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Voltage-to-Frequency/Frequency-to-Voltage Converter

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RATIOMETRIC MEASUREMENT (ANALOG DIVISION)

One of the most difficult circuits to build is one which will divide one analog signal by another. Two voltage-to-frequency (V/F) converters can do such division with ease. The numerator is counted directly as a signal, while the denominator forms the time base.

FIGURE 1: Ratiometric measurement (analog division).

RPM/SPEED INDICATOR

Flow rates and revolutions per second are nothing more than frequency signals, since they measure the number of events per time period. Optical and magnetic sensors will convert these flows and revolutions into a digital signal which, in turn, can be converted to a proportional voltage by the use of a frequency-to-voltage (F/V) converter. A simple voltmeter will then give a visual indication of the speed.

FIGURE 2: RPM/speed indicator.

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MOTOR SPEED CONTROL

The motor's speed is measured with the F/V converter, which converts RPM into a proportional voltage. This voltage is used in a negative feedback system to maintain the motor at the controlled setting.
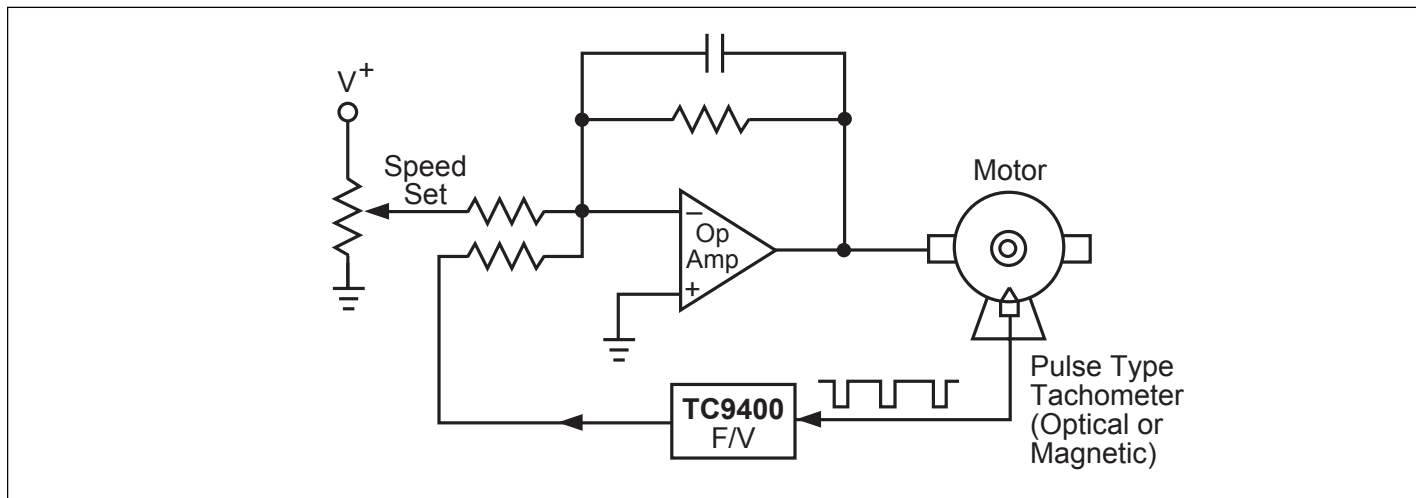

FIGURE 3: Motor speed control.

PROPORTIONAL FLOW-RATE CONTROLLER

A TC9400 F/V converter can be used to regulate the amount of liquid or gas flowing through a pipeline. The flow-rate detector generates a pulse train whose frequency is proportional to the rate of flow through it. The F/V converts this frequency to a proportional analog voltage which is used to drive the valve controller. The valve controller regulates the valve so that the flow is steady, even though pipeline pressure goes up and down. A voltmeter connected to the F/V converter output will indicate the actual instantaneous flow rate.
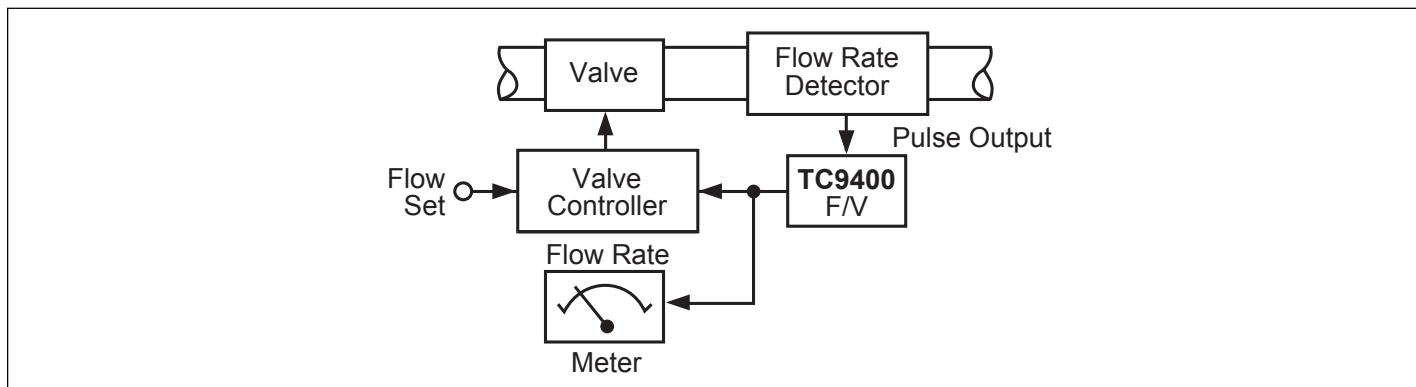
FIGURE 4: Proportional flow-rate controller.

TEMPERATURE METER

A temperature meter using the voltage output of a probe, such as one of the three shown, can be economically and straightforwardly implemented with the TC9400 V/F converter. The V/F output is simply counted to display the temperature. For long-distance data transmission, the TC9400 can be used to modulate an RF transmitter.
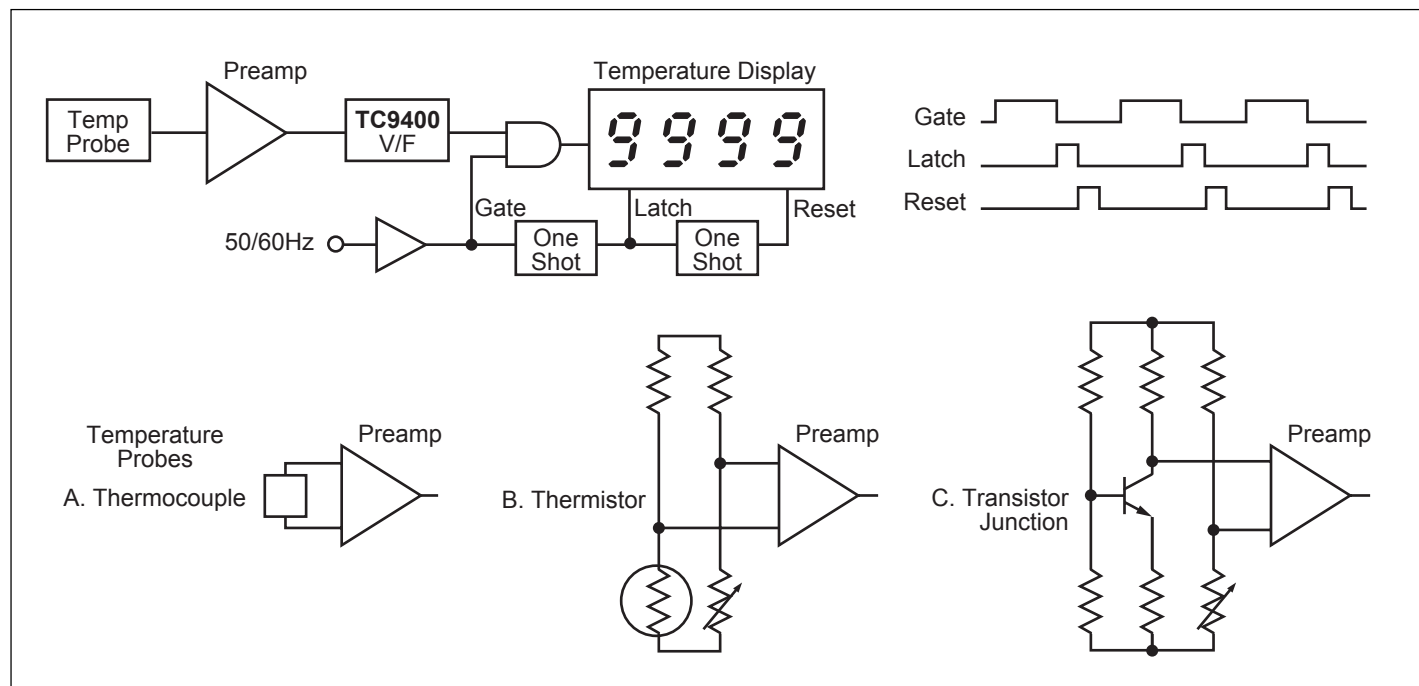

FIGURE 5: Temperature meter.

A/D CONVERSION WITH A MICROCONTROLLER

There are two schemes that can be utilized to accomplish A/D conversion with a microcontroller:

1. Depending on the number of digits of resolution required, V_{IN} is measured by counting the F_{OUT} frequency for 1ms, 10ms, 100ms, or 1 second. The final count is then directly proportional to V_{IN}. (The microcontroller provides the time base.)

2. V_{IN} is measured by determining the time between two pulses (negative edges). F_{OUT} is used as a gate for counting the microcontroller's clock. The final count will then be inversely proportional to V_{IN}.

By taking the one's complement (changing 1's to 0's and 0's to 1's) of the final binary count, a value directly proportional to V_{IN} will result. This technique will give a faster conversion time when resolution is very important, but dynamic range is limited.
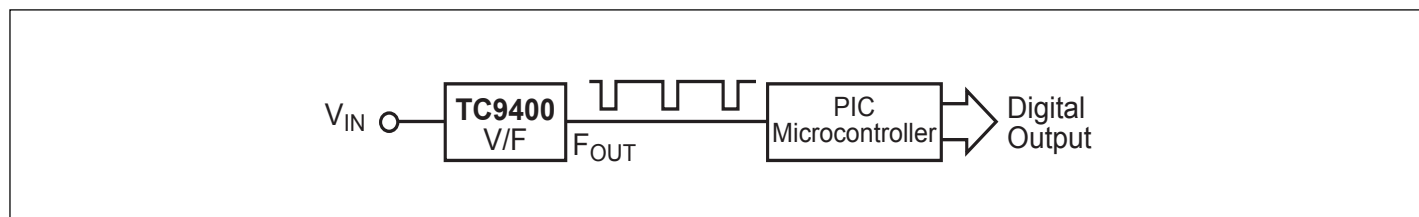

FIGURE 6: A/D conversion with a microcontroller.

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13-BIT A/D CONVERTER

A 13-bit binary A/D converter can be built by combining the TC9400 V/F converter with a counter, latch, and time base. When the V/F converter is set up for 10kHz full scale, a 1-second time base will provide one conversion per second.
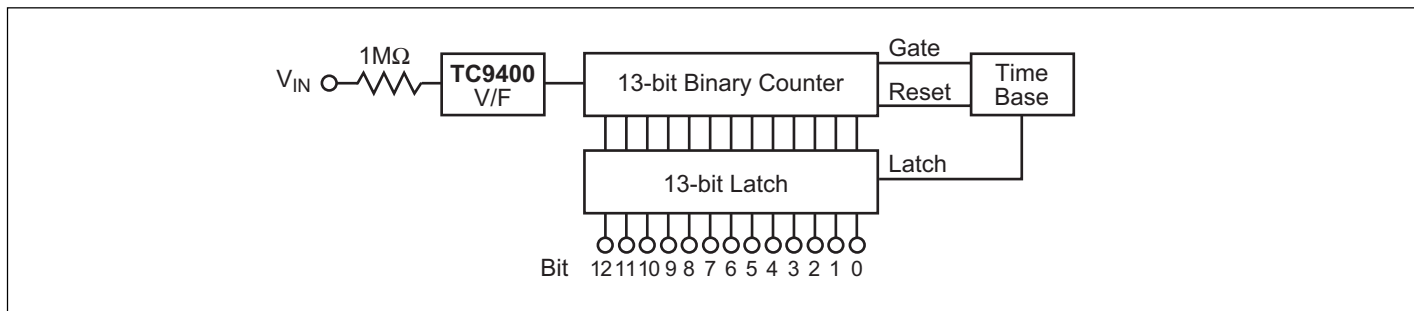

FIGURE 7: 13-Bit A/D converter.

4-DIGIT VOLTMETER WITH OPTOISOLATED INPUT

The use of a frequency counter will give a display of the V/F converter's frequency, which is directly proportional to the input voltage.

When the V/F converter is running at 10kHz full scale, a 1-second time base will give 4-digit resolution with 1 reading per second.

The optoisolator is used for transmitting the frequency, so there is no DC path to the frequency counter. This is especially useful in medical applications, where a voltage probe should not be directly connected to the human body.
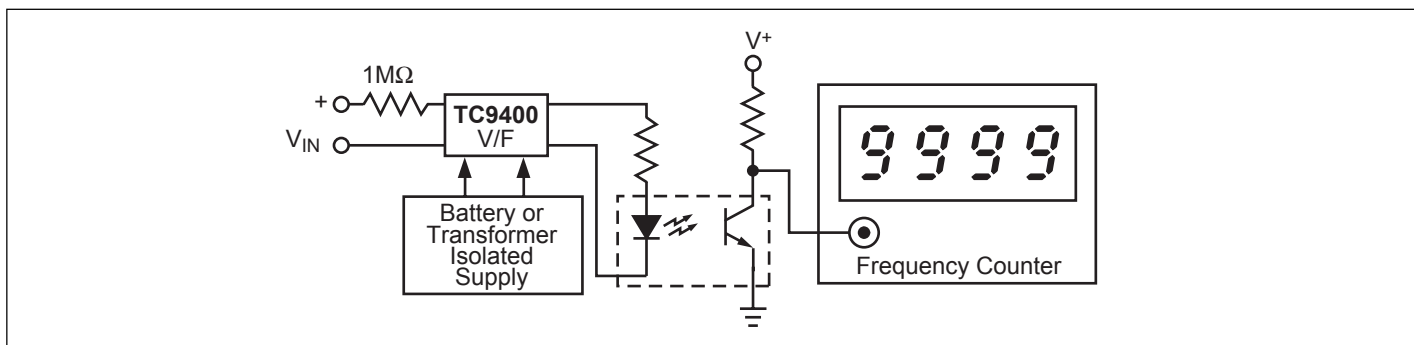

FIGURE 8: 4-Digit voltmeter with optoisolated input.

LONG-TERM INTEGRATOR WITH INFINITE HOLD

This system will integrate an input signal for minutes or days, and hold its output indefinitely. The data is held in a digital counter and stays there until the counter is reset. Typical applications involve controlling the amount of surface metal deposited in a plating system or how much charge a battery has taken on.
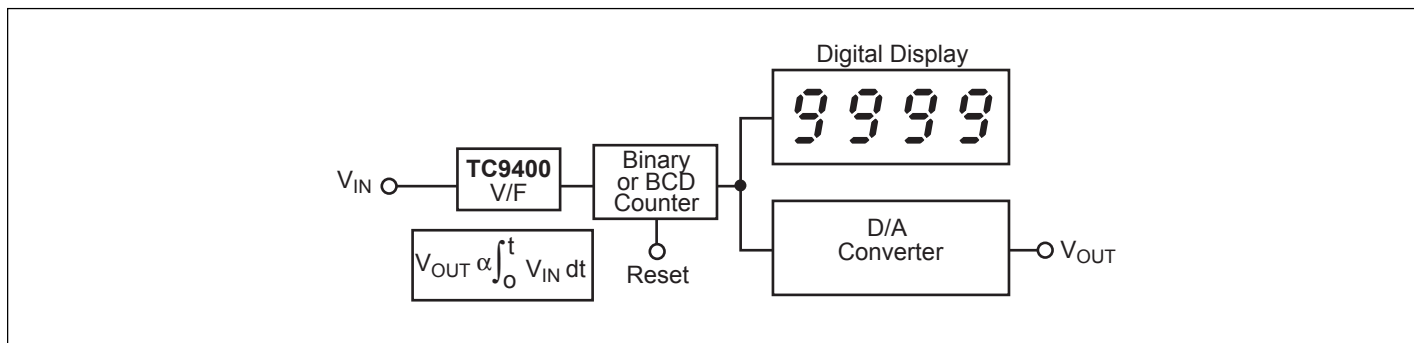

FIGURE 9: Long-term integrator with infinite hold.

LONG-TERM INTEGRATOR FOR BIPOLAR (±) SIGNALS

When the input signal is negative as well as positive, there has to be a way of generating "negative" frequencies. An absolute value circuit accomplishes this by giving the V/F converter a positive voltage only; and also telling the counter to count up for a positive voltage and to count down for a negative voltage.
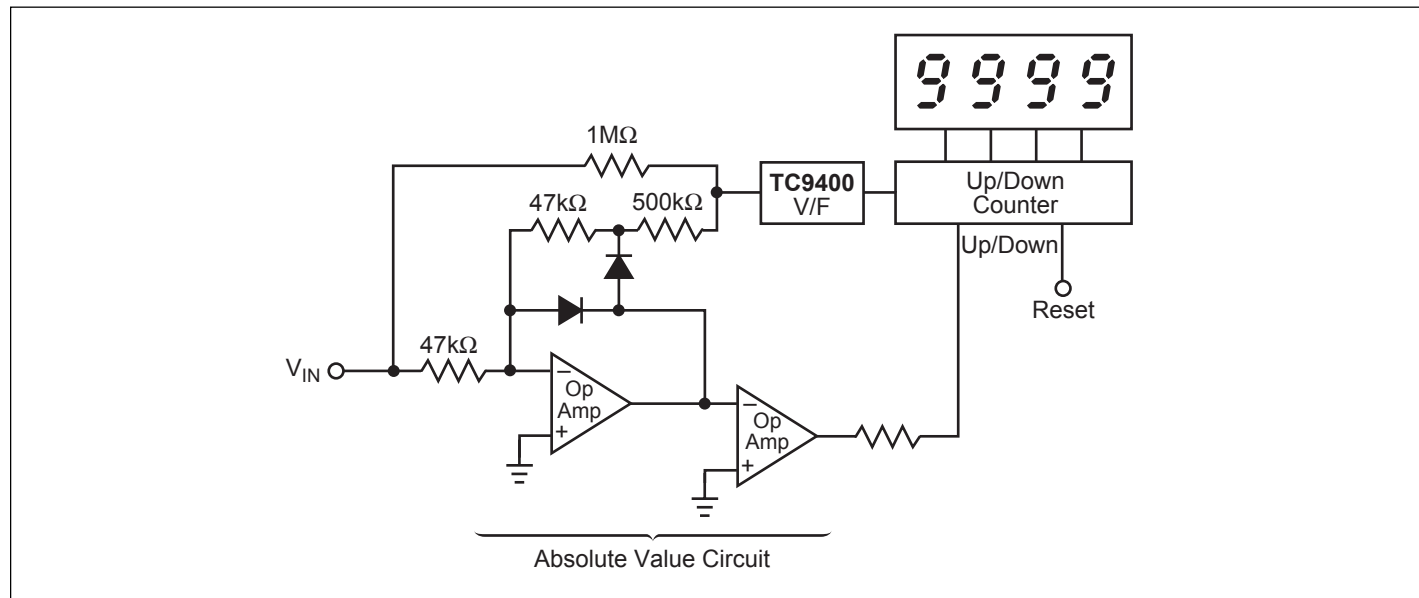

FIGURE 10: Long-term integrator for bipolar (±) signals.

ANALOG SIGNAL TRANSMISSION OVER TELEPHONE LINES

The TC9400's square-wave output is ideal for transmitting analog data over telephone lines. A square wave is actually preferred over a pulse waveform for data transmission, since the square wave takes up less frequency spectrum.

The square wave's spectrum can be further reduced by use of low-pass filters.

At the other end of the telephone line, the TC9400 converts the frequency signal back into a voltage output linearly proportional to the original input voltage.
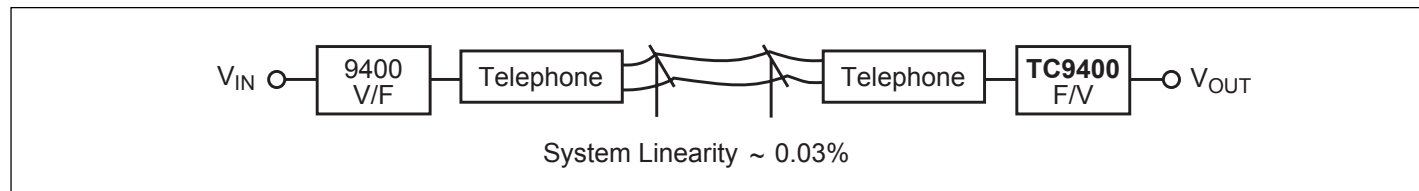

FIGURE 11: Analog signal transmission over telephone lines.

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TELEMETRY

In a telemetry system, the TC9400 converts the analog input (V_{IN}) into frequencies (10Hz to 100kHz) which can be used to modulate an RF transmitter.

At the other end, a receiver picks up the RF signal and demodulates it back into the 10Hz to 100kHz spectrum. A frequency counter connected to this signal then gives a count linearly proportional to the original analog voltage (V_{IN}).

If a linearly-proportional analog output voltage is required, the counter can be replaced by a TC9400 used in the F/V mode.
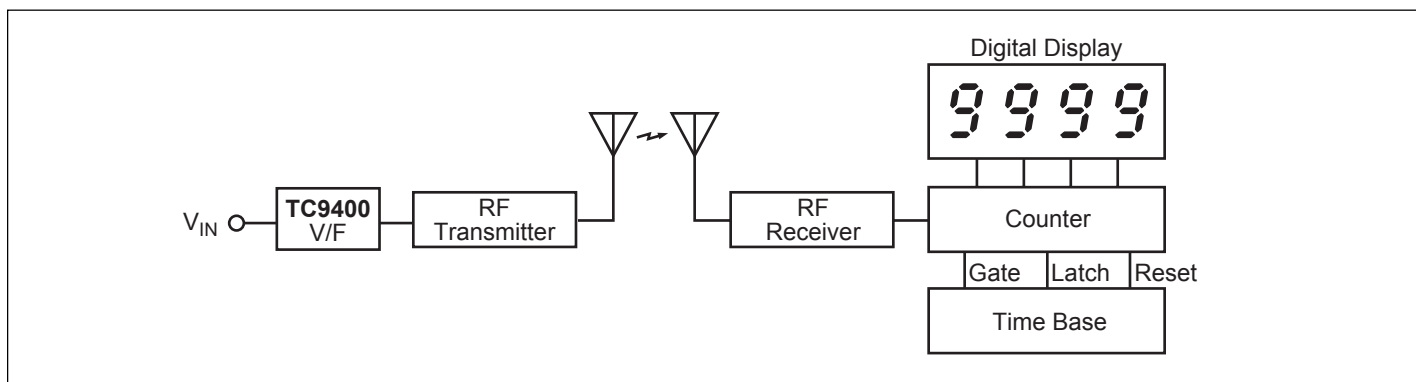

FIGURE 12: Telemetry.

HIGH NOISE IMMUNITY DATA TRANSMISSION

When transmitting analog data over long distances, it is advantageous to convert the analog signal into a digital signal, which is less susceptible to noise pick-up.

In the system shown below, the TC9400 converts the input voltage into a pulse or square wave which is transmitted on a pair of wires by use of a line driver and receiver. At the other end, the original voltage (V_{IN}), can be digitally displayed on a frequency counter or converted back to an analog voltage by use of a TC9400 F/V converter.
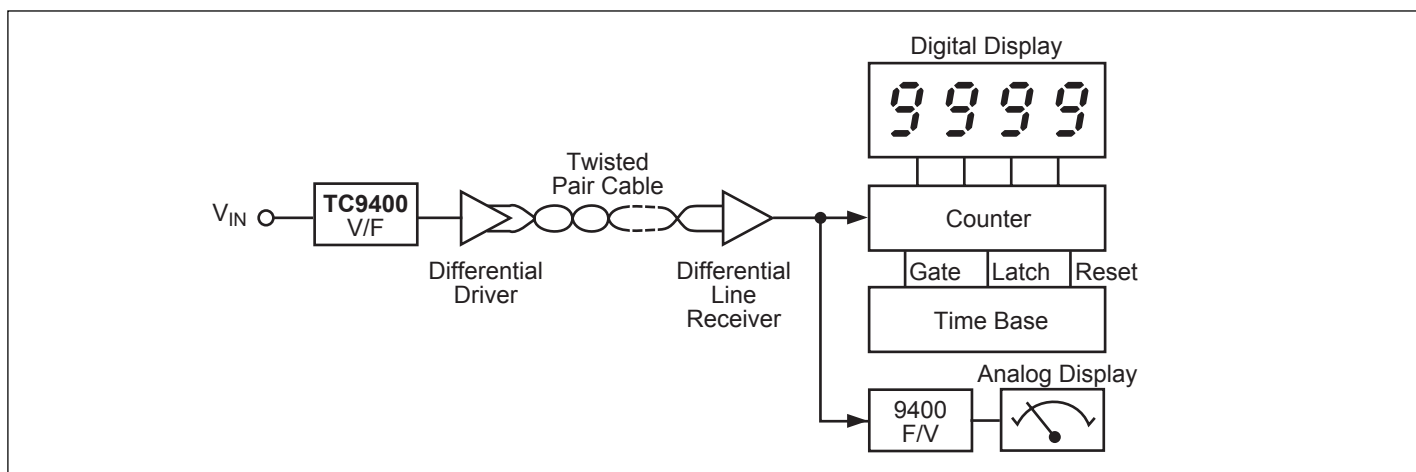

FIGURE 13: High noise immunity data transmission.

DC RESPONSE DATA RECORDING SYSTEM

Low-frequency analog data (DC to 10kHz) can be recorded anywhere, stored, and then reproduced. By varying the playback speed, the frequency spectrum of the original data can be shifted up or down.
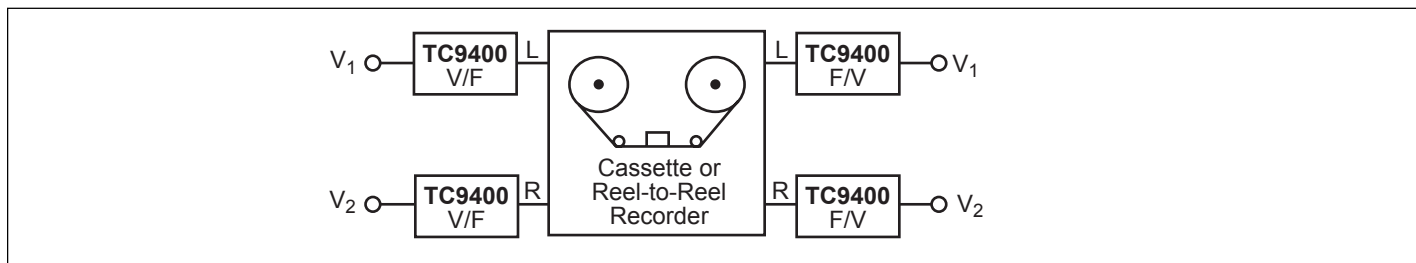

FIGURE 14: DC response data recording system.

FREQUENCY SHIFT KEYING (FSK) GENERATION AND DECODING

Frequency Shift Keying (FSK) is a simple means of transmitting digital data over a signal path (two wires, telephone lines, AM or FM transmitters).

Typically, only two frequencies are transmitted. One corresponds to a logical "0," the other to a logical "1." A TC9400 V/F converter will generate these two frequencies when connected as shown below. The potentiometer sets the V/F converter to the lower frequency. The digital input then determines which frequency is selected. A "0" selects the lower frequency, a "1" selects the upper frequency.

The digital frequency signal is converted back into a digital format by a TC9400 used in the F/V mode.
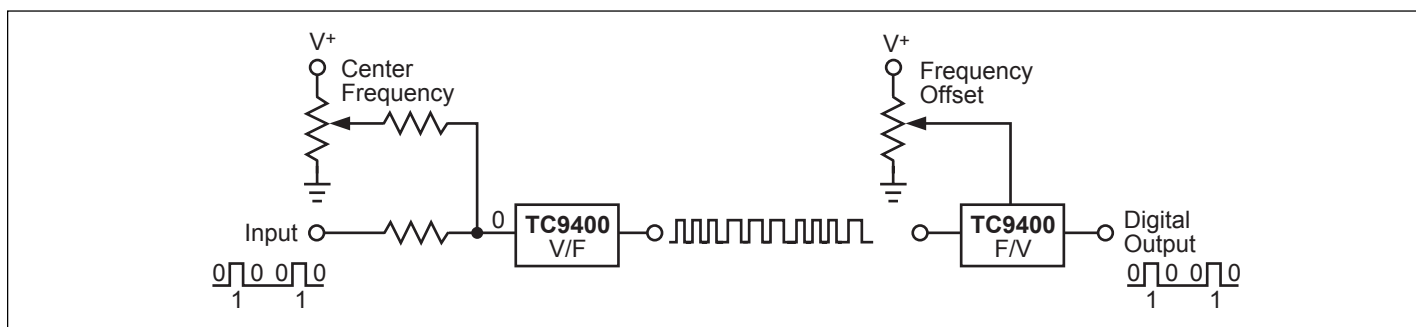

FIGURE 15: Frequency Shift Keying (FSK) generation and decoding.

ULTRALINEAR FREQUENCY MODULATOR

Since the TC9400 is a very linear V/F converter, an FM modulator is very easy to build.

The potentiometer determines the center frequency, while V_{IN} determines the amount of modulation (FM deviation) around the center frequency. V_{IN} can be negative as well as positive.
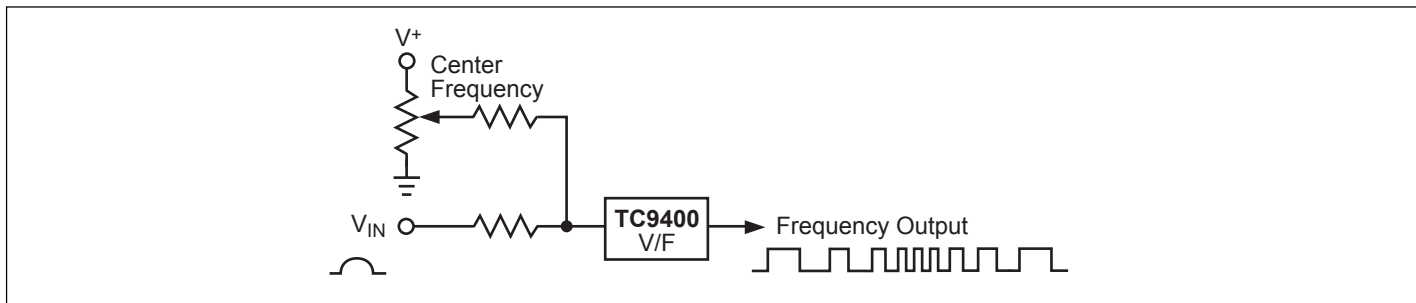

FIGURE 16: Ultralinear frequency modulator.

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FREQUENCY METER

The TC9400 will convert any frequency below 100kHz into an output voltage, which is linearly proportional to the input frequency. The equivalent frequency is then displayed on an analog meter. If the incoming frequency is above 100kHz, a frequency divider in front of the TC9400 can be used to scale the frequency down into the 100kHz region.
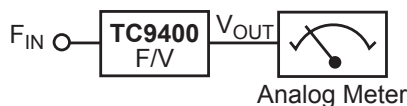

FIGURE 17: Frequency meter.

TACHOMETER BAR GRAPH DISPLAY

A tachometer can be constructed by using the TC9400 in the F/V mode to convert the frequency information (RPM) into a a linearly-proportional voltage. This voltage is then compared to one of "n" comparators (8 in this example). When the voltage exceeds the trip point of a comparator, the respective LED lights up and will continue to stay lit as long as the voltage exceeds the trip point. This gives a bar-graph-type display, with the height of the bar being proportional to RPM.
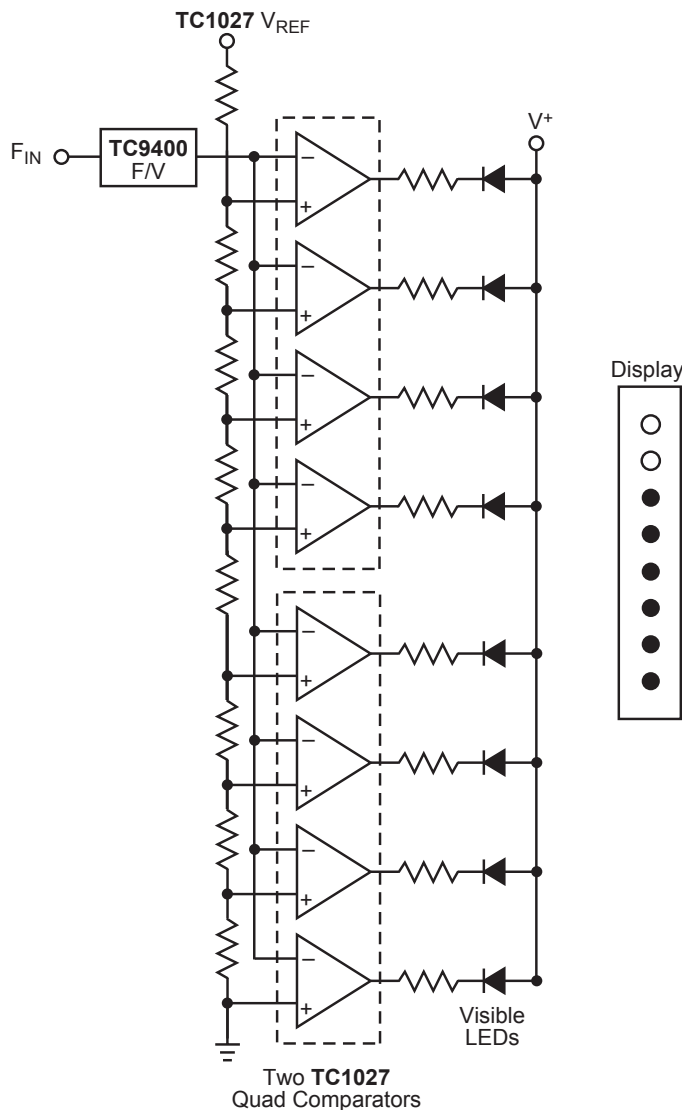

FIGURE 18: Tachometer bar graph display.

FREQUENCY/TONE DECODER

The frequency, or tone, to be detected is converted into a proportional analog voltage by the TC9400 F/V converter. The quad comparators sense when the voltage (frequency) exceeds any of the four preset frequency limits. A logical "1" at any of the five outputs indicates the frequency is within those limits.

This system is useful for determining which frequency band a signal is in, or for remote control, where each frequency band corresponds to a different command.
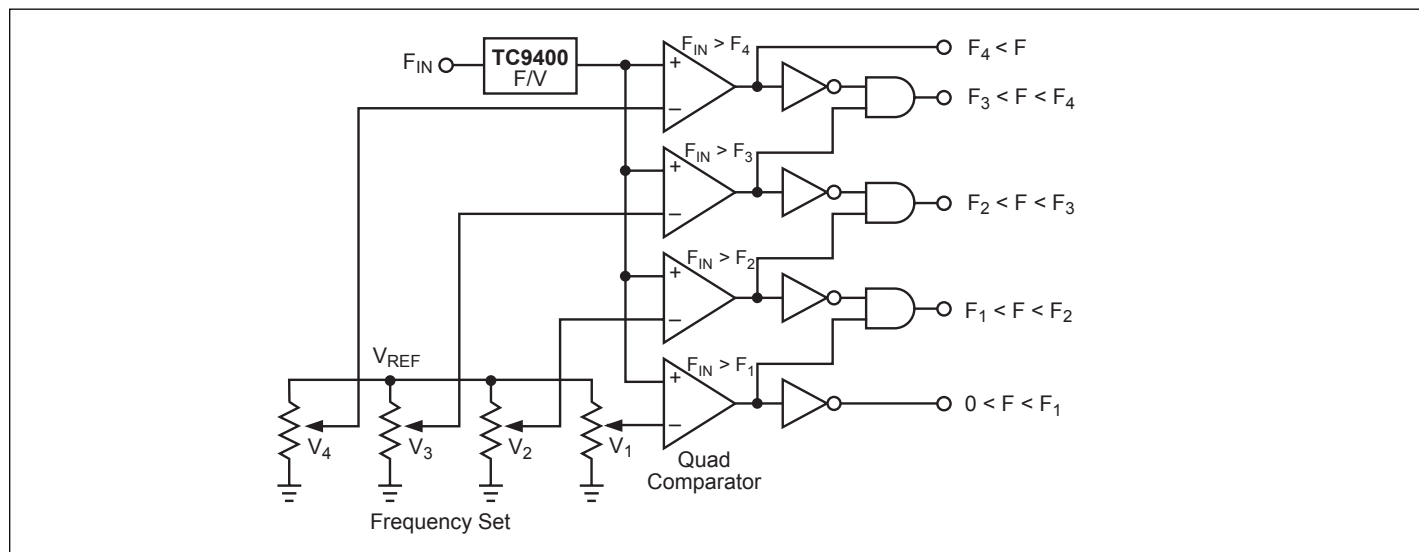

FIGURE 19: Frequency/tone decoder.

FM DEMODULATION WITH A PHASE-LOCKED LOOP

The high linearity of the TC9400 (0.01%) is used to greatly improve the performance of a phase-locked loop, resulting in very precise tracking of V_{OUT} with respect to F_{IN}.
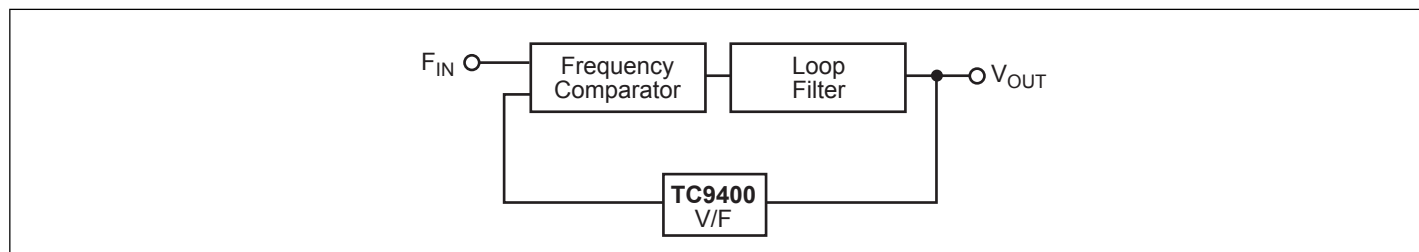

FIGURE 20: FM demodulation with a phase-locked loop.

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ANALOG DATA TRANSMISSION ON DC SUPPLY LINES (TWO-WAY TRANSMITTER)

By converting an analog voltage to a linearly-proportional pulse train of short duration, it is possible to transmit this data on the same wires used to energize the V/F converter.

The TC9400 V/F converter shorts out the DC supply for 3µsec out of each period. At 100kHz, the supply line is down 30% of the 10µsec period. As the frequency is lowered, the down-time decreases, so that at 1kHz the line is down only 0.3% of the time.

Two precautions are necessary to assure that the system does not stop functioning during the shorting period. At the power supply end, a 1.2k resistor limits the current to 10mA on a 15V supply line. This prevents the TC9400 from being operated beyond its output rating and at the same time prevents the supply from being shorted out. At the V/F end, a capacitor is used to keep the TC9400 energized, while the diode keeps the capacitor from being discharged.

Since the TC9400 requires only 2mA of current, a 1µF capacitor ensures a stable voltage (the ripple is only 6mV). Since the 3µsec pulses appear at the left side of the 1.2kΩ resistor, it is easy to sense the signal here and convert the data back into a recognizable format. A frequency counter connected at this point will directly display the input voltage by counting the frequency.

If an analog output is required, a TC9400 in the F/V mode can be used to convert the frequency back into a voltage. The overall linearity is on the order of 0.03%, when both V/F and F/V are used. If only the V/F is used, 0.01% linearity can easily be achieved.
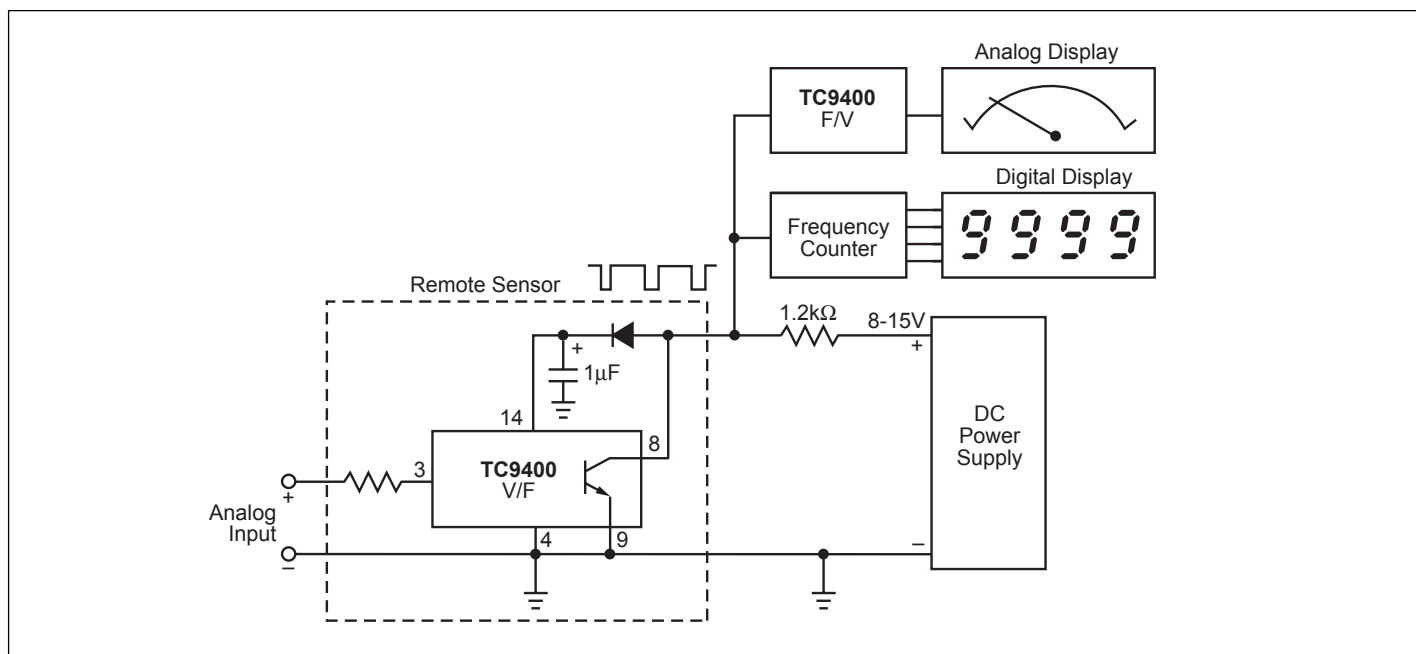

FIGURE 21: Analog data transmission on DC supply lines (two-way transmitter).

DIGITALLY CONTROLLED FREQUENCY SOURCE

This system generates frequencies controlled by a microcontroller counter, register, or thumb-wheel switches. Applications for such a system include computer-controlled test equipment and numerically-controlled machine tools.
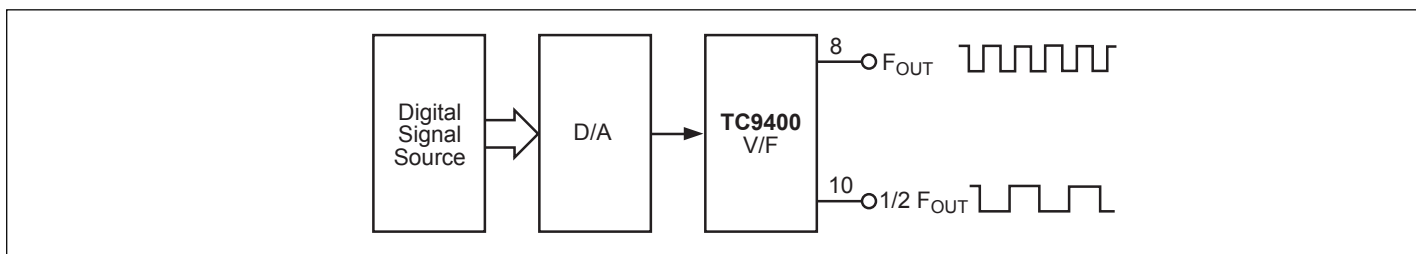

FIGURE 22: Digitally controlled frequency source.

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WIDE FREQUENCY RANGE PULSE GENERATOR

The TC9400 V/F converter is useful in the laboratory as a portable, battery-operated, low-cost frequency source. The TC9400 provides both pulse and square-wave outputs. By adding an op-amp integrator, a triangular waveform can also be generated. The outputs can be frequency-modulated via the FM input.
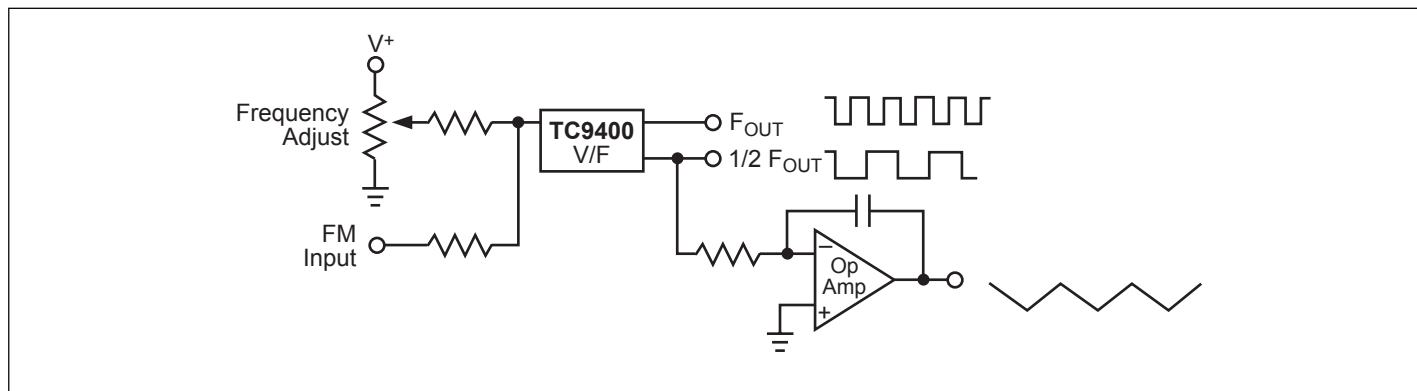

FIGURE 23: Wide frequency range pulse generator.

FREQUENCY MULTIPLIER/DIVIDER WITH INFINITE RESOLUTION

Frequency scaling can easily be performed by first converting the incoming frequency into a proportional DC voltage. This is accomplished by using the TC9400 in the F/V mode. Once the frequency is in a voltage format, it is easy to scale this voltage up or down by use of a single potentiometer. The resultant voltage is then applied to a TC9400 V/F converter, which generates a proportional output frequency.

Since the potentiometer is infinitely variable, the division/multiplication factor can be any number, including fractions (K_1 is simply V_{OUT}/F_{IN}, while K_2 is F_{OUT}/V_{IN}).
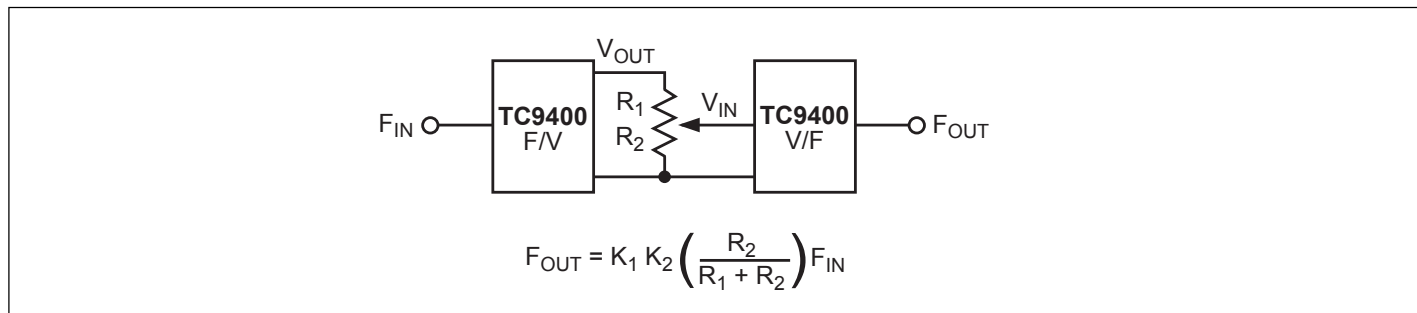

FIGURE 24: Frequency multiplier/divider with infinite resolution.

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FREQUENCY DIFFERENCE MEASUREMENT

Frequency-difference measurement is accomplished by using two TC9400's in the F/V mode to convert both frequencies into two proportional analog voltages (V_1 and V_2). V_2 is inverted by a unity gain inverter. V_1 and $-V_2$ are then added by the summing op-amp to give a voltage proportional to the frequency difference between F_2 and F_1.

Since the TC9400 V/F input is actually the summing junction to an op-amp, V_1 and $-V_2$ can be summed at the TC9400 input to generate a frequency output proportional to the difference between F_1 and F_2.
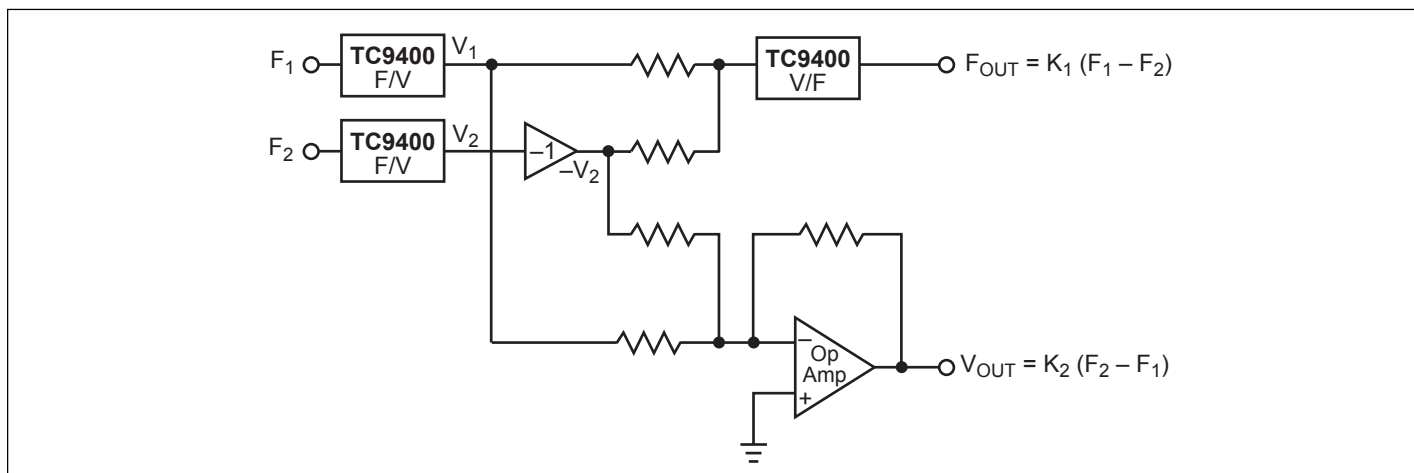

FIGURE 25: Frequency difference measurement.

CONVERTERS SIMPLIFY DESIGN OF FREQUENCY MULTIPLIER*

By using a programmable digital-to-analog converter in combination with frequency-to-voltage and voltage-to-frequency converters, this circuit can multiply an input frequency by any number. Because it needs neither combinational logic nor a high-speed counter, it is more flexible than competing designs, uses fewer parts, and is simpler to build.

As shown in the figure on the next page, the V/F converter, a TC9400, transforms the input frequency into a corresponding voltage. An inexpensive device, the converter, requires only a few external components for setting its upper operating frequency as high as 100kHz.

Next the signal is applied to the reference port of the DAC-03 D/A converter, where it is amplified by the frequency-multiplying factor programmed into the converter by thumbwheel switches or a microcontroller. The D/A converter's output is the product of the analog input voltage and the digital gain factor.

R_3 sets the gain of the op-amp to any value, providing trim adjustment or a convenient way to scale the D/A converter's output to a much higher or lower voltage for the final stage, a TC9400 converter that operates in the voltage-to-frequency mode. The op-amp and R_3 can also be used to set circuit gain to non-integer values. The V/F device then converts the input voltage into a proportionally higher or lower frequency.
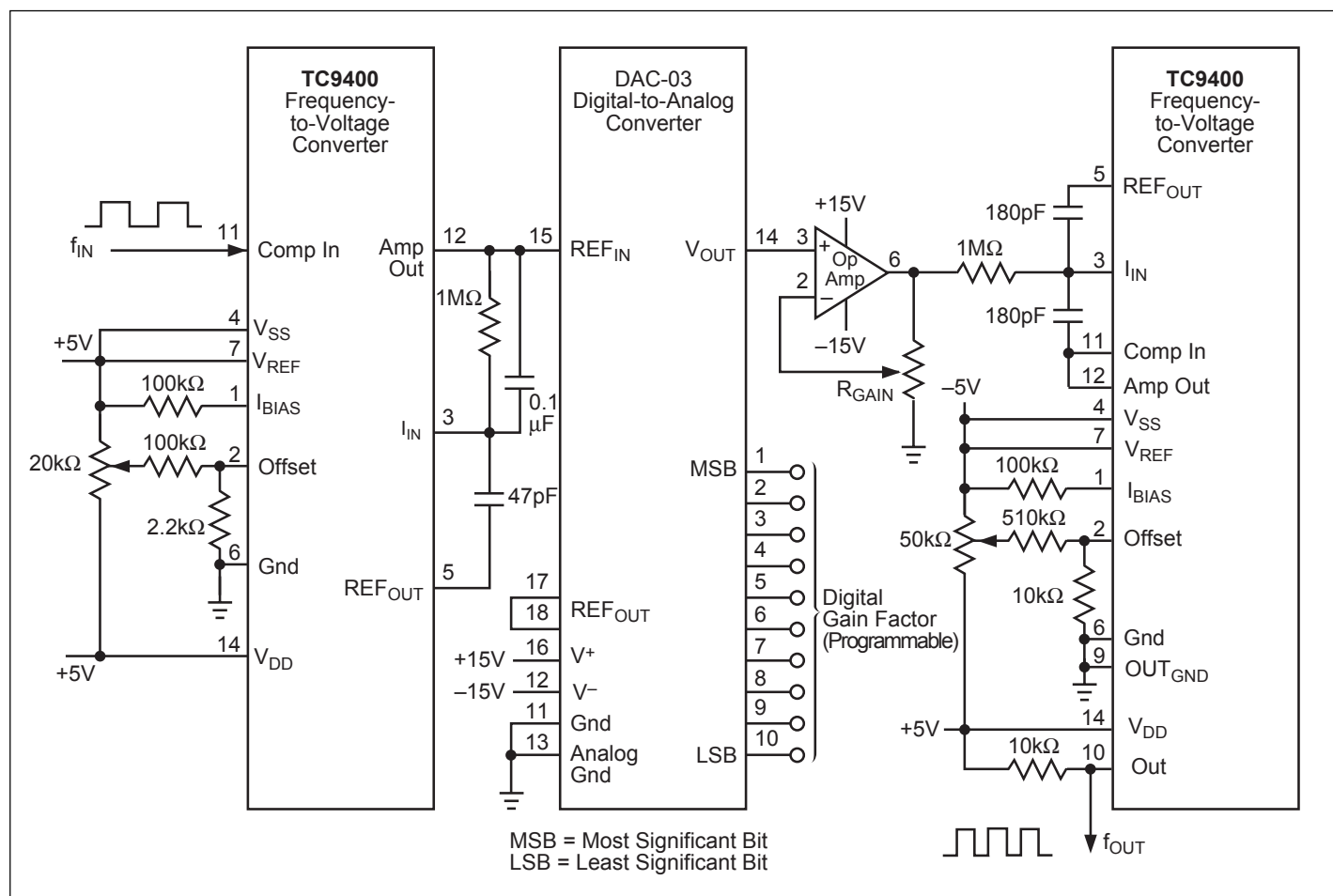
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FIGURE 26: Circuit uses frequency-to-voltage-to-frequency conversion, with intermediate stage of gain between conversions, for multiplying input frequency by any number. Digital-to-analog converter is programmed digitally, by thumbwheel switches or microcontroller, for coarse selection of frequency-multiplying factor; op-amp provides fine gain, enables choice of non-integer multiplication values.

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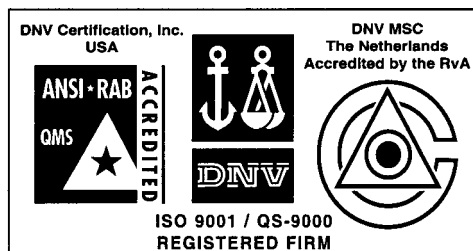
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