APPLICATION NOTE

AN1182

Using the NE5521 signal conditioner in multi-faceted applications

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December 1988

Philips Semiconductors

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Position transducers call for a great deal of complex interface circuitry for input and output signal conditioning. The Philips Semiconductors NE/SA/SE5521 packs all the interface circuitry on one chip and provides a complete monolithic solution to all the signal conditioning required for position transducers.

Position transducers are widely used in industrial and commercial applications for measuring very small displacement or rotation. In fact, such transducers can be used for any application where a given parameter can be converted to linear or angular motion. Weight, force, pressure, torque, and acceleration are often converted to linear displacement or linear rotation using position transducers. The displacement or rotation information is next conditioned to provide an accurate measurement of the parameter.

SE5521 can interface with all of the popular position transducers such as the LVDT, RVDT, and LPDT. In addition, by varying the arrangement of external components, you can also configure a phase detector, an AC bridge circuit, and an AC voltmeter. For a brief description of the IC, see the section entitled “A Look at the Signal Conditioning IC.“

IC PROVIDES SINGLE-CHIP SOLUTION TO LVDT MEASUREMENTS

Figure 1a shows a typical single supply LVDT displacement measurement circuit. The uncommitted amplifier is configured as a second-order, low-pass Butterworth filter with gain. The gain of the amplifier is $1+R_F/(R/2)$. The 1k offset adjust potentiometer is used to trim out the LVDT/signal conditioner system offset at null.

Exciting an LVDT at zero phase angle frequency results in minimum null voltage and optimum linearity (for a discussion, see “How an LVDT Works”). There are two ways of reducing null voltage—the first method is to adjust the oscillator frequency so that the secondary voltage is in phase with the primary excitation. The demodulator and oscillator voltage can be monitored on an oscilloscope for correct phasing as depicted in Figures 1b and 1c. A second method of phase compensation is to use a variable phase shift network between the oscillator output and the sync input to the device. An optional phase shift network in Figure 1a consists of a 20k phase adjust potentiometer in series with capacitor C_3. The potentiometer is adjusted for correct demodulator phasing as illustrated in Figures 1b and 1c. With R_O=10k, C_O=2nF, and at oscillator frequency, f_{OSC}=2900Hz, the phase shift is $\varphi=-\tan^{-1}(\omega R_O C_O)=-20°$.

The LVDT output is referenced to $V_{R/2}$ by tying one end of the secondary to Pin 12 of the device. A capacitor between Pin 12 and ground provides an AC ground for $V_{R/2}$. Since the output of Pin 12 is a source of high impedance, Pin 12 may need to be buffered in some applications so as to prevent loading effects on the voltage divider. The common mode voltage and the RMS value of the oscillator signals are determined by V_R; consequently, V_R should be a fixed reference voltage. By making V+ greater than V_R, the output swing of the auxiliary amplifier is increased and the filter can accommodate higher closed-loop gain.

The demodulator output has positive polarity when the LVDT output signal is 180° out of phase with the primary excitation (see Figure 1d), and has negative polarity when the LVDT output is in phase with the primary excitation (see Figure 1e). The polarity of the demodulator signal indicates on which side of null the core is while the amplitude indicates the relative displacement of the core from the null position.

Filtered DC output appears at Pin 1 of the device. Measurements with 10-bit accuracy at -55°C to +125°C temperature range are easily achieved by the circuit in Figure 1.

PHASE DETECTOR MEASURES PHASE DIFFERENCE WITH 10-BIT ACCURACY

The synchronous demodulator easily lends itself to phase detection as illustrated in Figure 2a. If signals of identical frequency are applied to sync input (Pin 6) and to the demodulator input (Pin 4), respectively, the demodulator functions as a phase detector with output DC component being proportional to phase difference between the two inputs. The signals must be referenced to 0V for dual supply operation or to $V_{R/2}$ for single supply operation. At ±5V supplies, the demodulator can easily handle 7V peak-to-peak signals. The low-pass network configured with the uncommitted amplifier provides DC output at Pin 1 of the device. The DC output is maximum (+full-scale) when V_1 and V_2 are 180° out of phase (see Figure 1d) and minimum (-full-scale) when the signals are in phase (see Figure 1e). At quadrature (φ = 90°), the DC output is 0V as shown in Figure 2b. By calibrating the -FS, 0, and +FS points, any unknown phase difference may be determined by just measuring the DC output at Pin 1. A linear relationship between the DC output and phase difference is shown by the transfer curve in Figure 2c.

Even though the oscillator signals are not utilized in this particular application, the use of C_T and R_T is still recommended in order to prevent saturation of active devices in the IC.

SIGNAL CONDITIONER EASES LPDT MEASUREMENTS

Figure 3 shows a simple dual supply setup for LPDT measurements. Op amp IC_1 is configured as a low-pass filter with cut-off frequency equal to the oscillator frequency of 2900Hz. The filter attenuates the higher order spectral components of the oscillator signal and produces a low-distortion sine wave at the output. This sine wave excites one primary, while the other primary is excited by a cosine wave produced by amp IC_2. Amp IC_2 is configured as a constant amplitude lag circuit that preserves the amplitude of the sine wave input from IC_1, but phase shifts the signal by 90° at the output. The phase shift, φ, is given by $\varphi = -2\tan^{-1}(2\pi f_{OSC} R_5 C_3)$. Thus, at 90° phase shift, $f_{OSC}=1/(2\pi R_5 C_3)$. R_5 is a 10k potentiometer with its center wiper tied to one end. The potentiometer is tweaked and the wave forms from IC_1 and IC_2 are observed on an ocilloscope for 90° phase difference and 0V at the output of the device (Pin 1). The system is now ready to make phase measurements as discussed earlier.

For dual supply operation, both the positive and negative supplies should be closely regulated since the oscillator common mode voltage varies with the supplies.

AC BRIDGE CALIBRATES RESISTORS AND CAPACITORS WITH 10-BIT ACCURACY

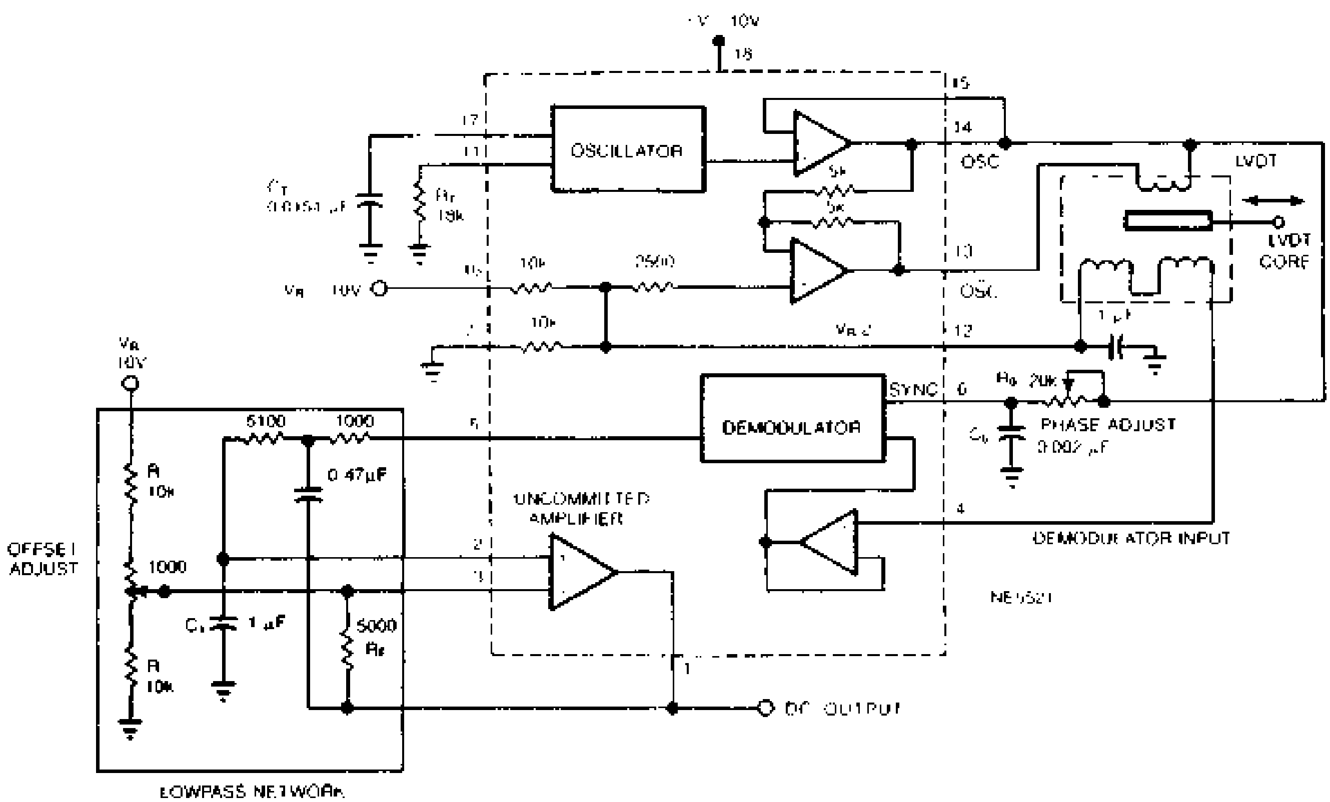
An AC bridge, shown in Figure 4, provides a simple and cost-effective solution to matching resistors and capacitors on production lines. Impedances Z_R and Z_X form a half-bridge, while OSC and $\overline{OSC}$ excite the bridge differentially. The external op amp is a JFET input amplifier (LF356) with very low input bias current on the order of 30pA (typical). C_1 allows AC coupling by blocking the DC common mode voltage from the bridge, while R_1 biases the output of LF356 to 0V at DC. Use of FET input op amp insures that DC offset due to bias current through R_1 is negligible. AC output of the demodulator is filtered via the uncommitted amp to provide DC voltage for the meter. The 10k potentiometer, R_5, limits the current into the meter to a safe level. Calibration begins by placing equal impedances at Z_R and Z_X, and the system offset is nulled by the offset adjust circuit so that Pin 1 is at 0V. Next, known values are placed at Z_X and the meter deviations are calibrated. The bridge is now ready to measure an unknown impedance at Z_X with ±0.05% accuracy or better.

RMS-TO-DC CONVERTER YIELDS 10-BIT ACCURACY

An AC voltmeter may be easily constructed as in Figure 5; the simplicity of the circuit and low component count make it particularly attractive. The demodulator output is a full-wave rectified signal from the AC input at Pin 4. DC component of the rectified signal at Pin 5 varies linearly with the RMS input at Pin 4 and thus provides an accurate RMS-to-DC conversion at the output of the filter (Pin 1). C_T is a variable capacitor that is tweaked until the oscillator signal to the sync input of the demodulator is in phase with the AC signal at Pin 4.

In many applications it may not be desirable to adjust C_T each time the AC signal frequency changes. An alternate approach is to use a zero-crossing detector to excite the sync input of the device. The LM311 comparator in Figure 6 produces a square wave (trace A in Figure 6b) in phase with the AC signal (trace B). Optimum rectification thus occurs at the demodulator output (trace C). For precision measurements at high frequencies, a fast, low offset comparator is recommended.

2. C_T is tweaked until the sync signal is in phase with the AC signal.



NOTE:
V_R is a fixed reference voltage, OSC frequency, f_{OSC} = 2.9kHz. Phase shift, $\phi = -\tan^{-1} (\omega R_O C_O)$.

a. Typical Single Supply LVDT Measuring Circuit

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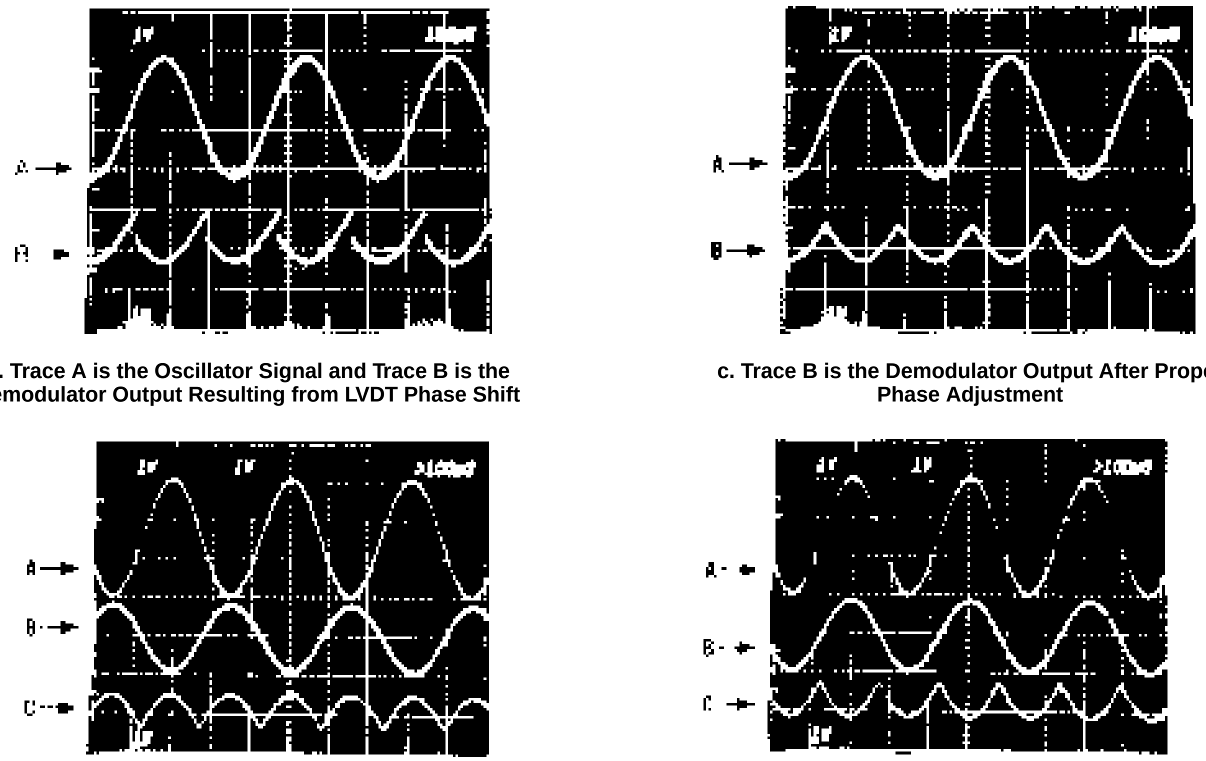
Figure 1.



b. Trace A is the Oscillator Signal and Trace B is the Demodulator Output Resulting from LVDT Phase Shift

c. Trace B is the Demodulator Output After Proper Phase Adjustment

b. With LVDT Output (Trace B) at 180° Out of Phase With Excitation Signal (Trace A), the Demodulator Output has Positive Polarity (Trace C)

d. Demodulator Output has Negative Polarity (Trace C) When LVDT Output (Trace B) is in Phase With Primary Signal (Trace A)

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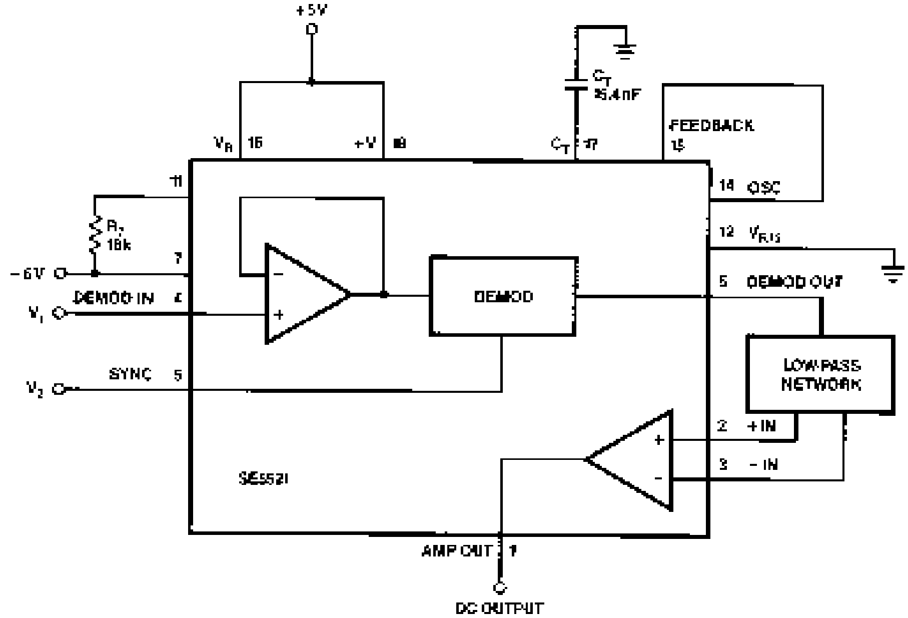
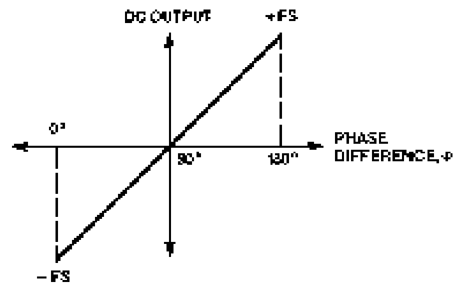
Figure 1 (Continued)



a. Phase Detector Measures Difference Between Signals V_1 and V_2 and Provides DC Output at Pin 1



c. When V1 and V2 in (a) are at Quadrature (Traces A and B), the DC Component of Demodulator Output (Trace C) is at 0V

c. The DC Output and Phase Vary Linearly

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Figure 2.

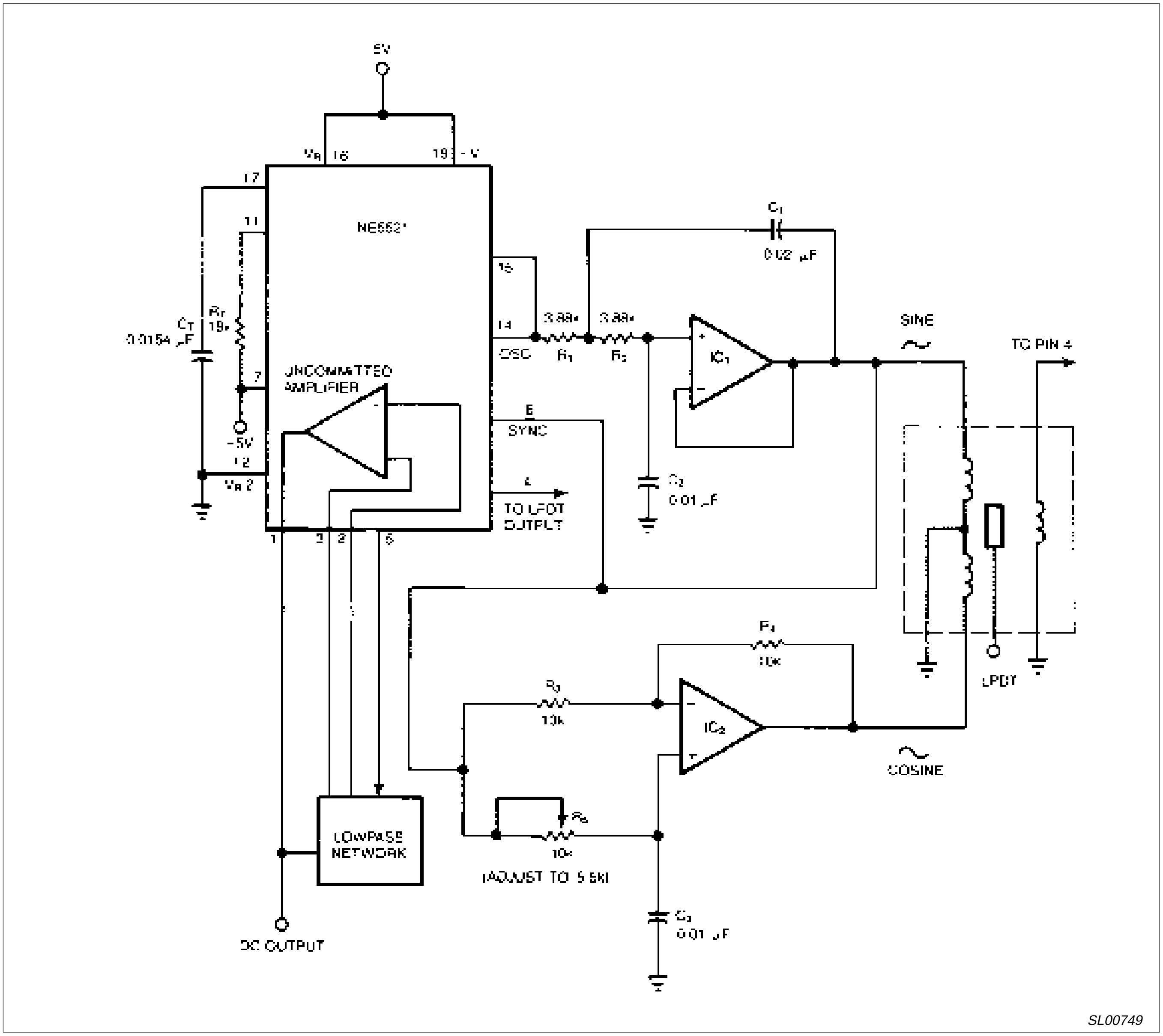
5V
NE5521
UNCOMMITTED AMPLIFIER
OSC
SYNC
TO LPDT OUTPUT
0.02 μF
SINE
TO PIN 4
COSINE
LPDT
LOWPASS NETWORK
DC OUTPUT
(ADJUST TO 5.5k)
0.01 μF
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Figure 3.

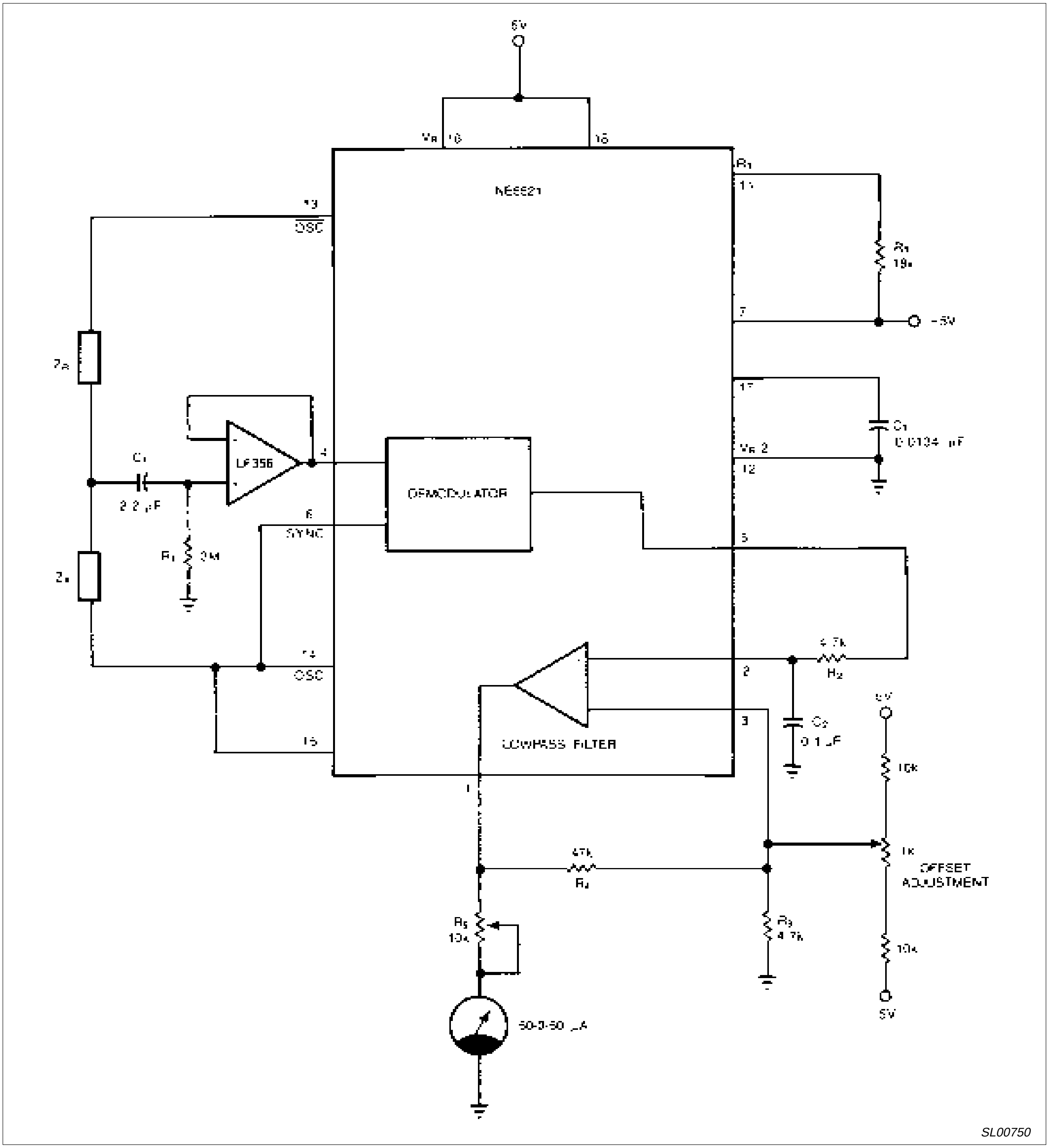
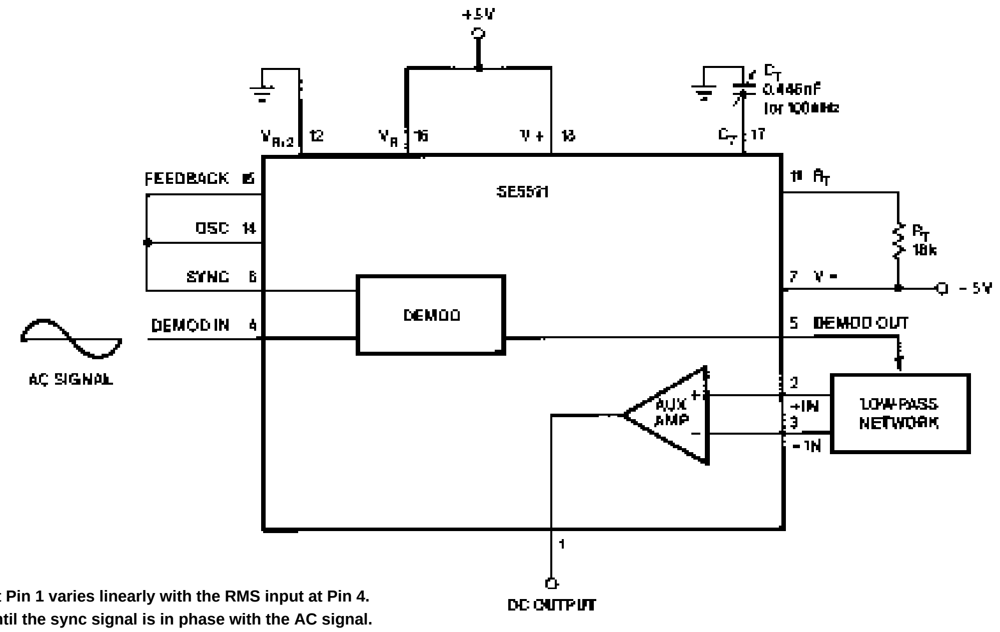


Figure 4. Signal Conditioner Used as an AC Bridge to Calibrate Resistors/Capacitors



NOTE:
1. The DC output at Pin 1 varies linearly with the RMS input at Pin 4.
2. CT is tweaked until the sync signal is in phase with the AC signal.

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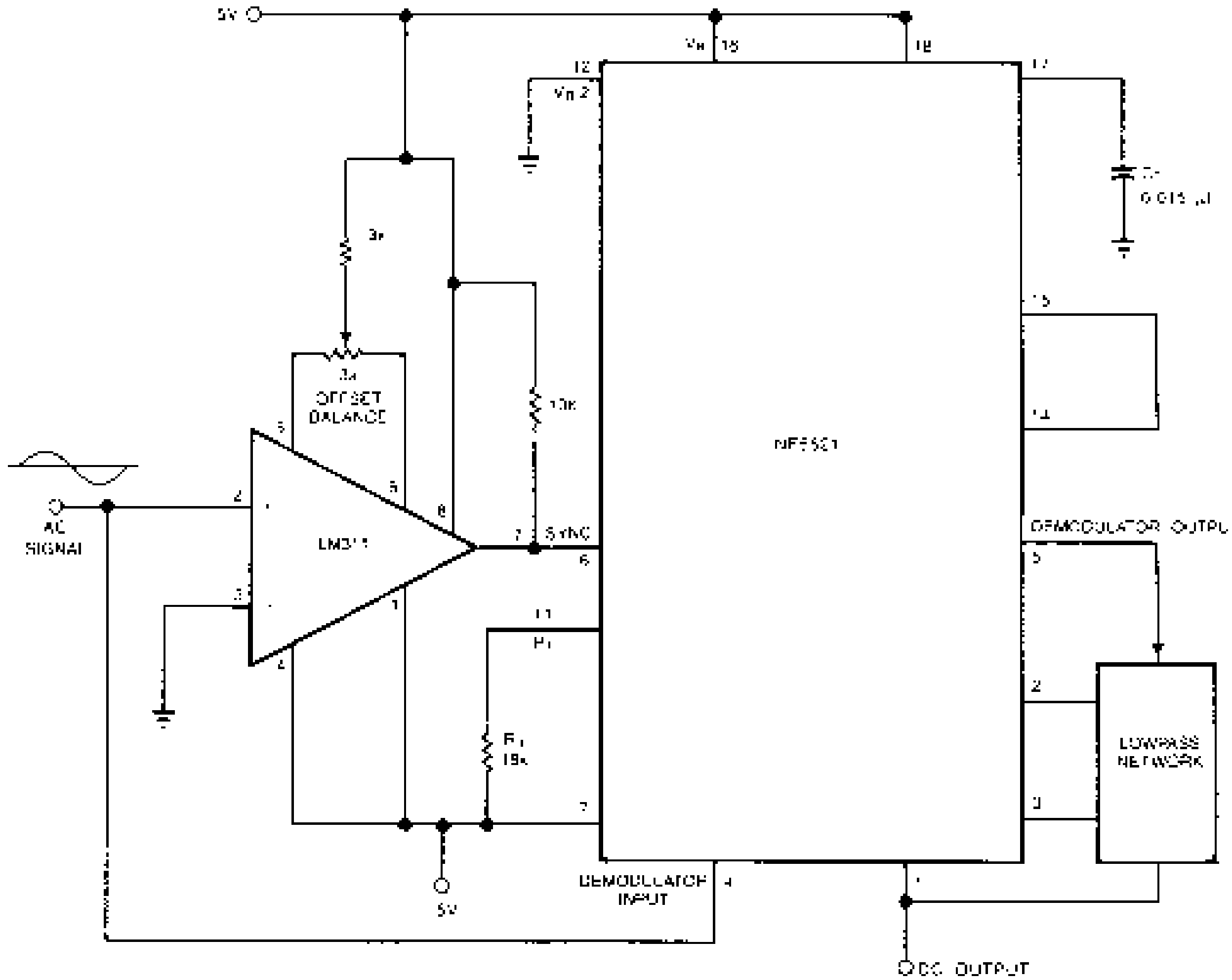
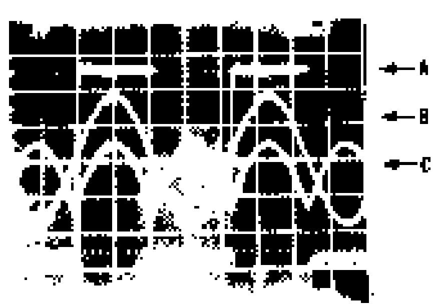
Figure 5. AC Voltmeter



a. AC Voltmeter. Comparator CI (LM311, Used as a Zero-Crossing Detector, Produces a Constant Amplitude Square Wave to Excite the Sync Input of the Demodulator. DC Output Appears at Pin 1



b. Trace B is the AC Signal at the Comparator and Demodulator Input. The Output of the Zero-Crossing Detector (Trace A) at Sync Input Causes Synchronous Rectification at the Demodulator Output (Trace C). Auxiliary Amplifier Filter Produces DC Output at Pin 1

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Figure 6.

APPENDIX I

A LOOK AT THE SIGNAL CONDITIONING IC

The signal conditioner essentially consists of three major blocks: an oscillator with programmable frequency, a synchronous demodulator, and an auxiliary amplifier (see Figure 7).

The oscillator generates a stable amplitude sine wave with an RMS value determined by a fixed reference voltage, V_R, at Pin 16 of the device, and referenced to $V_{R/2}$. Next, the oscillator signal is buffered by two high-gain, low-offset op amps to produce the buffered oscillator signal, OSC, and the inverted signal, $\overline{OSC}$. The OSC and $\overline{OSC}$ signals exhibit less than 50ppm/°Camplitude drift (at -55°C to +125°C temperature range) with total harmonic distortion under 2%. OSC and $\overline{OSC}$ signals are used to differentially excite the primary of the LVDT/RVDT. A fixed 18k resistor, R_T (external to chip), and an external timing capacitor, C_T, determine the frequency of the oscillator. The oscillator frequency is given by the following: $f_{OSC}=(V_R-1.3V)/[V_R(R_T+1.5k\Omega)\ C_T]$.

The signal conditioner employs a synchronous demodulatorulation technique to extract position and phase information of the transducer core. The synchronous demodulator block not only conditions the transducer output to provide usable information, but also provides a very high impedance load to the transducer output (on the order of several MΩ for maximum linearity and for relative insensitivity to frequency drift (see “How an LVDT Works”, Figure 11). Figure 8 shows how the demodulator functions. The oscillator signal, which is also the primary drive for the transducer, is tied to the sync input of the demodulator. Note that the OSC signal and the transducer output (demodulator input) are both referenced to $V_{R/2}$. The sync signal is compared to an internally-generated reference voltage, $V_{R/2}$. During the first half-cycle, as the sync signal goes above $V_{R/2}$, the demodulator functions as an inverter and, thus, the demodulator input appears inverted at the output. However, during the second half-cycle, as the sync signal goes below $V_{R/2}$, the demodulator functions as a follower and, thus, the demodulator input appears at the output with unity gain. Full-wave rectification thus occurs in synchronism with the primary drive signal. The amplitude of the rectified signal tells the position of the core, while the polarity of the output indicates on which side of null the core is. The demodulator offset is measured at less than 2mV with 5µV/°C offset drift, and linearity error is measured at ±0.05% full-scale (at -55°C to +125°C temperature range). A low offset is essential for transducer systems in precision applications since a high offset will not only mask the transducer null, but will also make position measurements inaccurate as the ambient temperature varies.

Since all readout devices (meters, recorders, etc.) are DC input devices, the AC output of the demodulator has to be converted to filtered DC before being applied to the readouts. Consequently, an on-chip amplifier may be used as an active filter with programmable gain for the demodulator output. The filter removes the carrier frequency and other higher-order harmonics from the demodulator output and produces a ripple-free DC output. The amplifier exhibits an open-loop gain of 380V/mV (typical) and 0.5mV input offset (typical). DC offsets from the transducer/signal conditioner system can be nulled by offset adjustment at the auxiliary amplifier. The device operates from 4.5V to 22V with single supply, or ±2.25V to ±11V with dual supplies.

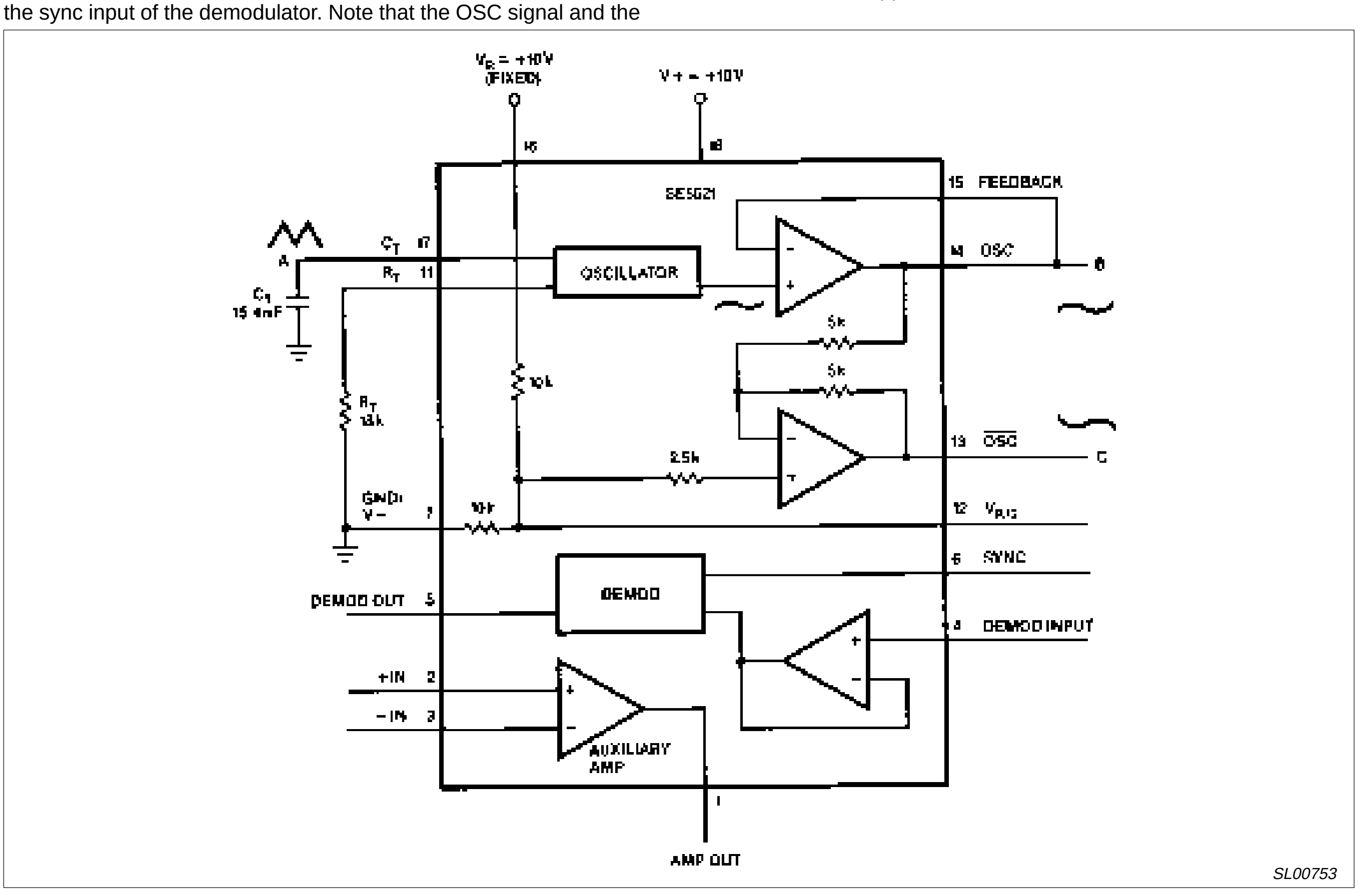


Figure 7. SE5521 Block Diagram

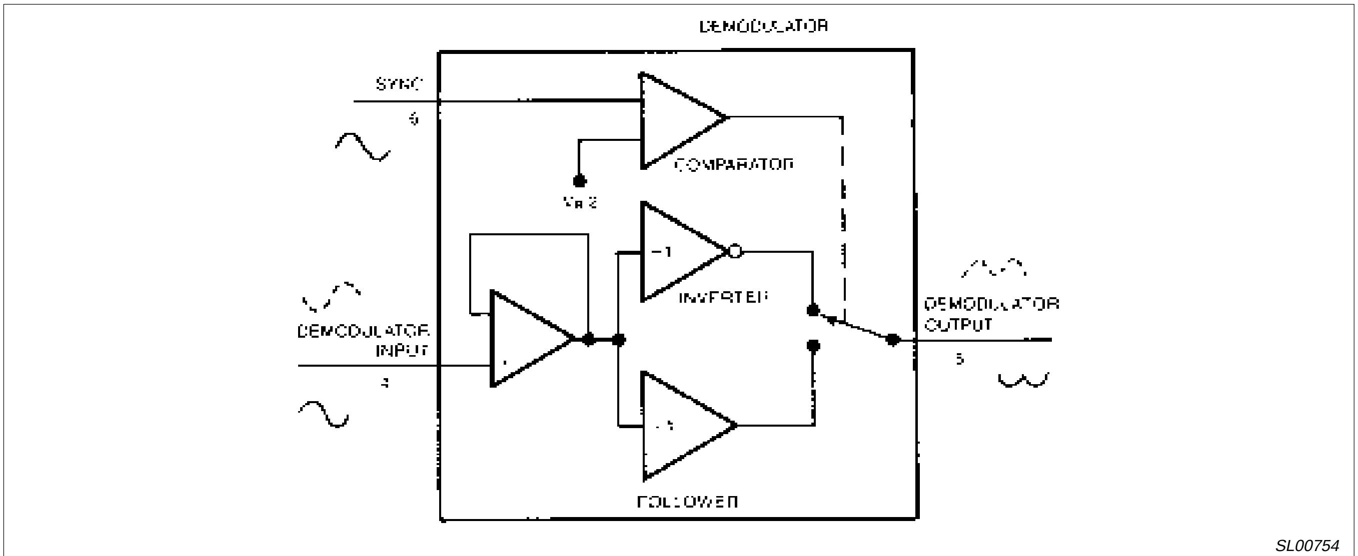


Figure 8. Synchronous Demodulator Full-Wave Rectifies the Demodulator Input Signal in Synchronization With the Sync Signal at Pin 6

APPENDIX II

HOW AN LVDT WORKS

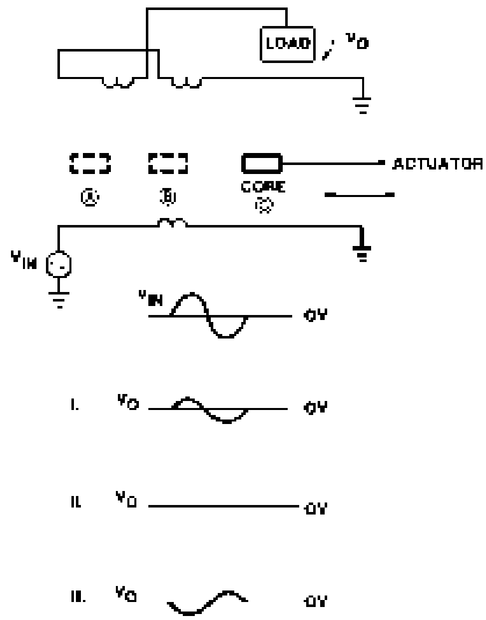
Linear Variable Differential Transformers (LVDTs) are position transducers that have long been used to measure very small displacement and any parameter that can be converted to linear motion. LVDTs are mutual inductance devices consisting of a primary winding and a pair of secondary windings that are wound on an insulated bobbin, and a non-contacting magnetic core capable of free motion inside the transformer. The secondaries are tied together externally in a series-opposing configuration.

With AC excitation at the primary, the core controls the coupling between the primary and the secondaries and produces a differential voltage across the secondaries. The magnitude of the voltage across the secondaries varies linearly with core displacement and contains both the position and phase information (direction of motion) of the core with respect to the center of the secondaries (null position).

With the core at null, the voltage induced at each secondary is equal and of opposite phase; thus cancellation occurs, resulting in a zero AC output. As the core traverses away from the null position, a sinusoidal voltage is developed across the secondaries, the amplitude of which contains the position information. Once the core moves through null, a 180° phase reversal occurs in the output signal with respect to the primary signal. Direction of the core (phase information) with respect to the null position is thus indicated as illustrated in Figure i.

In order to obtain any useful information, some form of signal conditioning is required. Figure 10 shows the DC output of the LVDT as a linear function of the core position after proper signal conditioning. The output voltage of the LVDT is directly proportional to the excitation voltage; therefore, it is essential that the excitation signals have a constant amplitude over the operating temperature range. Output voltage also varies with the excitation frequency. However, the change is not directly proportional to frequency, as shown in Figure 11. Most LVDTs show a small amount of phase shift between the excitation signal at the primary and the output signal at the secondaries. The phase shift introduces a DC offset at null and thus tends to mask the LVDT null. The LVDT null voltage may be reduced by exciting the primary at a frequency where both the primary signal and the output signal are in phase—this is the zero phase angle frequency. Exciting the LVDT at its zero-phase angle frequency optimizes linearity and repeatability of the measurements, while a high impedance load at the LVDT output eliminates the need for frequency regulation, as can be observed from Figures iiia and iiib.

Another popular position transducer is the Rotary Variable Differential Transformer (RVDT). The RVDT operation is analogous to the LVDT, except that the core motion is rotary.



NOTES:
1. With core at a, output is in phase with input. Output amplitude decreases as core moves from A to B.
2. AC output is zero when core is at B (null).
3. Output amplitude increases as core moves from B to C, output is 180° out of phase with respect to input.

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Figure 9. The LVDT Output Signal Changes Relative to Core Position

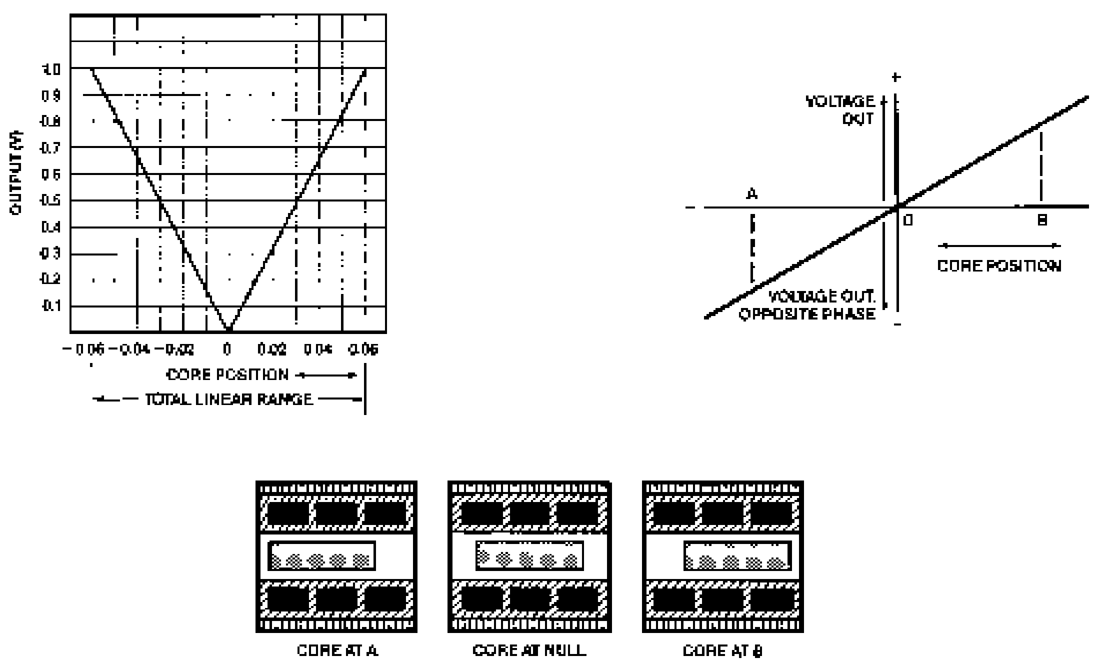

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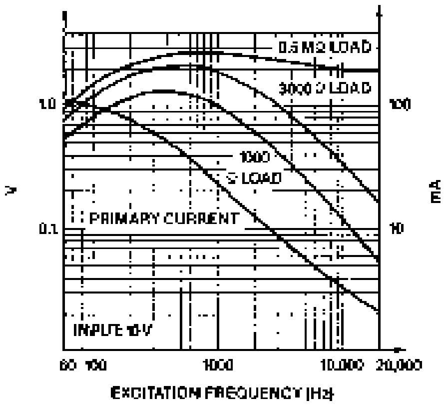
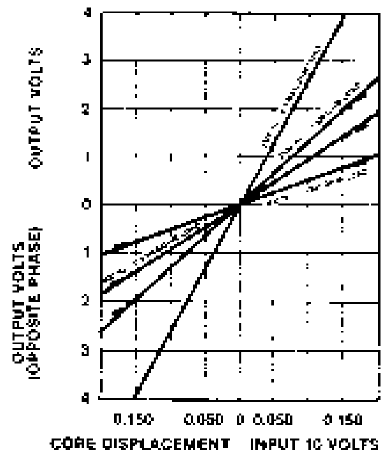
Figure 10. Absolute Magnitude of Output Voltage (Left) and Phase-Referenced Output Voltage (Right) as a Function of LVDT Core Position (Courtesy Schaevitz Engineering)



a, Nominal Full-Scale Output at Various Loads and Primary Current vs Ecitation Frequency for a Typical LVDT



a, Output Characteristics of a Typical LVDT for Various Loads and Excitation Frequencies (Courtesy Schaevitz Engineering)

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Figure 11.

APPENDIX III

LPDT CHANGES PHASE INSTEAD OF AMPLITUDE

A recently developed linear position transducer, the LPDT (Linear Phase Differential Transformer), produces a phase output linear with the core motion. The transducer construction is similar to the LVDT, the main exception being that there are six primary coils which are wound on a bobbin at a slant. The excitation to the transducer primaries consists of a sine wave and a cosine wave of equal magnitude. The output at the secondary is an AC signal of constant amplitude, which is the vector sum of the sine and cosine excitation signals, with a phase angle that varies linearly with core position. Figure 12 shows how the transducer is energized.

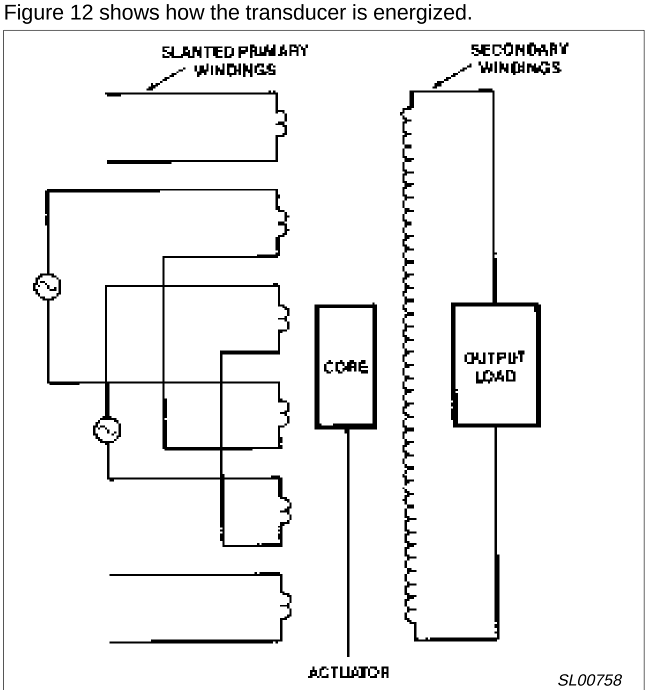

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Figure 12. LPDT with AC Excitation Signals at the Input

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1. Handbook of Measurement and Control, Revised Edition 1976, by Edward Herceg, Schaevitz Engineering Publication, Pennsauken, New Jersey.
2. Philips Semiconductors Linear LSI Data and Applications Manual, 1985 Edition, pg 4-212, 9-41. Philips Semiconductors Corporation, Sunnyvale, CA, 94086.
3. Frank Yeaple, “Linear Position Transducer Changes Phase Instead Of Amplitude”, Design News, November 5, 1984, pg 180.