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IN ADDITION TO THEIR COMMON ROLE AS CLOCK SOURCES IN DIGITAL SYSTEMS, OSCILLATORS PLAY AN IMPORTANT ROLE IN INSTRUMENTATION APPLICATIONS. A SIMPLE AND TUNABLE OSCILLATOR BOOSTS THE PERFORMANCE OF A RANGE OF CIRCUITS. PART 1 OF THIS SERIES PRESENTS AN RTD DIGITIZER, THERMISTOR-TO-FREQUENCY CONVERTERS, AND RELATIVE-HUMIDITY DIGITIZERS.

A clock for all reasons, part 1: Monolithic oscillator invigorates instrumentation applications

Oscillators are fundamental circuit building blocks. A substantial percentage of electronic apparatus use oscillators as timekeeping references, as clock sources, for excitation, and for other tasks. The most obvious oscillator application is a clock source in digital systems. A second area is instrumentation. Transducer circuitry, carrier-based amplifiers, sine-wave generators, filters, interval generators, and data converters all use forms of oscillators. Although various techniques are common, a simply applied, broadly tunable oscillator with good accuracy widens the design possibilities of many of these circuits.

Commonly employed oscillators are resonant-element based or RC types (**Table 1**.) Quartz crystals and ceramic resonators offer high initial accuracy and low drift—particularly quartz types—but are

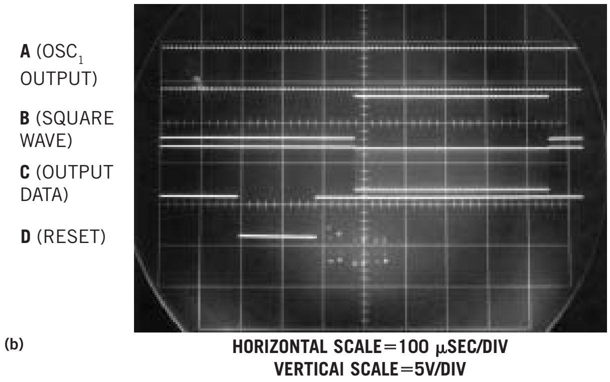
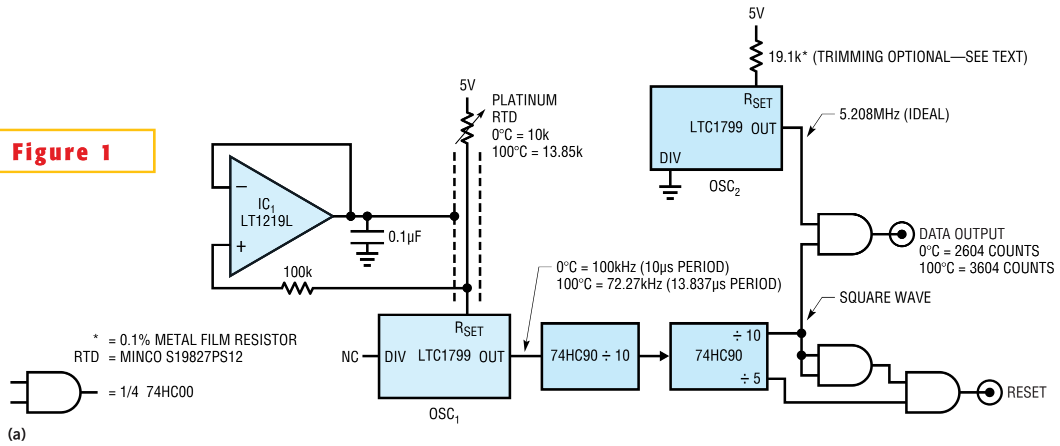


Figure 1



A platinum RTD digitizer is accurate to within 1° from 0 to 100°C (a). The circuit divides OSC$_1$'s output (Trace A) by 100 and gates the result with a 5.2-MHz clock, to produce data bursts (Trace C) that correspond to temperature (b).

essentially not tunable over any significant range. Typical RC types have lower initial accuracy and increased drift but are easily tunable over broad ranges. A problem with conventional RC oscillators is that considerable design effort is necessary to achieve good specifications. The LTC1799 is also an RC type, but its accuracy and drift specifications fit between resonator-based types and typical RC oscillators (see **sidebar** "A simple, high-performance oscillator"). The device's combination of simplicity, broad tuning range, and good accuracy invites use in instrumentation circuitry, as in the following examples.

PLATINUM RTD DIGITIZER

Using a platinum RTD for R_{SET} of the LTC1799 oscillator results in a highly predictable OSC_1 output period versus temperature (**Figure 1a**). A series of counters scale the OSC_1 output and present the resultant signal to a clocked, period-determining logic network that delivers digital output data. Over a sensed-temperature range of 0 to 100°C, the circuit delivers 1000 counts with accuracy inside 1°C. You can extend the circuit's range for sensor limits of −50 to +400°C by using a monitoring processor to implement linearity correction in accordance with sensor characteristics. Linearity deviation over −50 to +400°C is several degrees (**Reference 1**).

If the RTD is at the end of a cable, IC_1 should drive the cable shield, as the **figure** shows. This action bootstraps the cable shield to the same potential as R_{SET}, eliminating jitter-inducing capacitive-loading effects at the R_{SET} node. The R_{SET} node of the LTC1799 is not unduly sensitive but does require management of stray capacitance (also see **sidebar**).

Waveforms show the circuit's operation (**Figure 1b**). The RTD determines OSC_1's output (Trace A), which the circuit divides by 100 and produces in square-wave form (Trace B). The logic network combines with OSC_2's fixed frequency to digitize the period measurement, which appears as output data bursts (Trace C). The logic also produces a reset output (Trace D), facilitating synchronization of monitoring logic.

The accuracy is approximately 1.5°C, primarily due to the initial error of the LTC1799. Obtaining accuracy inside 1°C involves simulating a temperature of 100°C, which is equivalent to 13,850Ω, at the sensor terminals and trimming R_{SET} for the appropriate output. A precision resistor decade box, such as the ESI DB62 (www.esi.com), allows convenient calibration.

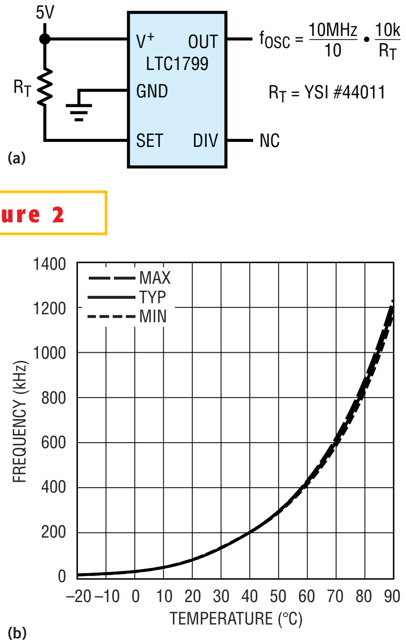


Figure 2

A simple temperature-to-frequency converter uses a thermistor to bias R_{SET} (a) and produces a predicable but nonlinear frequency output (b).

THERMISTOR-TO-FREQUENCY CONVERTER

A simple circuit also directly converts temperature to digital data (**Figure 2a**). In this case, a thermistor sensor, R_T, biases the R_{SET} pin. The LTC1799 frequency output is predictable although nonlinear. The inverse R_{SET}-versus-frequency relationship combines with the thermistor's nonlinear characteristic to give **Figure 2b**'s data. The curve is nonlinear although tightly controlled.

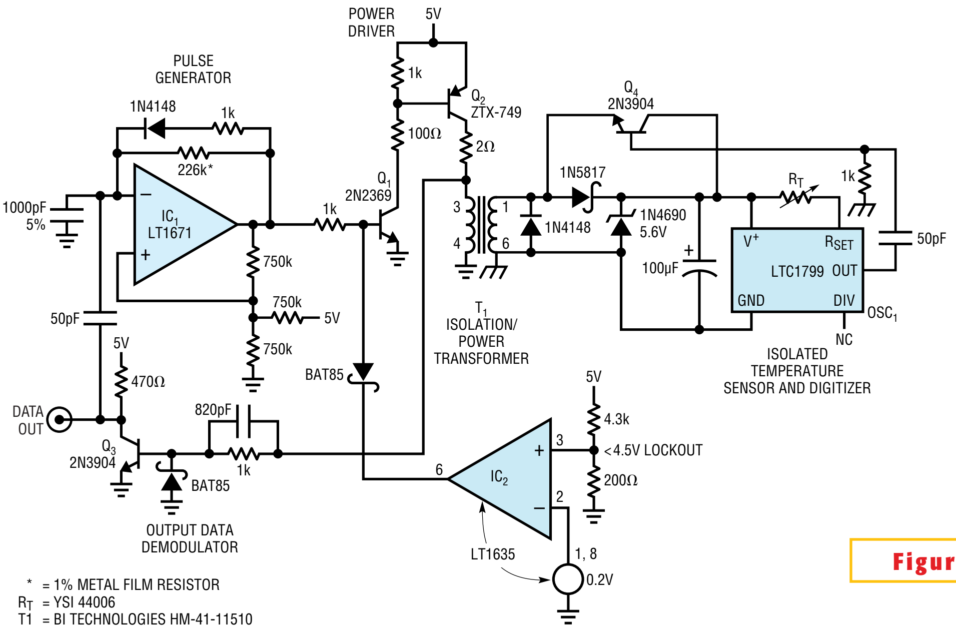
ISOLATED CONVERTER

An alternative circuit, which builds on the previous approach, galvanically isolates the thermistor from the circuit's power-and data-output ports (**Figure 3a**). The 3500V breakdown barrier between the thermistor and the power- and data-output ports permits operation at high common-mode voltages, which are common in industrial-measurement situations.

The pulse generator comprising IC_1 and associated components runs at approximately 10 kHz and produces a 2.5-µsec-wide output Trace A (**Figure 3b**). Q_1 and Q_2 provide power gain, driving T_1. (Trace B is Q_2's collector.) T_1's secondary responds by charging the 100-µF capacitor to a dc level via the 1N5817 rectifier. The capacitor powers OSC_1, which oscillates at the sensor-determined frequency. OSC_1's output, which the circuit differentiates to conserve power, switches Q_4. Q_4, in turn, drives T_1's secondary. T_1's primary receives Q_4's signal, and Q_3 amplifies this signal, producing the circuit's data output (Trace C). Q_3's collector also lightly modulates IC_1's negative input (Trace D), which synchronizes T_1's

TABLE 1–CHARACTERISTICS OF OSCILLATOR TYPES

Clock type	Typical frequency accuracy (%)	Typical frequency range	Tunability	Temperature coefficient	Power-supply-rejection ratio	Comments
Quartz	0.005	10 kHz to 200 MHz	Poor	0.5 ppm/°C, easily achieved	1 ppm/V	High stability and initial accuracy at expense of tunability; essentially no tunability; stability of 1×10^{-9} achievable with compensation techniques
Ceramic resonator	0.5	250 kHz to 60 MHz	Poor	30 ppm/°C	20 ppm/V	Lower performance and cost than quartz; essentially untunable
LTC1799	1.5	1 kHz to 33 MHz	Good	40 ppm/°C plus resistor-temperature coefficient	500 ppm/V	Add 10 to 50 ppm/°C temperature coefficient, depending on resistor type; extremely small footprint: SOT-23 and one resistor
Typical RC-based clock	10	1 Hz to 25 MHz	Good	200 ppm/°C	2500 ppm/V	Requires careful design and component selection for best results



CKT GROUND

FLOATING COMMON

(a)

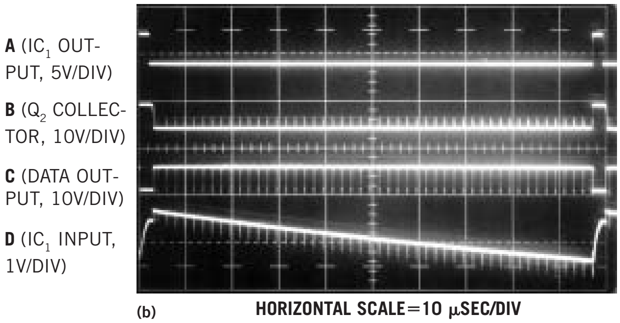


Figure 3

A galvanically isolated thermistor digitizer has a 3500V breakdown barrier (a). IC_1 provides pulsed power (Trace A) to OSC_1 via Q_1, Q_2, and T_1. Q_3 extracts data and presents it to the output (Trace C) (b).

primary drive to the data output. IC_2 prevents erratic circuit operation below 4.5V by removing Q_1's drive.

The pulse generator's clocking, while maintaining OSC_1's isolated dc power supply, generates periodic cessations in the frequency-coded output. You can use these interruptions as markers to control the operation of monitoring logic. Thermistor characteristics determine the output frequency as the **Table 2** shows.

HETERODYNE-BASED RH-SENSOR DIGITIZER

You can also design a circuit to convert the varying capacitance of a linearly responding RH (relative-humidity) sensor to a frequency output (**Figure 4a**). The 0-Hz to 1-kHz output corresponds to 0 to 100% sensed RH. Circuit accuracy is 2%, plus an additional tolerance dictated by the selected sensor's grade. Circuit temperature coefficient is 400 ppm/°C, and PSRR (power-supply rejection ratio) is less than 1% over 4.5 to 5.5V. Additionally, one sensor terminal attaches to ground, which is often beneficial for noise rejection.

This circuit is basically a heterodyne circuit. The circuit mixes two oscillators—one variable and one fixed—to produce sum and difference frequencies. The capacitive humidity sensor controls the variable oscillator. The demodulated difference frequency is the output. (Other examples have applied heterodyne techniques, which you usually associate with communications circuitry, to instrumentation. This circuit's operation is adapted from approaches in **references 2**, **3**, and **4**.) The heterodyne frequency-subtraction approach permits a sensed 0% RH to give a 0-Hz output, even though sensor capacitance is not zero at an RH of 0%.

IC_1 and associated components comprise a sensor-controlled variable oscillator that runs between the indicated output frequencies for the noted RH-

A SIMPLE, HIGH-PERFORMANCE OSCILLATOR

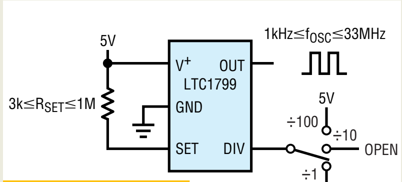


Figure A

The ratio of the voltage between the V^+ and SET pin and the current entering the SET pin controls the master-oscillator frequency of the LTC1799. A pin-programmable frequency divider permits output-frequency ranging.

The LTC1799 is a simple device with a sole analog input, the R_{SET} node (**Figure A**). A single R_{SET} resistor at this node programs the device's internal clock, and pin-settable decade dividers scale the output frequency. Various combinations of resistor value and divider choice permit outputs of 1 kHz to 33 MHz. An inverse relationship between resistance and frequency means that the LTC1799's period versus resistance is linear. Its board footprint, a five-pin SOT-23 package and a single resistor, is notably small, and an external timing capacitor is unnecessary.

The ratio of the voltage between the V^+ and SET pins and the current entering the SET pin controls the device's internal master oscillator. A PMOS transistor and its gate bias force the voltage on the SET pin to approximately 1.13V less than V^+. This voltage is accurate to ±7% at a particular input current and supply voltage. The effective input resistance is approximately 2 kΩ. The R_{SET} resistor connects internally between the V^+ and SET pins and locks together the variation between the voltage V^+-V_{SET} and current I_{RES}. This design provides the LTC1799's high precision.

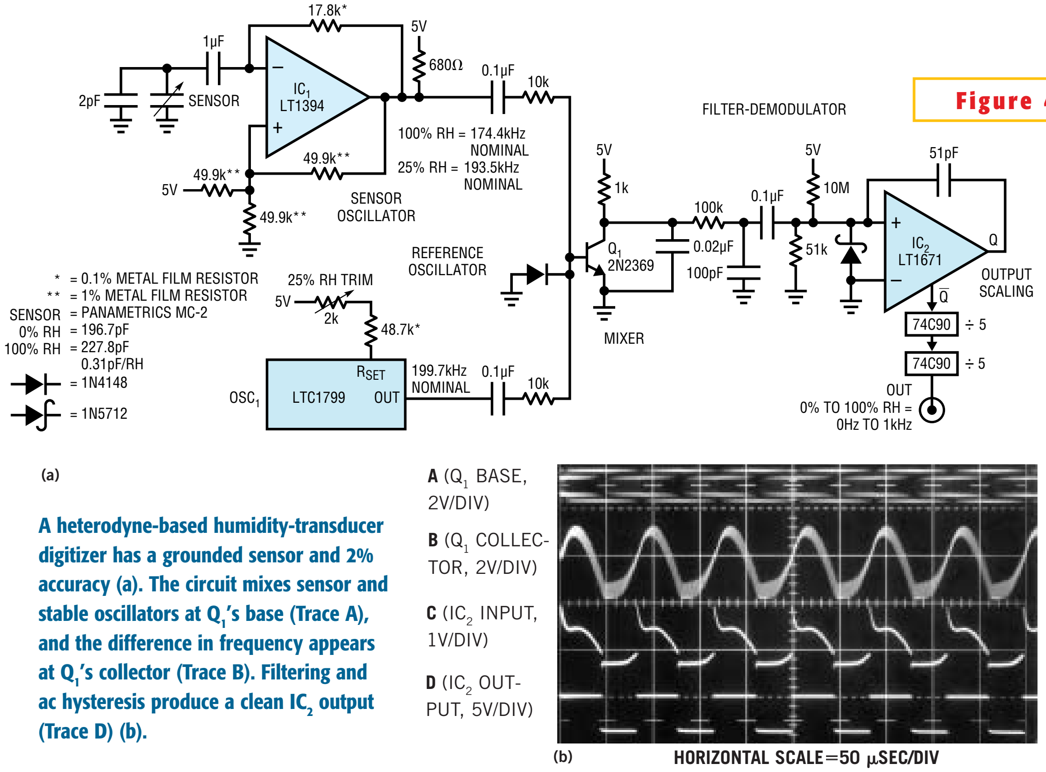


Figure 4

A heterodyne-based humidity-transducer digitizer has a grounded sensor and 2% accuracy (a). The circuit mixes sensor and stable oscillators at Q$_1$'s base (Trace A), and the difference in frequency appears at Q$_1$'s collector (Trace B). Filtering and ac hysteresis produce a clean IC$_2$ output (Trace D) (b).

sensor excursion. The RH sensor is ac-coupled in accordance with its manufacturer's data sheet; dc coupling introduces destructive electromigration effects (**Reference 5**). You use the RH trim to tune reference oscillator OSC$_1$ to IC$_1$'s nominal 0% RH-dictated frequency. The circuit mixes the two oscillators at Q$_1$'s base, Trace A (**Figure 4b**). Q$_1$ amplifies the mixed-frequency components, although collector filtering attenuates the sum frequency. The RH-determined difference frequency, appearing as a sine wave at Q$_1$'s collector (Trace B), remains. The circuit filters this waveform and ac-couples the result to zero-crossing detector IC$_2$. Hysteretic ac feedback at IC$_2$'s input (Trace C) produces a clean IC$_2$ output (Trace D). Counter-based scaling at IC$_2$'s output combines with slight sensor padding, via the 2-pF value across the sensor, to provide numeric output-frequency correspondence to RH. Calibration involves simulating the RH sensor's 25% value and trimming OSC$_1$ for a 250-Hz output. You can build the simulated value using known discrete capacitors or simply dial out the value using a precision, variable air capacitor (General Radio 1422D).

When evaluating the circuit's operation, it is useful to consider that the sensor oscillator's frequency changes inversely with sensor capacitance; oscillator period is linear versus sensor capacitance. This relationship would normally corrupt the desired linear output relationship between frequency and RH. Practically, because the sensor's excursion range is small compared with its 0% RH value, the error is similarly small. This term almost entirely accounts for the circuit's stated 2% accuracy.

CHARGE-PUMP-BASED RH-SENSOR DIGITIZER

A circuit that digitizes the capacitive humidity sensor's output also has better specifications than the previous circuit (**Figure 5a**). Circuit accuracy is 0.3%, plus the selected sensor grade's tolerance. Temperature coefficient is approximately 300 ppm/°C, and PSRR is 0.25% for 5V±0.5V. Compromises include a floating sensor and somewhat more complex circuitry.

OSC$_1$ (Trace A, **Figure 5b**) clocks an LTC1043 switch-array-based charge pump. This configuration alternately connects the ac-coupled RH sensor to a 4V-reference-derived potential and then discharges the potential into IC$_1$'s summing point. IC$_1$, an integrator, responds with a ramping output (Trace B). When IC$_1$'s output exceeds IC$_2$'s negative input voltage, IC$_2$'s Q output (Trace C) goes high, triggering Q$_1$ and resetting the ramp. AC feedback to IC$_2$'s negative input (Trace D) ensures long enough on-time for Q$_1$ to completely reset the ramp. This action's repetition rate depends on the RH sensor's value. OSC$_1$'s output path to IC$_2$'s latch input synchronizes the IC$_1$-IC$_2$ loop to the charge pump's clocking. In theory, if the charge pump, the offset term (25% trim current), and the ramp amplitude tie to the same potential, this circuit does not require a voltage reference. In practice, the sensor's extremely small capacitance shifts magnify the effect of charge-pump errors versus the supply, necessitating powering the LTC1043 from the 4V reference, which effectively ties all of these points to the 4V reference. Note that the 5V-powered OSC$_1$ output requires level shifting to drive the LTC1043.

A trimmed dc-offset current, via the 100-kΩ potentiometer, into IC$_1$'s summing junction compensates the RH sensor's offset term (without compensation 0% RH$\neq$0 pF). The 20-kΩ trim at IC$_2$ scales the output frequency so that 0 to 100% RH equates to a range of 0 to 1 kHz. Trimming involves substituting capacitance for the sensor's known 100 and 25% values and trimming the appropriate adjustments. The adjustments are somewhat interactive, necessitating repetition until convergence occurs. A precision variable capacitor (General Radio type 1422D) is invaluable in this regard, although you can achieve acceptable re-

TABLE 2—OUTPUT FREQUENCY VERSUS THERMISTOR CHARACTERISTICS

Thermistor value (kΩ)	Sensor temperature (°F)	Output frequency
5	109	2.01 MHz
10	77	1.01 kHz
20	47	505 kHz
30	31	337 kHz
40	20	253 kHz
50	12	203 kHz
60	6	168 kHz
70	−1.3	145 kHz
80	−4.7	127 kHz
90	−8.5	113 kHz
100	−12	101 kHz

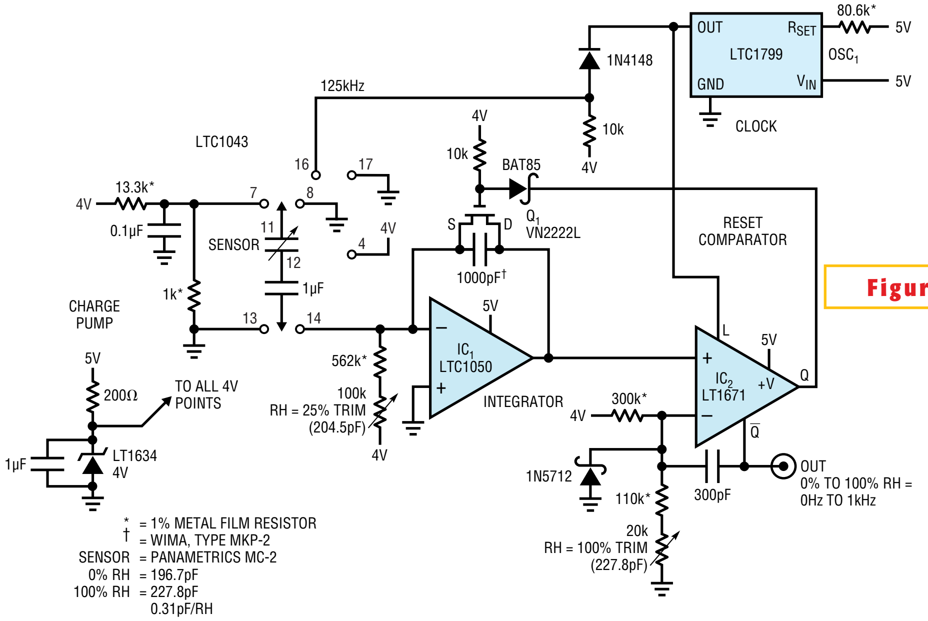
sults with built-up calibrated discrete capacitors.

RH-SENSOR DIGITIZER

Another RH digitizer features 1% accuracy, PSRR of 1% over 4.5 to 5.5V, temperature coefficient of 350 ppm/°C, and a ground-referred sensor (**Figure 6a**). Additionally, the circuit's trim scheme accommodates RH sensors with a wide tolerance grade. The circuit is basically a time-domain bridge; it subtracts time intervals representing sensor and sensor-offset values to determine the sensor value extrapolated to RH=0%. This measurement is digitized and scaled so that 0 to 100 counts corresponds to 0 to 100% RH at the output.

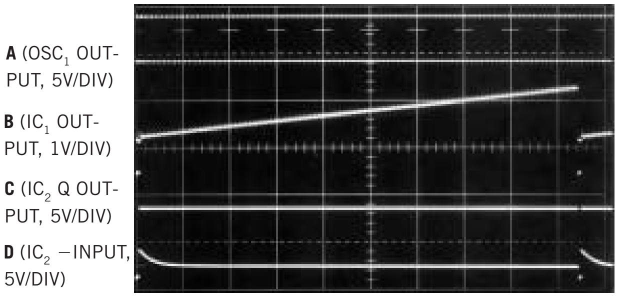
OSC_1's nominal 12.77-MHz output, which the circuit conditions using a counter chain and an inverter-configured gate, presents a 12.4-kHz, 2.5-µsec pulse, Trace A (**Figure 6b**), to Q_{1A} and Q_{1B}. The transistors' collectors fall to 0V. (Trace B is Q_{1A}'s collector, Trace C is Q_{1B}'s collector.) When the base drive ceases, both collectors ramp toward 5V. The slope of Trace B's ramp varies with the RH sensor's capacitance; the slope of Trace C's ramp represents the sensor's offset value (0% RH≠0 pF). IC_1 and IC_2 switch when their associated ramp inputs cross the comparators' common dc-input potential. The comparator outputs (Trace D=IC_1, Trace E=IC_2) define a "both-high" time region proportional to the ramp slopes' difference and, hence, an offset-corrected version of the sensor's value. The circuit gates this time interval with OSC_1's output to provide the data output (Trace F).

Circuit operation is fairly straightforward, although some details bear



* = 1% METAL FILM RESISTOR
† = WIMA, TYPE MKP-2
SENSOR = PANAMETRICS MC-2
0% RH = 196.7pF
100% RH = 227.8pF
0.31pF/RH

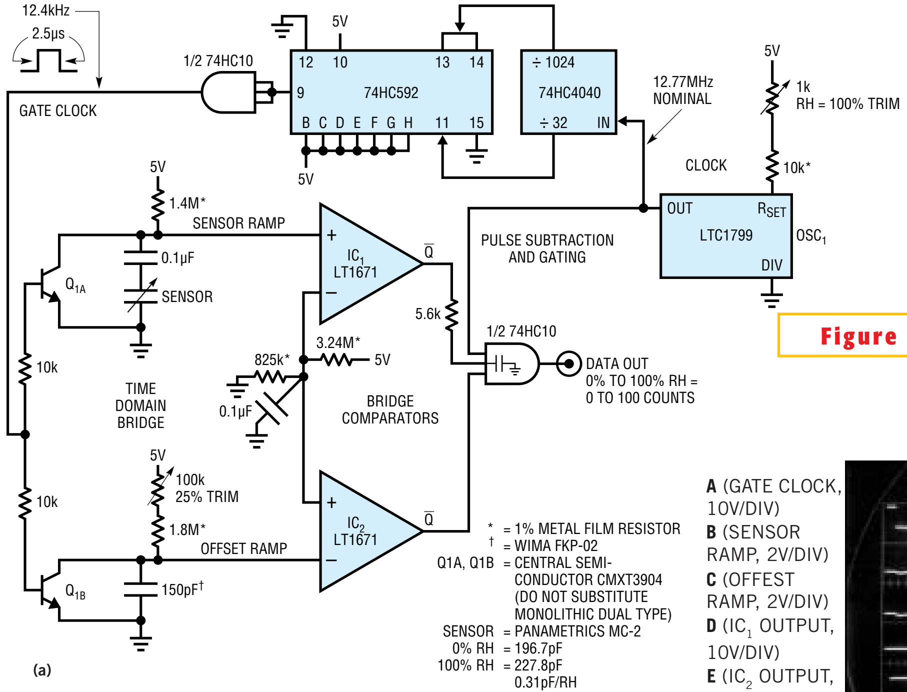
(a)



(b) HORIZONTAL SCALE=100 µSEC/DIV

A hygrometer digitizer has 0.3% accuracy, but the sensor must float off-ground (a). OSC_1 drives an RH-sensor-based charge pump, producing a ramp at IC_1 (Trace B). IC_2's Q output biases Q_1 to reset the ramp (Trace C), and the frequency output at $\overline{Q}$ varies with humidity (b).

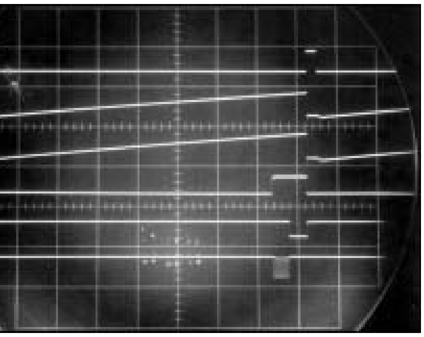
Figure 5



* = 1% METAL FILM RESISTOR
† = WIMA FKP-02
Q1A, Q1B = CENTRAL SEMICONDUCTOR CMXT3904 (DO NOT SUBSTITUTE MONOLITHIC DUAL TYPE)
SENSOR = PANAMETRICS MC-2
0% RH = 196.7pF
100% RH = 227.8pF
0.31pF/RH

(a)

Figure 6



A (GATE CLOCK, 10V/DIV)
B (SENSOR RAMP, 2V/DIV)
C (OFFEST RAMP, 2V/DIV)
D (IC_1 OUTPUT, 10V/DIV)
E (IC_2 OUTPUT, 10V/DIV)
F (DIGITIZED OUPUT, 10V/DIV)

(b) HORIZONTAL SCALE=10 µSEC/DIV

A humidity-transducer digitizer has a grounded sensor and 1% accuracy (a). Q_{1A} and Q_{1B} produce ramp outputs (Traces B and C), and IC_1 and IC_2 digitize the ramp times (Traces D and E). The digitized output consists of 0 to 100 counts for 0 to 100% RH (Trace F) (b).

mention. Q_1, a dual transistor, promotes cancellation of the individual transistors' V_{CE}-versus-temperature terms, minimizing their error contribution. Q_1's transistor is a two-die type to minimize crosstalk; do not substitute monolithic types. Similarly, do not substitute a dual comparator for the single types of IC_1 and IC_2. Also, the comparators operate at high source impedance relative to their input characteristics, but symmetry provides adequate error cancellation. Finally, the 5.6-kΩ resistor combines with the output gates' input capacitances, forming a lag of approximately 20 nsec. This delay prevents false output-data transients when the ramps are resetting.

The trimming procedure is similar to that of the previous RH circuit. Trimming involves substituting capacitance for the sensor's known 100 and 25% values and trimming the indicated adjustments. The adjustments are somewhat interactive, necessitating repetition until convergence occurs. As with the previous circuits, a precision variable capacitor (General Radio type 1422D) is invaluable for this work, although acceptable results are possible with calibrated discrete-capacitor assemblies.□

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