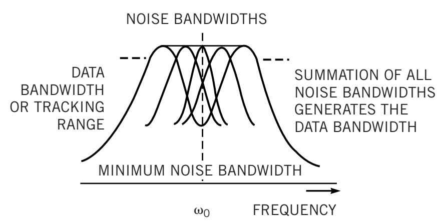
Gain- and phase-frequency curves show a flat gain curve with abrupt transition corners and that the phase of an SO is always 180° within the tracking range.

Figure 3



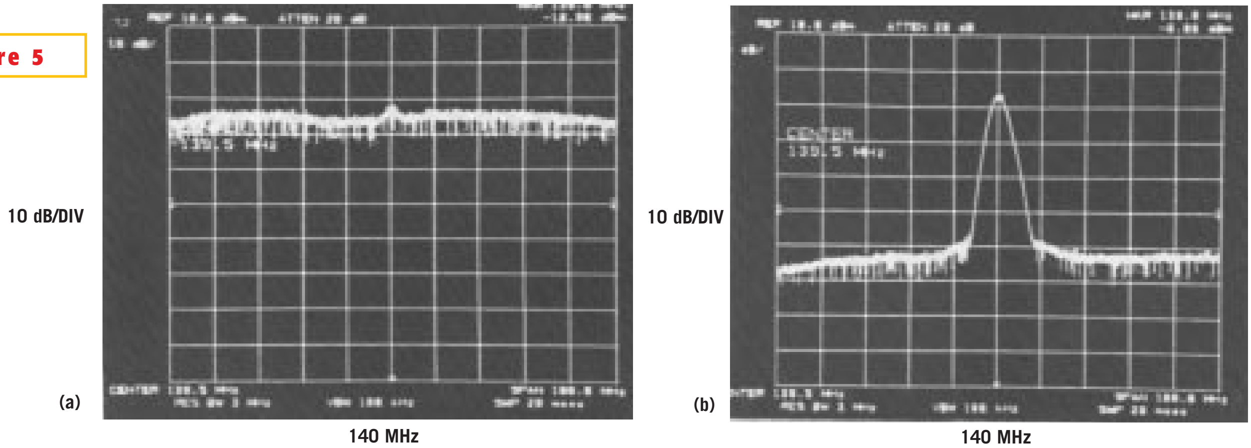
The high-Q noise-rejection filter moves according to the input frequency and its immediate surrounding frequencies to form the tracking range, or data bandwidth.

Figure 4



The summation of the noise filters forms the tracking range.

Figure 5

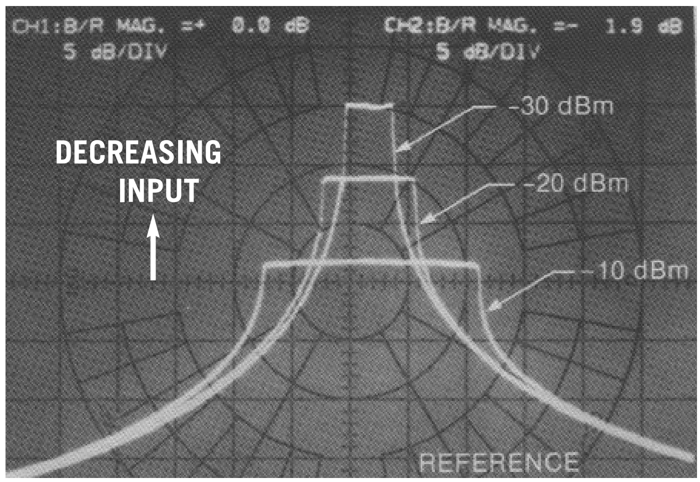


Applying a noisy signal directly to a spectrum analyzer results in an SNR of approximately 0 dB (a). Applying the same signal to the spectrum analyzer through an SO improves the SNR by more than 40 dB (b).

is self-regulation, which provides a flat and wide tracking range with abrupt transition corners. The SO also features a maximization process, whereby the product of two parameters leads to optimization. For example, you can independently reduce the noise-rejection bandwidth and increase the tracking range of the SO. Classical networks lack this type of optimization; the product of the two parameters is constant.

The SO is a simple circuit that dissipates few milliwatts. It also has good frequency stability and low phase jitter because it has an instantaneous, or noise-rejection, Q as high as 4×10^6. The SO has no frequency limitation and no limitation in noise rejection or tracking range. The thermal noise of the individual circuit components limits the noise rejection.

Figure 6



The lowest input to the SO provides the highest gain.

RESULTS CONFIRM PERFORMANCE

An independent group at Comsat Laboratories performed experiments comparing the performance of SOs to PLLs in clock-recovery networks working at 30 Mbps (**Reference 1**). **Tables 1** and **2** show the results of two experiments. The test results in **Table 2** show the effect of changing the number of zeros in the data stream. This experiment includes no noise because noise in this case renders the PLL useless.

Figure 2 shows the gain- and phase-frequency curves that correspond to **Figure 1**. The phase is always 180° within the tracking range. The SO provides as much as 80 dB of regeneration gain and a 70-dB improvement in SNR over the PLL. Recall that the SO can detect signals as low as −100 dBm and signals with SNRs as low as −40 dB compared with a PLL's respective numbers of −25 dBm and 3 dB. Thus, the SO can dig out signals when the noise power is 10,000 times higher than the signal power.

TABLE 2–MORE RESULTS

Data-stream zeros	PLL (μsec)	SO (μsec)
0	7.46	2.9
10	7.50	2.9
20	8.50	2.9
30	13.70	2.9
100	Falls apart	2.9
200	Falls apart	2.9
300	Falls apart	6.2

Figure 3 shows the gain-frequency and noise-rejection responses of an SO within the tracking range, or data bandwidth. The high-Q noise-rejection filter moves left and right responding to the input frequency and its immediate surrounding frequencies and forms the entire tracking range. The summation of all noise-rejection filters determines the tracking range. **Figure 4** shows the summation of the noise bandwidths that form the tracking range. Two internal filters are enough to provide a powerful network. The SO also has a third filter that stems from the Class C operation of the SO, for which positive feedback occurs in bursts. This filter is a sampling filter and in this case is a lowpass filter.

Remember that noise bandwidths

can be as low as 100 Hz. **Figure 5a** shows a display of noise signals applied directly to a spectrum analyzer. The SNR of the signal is approximately 0 dB. When you apply the same signal to the spectrum analyzer through an SO, the SNR improvement is greater than 40 dB (**Figure 5b**). You minimize the effect of the resolution bandwidth of the spectrum analyzer by setting it to 3 MHz. You can approximate the SNR improvement according to the following equation:

$$\text{SNR} = 40\text{ dB} = \frac{10\log 3\text{ MHz}}{\text{SO noise bandwidth}}.$$

The noise bandwidth is 300 Hz, and the SO has a 1-MHz tracking range. For an IF of 140 MHz, the Q of the SO is 2.9×10^6, which is a moderate Q. You can use the following equation to obtain this result:

$$Q = \frac{140\text{ MHz}}{3-\text{dB bandwidth}}.$$

The sampling filter is a correlation filter, whereby the following equation determines the noise rejection: SNR=10logN, where N is the number of samples. By sampling 1000 times, the SNR improvement is 30 dB.

THE SO IS AN ENERGY FUNCTION

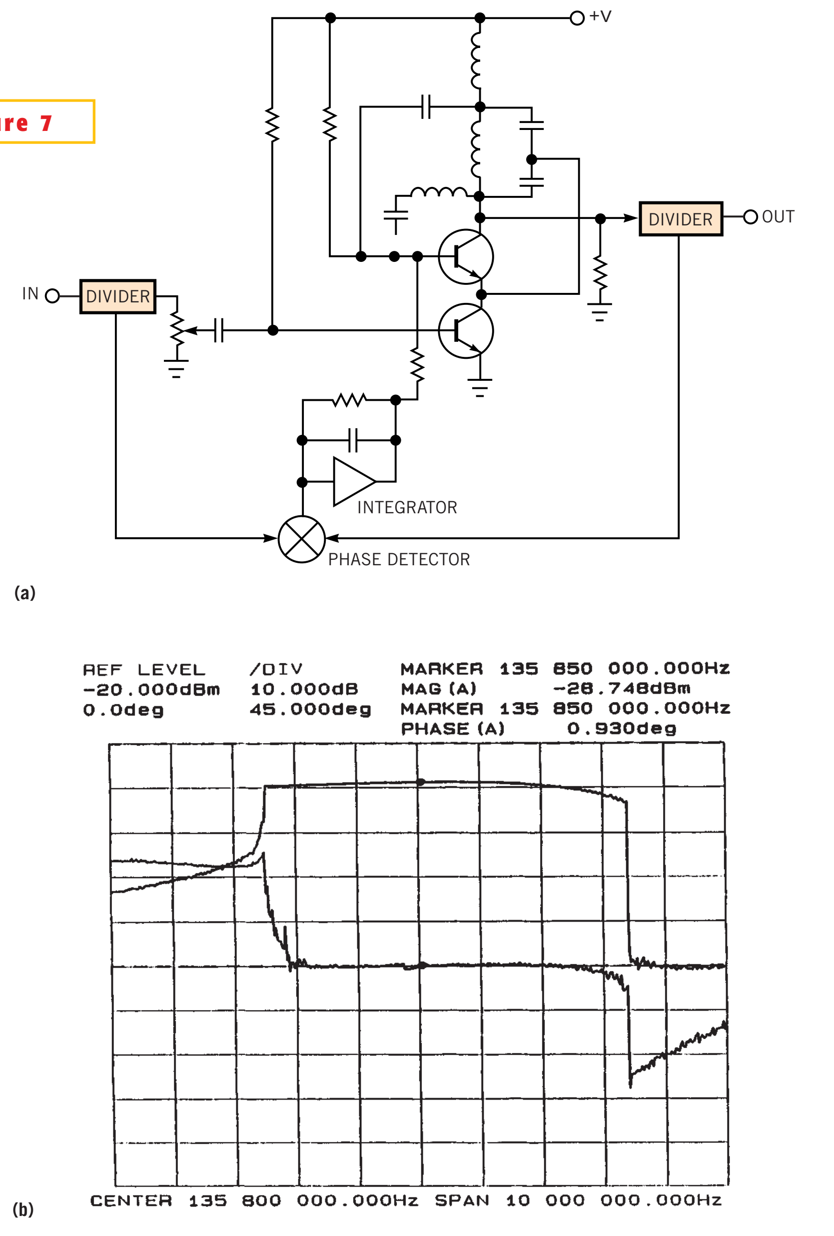
The SO belongs to a new class of networks called "energy functions"; the level of applied external energy and the level of internal energy determine all the functional properties of the SO. The applied external energy must be below −5 dBm so that it does not disturb oscillations but becomes part of the regeneration. Also, the regeneration gain must be high so that input signals do not disturb regeneration.

Specifically, there are two energies associated with SOs: the input-signal energy and the internal regeneration gain. The regeneration gain and the input-signal sensitivity are inversely proportional to the input-signal level. This relationship implies that the regeneration gain and the input-signal sensitivity go to infinity as the input-signal level goes to zero. The input energy level determines the tracking range and the regeneration gain. In turn, the regeneration gain determines the noise rejection, the frequency stability, and the amount of jitter. High regeneration gain implies high noise rejection, wider tracking range, and faster acquisition. The two transistors in **Figure 2**, Q_1 and Q_2, usually have high β greater than 80.

To provide high regeneration gain, the circuit has two positive-feedback paths. The main positive-feedback path is from the top of the tank circuit to the base of the oscillator transistor, Q_2, through C_1. The second positive-feedback path is from the center of the tank circuit's capacitor, between C_2 and C_3, to the collector of Q_1. Another means of providing high regeneration gain is to decrease the input-signal level. An input level of −30 dBm has the highest gain (**Figure 6**). The input-signal sensitivity is as follows, where K is a constant and E is the input-energy level: Sensitivity=$KE^{-2/3}$.

This **equation** and **Figure 6** provide proof of this paradoxical performance. According to **Reference 2**, which includes a mathematical proof, if two oscillators are loosely coupled, the one with the low-

Figure 7



A coherent phase-locked SO (CPSO) retains all of the properties of the SO and provides coherency (a). The corresponding gain and phase curves appear in (b).

est energy imposes its frequency on the one with the highest energy.

SOs SELF-REGULATE

Self-regulation is not a saturation process, such as **Reference 3** defines. Self-regulation provides continuity in functional properties by conserving energy and balancing the energy states of self-regulating functions. Saturation does not exist in the functional properties of the SO. Self-regulation provides the SO with the flat tracking range and abrupt transition corners that **Figure 2** shows.

The following functions perform self-regulation: input-signal sensitivity times the input-signal level, regeneration gain times the input-signal level, and the regeneration gain times the amplitude of the oscillations. These self-regulation properties are constant and are powerful functions that reinforce the functional properties of SOs. The self-regulation property also prevents the SO from self-destructing. Continued positive feedback should lead to self-destruction but does not because regeneration gain times the amplitude of the oscillations is constant. Whenever regeneration goes up, the amplitude of oscillations goes down, or vice versa. Self-regulation is a natural phenomenon. The maximization process is unique to an SO. The SO maximizes the product of the noise rejection and the tracking range. Maximization leads to optimization in the SO, but, in any other field or circuit, maximization of two parameters leads to self-destruction.

Sampling is also a natural phenomenon for an SO. **Figure 1** shows the sampling process of an SO. The input signal enters the bursts that burst-mode operation of the SO produces. The positive feedback is not continuous but occurs in bursts. The input signal enters the burst, and the combined signal enters the SO for synchronization. The burst, or sampling, process is an optimum filtering process.

The coherent phase-locked SO (CPSO) in **Figure 7a** retains all of the properties of the SO and provides coherency, or zero-phase error. The CPSO also provides wider tracking range than an SO for the same input level. **Figure 7b** shows the corresponding gain-phase curves.□

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Author Biography

Vasil Uzunoglu designs and develops circuits and systems using synchronous oscillators for his company, Synchtrack (Gaithersburg, MD). He has an MSEE from the University of Missouri—Rolla and is a member of the IEEE. He has published numerous papers on synchronous oscillators and related circuits.