USING A REVERSIBLE COUNTER

SPECIFICATIONS

5280A REVERSIBLE COUNTER

GENERAL

Range: DC to 2 MHz Channel A or Channel B (see 5285A specifications for details concerning other input requirements).

Registration: 6 Long-life Rectangular Nixie tubes (7th and 8th digit of readout available). + and - indication by long-life rectangular Nixie tube. Overflow indication by front panel neon light.

Reset: Remote by contact closure or saturated NPN transistor to ground. Input via rear panel BNC. Manual by front panel push button.

GATE CONTROL

Manual: Controlled by front panel function switch for OPEN and CLOSED positions.

EXTERNAL DUAL

Input: Separate BNC's on rear panel for START and STOP inputs. Triggered by DC level change or pulse.

Sensitivity: sine wave; 1 V rms. Pulse; 2V p-p.

Impedance: Approximately 100 kΩ. 25 pF shunt.

Trigger Level: +10 volts to -10 volts, adjustable at the rear panel. Independent controls on each input.

Polarity: + or - rear panel switch selects triggering slope.

EXTERNAL SINGLE

Input: START BNC on rear panel.

Sensitivity: sine wave; 1 V rms. Pulse; 2V p-p.

Impedance: Approximately 100kΩ. 25 pF shunt.

Trigger Level: +10 volts to -10 volts, adjustable at rear panel.

Polarity: + or - rear panel switch selects gate open polarity.

Gate: (+) Opens when input is positive with respect to the trigger level. Closes when input is negative with respect to the trigger level. (-) Inverse of (+). Manually switched DC voltage is a satisfactory gating input.

PRINTER OUTPUT

Output*: 4-line 1-2-4-8 BCD.
"0" State Level: approximately -14 volts.
"1" State Level: approximately +14 volts.
Overflow: Single line output
    off level approximately +17V.
    on level approximately -13V.

±Nixie Sign (indicates sign of count).
    Single line output
    + level approximately -15V.
    - level approximatly +13V.

5285A UNIVERSAL INPUT PLUG-IN
(for operation in HP Model 5280A only)

INPUT CHANNELS (A and B)

Range: DC coupled: 0 to more than 2 MHz. AC coupled: 10 Hz to more than 2 MHz.

Impedance: Approximately 1 megohm, 75 pF shunt.

Maximum Input: AC coupled, ±600 volts peak; DC coupled, 25 volts RMS (x1), 150 volts RMS (x10), 350 volts RMS (x100).

Sensitivity: 0.1 volt RMS sine wave; 1 volt pulse, 0.2 μsec minimum width.

Trigger Level: -100 to +100 volts, adjustable, independent controls on each channel.

MODES OF OPERATION

A Quad B: Totalizes A as a function of B phase Maximum rate 1 MHz (same frequency in both channels).
    Totalizes A positively if B leads A.
    Totalizes A negatively if B lags A.
    (Above for directional MODE switch in FWD position. Count direction reversed with switch in REV position.)

Af(B): Totalizes A as a function of B from DC to more than 2 MHz. If B is positive, A is totalized positively. If B is negative, A is totalized negatively. Count direction reversed within 250 nsec of B step function command. (Direction of A counted as a function of B is reversed with directional MODE switch in REV position.)

Algebraic A, B: Counts both A and B according to MODE selector setting.

A: A only to greater than 2 MHz.

A-B: Input A minus Input B: to 1 MHz per channel Anti-coincident circuit prevents count loss when pulses arrive in time coincidence.

A+B: Input A plus Input B; 1 MHz per channel. Anti-concident circuit prevents count loss when pulses arrive in time coincidence.

B: B only to greater than 2 MHz. (Direction of counting is reversed with the direction MODE switch in -position, i.e., modes would be -A, -A+B, -A-B, -B.)

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*4-line BCD outputs for the 7th or 8th digits of readout available on special order only.

1-2-2-4 BCD "1" state positive in lieu of 1-2-4-8 available as option 01.

USING A REVERSIBLE COUNTER

SUMMARY

This Application Note gives a broad coverage of the measurement and control situations for which a reversible (or bidirectional) counter is eminently suited. The decades in such a counter have the ability to totalize in a negative as well as a positive direction, and to count through zero in both directions. As a result, the counter finds great use where a need to subtract is required, where two frequencies or rates are to be compared, where a variable is to be compared against a reference, or where absolute position, positive or negative, is to be indicated.

This note initially describes the HP 5280A/5285A Reversible Counter and its many features. The input signal requirements and limitations are then detailed, followed by a discussion of those transducers that may be used to measure a physical property and convert this measurement into an electrical signal suitable for feeding into the Reversible Counter.

Next, there is brief mention of the output signals provided by the counter, and of the devices that may be coupled to the output for recording, scanning or transmission of data to an indicating instrument or a complete data acquisition system.

Finally, there is a description of a few typical applications in which this versatile counter may be used; the intention is not only to describe what has been done before, but mainly to stimulate the reader's imagination to seek further applications for the counter.

The Reversible Counter has achieved great success in research laboratories, but its potential in industrial situations, although as yet not fully recognized, is virtually unlimited.

APPLICATIONS

There are varied applications for reversible counters in many diverse fields. Note that "A" and "B" refer to the two independent input channels of the counter.

The first area that suggests itself is machine control. Reversible totalizers are now being used, and will be used more as manufacturers go to automated machine control. The movement of a tool along an axis can be accurately indicated by the reversible totalizer when used with the proper transducers. The zero crossing feature allows plus and minus readings from an arbitrary zero point.

The introduction of the laser interferometer to the machine control industry has created a need for the high speed reversible totalizers such as the 5280A/5285A. The interferometer contains mirrors, one of which is mounted on a movable platform such as the carriage of a machine tool. As it moves, light fringes or light and dark areas are generated which are approximately 10 micro-inches apart; these light intensity changes are detected by a photo-device such as a photocell which converts them to electrical signals. The signals are totalized by the reversible counter which therefore indicates movement plus or minus so many tens of micro-inches. Directional information is available because a second sensor is located so that its output differs in phase from that of the first sensor by 90 electrical degrees.

Machine control devices that might use totalizers are milling machines, grinders, drilling machines, lathes and jib borers. Reversible totalizers can be used with rectilinear plotters in preparing and checking punched tape used for control of automatic machines.

The chemical processing industry makes use of reversible totalizers and counters in liquid flow metering and blending operations. The relative flow rate of two liquids can be monitored by use of the counter's gated A-B mode. The amount of liquid contained in a tank could be constantly displayed by an A-B totalizer.

The totalizer A input would be proportional to the amount of liquid put into the tank and the B input proportional to the amount drained from the tank. The difference would be the amount of liquid in the tank.

Gyroscope testing requires reversible counters. There seem to be many different ways to test gyros but reversible counters are often employed. If a dc voltage is generated proportional to the drift of the gyro, it can be applied to a voltage-to-frequency converter, the output of which is counted by the reversible counter. The A input is the frequency rate for zero drift and the B input is the output of the converter. The difference reading would be an indication of the gryo's average drift for the period of the sample time. The sample time can be made as long as desired. Readout of gyro test table position can be accomplished by using the reversible counter, and electrical or optical transducers.

In the nuclear field, reversible totalizers can be used to indicate control rod position in nuclear reactors.

In radiation counting, the operator can remove background noise by using the counter in the A-B mode, where A is counting the test sample radiation including background and B is counting just background radiation.

Astronomers have used reversible counters to measure the relative light intensities of various star fields and star positions.

Geologists have used the counter in similar manner to measure relative magnetic field strengths.

In electronics, two frequencies often must be compared, a comparison made easy by use of the reversible counter. When the readout stops changing they are equal. The counter can then be reset to zero, and the amount and direction of relative drift monitored. Symmetry of square waves can be measured to high resolution with the reversible counter.

TABLE OF CONTENTS

SECTION I
GENERAL INFORMATION

GENERAL

This Application Note surveys in broad terms the wide range of measurement and control situations in which reversible counters are potentially useful. The aim is to stimulate the reader's imagination and creative instincts by detailing some possible applications of a particular reversible counter, in order that he may consider ways and means of employing such a counter for his own purposes.

To this end, a fair portion of the Application Note is devoted to descriptions of those features which make the reversible counter such a valuable unit, and of the input and output requirements of the counter.

It is essential that the potential user be acquainted with the various operating modes of the reversible counter; it is essential that he have some rough idea of the types of electrical signals that are necessary to drive the counter. If his application is such that he will be relying not entirely on visual display (readout), but will be using recorders or data gathering and transmission systems, or remote warning devices, then it is also necessary that he be acquainted with the characteristics of the electrical output signals.

In many cases when the HP 5280A Reversible Counter is being considered for use in monitoring a physical property, the feasibility of the application will depend upon the ability of the user to provide a suitable means of transforming that physical property to an appropriate electrical signal. Such a transducer will have an output in the form of a sinewave, a squarewave, or rectangular pulses; the rate or time of appearance of these signals is related in some way to the magnitude of the physical property being measured. It will be up to the user, whether he be a nuclear physicist or a production engineer, to seek out a transducer suitable for his purpose. He will also have to ensure that the transducer is accurate enough and/or inexpensive enough for his purposes, and that it mates to the reversible counter. It is for these reasons that he should be aware of the input requirements of the counter.

Because of the importance of transducers, Appendix I describes some suitable ones and how they work. Because these are comparatively few in number, applications of the reversible counter will be increased considerably by the user's ingenuity in seeking out or inventing suitable transducers, or in adapting presently available transducers and techniques to his particular requirements.

UNIDIRECTIONAL COUNTERS

Since the introduction of the first electronic counter by Hewlett-Packard way back in 1951, the electronic counter has gained wide and increasing acceptance, until now it is one of the most important measuring instruments in the electronics field. Initially an electrical frequency measuring device, the counter has been made so versatile that it can now be used for a wide variety of frequency (rate) and time measurements. Basic measurements which can be made include frequency, period and multiple period average, ratio and multiple ratio, time interval, and prescaling (to increase allowable maximum frequency to be measured), depending upon the versatility of the counter and plug-ins. In addition, preset counters, which allow the counter main gate to be held open for N periods of a selected counter time base frequency, permit multiplication and division by N, and the selection of a time interval for N events to occur.

The basic input to an electronic counter consists of a time series of electrical signals, with shapes that may vary from sine-wave to square-wave to some in-between irregular shape. The shape and amplitude of the signals are immaterial, except insofar as they must allow satisfactory triggering of the counter. By appropriate circuitry a signal is "shaped" to sharpen the edge and the pulse is then fed into binary logic circuits which in effect, "add 1". This "one" count is transmitted to decade circuits, and the output is displayed on Nixie tubes in decimal form - 0, 1, 2, etc.

Every pulse that arrives in sequence is totalled in a positive direction, and the display will keep on increasing with the receipt of every additional pulse while the counter gate is open. By the provision of a time base which opens the counter gate for an accurately predetermined period of time, a counter is able to measure frequency: if 1500 pulses are counted in a time period of 0.1 sec, then the frequency or rate is $\frac{1500 \text{ pulses}}{0.1 \text{ seconds}} = 15,000$ pulses per second

The counter display may be reset manually or automatically to enable it to start counting afresh from zero, and the sample rate, or rate at which the counter is reset, may also be selected for convenience of readout.

The electronic counter has gained such wide acceptance because of its automatic operation and its extremely high accuracy. Another characteristic, particularly important in, say, production testing, is of course the simple direct count display, allowing rapid measurement and recording by unskilled operators with minimum possibility of readout error.

These features are also present in the 5280A Reversible Counter, making it an ideal instrument for both laboratory and industrial use.

The decades in the well-known unidirectional counter will totalize in a forward direction alone; the receipt of any pulse can result only in the addition of a positive

increment to the count. The unique feature of a reversible counter is that it accepts and records negative increments, and thus the count is able to decrease in numerical value, and even to record negative totals.

REVERSIBLE COUNTERS

A typical counting sequence of the Hewlett-Packard 5280A Reversible Counter might be

0 1 2 3 4 3 2 3 2 1 0 -1 -2 -3 -2 -3 -2 -1 0 +1 etc. As explained in Section II, such a sequence might be obtained by adding pulses on one channel and subtracting pulses on the second channel. Alternately, such a sequence might be obtained by, in effect, counting pulses on the first channel only, but at the same time feeding information into the second channel which instructs the counter as to whether these pulses are to be added or subtracted.

When the Reversible Counter is operated as a "totalizer" with the count gate left open, then, for example, it may be used to indicate linear position with respect to a selected reference point. Assume that every incremental change of position of one thousandth of an

inch leads to one pulse being fed to the counter. Assume also that information detailing whether that incremental change was in a forward or backward direction is supplied to the counter. Now in the counting sequence above, the count at any point in time would indicate the position of the variable forward or backward of the reference position, measured by n x 1/1000 inches.

This means of measuring position cannot be achieved using a unidirectional counter; its count can only increase positively.

The reversible totalizer becomes a true counter by the provision of a time base, either internal or external, which controls the length of time for which the count gate is open. The instrument is now able to measure and compare frequencies or rates, such as revolutions per minute, gallons per second, averaged over time intervals whose duration is selected by the user.

The 5280A/5285A may be used either as a totalizer or as a counter (with external time base). An internal time-base is now available on special order. See Appendix III for details.

SECTION II

THE HP 5280A REVERSIBLE COUNTER

Now that the reader has some idea of the potential applications of reversible counters, and where such counters differ from unidirectional electronic counters, it will be beneficial if some of the important features of the HP 5280A are briefly discussed.

At present, there is one plug-in unit available for use with the 5280A Reversible Counter; this is the HP 5285A Universal Input Plug-in. We shall consider the two components as one unit since both must be ordered; neither one will operate independently of the other.

Appendix II shows front panel and rear panel views of the counter, together with short descriptions of the features and controls.
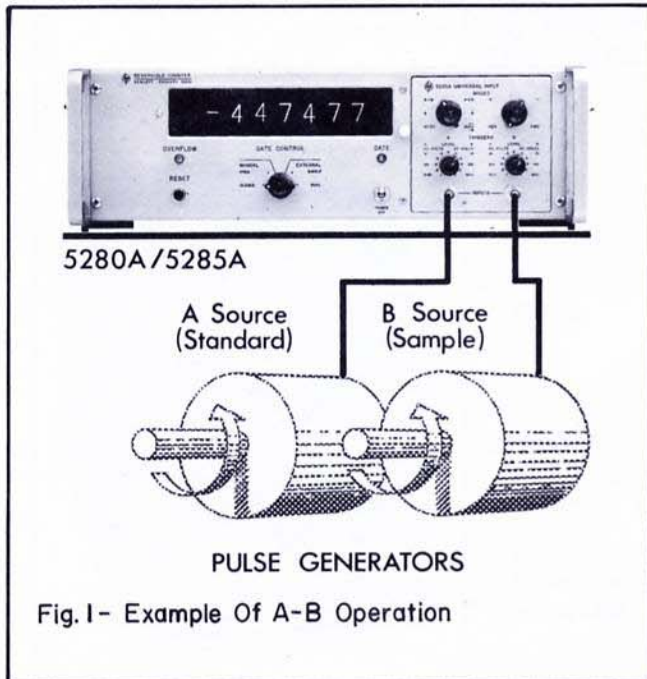
FEATURES AND BENEFITS.

The first characteristic that should be borne in mind is the great versatility of this counter. It has six basic modes of operation:

Algebraic A: totalizes input pulses on channel A.
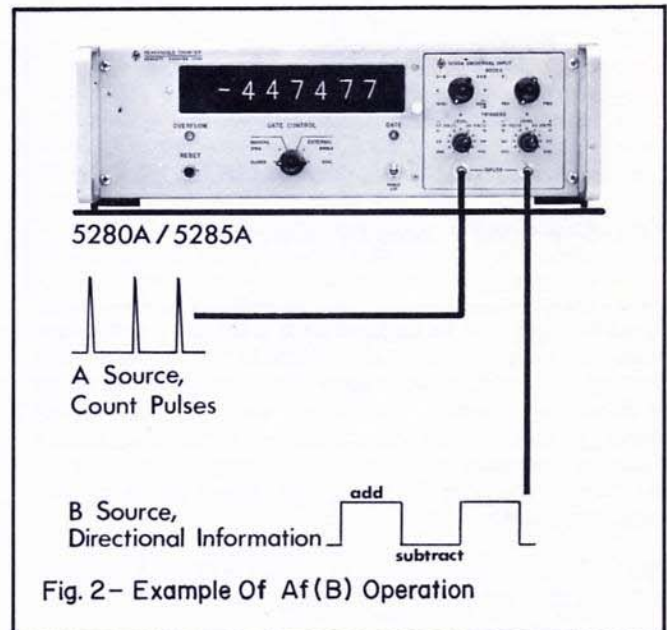Algebraic B: totalizes input pulses on channel B.
Algebraic A+B: totalizes the sum of the input pulses on channel A and channel B.
Algebraic A-B: totalizes the pulses on the two channels in such a way that channel A pulses are counted positive, while channel B pulses are counted negative. See Figure 1.

5280A/5285A

A Source
(Standard)

B Source
(Sample)

PULSE GENERATORS

Fig. I - Example Of A-B Operation

Af(B): in this mode, which is called A as a function of B, only channel A is totalized. Its count direction is controlled by the voltage level on the B channel. When the signal on channel B is more positive than its set trigger level, channel A is added. When channel B is more negative than its trigger level, A is subtracted. See Figure 2.

5280A/5285A

A Source,
Count Pulses

B Source,
Directional Information

add
subtract

Fig. 2 - Example Of Af(B) Operation

A Quad B: this mode is similar to Af(B) above in that only channel A is totalized, but the direction of count is controlled by the phase relationship between inputs A and B. When the pulses on channel B lead those on channel A by a 90 degree phase angle, then channel A pulses are counted in a positive direction. However, when the pulses on channel B lag those on channel A by 90°, then the channel A pulses are counted in a negative direction: for example, +3, +2, +1, 0, -1, -2, etc. See Figure 3.

As a further convenience, a count reversing switch is provided. Thus the above modes may be converted to: -A, -B, -(A+B), -(A-B), ie., -A+B, -Af(B), -A Quad B.

To ensure easy mating between the pre-counter units and the counter, the trigger levels are continuously variable between +100 volts and -100 volts, with provision for ac and dc coupling. In addition, the A and B triggering waveforms are available through buffers on two rear panel monitor BNC's. In the A Quad B mode, and particularly at high count rates, it is important that the A and B signals be 90° out of phase. Through the above provision, the waveforms can be displayed on a scope to check that the signals are indeed in phase quadrature.

The versatility of the machine is further evidenced by its gating provisions. It has, of course, a manual control for opening and closing the gate. Strictly
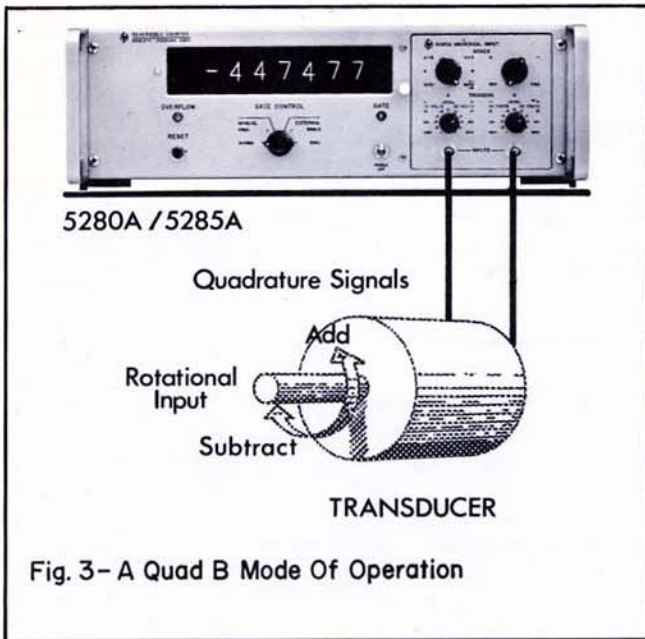
5280A / 5285A

Quadrature Signals

Rotational
Input

Add

Subtract

TRANSDUCER

Fig. 3 – A Quad B Mode Of Operation

speaking this unit is defined as a totalizer; nevertheless, by supplying suitable signals for opening and closing the gate, it will then measure rates such as gallons per minute, cycles per second, etc. Provision is made for external gating control on either a single line (positive signal opens gate; negative signal closes gate) or by start and stop signals on two separate lines.

The second important characteristic of this counter is its ability to count very rapidly in both directions.

In the A, B and Af(B) modes, the instrument will totalize at a maximum rate of 2 MHz (the maximum rate in the other modes is 1 MHz). A very important spec-

ification of a bidirectional counter is the time required to reverse the direction of count; the 5280A can handle a reversal of direction in 250 nanoseconds with no loss of counts. In addition, it should be noted that this unit will count through zero at the full specified rate; some counters require that the system be slowed down when counting through zero to ensure sensing of the zero crossing.

Other features of varying importance are:

1. The 5280A has anti-coincidence circuitry as a standard feature. This ensures that, in the A+B and A-B modes, every single input pulse is counted, no matter what the relative phasing of the signals on the A and B input channels. If pulses are received simultaneously on the two channels, this circuit delays one of the pulses so that both may be totalized with no loss of counts.

2. Read-out incorporates a six-decade, in-line Nixie display for easy visibility. An additional one or two decades (digits) may be supplied on special order, with no decrease in maximum count rate. Some other designs require that when extra decades are added, the count rate be reduced so that no counts are missed. Thus it is possible to increase count registration up to an eight-digit readout.

3. A 1-2-4-8 BCD output is available at the rear panel to operate a digital printer, or for control or recording purposes within a system. This feature will be discussed in greater detail later.

4. The 5280A counter is provided with plus and minus polarity indication, overflow indication, and a reset feature controlled by both a front panel pushbutton and a remote signal.

SECTION III

INPUT SIGNALS

Before specific applications are discussed, it is necessary that the reader understand clearly what type of input information is acceptable to the 5280A/5285A Counter.

5285A PLUG-IN.

One parameter of an electrical signal is amplitude. It is obvious that excessively large signals will damage an instrument and care should be taken not to exceed the specifications. However, the 5280A does allow a wide range of input amplitude magnitudes. With ac coupling, the maximum input allowable goes up to ± 600 volts peak. With dc coupling and maximum attenuation (i. e. x 100), the maximum allowable signal is 350 volts rms. (However, it should be noted that for dc coupling with X10 attenuation the maximum is 150 volts rms; with X1 attenuation, the maximum is 25 volts rms). Thus it can be seen that almost any input signal will be acceptable to the 5280A counter (with respect to the possibility of damage due to excessive amplitude).

The minimum input level is just as important. At what input levels will the signal amplitude be so small that it will not activate the counting circuits? The sensitivity of the counter depends upon the wave shape of the input signal. For sine waves the sensitivity is 0. 1 volts rms (or 0. 28 volts peak-to-peak), while for square waves or pulses, a minimum pulse amplitude of 1 volt peak-to-peak has been specified.

The user must be sure that the signals supplied to the counter exceed these minimum levels, or the counter will not perform properly. It will either not count at all, or may count haphazardly and so miss a certain percentage of counts.

The counter is designed not to respond to signals below these levels, so that noisy signals or the presence of background noise do not lead to incorrect counting. The user should attempt to provide as "clean" an input signal as possible, but noise amplitudes of a few millivolts are tolerable.

Another parameter of an electrical signal that is of great importance is frequency or pulse rate. The 5280A Counter is slow considered within an overall spectrum of electronic counters; viewed with respect to the class of reversible counters, it is extremely fast indeed. Given a sine wave input, this counter will totalize in 3 modes, A, B, and Af(B) up to frequencies of 2 MHz; in the other modes the maximum permissible frequency is 1 MHz.

When pulse inputs are under consideration care has to be exercised. These same high frequency limits just mentioned apply to square-wave signals. However, what about the case where the average pulse rate may be acceptable, but the pulses come in bursts?

Consider the pulse train shown in Figure 4A. Here the average pulse rate is 2×10^5 pulses per second, but the effective pulse rate required is 10^6 pulses per second, because the two pulses in a pulse burst are only 1. 0 μsec apart. The 5280A counter will perform perfectly. However, a counter rated at 200 kHz (the average pulse rate) may count only every second pulse and the display will then read one half the actual count rate. It is more likely that such a counter would not count at all, or at best haphazardly. In general we may say that the 5280A counter will handle pulses as little as 0. 5 μsec apart.

The high count rate is important in many applications, particularly in position sensing. In this application, rapid vibration or slewing of the transducer will require that the counter be able to handle bursts of pulses that may be very close together.
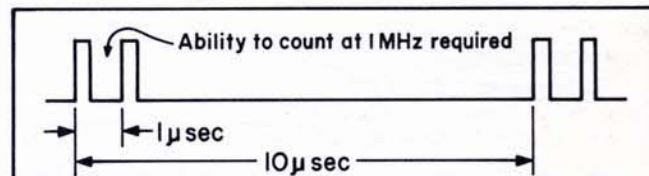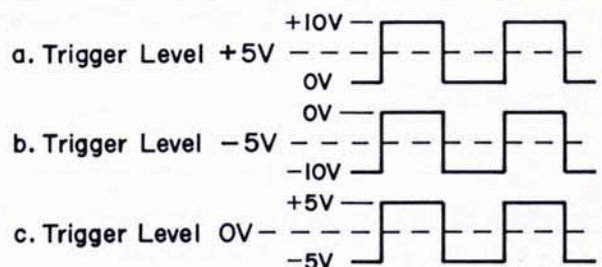

Fig. 4A- 200kHz Pulse Train

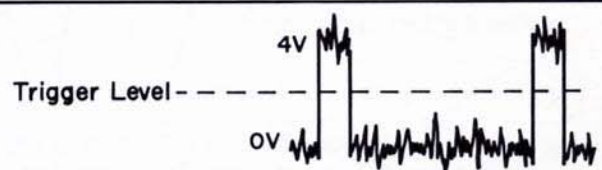Fig. 4B- Trigger Level Settings For Various DC Coupled Input Signals

Fig. 4C- Noisy Signal

A further consideration to bear in mind when counting pulses, as opposed to sine wave signals, is the width of the pulses. The 5280A requires pulses that are greater than 0.2 microseconds in duration.

In the majority of cases, use of either the ac or dc coupling modes will lead to perfect triggering of the Counter by the input signal. The trigger level controls allow this counter to be relatively indifferent to input signal polarity.

Using dc coupling, we would adjust the level control to give a trigger level of approximately +5 volts in the case of Figure 4B(a). For Figure 4B(b), we would adjust the level to -5 volts and for Figure 4B(c) we would adjust the level to 0 volts.

A situation where dc coupling would be required is where the input frequency is very low (from 10 Hz down to a cycle every few seconds or few minutes) and where the wave shape is sinusoidal or the signals have slow rise times. Spasmodic and infrequent pulses may

still trigger the input circuitry correctly in the ac coupling mode, provided that the rise time is less than 20 ms. One precaution required is that the signal be of sufficient amplitude to avoid counting noise pulses. See Figure 4C.

The ac coupling provision is particularly useful where the input signal is offset by a large dc voltage. If dc coupling were employed in this case, the trigger level would have to be set to some large value and drift problems might arise, particularly if it were necessary that the triggering point remain at the same position in the cycle, as in A Quad B operation (see Figure 5A). In another situation, the use of the attenuator control to enable triggering under large dc offset conditions might reduce the amplitude of the informational signal to a value below the sensitivity of the counter, and triggering would not take place (see Figure 5B).

Now let us look at the situation if ac coupling were employed. The dc offset voltage would, in effect, be removed and the trigger level could be set to 0 volts. This action leads to the avoidance of drift problems, while the signal level is more than sufficient to drive the counter correctly. See Figure 5C.

It has been explained what electrical signals are required to trigger this counter correctly on either the A or B input channels. Before it is discussed how and from where these signals are obtained, the Af(B) and A Quad B modes of operation and their further requirements will be described briefly.

In the Af(B) mode, the signals that are counted are those on the A channel. The B signal channel controls only the direction of count. However, it is still necessary that the direction indicating signal correctly triggers the B channel; this should be checked beforehand by using the B mode of operation and ensuring that correct counting is taking place.

In this mode, the count direction will be positive when the B channel signal is more positive than the trigger level setting, and negative when the B channel signal is more negative than the trigger level setting. Thus if the direction indicating signal varies between, say 10 volts and 0 volts (see Figure 6A), then the trigger level setting would be adjusted to dc +5 volts. It is still essential that the signal amplitudes be sufficient to meet the sensitivity requirements, and to swamp out signal and background noise.

In the A Quad B mode as in the Af(B) mode, the signals that are counted are those on the A channel, while the B channel controls only the direction of count. Once more it is necessary that the direction-indicating signal correctly triggers the B channel, and this could be checked beforehand by using the B mode of operation.

The direction of count is controlled by the phase relationship between the A and B signals, and the two signals should be in 90 degrees out of phase.

The pre-counter equipment must provide a signal to the B channel that leads the signal to be counted by

Trigger Level
Drift

12V
10V
8V

DC COUPLING:
Attenuator Setting X10

0V
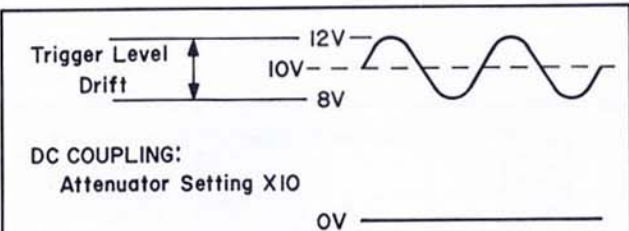
Fig. 5A- Trigger Level Drift Causes The Point Of Triggering To Vary Along The Cycle

10V
10.5V
9.5V

DC COUPLING:
Attenuator Setting X10

0V
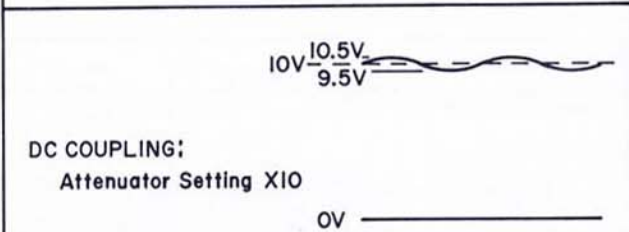
Fig. 5B- The Amplitude Of The AC Signal Is Insufficient To Trigger The Counter
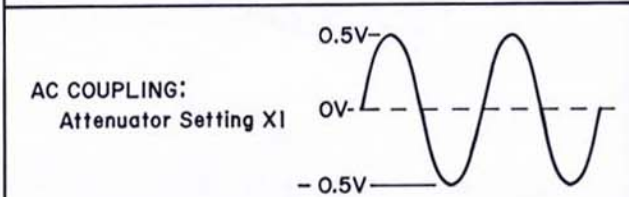

0.5V

AC COUPLING:
Attenuator Setting X1

0V

-0.5V

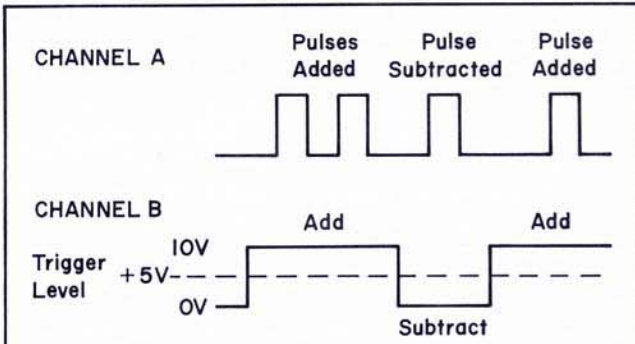Fig. 5C- The Amplitude Of The AC Signal Is Well In Excess Of That Required To Tigger The Counter; Drift Problems Are Reduced
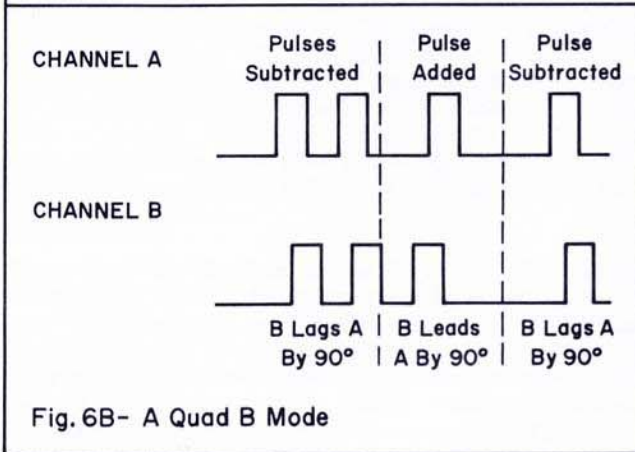
Fig. 6A- Af(B) Mode

Fig. 6B- A Quad B Mode

90° for positive direction of count and lags by 90° for negative direction of count (see Figure 6B).

The foregoing has explained what properties an electrical signal must have in order that pulses, square wave signals, or sine wave signals may be counted by the 5280 Reversible Counter. However, it should be made clear that, in fact, a totalizing operation has been discussed. If no other types of signals were fed to the counter, it would totalize ad infinitum in a positive and/or negative direction depending upon the informational content of the trigger input signals to channels A and B, starting from zero. Thus with a suitable transducer, the counter might indicate displacement or position of the sensor with reference to a zero point, at any and every point in time after the count pattern has been initiated.

However, on many occasions, the user will wish to tell the counter when to count and when not to count. If this can be done, then a second variable, time, can be introduced, and so rates can be measured. For example, the display will read out a pulse rate or frequency, i. e., n pulses per second.

5280A REVERSIBLE COUNTER

The 5280A counter has a number of facilities for gating the counter; in other words, for controlling the period of time during which the counting circuit is operative.

1. Manual. By means of a front panel control, the operator can open the gate and initiate counting, and then close the gate and so stop the count. The count accumulated during that period will be displayed.

2. Remote. (a). By applying a signal to a rear connector, the gate can be opened when its input is positive with respect to the gate trigger level, and can be closed when the signal is negative with respect to the gate trigger level. (Inverse operation is possible.) The gate trigger level is adjustable from +10 volts to -10 volts.

3. Remote. (b). By start and stop signals to start and stop connectors on the rear panel, the gating period can be controlled. On receipt of a positive pulse on the start line, the gate will open. On receipt of a positive pulse on the stop line, the gate will close. (Inverse operation is possible.)

By use of these remote gating controls, the period of count can be set with an accuracy dependent upon only the precision and stability of the gating signal source. (The accuracy is limited by trigger level jitter and jitter and noise on the input signal.)

The final provision required is to be able to clear the display and reset it to zero. This can be done manually or by remote control. For example, by feeding in a series of one second gating commands and resetting the display automatically after each gating period, the frequency of an input signal can be monitored every few seconds.

SECTION IV

INPUT SOURCES

In the previous section the properties of the input electrical signals required to operate the reversible counter correctly have been explained. Distinction can be made among various possible sources as follows:

SOURCE 1. Provides a signal that contains the desired information with respect to the variable to be measured, monitored or controlled.

SOURCE 2. Provides reference information, that is, information as to what should be the value of the measured variable, or perhaps zero point information.

SOURCE 3. Provides signals to control the counter gate. At what points in time, and for how long, should it be open?

SOURCE 4. Provides reset information. In many cases, this information will be supplied to the counter simply by means of a manual push button on the front panel.

Sources 2, 3, and 4 may or may not be present depending on the application. Let us begin by discussing Source 1, which must always be present.

SOURCE 1 - DESIRED INFORMATION

In general, physical properties that we want to measure with the reversible counter may be classified into two distinct categories.

a. The variable may be applied directly to the counter, which then indicates the value of the variable in appropriate units. Basically the counter adds or subtracts pulses over a specified period of time, therefore the only variable suitable for direct measurement is a frequency modulated signal, where the primary information consists of frequency variations. Thus, as one example, a frequency to be measured may be applied to the A channel, and a reference frequency (Source 2) to the B input. By totalizing in the A-B mode for a specified period, an indication is given of the drift of the measured frequency with respect to the standard frequency over the specified period of time.

This type of application, frequency monitoring, constitutes a very small part of the total spectrum of reversible counter applications.

b. In the second category, the variable to be measured must somehow be transformed to another variable which provides a suitable input to the reversible counter. For example, assume that measurement of shaft angular velocity in rpm has to be made. Transformation of this variable into a time series of pulses whose frequency at any point in time is directly equivalent to the angular velocity of the shaft at that same point in time would have to occur. These pulses could now be fed to the reversible counter, whose

readout would indicate shaft angular velocity. The transformation would be carried out by a unit known as a transducer (in this case, perhaps a tachometer generator). The transducer provides a source 1 input to the counter (see Figure 7).

Fig. 7 - Transducer Transforms Variable Into Signals Suitable For The 5280A
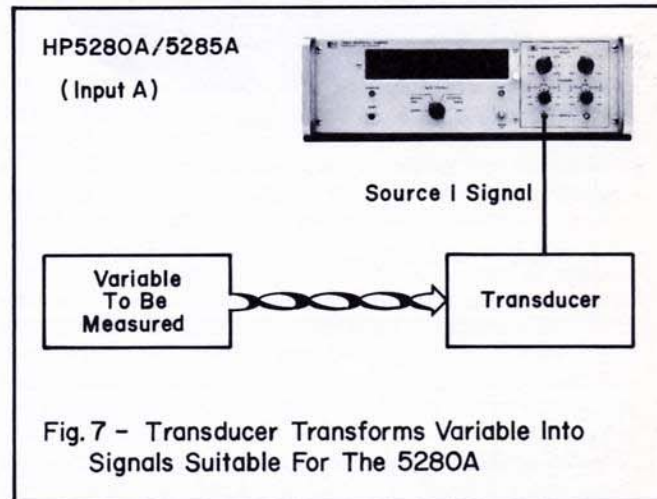
A brief discussion will follow of the types of transducers that may be used to convert variables of interest such as pressure, position, flow, into Source 1 signals suitable for the reversible counter, and so measure these variables. Appendix I discusses suitable transducers at greater length.

1. The first category of transducers will provide the majority of units suitable for reversible counter applications. Transducers that provide one pulse when a known incremental change takes place in the measured variable belong in this category.

    a. Turbine Flow-meter. This transducer is located in the fluid flow line, hence the liquid must be clear. No particles that could damage the mechanism should be present. The transducer is widely known and used, and is capable of handling a large range of flow rates at high pressure. It meters n gallons for every revolution of the turbine blade and can, of course, be used to monitor total flow as well as instantaneous flow rates (see Figure 8). Commonly the pulses to feed the counter are generated by magnetic induction, hence minimum rates of flow must be maintained to generate pulses of sufficient amplitude to trigger the counter.

    b. Tachometer Generator. This transducer may be connected to a rotating shaft and generates by magnetic induction a series of pulses at a rate proportional to angular shaft speed. By suitable
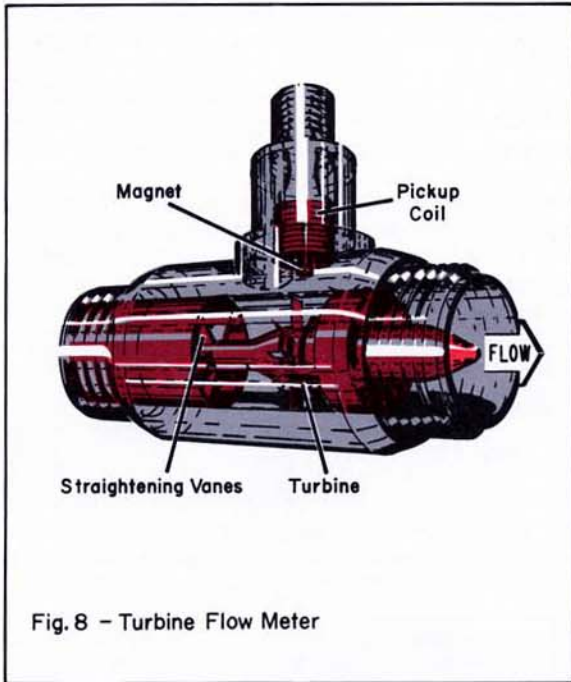
Fig. 8 - Turbine Flow Meter

d. Laser Interferometer. The principles of interferometry have been used for measuring length for half a century, but only recently, with the development of a highly coherent light source provided by the gas laser, has it become possible to measure length over long distances in an industrial environment.

In the Michelson interferometer a light beam is divided into two by a beam splitter (in effect a half silvered plane mirror). Beam 1 is reflected back by a fixed mirror to the beam splitter where it is recombined with beam 2, which is reflected back by a moveable mirror (see Figure 10). If the distance travelled by beam 1 is exactly equal to that travelled by beam 2, then the two beams will recombine constructively since the two waves are in phase (see Figure 11A). Assume the mirror moves so that the length of beam 2 is changed by $\lambda/2$ where λ is the wavelength of light. Figure 11B shows how destructive interference now occurs, since the two waves are out of phase. Further movement of $\lambda/2$ will once again lead to constructive interference.
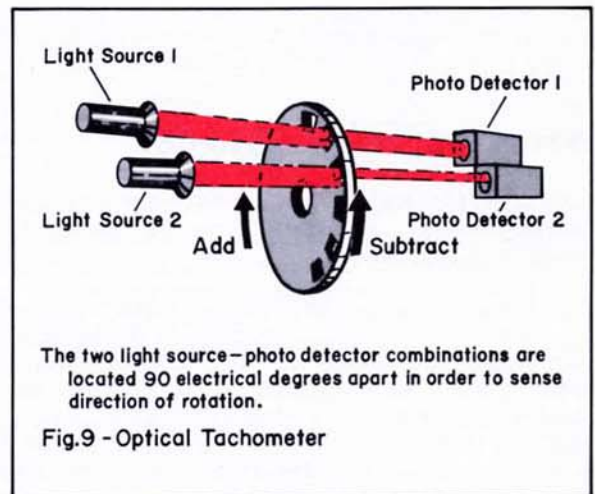
gearing and coupling, it can be used to measure angular and linear velocity. As before, due to the method of pulse generation, minimum shaft speeds are necessary to provide pulses of sufficient amplitude. The user should check to ensure that starting and running torques do not affect the motion of the moving mechanism.

c. Optical Tachometer. This is a highly suitable and useful transducer for monitoring angular motion (and linear motion using proper coupling). The basic principle involves a light source directing a beam onto alternately transparent and opaque areas on a rotating disc connected to the shaft (see Figure 9). A photo-detector (normally a photo diode or a solar cell) is energized whenever light reaches it through the disc, and therefore rotation of the disc causes a series of electrical pulses. Energy generation is independent of angular velocity (except that the response drops off at high frequencies) and hence the device is extremely suitable for position indication where movement of the shaft is irregular with respect to both time and speed. The number of output pulses per revolution can be varied according to user specifications from a few to several thousand, thus high resolution can be obtained.

When a second light source and detector are built into the transducer and located 90 electrical degrees away from the first source-detector combination, two in-quadrature pulse trains are available as outputs. The reversible counter, operated in the A Quad B mode, will now count incremental movements in both forward and reverse directions.

The two light source – photo detector combinations are located 90 electrical degrees apart in order to sense direction of rotation.
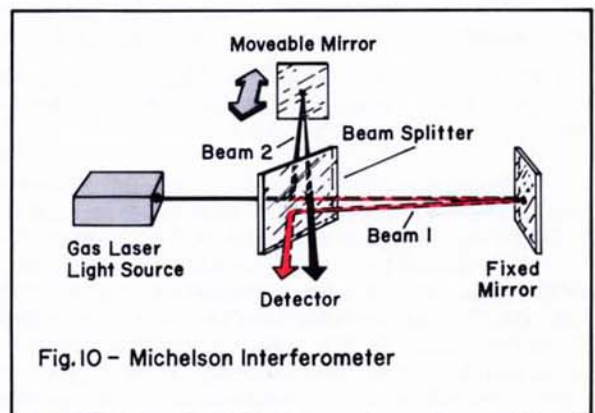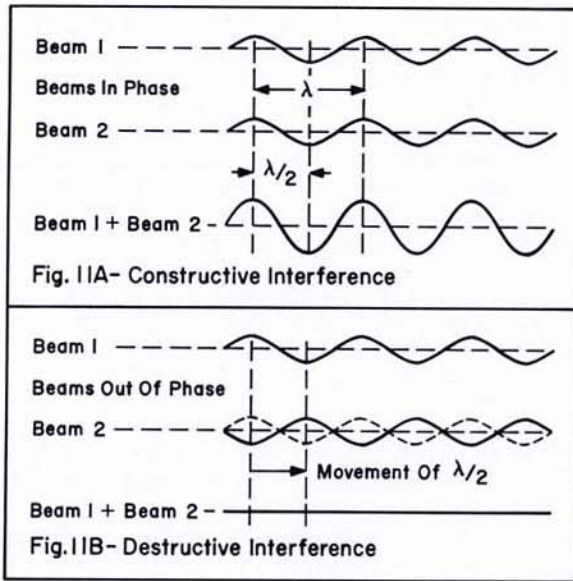
Fig. 9 - Optical Tachometer

Fig. 10 - Michelson Interferometer

Fig. IIA- Constructive Interference

Fig.IIB- Destructive Interference

Backward or forward movement of the mirror will thus cause alternate light and dark fringes to sweep across the viewing area in the corresponding direction. Every appearance of a fresh light/dark fringe combination indicates that the mirror has moved by $\lambda/2$.

It is important to note that the light beam is folded back on itself once, thus a movement of the mirror of $\lambda/2$ causes an increase in the length of the beam by λ. This is why the distance moved is indicated in increments of $\lambda/2$ rather than λ.

These fringes can be detected by a photo-cell; if a second photo detector is located 90 degrees out of phase with respect to the first detector, pulse trains are available to drive the 5280A operated in the A Quad B mode. Positive and negative incremental movements will be indicated by the counter in terms of half wavelengths of light.

The problem with light sources has been that they have not been sufficiently spectrally pure; the radiation has not maintained a single highly constant wavelength. In addition, the waves sent out from the various atoms have not been exactly in phase with one another. Because of this, as the difference in length between beam I and beam 2 is increased, the contrast between light and dark becomes less noticeable and interference fringes are hard to observe. Before the advent of the laser, measurements over lengths considerably less than a meter were possible.

The gas laser, however, produces very stable single mode radiations which are also highly coherent, that is, in phase, thus measurements over several meters are easily possible. The gas used is an He-Ne combination which emits radiation at a wavelength of 6328 Angstrom. One half wavelength is therefore 12.5 micro-inches and measurements to this order of precision or better are possible today, and are already being demonstrated in machine tool control systems.

Note that the standard of measurement is a wavelength of a stable light source, and the basic accuracy is limited only by the stability and precision with which that wavelength can be maintained. The unit of length is completely independent of any mechanical calibration system.

e) Optical Gratings. This type of transducer system also makes use of the technique of fringe counting, but the basic precision depends upon the accuracy with which gratings can be ruled on a substrate. The distance between the lines of the grating is the standard of measurement. Depending upon the type of scale, line frequency may vary from 1000 to 5000 per inch.

Two ruled scales are mounted in very close proximity, one a moving scale attached to the carriage, and the other a fixed index attached to the frame. When the index is set at some small angle to the moving scale, and the gratings are properly illuminated, then a number of Moire fringes (or Ferranti fringes) will be seen (see Figure 12). These fringes move at right angles to the movement of the scale, and one fringe represents the

Fig. 12A- Optical Grating

Fig. 12B- Moire' Fringes
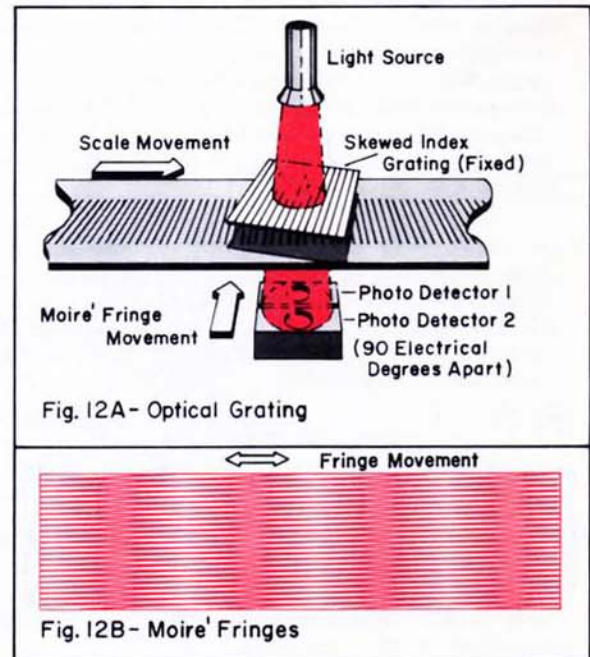
distance between co-existent lines on the scale. The fringes can be counted by a photo detector-counter combination. As before, two photo-detectors are necessary in order to provide information as to the direction of travel of the moving scale.

f) Incremental Pulsers. These may be used to count objects moving past the transducer. An example of this application might be packages moving along a conveyor belt being totalled for record keeping purposes. Commonly, the objects might break a light beam to a photo detector and thus provide a pulse to the counter; if the objects were of magnetic material, they might break an oscillating circuit and so provide pulses. Nuclear radiation sources are another means of providing energy beams, whose presence or non-presence can be easily detected.

Note that the above transducers provide no reference information; they do not measure directly in absolute terms. Missed counts, or resetting the recording counter to zero, will destroy information that up to that time was accurate.

2. The second category of transducers makes use of an oscillating device to provide an output frequency that varies with changes in the environmental function. The output frequency provides an absolute indication of the measured variable. Typically the "normal" or reference value of the variable will be represented by some fairly high frequency, and wide swings in the variable about that reference point will be represented by a small frequency variation about the reference frequency ($\Delta f/f \ll 1$).

Points to watch are the stability of the basic oscillator with changes in time and with changes in the environmental conditions. Very often the frequency may vary inversely with changes in the property of interest; thus to maintain acceptable linearity, it is necessary to keep $\Delta f/f_0$ small. In any case, the linearity of the relationship should be checked.

In most reversible counter applications, it will be necessary to subtract the "zero point", or reference frequency, from the input frequency representing the value of the measured variable. If this is done, then the absolute value of measured variable will be indicated directly on the counter read-out.

a) The vibration or vibrating wire is best known in connection with pressure measurements. The output is a frequency-modulated signal inversely proportional to pressure.

The transducer consists of a tungsten wire tensioned in a magnetic field between an anchor point and the pressure diaphragm; the wire forms one arm of a bridge oscillator circuit. A feedback amplifier excites the wire to a sustained vibration at the natural frequency determined by its tension, which is controlled by the pressure on the diaphragm.

b) The quartz crystal oscillator may be used in the measurement of temperature, pressure and dew point. Thus, a quartz crystal may be cut in such a manner that the frequency of the oscillator output varies linearly with temperature. Hewlett-Packard has sliced a resonator in the LC orientation to exhibit a temperature coefficient of 35.4 ppm/°C. Using a basic reference

frequency near 28 MHz, a frequency slope of 1000 Hz/°C is achieved; this shows the magnitude of the resolution that can be obtained. The quartz crystal is contained in a remote temperature sensor, and its frequency is compared to a reference frequency of 28.208 MHz, which by design is also its frequency at 0°C. By gating a counter appropriately, a numerical readout directly in degrees centigrade is obtained.

Hewlett-Packard manufactures a complete quartz thermometer, Model 2800A/2801A. However, no temperature probe circuits can be supplied independently for use with the 5280A Reversible Counter.

In similar fashion, pressure may be applied to a quartz crystal to vary its resonant frequency.

Besides the lesser problem of achieving linearity, the major difficulty lies in cradling the crystal in such a manner that a wide range of pressures can be measured without destruction of the crystal.

c) Similar techniques may be used in variable reluctance and variable capacitance bridge circuits to achieve changes in frequency with changes in the property undergoing measurement.

3. The third category of transducers contains no digital transducers at all; it consists entirely of analog transducers with dc output. If the output of such a transducer is transferred into digital form by means of an analog-to-digital converter, then this whole field of low cost transducers is available for use with the HP 5280A Reversible Counter.

The HP Model 2212A Voltage-to-Frequency Converter produces an output pulse train whose pulse rate is directly proportional to the magnitude of a dc voltage applied to its input terminals. Full scale output of the converter is 100 kHz for switch-selected ranges in decade steps from 1 volt down to 10 mV full scale. The converter responds equally to positive and negative inputs.

Assume that we have a strain gage whose dc output voltage is proportional to pressure. If this dc voltage is fed into a voltage to frequency converter which is coupled to an appropriately gated electronic counter, the readout on the counter will represent pressure. Scaling or normalizing can be performed with the optional range vernier for the HP 2212A or by using a variable gate time base to gate the counter.

This system performs true integration over the period of time selected for gating; the response time for the converter is less than 100 μsec.

4. A fourth category consists of nuclear digital transducers. Basically, radiation from a nuclear source passes through a variable shutter which is mechanically coupled to and controlled by the measuring element, for example, a bourdon pressure tube or a bimetallic thermometer strip. A

nuclear radiation detector counts the random radiations after they pass through the variable shutter and read-out is displayed on a counter. The count rate will vary from zero, when the shutter is closed, to a high number when it is wide open. Because of the mechanical devices and coupling employed, the response time is very slow, of the order of seconds. (See Reference No. 14).

The above discussion has dealt with Source 1 devices, those that supply basic measurement information. The following are auxiliary sources, which may or may not be present depending on the particular application.

SOURCE 2 - REFERENCE INFORMATION

This source provides reference information, invariably in the form of a highly stable frequency, against which the converted physical property can be prepared.

Assume that the stability of a 50 mV dc supply voltage is to be monitored. This supply could be converted to 50 kHz by a voltage-to-frequency converter and fed to the A channel of the Reversible Counter. If a stable 50 kHz was fed to the B channel and the counter operated in the A-B mode, then the read-out on the counter would indicate dc voltage drift over time.

Suitable source devices are frequency synthesizers (high precision, any frequency selectable, very stable, expensive), quartz oscillators (very stable, few output frequencies, less expensive) and audio oscillators (low stability and accuracy, infinitely variable, inexpensive). Appendix IV describes equipment suitable for operation in conjunction with the 5280A.

SOURCE 3 - GATE CONTROL INFORMATION

This source provides signals to control the counter, that is, to determine when and for how long it should be open.

A suitable external source might be the 3300A Function Generator to provide frequencies varying from 0.01 Hz to 100 kHz.

SOURCE 4 - RESET INFORMATION

This source provides reset information by contact closure or by saturated NPN transistor to ground. Alternately, of course, manual operation is possible by front panel pushbutton.

Appendix III briefly describes an internal time base for the 5280A that is now available on special order. This time base, in effect, provides both source 3 and source 4 information to the counter. The gate time and the rate at which sampling and automatic resetting occur can be selected at the front panel.

SECTION V
OUTPUT SIGNALS

The output signals of the 5280A/5285A are few in number. The primary output that comes to mind is, of course, the visual display of six in-line Nixie tubes with polarity indication. Instant readability is associated with storage of the display until the count changes. The operator is able to read the number displayed very rapidly and with very little possibility of error.

For situations where it is necessary to maintain a record of the count display, or for use within data or control systems, the read-out is available on the rear panel through a 50 pin connector. The information is coded in 4-line 1-2-4-8 BCD, with the "0" state level approximately -14 volts and the "1" state level approximately +14 volts.

In addition, output signals are available to indicate when the count has overflowed and the polarity of the count. This information is available to drive digital recorders, digital-to-analog converters and other such devices as mentioned in Section VI.

The above output may be replaced by a "Readout on the Fly" feature, available on special order, which is intended for systems use. This modification allows count information to be transferred into the system on command without interrupting counting, missing counts or slowing down the system. See Appendix III.

Finally, the output waveforms of the channel A and B triggering circuits are available on rear panel BNC's. By monitoring these waveforms on an oscilloscope, and adjusting their phase difference, proper operation in the A Quad B mode may be obtained. The wave forms may also be used as marker signals for other modes of operation.

SECTION VI
OUTPUT DEVICES

This section touches only briefly on the immense variety of output devices that can be mated to the 5280A Reversible Counter.

1. The first type is one that maintains a continual record of the counter readout. Recorders can be further sub-divided into two classes, digital and analog.

    Digital: The HP Model 562A Digital Recorder is a transistorized electro-mechanical device providing a printed record of electronic digital information. Printing rates as high as 5 lines per second are possible, while a unique storage feature allows BCD input data to be transferred to the recorder in 2 milliseconds.

    This recorder can be operated directly from the 5280A counter through the 50 pin rear connector.

    Analog: Here the interest lies not so much in the extreme accuracy of digital print out, but rather the convenience and visibility of a graphical plot of the desired information. For example, one suitable recorder might be the HP Model 680A Strip Chart Recorder in which one Y span (or sensitivity) and one chart speed (in units of distance per unit of time) may be selected by the customer. This type of recorder is particularly suitable where a permanent record of events is required, and yet the information may be assimilated at a glance by the operator at intervals of a few minutes or a few hours.

It should be noted that such a recorder cannot be mated directly to the reversible counter. A 562A digital recorder with the correct option constitutes a suitable drive unit; alternately the counter may be coupled to the strip chart recorder by means of a digital-to-analog converter (HP 580A), which transforms the BCD output from the counter into analog information. Note that polarity information cannot be transmitted by the digital-to-analog converter.

Another useful analog recorder is a servo potentiometer X-Y recorder which plots an X-Y graph according to the changes in the variables fed into the X and Y channels; both channels have completely independent servo systems. Example: HP 7035A X-Y recorder. Say a system for measuring X and Y position of a machine tool carriage provides readouts on two reversible counters for instantaneous monitoring. If the two counters are coupled to the X and Y channels of the recorder, every movement of the carriage on the X and Y plane will be faithfully reproduced on the chart, and will be available for leisurely inspection and post-production check-out.

Note that, as before, the recorder must be mated to the reversible counters through suitable coupling devices such as digital-to-analog converters.

2. A second type of output device is one that is generally used within a complete data acquisition or control system.

The HP Model 2514A Digital Scanner is one such device. It will accept data directly from 3 counters (6 sources with option) and transfer this data at a rate of up to 20 sources per second to a suitable unit, e.g., a 562A Digital Recorder. The scanner provides 1 BCD digit of source identification. As an example, the rotational speeds of a number of rolls within a paper mill installation may be monitored by separate counters, and data transmitted via the scanner for recording, computation or control purposes.

A similar type device would be the HP Model 2540 Coupler, which transfers information from a group of parallel reversible counters (and other sources) to a wide variety of serial-entry recorders. The coupler may be used to drive an adding machine or electric typewriter for printed record purposes, a tape punch for telegraph code transmission via wire or radio link, or a tape punch, card panel or flexo-writer for computer input requirements.

Another potentially very useful device is the HP Model 2539A Digital Comparator, which compares digital information from the reversible counter against single or dual preset limits, providing HI/ = /LO or HI/GO/LO lamp indications and electrical output respectively. The instrument can be operated manually or automatically in a programmed data acquisition system, and gives immediate indication wherever danger or tolerance points are exceeded.

Other HP units which will accept data directly from the 5280A Reversible Counter include the HP 2526 Card Punch Set, the HP 2546 Magnetic Recorder Set and the HP 2545 Tape Punch Set.

SECTION VII
APPLICATIONS

The types of applications that are briefly discussed show such diversity that it is difficult to arrive at a logical order of classification. Those applications where the counter is operated in the A-B mode will be dealt with first.

Application 1: Measurement of volume in a tank. The counter is operated in the A-B mode. The A channel is fed pulses from a turbine flow meter TF1 located in the input line to a tank, and counts input gallons; the B channel is fed pulses from a turbine flow meter TF2 located in the output line from the tank and counts output gallons. The two turbine flow-meters act as source 1 inputs; no other sources are active, although the gating and reset controls might be operated manually at suitable intervals. The 5280A is thus operating as a totalizer (see Figure 13).

HP5280A/5285A

(A-B Mode)

Input

TF1

TF = Turbine Flowmeter   Tank   TF2   Output

Fig. 13 – Continuous Indication Of Volume Of Liquid In A Tank
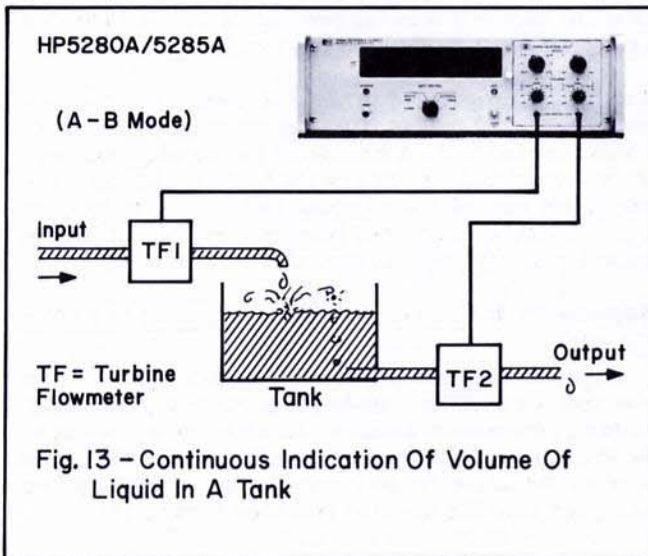
The counter read-out will indicate the net volume of the liquid that has flowed into or out of the tank from the time of opening of the counter gate. The polarity signal will show whether there has been more fluid flowing in than out, and vice versa.

If the tank was empty when the counter gate was opened, then the counter will read the volume of liquid in the tank at that point in time when the reading was taken. The level may be continuously monitored by feeding the counter BCD output into a HP 562A digital recorder and instructing the counter-recorder combination when to record.

Precautions:

1. The fluid has to be free of solids to avoid damage to the turbine flow meter.

2. Accuracy of the system will be dependent on the accuracy of the flow-meter, and the possible error will be double that of one flow-meter alone.

3. Turbine flow meters do not operate down to zero flow, in general. The rate of flow should always be maintained above the lower limit specified.

There are numerous variations on the above theme. It is possible to calibrate one flow meter against another, or to select two flow-meters for similarity, provided that they are placed in the same line far enough apart to minimize turbulent effects. If the B channel were connected to an electrical reference frequency, then the rate of flow in the line could be checked for constancy and accuracy (using a source 3 gate control input). The counter operated in the A-B mode would provide an indication of the average drift.

Assume that it was desired to pump liquid along a line at a known rate of flow, say 10 gallons per second. Assume further that the flow meter used provides 10 pulses/gallon. Therefore the nominal input frequency to channel A should be

10 pulse/gal x 10 gal/sec = 100 pulse/sec

A highly stable 100 Hz signal from an oscillator should now be fed into channel B (HP Model 100E Quartz Oscillator would provide a suitable signal).

By manually or automatically controlling the rate of flow so that the counter always reads zero; it is known that the rate of flow has been held constant at the desired rate for the period under consideration. Furthermore, despite any variations in rates of flow, the total flow in gallons will be correct, provided the counter reads zero when flow ceases.

See Appendix 1, page 23, for further information on turbine flow meters.

Application 2: Flow measurement, using an ultrasonic technique. In this application the counter is used as an integral part of the transducer. If the ultra sonic transducer is set up so that its two transmitter receiver systems are cycling, one at a frequency f1 where transmission is in the direction of fluid motion, and the other with a frequency f2 where transmission is counter to the fluid motion, then f1-f2 gives a linear representation of fluid velocity and hence fluid flow. By applying the f1 signal to the A channel and the f2 signal to the B channel, the counter, operated in the A-B mode, will read out rate of flow (see Figure 14).
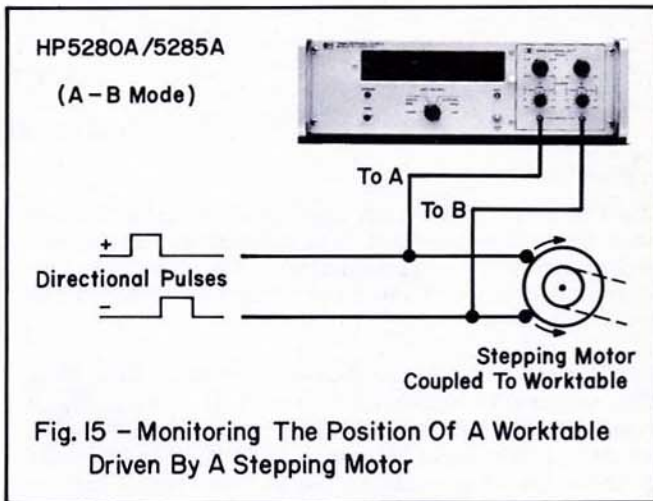
It should be noted that source 3 and source 4 signals are necessary to gate the counter at appropriate intervals for suitable time periods, and to provide

automatic resetting after every count. Thus, if the counter were gated for periods of 10 seconds, and if a frequency difference of 1 Hz represented a rate of flow of 0.1 gallon per second, then a readout of 100 would indicate that the average rate of flow over that 10 second period has been

$$100 \text{ counts} \times 0.1 \frac{\text{gal}}{\text{count}} \times \frac{1}{10} \text{ secs} = 1 \text{ gal per sec}$$

It should be noted that this transducer is sensitive to changes in velocity profile (as are all flow meters), and velocity distortion can lead to measurement error. (However there is no blockage in the line so there are few restrictions on the type of fluid carried.) This transducer is particularly suitable for high rates of flow.

See Appendix 1, page 23, for further information on ultrasonic flow meters.

Fig. 14 - Ultrasonic Measurement Of Flow

Application 3: Monitoring the position of a work table of a numerically controlled milling machine.

A two input stepping motor is used to drive the work table of the milling machine. Pulses fed into one channel cause the motor to step in one direction and hence move the table positively; pulses fed into the other channel cause the motor to step in the reverse direction and hence move the table negatively. One pulse on either of the input lines causes one step in a corresponding direction, where one step represents "n" degrees of angular movement; one step also represents "X" inches linear movement of the work table (see Figure 15).

A numerically controlled tape system determines the direction and amount of travel at any point in time.

The 5280A Reversible Counter is employed purely as a monitoring device to audit the position of the work table. By this means, continuous information as to

Fig. 15 - Monitoring The Position Of A Worktable Driven By A Stepping Motor
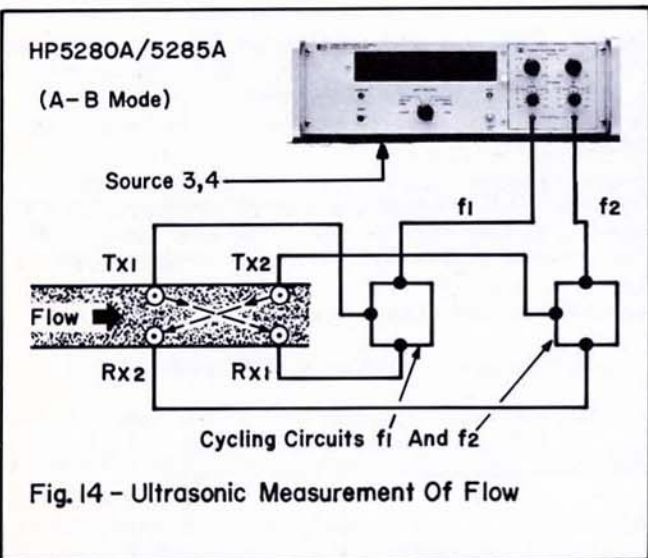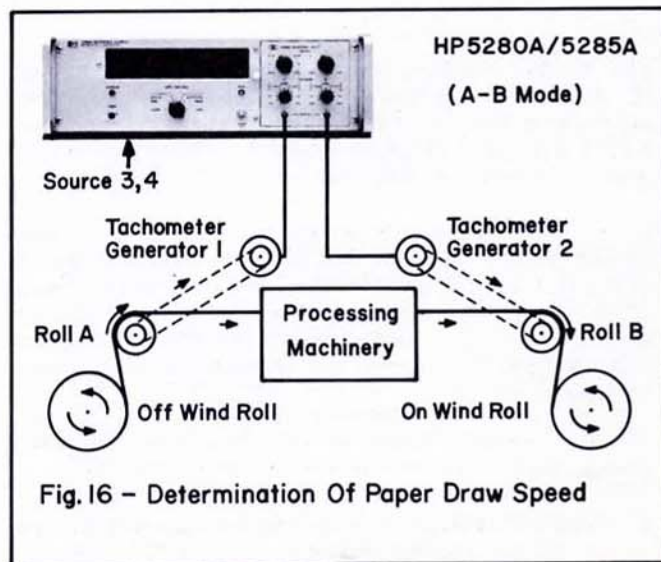
the position of the work table is available for easy display, and most important, the operation of the control system can be checked. By use of the Reversible Counter, the operator is able to return the stepping motor (and the work table) to its original position and be quite sure that this has been achieved, as indicated by a zero count readout on the counter.

The 5280A is operated in the A-B mode, where positive directional pulses from the stepping motor drive circuit are fed to the A channel of the counter and negative directional pulses are fed to the B channel. The maximum rate of the stepping motor is quite low, so there is no concern over whether the counter maximum frequency specification is sufficient.

Application 4: Comparison of paper speeds in a rolling mill.

In a typical situation, paper might be transferred from one roll to another, undergoing some type of paper making process on the way. It might be necessary to determine the difference between the speed of the paper leaving the off-wind roll and the speed of the paper being fed onto the on-wind roll (see Figure 16).

Fig. 16 - Determination Of Paper Draw Speed

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Each of the rolls A and B could be coupled by suitable gearing to tachometer generators of the type described on page 26. Since the interest lies only in velocity sensing and not position sensing, this type of tacho-generator (of which the response does not extend down to 0 Hz) would be quite suitable. Assume that direct coupling is employed, that the tacho-generators produce 60 output pulses per revolution and that a paper speed of 1800 feet/minute produces 15 revolutions/second of either roll and its associated tacho-generator.

Source 3 and 4 inputs to provide automatic gating and resetting of the 5280A Reversible Counter are required and hence a counter with the built-in time base available on special order could be used (see Appendix 3). If the gate period is set to be 2 seconds, then a paper speed of 1800 feet per minute will produce a count, at the end of this 2 second period, of 1800.

15 revolutions/sec x 60 pulses/revolution x 2 sec = 1800.

As a typical example of draw speed measurement, assume that the input section is running at 1800 feet/min and the output section at 1810 feet/min. With the 5280A operated in the A-B mode, and the counter gate time set at 2 seconds, the display would indicate a minus 10 feet/sec draw speed figure. Depending on the sample rate, selectable on the front panel of this special counter, the readout might change every few seconds (-10, -10, -9, -10-, -9, -9, -10) because of the ± 1 count error inherent in the operation of electronic counters.

To increase the resolution, one might use an optical tachometer with an output of 600 pulses per revolution (or more) or one might use step-up gearing between the roll and the tacho-generator, or one might increase the gate time. The last remedy decreases the sampling rate and this might not be acceptable.

Note that by changing the Mode switch on the counter from A-B to A or B, one is able to measure immediately the absolute speed of the paper passing over roll A or B.

Application 5: Integration of a dc voltage that varies positive and negative about zero.

The 5280A Reversible Counter is ideally suited to measuring the average value of a noisy signal which may go positive and negative with respect to zero during the time period under consideration. True integration is performed and no scaling is required.

The Reversible Counter is operated in the Af(B) mode. The signal to be measured is transformed by a voltage-to-frequency converter, such as the HP Model 2212A, into a variable frequency output which is fed into the A channel of the counter. The v/f converter also provides a polarity indication signal of which the level is -1V to 0V for positive indication and -31V to -23V for negative indication. This signal is fed to the B channel of the counter (see Figure 17). Whenever the input voltage is positive, this information is fed to the counter via the B channel, and the counter will totalize in a positive direction. Conversely, a negative input voltage will cause the counter to totalize in a negative
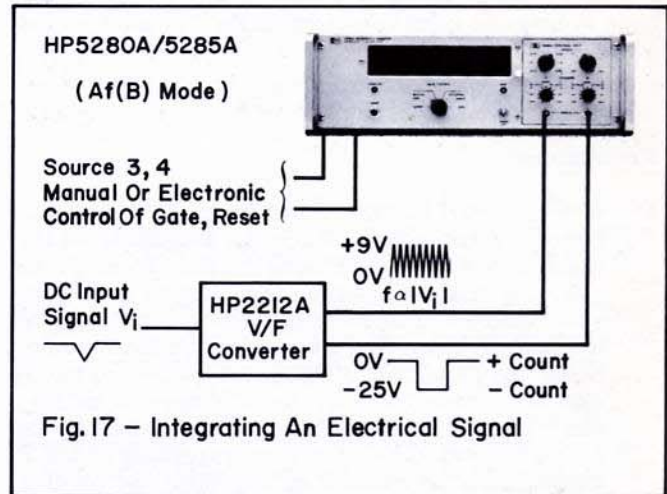

Fig. 17 – Integrating An Electrical Signal

direction. The count rate is, of course, proportional to the absolute magnitude of the input voltage.

To illustrate the operation of the system, assume that the signal to be integrated is as shown in Figure 18. The signal level is at +20 mV for 10 msec, and decreases linearly to -20 mV over the next 5 msecs, returning to +20 mV during the following 5 msecs. The v/f converter range is selected so that maximum output, 100 kHz, is obtained for an input of 100 mV, so 1 mV is equivalent to 1000 Hz.
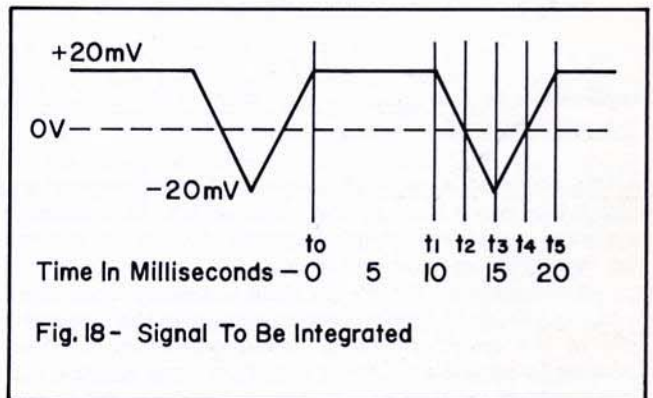

Fig. 18 – Signal To Be Integrated

Assume that the counter is gated for a period of 1 second. Now over the first 10 msec, from t_0 to t_1 the count will reach a total of +200.

$$20 \text{ kHz for 10 msec} = \frac{20,000}{1} \times \frac{10}{1000} = 200$$

Over the following 2.5 msecs from t_1 to t_2, the count rate will decrease from 20 kHz to 0, but the count will increase from +200 to +225. From t_2 to t_3, the count rate will rise to 20 kHz, but the polarity indication will now be negative, therefore the actual count will decrease from 225 to 200. From t_3 to t_4 the count will decrease further to +175. However, as the input voltage becomes positive again from t_4 to t_5, the direction of count will reverse and at t_5 the count will be 200. This will continue for 50 cycles. At the end of 1 sec-

ond, the total count will be 10,000, which is equivalent to an average dc input voltage over the 1 second period of 10 mV.

$$\frac{10,000 \text{ counts/sec}}{1000 \text{ counts/sec per mV}} = 10 \text{ mV}$$

Precautions:

1. It is essential to ensure that the counter is being correctly triggered. Since the amplitude of the input pulses to the A channel varies from 0V to +9V, the trigger level control may be set to dc, +5V. Correct triggering of the A channel may be checked by operating the counter in the A mode. Since the amplitude of the input pulses to the B channel varies from 0V to -25V approximately, the trigger level control of this B channel may be set to dc, say -15V. Correct triggering of the B channel may be checked by operating the counter in the B mode. (See Model 2212A Data Sheet for amplitude specifications.)

2. The response time of the V/f converter is better than 100 μsecs. Signal noise and ripple at frequencies greater than 10 kHz may lead to missed counts.

3. The gate period can be any value, depending upon the period of integration desired. Note, however, that the count at the end of the gate period must be divided by N, where N is the gating period duration in seconds, to obtain the average value of the input signal. The gating period should probably be related to 1 second by a factor of 10 ($\div$ 10, X1, X10, X100) to cancel out 60 Hz or 400 Hz ripple.

Application 6: Indication of the position of a worktable of a machine tool.

In this application a work table of a machine tool is driven through a lead screw. The optical tachometer or rotary encoder is coupled directly to the lead screw. The two pulse outputs of the encoder are fed to the A and B channels of the Reversible Counter; operation is in the A Quad B mode. (Remember that the two outputs of the encoder are in phase quadrature). The encoder is acting as a source 1 input; the Reversible Counter is operating as a totalizer hence no other inputs are required, except for initial operation of the reset button to set the zero reference point of the machine worktable.

Assume some typical specifications in order to give an indication of how the required encoder resolution and counter capacity are calculated. Assume that the lead screw takes 10 revolutions to move the table one inch. Assume further that the total travel of the worktable is 100 inches. If the required accuracy is 0.0001 inches (a tenth of a thousand), then the total count capacity of the reversible counter for a movement of the worktable from one stop to the other is 1,000,000.

100 inches $\div$ 0.0001 inches = 1,000,000

The count capacity of the reversible counter is 999,999 (6 decades) one count less than that calcu-

lated above, so the counter would be suitable for this application. (Note that if the zero reference point were set in the center of the table span, the counter capacity required would be ± 500,000 which is one half the capacity of the 5280A Reversible Counter.)

The total number of lead screw revolutions (and therefore optical tachometer revolutions) for one span of the work table is 1000 revolutions.

10 revolutions per inch x 100 inches = 1000 rev.

As a result, the resolution of the optical encoder would have to be 1000 pulses per revolution.

$$\frac{1,000,000 \text{ total counts}}{1000 \text{ total revolutions}} = 1000 \text{ pulses per revolution}$$

Precautions:

1. The maximum speed of the encoder is limited by mechanical considerations, and by the fact that the electrical pulse amplitude decreases at high speed. Assume that the maximum angular velocity specified is 3000 rpm or 50 revs per second. This is equivalent to a linear travel velocity of

$$\frac{50 \text{ revs/sec}}{10 \text{ revs/inch}} = 5 \text{ inches per second.}$$

It should, therefore, be ensured that the maximum linear velocity of the worktable will not exceed 5 inches per second in this case.

2. It should be checked that the frequency of the pulse output, when the table is moving at maximum speed, does not exceed the rated specification of the counter. For the high frequency 5280A Reversible Counter, this consideration is most unlikely to cause problems. For example, at 5 inches per second table velocity, the pulse frequency is 50 kHz,

5 inches per sec x 10,000 pulses per inch = 50,000 pulses per second,

which is well below the rated frequency of 1 MHz.

3. It is very important that the reversal rate of the reversible counter be checked. The 5280A Reversible Counter will reverse at the same rate at which it will count forward or backwards, i.e., greater than 1 MHz. For some electronic counters, however, the reversing rate is far inferior to its normal counting rate.

Reversal of direction of travel usually causes no difficulty because electronic counters can reverse many times faster than most machine tools (or other industrial equipment). However, the critical situation occurs when the counter counts up or down toward zero, through zero, and then down or up in the opposite direction. The 5280A Reversible Counter will count through zero at its specified measurement rate, which some other counters will not do. Note that machine vibration often requires very fast counting and reversing ability from the counter to avoid missing counts.

4. If the phase difference between the two pulse outputs from the optical encoder is not 90°, then the actual count rate as seen by the counter will be greater than the apparent rate. It should be checked that this does not cause the counter to miss pulses.

Application 7: Determination (and control) of the X and Y coordinates of a worktable.

Optical shaft encoders may be readily used as the position sensors in such an application, but laser interferometry enables the table to be positioned with much greater precision. Basic laser interferometry has been discussed in some detail in Section IV and Appendix 1 (pp. 10, 11, and pp. 26-28); given a prior reading of this material, the schematic diagram of the system is largely self-explanatory. See Figure 19.

The gas laser must have single mode output and is generally of the He-Ne variety. For extreme accuracy the wavelength, and hence the frequency must remain constant. Electronic feedback circuitry is therefore employed to tune the laser cavity length so that the

laser operates at the center of the red neon spectral line at a wavelength of 6328 Angstrom.

The beam diameter should be as small as possible to minimize the effect of air turbulence, but should be large enough so that diffraction is not too severe. A suitable compromise is reached by expanding and collimating the beam by means of a telescopic lens system.

A Michelson interferometer system is illustrated, although other more sophisticated interferometers are sometimes employed. Half the faces of the fixed mirrors are coated with phase retarding material to produce two fringe signals, separated by 90 electrical degrees, which will operate the 5280A Reversible Counter in the A Quad B mode. The design will often be such that four rather than two optical signals are produced as output from each interferometer system; not only do these signals provide the required directional information, but when combined appropriately, dc components are eliminated.

The moving mirrors attached to the worktable will generally have to be replaced by corner cube reflec-

Fig. 19 – Precise Worktable Positioning Using Laser Interferometry
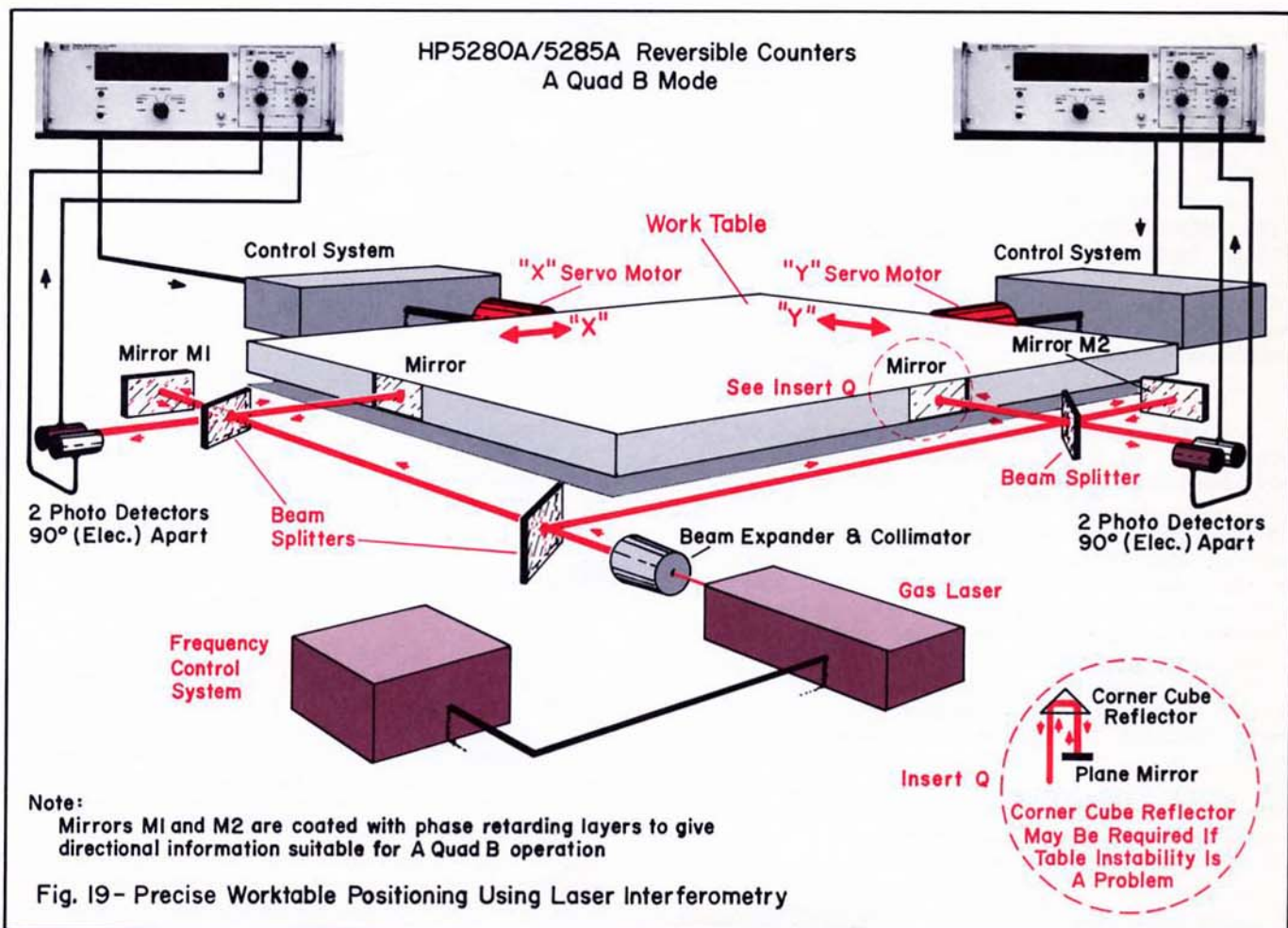
tors if the worktable is subjected to pitch, yaw and vibration, as will be the case if the table is attached to a machine tool.

If control of the worktable, rather than indication of the X and Y coordinates is required, then separate servo systems are necessary to drive the table forward and backward in the X and Y directions respectively. The "readout on the fly" feature of the Reversible Counter, available on special order, enables the count to be transferred at any point in time to a storage register without interrupting counting. The rate of data transfer is in excess of 100 kHz.

Pressure and temperature compensation is necessary if accuracy of the order of a few micro inches is desired. It is also important to remember that the X and Y coordinates are measured in increments of λ/n (n an even integer) where λ is 25 microseconds, thus mental or computer calculation is required to convert the readout to microinches. n depends on the optical system employed.

APPENDIX I
TRANSDUCERS

1. FLOW MEASUREMENT

TURBINE FLOW-METER: This device is particularly suitable for use with the 5280A/5285A Reversible Counter. It is a velocity sensing transducer, the output of which in pulses per second is proportional to the rate of flow in the pipe line. See Figure 8.

The detecting element, the turbine, is centered in the fluid flow; as the flowing material impinges on the turbine blades, the turbine rotates at an angular velocity which is proportional to the fluid velocity. Since rate of flow is given by velocity times cross sectional area, the angular velocity of the turbine, and therefore its output in pulses per second, is proportional to rate of flow.

One type of read out technique is to construct the turbine blade from magnetic material, and to mount a permanent magnet and pick-up coil on the transducer frame. As the turbine blades cut through the magnetic lines of force, electrical pulses are generated whose frequency is dependent on turbine angular velocity and hence on rate of flow. This technique has the disadvantage that the turbine suffers from magnetic drag, although how serious this disadvantage is will depend on the particular application.

Some manufacturers offer transducers using radio frequency transformer systems that eliminate such magnetic drag.

Because of the fact that the line is not clear, but contains a mechanical obstruction (the turbine), the material flowing must be in liquid form and free of solid particles which could cause damage or malfunctioning.

These transducers are sold in sizes and capabilities to satisfy almost any measurement situation. Maximum capacity may vary from 1 gallon per minute to 36,000 gallons per minute and higher; the larger flow meters will accommodate pressures to at least 7000 p.s.i., and temperature ranges from -450°F to 1000° F are common. Pipe diameter varies from 1/2" to 24" and larger. The range of velocities that can be handled is substantial; 10 to 1 is common, and 200 to 1 is found in more sophisticated units.

Perhaps this last point should be amplified. Although the turbine flow meter will measure absolute volume, i.e., the total quantity of liquid that has flowed through the instrument, its response does not extend down to dc; there is some low velocity at which it ceases to function accurately.

One further point should be noted. Each pulse generated is equal to a precisely known volume of liquid or gas metered. Now Boyle's Law tells us that volume depends upon environmental conditions, i.e., pressure and temperature. Thus to measure flow very accurately, pressure and temperature compensation factors must be applied to the measurement to obtain readings normalized to conditions of standard pressure and temperature. Of course, the problems caused by the need for pressure and temperature compensation are more severe for gases than for liquids.

To avoid the above problem, a turbine type mass flowmeter has been gaining increasing acceptance. See Figure 20.

Fig. 20 - Turbine Mass Flow Meter
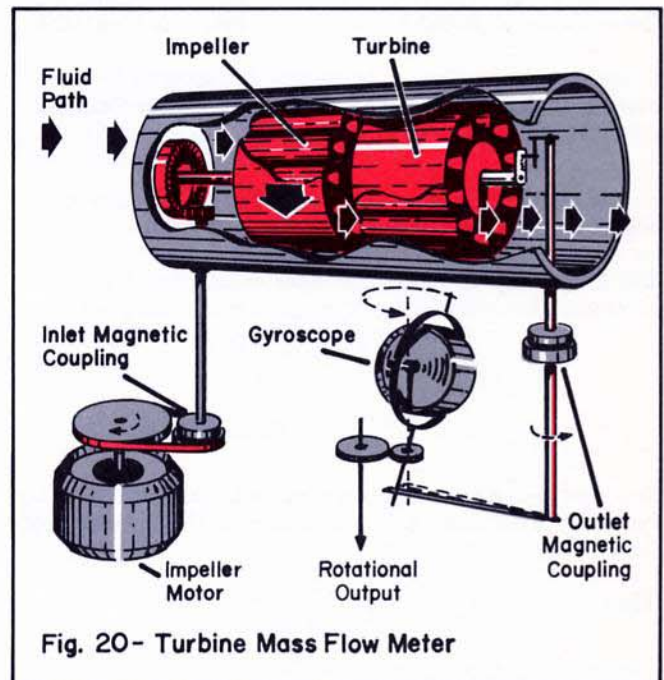
In essence, an impeller driven at constant speed by a synchronous motor imparts an angular velocity to the fluid; the value of angular momentum added is proportional to the mass rate of flow. A turbine located downstream now removes all this angular momentum from the fluid and is magnetically coupled to an output shaft to provide a torque proportional to the mass rate of flow. This torque is then applied around the minor axis of a gyroscope, which precesses about its major axis at a rate proportional to the mass flow rate. A photo-electric scanning system can be coupled to the gryoscope to provide an output of n pulses per revolution and hence per unit of mass flow. It seems that accuracy, linearity and range of flow are a little inferior to the turbine volumeric transducer, but, of course, no pressure-temperature compensation is required.

ULTRA SONIC FLOWMETER: Another technique for measuring flow that is exciting but not too well developed commercially at present, is one making use of the transmission of sound waves through fluids. There

are a number of approaches; one is described that utilizes the capabilities of the 5280A very effectively.

The application depends upon the modification of the apparent velocity of propagation of sound waves by the flow of fluid. In simple terms, the apparent velocity of propagation between two fixed points in a pipe is the algebraic sum of the sound propagation velocity in non-agitated fluid and the velocity of fluid flow. Assume that there is a transmitting mode and a receiving mode in the pipe situated d cms apart. The direction of propagation is forwards, i.e., in the direction of fluid flow. Now the propagation time will be given by

$$t_f = \frac{d}{c + v} \quad \text{where}$$

c is the velocity of propagation in still liquid and v is the velocity of flow.

Let the transmitter be triggered as soon as the previous pulse is received d cms away. The system will now cycle with period

$$\frac{d}{c + v} + \Delta t$$

where Δt is the triggering delay.

The frequency of cycling will be

$$f_f = \frac{c + v}{d + \Delta t (c + v)}$$

$$\approx \frac{c + v}{d + \Delta t . c} \quad \text{since } d \gg \Delta t . v$$

Now assume a second such system transmitting in the reverse direction, i.e., counter to the direction of fluid flow.

Then

$$f_r \approx \frac{c - v}{d + \Delta t . c}$$

Hence

$$f_f - f_r = \frac{2 v}{d + \Delta t . c}$$

The result is a transducer, the output of which consists of two frequencies whose difference is directly proportional to velocity or, in effect, to rate of flow. See Figure 14. The 5280A, operated in the A-B mode, will perform the difference calculation and will provide readouts that are proportional to the rate of flow. Note that source 3 and source 4 inputs are necessary for gating and resetting purposes.

The ultrasonic flowmeter has the advantage of no obstruction of the fluid flow, and hence there is no restriction on the type of fluid, since all fluids will transmit sound. However there are a number of disadvantages:

a. expensive.

b. The beam may be interrupted by air bubbles, or scattered by some types of slurries.

c. Since the beam is usually narrow, accuracy is affected by changes in the velocity profile. Although this problem can sometimes be minimized by proper placement of the transducer, long straight runs or flow straighteners may be needed to reduce the effects of piping configurations.

d. The velocity of propagation is a variable. However, if trigger delay Δt is small, as is normally the case, then this effect will have a negligible result on accuracy because $d \gg \Delta t . c$.

The frequency difference may be of the order of 20 Hz to 20 kHz, and hence is easily and accurately measureable.

2. ANGULAR MEASUREMENT

In this section transducers which provide n output pulses per revolution of transducer rotation will be considered. Such transducers may be used with the 5280A to measure angular displacement when the 5280A is gated in the appropriate manner. When suitably coupled to a member undergoing linear motion, such a transducer is able to measure linear displacement and velocity.

OPTICAL TACHOMETER: Initially a popular, sturdy, relatively inexpensive class of angular transducer will be discussed; this is the rotary optical encoder which makes use of photo-electric techniques.

In general, this type of encoder has a disc attached to the input shaft. The disc has a series of holes punched around the circumference or it may be etched with alternate transparent areas interspersed with areas which will not pass a light beam. A light source placed on one side of the disc shines through the transparent sections of the disc, and the incident light is sensed on the other side by some type of photodetection device, commonly a photo diode or a solar cell. As the disc rotates, the photo-detector is alternately activated and dead, and the transducer gives out an electrical signal which is suitable for triggering a counter. If the rotational speed is slow the pulses will be approximately triangular in shape; however as the angular velocity increases, the waveform comes to resemble a sine wave. Because of this, some transducers are provided with clipping circuits that follow the photo detector in order to shape the output to a near square wave. Such circuitry is not required to trigger the 5280A properly, but naturally will not cause any ill-effects.

Each output pulse now represents a discrete angle of rotation of the shaft. The resolution, or number of output pulses per revolution "n" depends upon the fineness of the etching (so that a large number of transparent-opaque pairs can be fitted onto the disc), the diameter of the disc, and the number of photodetectors present. A wide range of n may be obtained in commercially available transducers, the maximum being of the order of 5,000, or more.

Because signal amplitude is not related to the velocity of rotation, this transducer can be used for position sensing; its response extends down to zero revolutions per minute. Note however that because of photo detector limitations, the response does fall off at high speed. Typically at an output pulse rate of 40 kHz -50 kHz, the signal amplitude will be half of its level at

24

slow speeds. The problem is that when the signal amplitude decreases too much, the level may be insufficient to trigger a counter properly.

Solar cell photo-detectors have the worst high frequency response and the signal amplitude will normally be of the order of millivolts so some type of amplication may be necessary to provide a signal suitable for the 5280A. The solar cell provides, however, the least expensive means of photo-detection. The photo-diode has a better high frequency response; the output signal amplitude will generally be at least several volts.

If a long cable connection is necessary between the optical encoder and the counter, and pulse rates are high, then an amplifier with low output impedance will probably be necessary to avoid unwanted signal distortion and noise. In this situation, a solar cell device may as well be used because it requires an amplifier in any case and is less expensive.

The transducer described above will provide "n" pulses per revolution, but there is no way to sense direction. The counter will simply keep on totalizing in a positive direction; there will be no relationship between angular position and counter readout.

In order that directional information may be provided, a second light source with accompanying photo-detector and associated circuitry (if any) is mounted on the encoder such that its pulse output will be 90 degrees out of phase (i.e. half a pulse width) with the reference pulses. Except for this phase differential, the two outputs will be identical. The phase difference will be lead or lag depending upon whether the encoder is rotating clockwise or counterclockwise.

Figure 21 shows the position. Imagine that the disc is stationary. Now the light photo detector assemblies must be located as shown in order to satisfy the 90 degree out of phase requirement. These sensing devices are n + 1/2 sections apart, where a translucent/opaque combination area is regarded as a section. The two signals may be fed directly to the 5280A counter operating in the A Quad B mode.

Note that a distinction should be made between an optical tachometer as described above, and a digital shaft encoder. The former provides incremental pulse outputs, the latter provides pulses on a number of channels and the output is in the form of BCD code, indicating absolute position. This latter type is not suitable for operating the 5280A.

A number of commercially available optical tachometers make use of two multi-line reticules, one rotating and the other stationary, as opposed to the optical tachometer described above which simply has one rotating disk. The rotating reticule is in the form of a continuous symmetrical pattern of clear and opaque radial sectors on a glass disk, while the stationary reticule consists of the same pattern mounted to the housing. See Figure 22. Generally four photocell/lamp combinations are located around the circumference at 90° intervals. By differencing the outputs of each diametrically opposite pair of photocells, two

sinusoidal waveforms are generated. Modulation components resulting from shaft rotation are summed but individual dc components are cancelled. The resulting balanced symmetrical signal will not change its zero bias level with changes in lamp intensity, ambient temperature or supply voltage; the effects of shaft radial misalignment are also minimized.
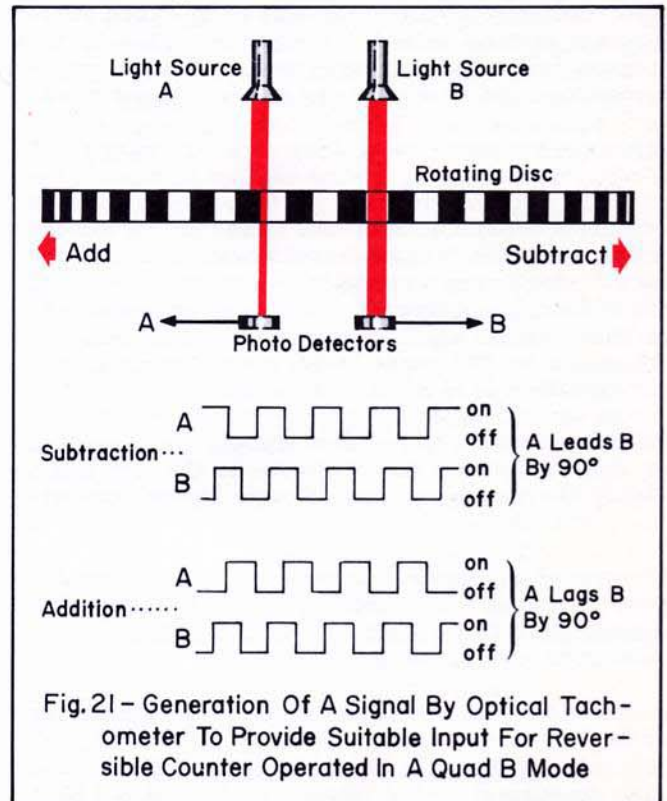

Fig. 21 – Generation Of A Signal By Optical Tachometer To Provide Suitable Input For Reversible Counter Operated In A Quad B Mode

In practice the line density is very much greater than that shown. Each light-photo detector combination may span over 100 lines.
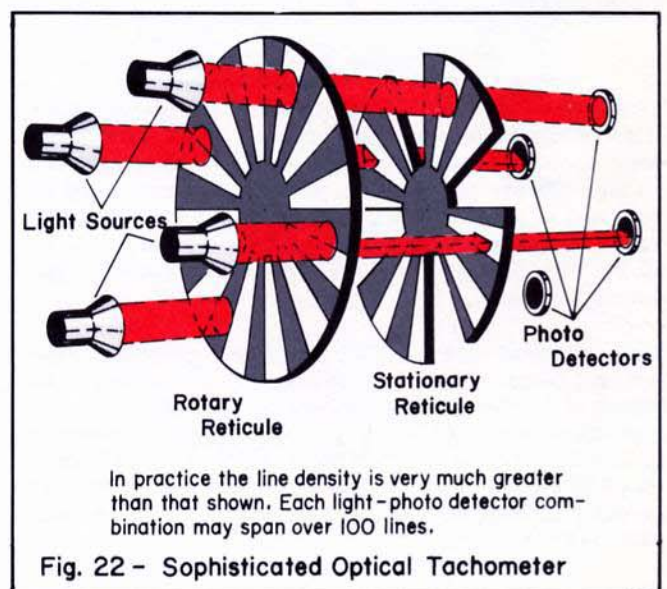
Fig. 22 – Sophisticated Optical Tachometer

One important advantage is that since each sensor spans many pattern sectors the signal is averaged over a large number of lines, thereby rendering the device insensitive to pattern imperfections. Furthermore, higher counting speeds (up to 100,000 counts per second) and higher resolution (over 100,000 counts per revolution in some models) are readily achieved.

ROTARY TRANSFORMER TRANSDUCER: This type of transducer is based on the transformer principle. A built-in oscillator provides a high frequency signal (500 kc/s), which is coupled to a primary winding (rotor) by means of slip-rings. This rotor forms one winding of an air core transformer, a stator forming the other winding. The stator and rotor plates, each plate containing two printed windings where each winding is a radially extended conductor, make up the transducer element necessary for conversion of angular position and/or speed to an electrical equivalent.

Since the current flowing through the primary rotor winding is alternating, a voltage will be induced in the secondary stator winding. As the rotor rotates, an amplitude modulated sinewave signal will be induced in the stator, the amplitude modulation providing information with regard to angular position. A second set of windings in the rotor and stator provide an out-of-phase signal which gives directional information. Reference No. 24, pages 71-73, gives more information on this type of rotating transducer.

The output voltage magnitude and phase is independent of angular velocity due of course to the fact that a steady alternating current is flowing through the primary winding.

The transducer described above will indicate angular position (and of course velocity) because the response extends down to dc. Output signal generation is independent of angular velocity.

It should be realized that some rotary transducers are of the tachometer type, i.e., they relay on angular motion as a means of providing output voltage. One such transducer is the Hewlett-Packard Model 508A Tachometer generator.

TACHOMETER GENERATOR: This transducer consists of an alnico magnet arranged in a closed magnetic loop. An arrangement of teeth on rotor and stators results in interruption of the magnetic loop as the shaft of the generator is turned, and therefore the output is an approximately sinusoidal voltage. A pick-up coil couples the induced voltage to a coaxial-type output connector.

These transducers run up to 500 revolutions per second and one provides 100 pulses per revolution, or an output of 50,000 pulses per second. As specified, the minimum rate is from 15 rpm up. These transducers cannot be used for position measurement, and although they will rotate in both directions and measure angular velocity in both directions, they will not give an indication of direction.

However they are very suitable for certain applications. Thus if one wanted to measure or control velocity drift about a set reference, one could feed the tachometer output into the A channel of the 5280A counter and a stable frequency representing the reference velocity into the B channel. The counter operated in the A-B mode would then indicate drift positive and negative about the reference speed.

OPTICAL TACHOMETER PICK-UP. This consists of light source and photo detector units clamped above the moving part, which is prepared with alternately reflecting and absorbing surfaces. The interrupted reflected light is picked up by the photo-tube, and the electrical impulses generated by the photo-tube are transmitted to the counter. Rates to at least 5000 Hz may be measured without amplification.

The unit is specially suitable for measuring speeds of moving parts which have small energy or which, for other mechanical reasons, cannot be connected mechanically to any transducer. HP manufacturers this type as the Model 506A.

3. LINEAR MEASUREMENT

The concern in this section is with optical methods of sensing position. These methods are on the whole used where high accuracy is required.

One optical method employs precisely ruled scales; the lines may be closely spaced and read with little or no interpolation, or widely spaced (for example, 20 lines per inch) in which case interpolation circuitry is necessary. Such scale systems have been frequently used in machine tool and inspection applications, but interferometer systems are hard to find; installations have been limited to laboratory environments where sub-micro inch accuracies are required. The recent development of the gas laser c.w. light source, however, has opened up a whole new field of potential applications of the principles of interferometry, including machine tool control systems and scientific measurement. With regard to ruled scales, we are talking in terms of 0.0001 inch; laser interferometry permits micro-inch accuracies in industrial situations.

GAS LASER INTERFEROMETER: Young first established the principles of interference in 1804 when he demonstrated that light from a given source can produce a series of light and dark bands called interference fringes. Michelson published a description of his famous interferometer in 1881 and subsequently use it in three different types of experiments. This basic interferometer has been used since that time to measure length and position very accurately; however, this has been possible only under closely controlled conditions and for distances of a few cms.

The Michelson interferometer in its simplest form is shown in Figure 23. Monochromatic light, after passing through a focussing lens is split by the semi-reflecting surface of a plane parallel glass plate D into two beams at right angles. These beams are reflected at plane mirrors M1 and M2 and return to the glass plate where they are recombined to enter the fringe detectors at F1, F2. The beam reflected from M1 transverses plate D three times compared with a single passage for that reflected from M2. To avoid this asymetry, a plate of identical material and thickness is placed at C, exactly parallel to the one at D. The mirror M2 is fixed in position, while M1 is attached to a moveable carriage so that its distance from D can be varied.
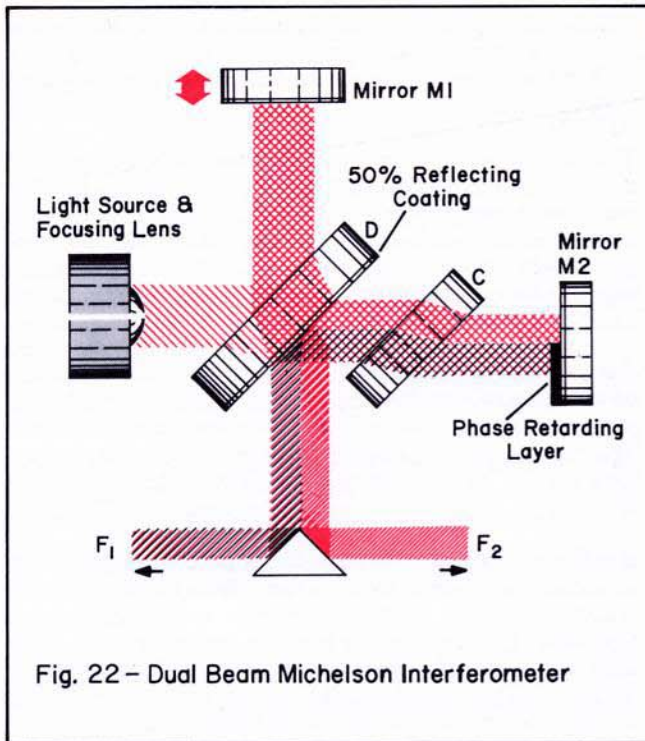
Fig. 22 – Dual Beam Michelson Interferometer

If the distances from D to the two mirrors are exactly equal, and if M1 and M2 are exactly at right angles to one another and at 45 degrees with D, the image of M1 coincides with the surface of M2. If M1 or M2 is not quite perpendicular to the beam reflected by it, then in effect a thin air film exists between the surface of M2 and the image of M1, and the interferometer fringes in this thin film are what are observed.

If M1 is moved along a line perpendicular to its face, the system of fringes moves laterally across the field of view, and a displacement of the mirror of one-half a wavelength causes each fringe to move from its original position to that formerly occupied by the next adjacent fringe. Note that a mirror movement of one half a wavelength is equal to an increase or decrease in the beam length of one wave length.

It is now clear that if the interferometer is mounted on a rigid frame and the mirror M1 is fixed to a moveable carriage, then as mirror M1 moves in one direction, fringes will move across the receiving area in a corresponding direction. As the direction of movement of the mirror is reversed so also is the direction of movement of the fringe reversed. If the number of fringes "n" that move across this area during any particular period of the carriage are counted, then it is known that the displacement has been $n\lambda/2$ where λ is the wavelength of the light source. If the fringes are counted in a reverse direction up to $n\lambda/2$, the carriage could be returned to its exact zero position. Since λ is of the order of microinches, it can be seen that we are talking about highly accurate measurements.

This interferometer, up until very recently, worked very well in practice, but was strictly a laboratory instrument. The reasons for this stem mainly from the light source. The larger the length it is desired to measure, the greater becomes the difference between

the lengths of the two light beams, one reflected from M1; the other reflected from mirror M2. This increase in the difference between the beam lengths leads to the light and dark fringes becoming indistinguishable from one another and accurate fringe counting is impossible. However the cause of this phenomenon is a result of deficiencies in the light source. Light sources of an earlier era provided radiations which were of slightly variable wavelength; in addition the waves were not exactly in phase with one another. The radiation was not highly coherent. The development of the gas laser light source has overcome this problem.

We are indebted to McNish (Ref 21) for the following explanation of the concept of coherence.

"If a pebble is dropped in a pool of water and a photograph is made of the wavelets propagated from the point of impact, one finds that, by displacing a copy of the photograph by one wavelength of the ripples, a fair degree of coincidence between crests and troughs along one radial line is preserved. Displacement of one photographic copy with respect to the other by several wavelengths decreases the degree of coincidence. For large displacements the coincidence of crests and troughs is completely unobtainable. It is thus with the light waves coming from a tube filled with radiating atoms. If one could map instantaneously the electromagnetic fields of such a train of waves, he would find that for small displacements of the mapping along the direction of propagation coincidence between crests and troughs would be maintained, but for large displacements coincidence would disappear except for a short region near the matching point. In the wave train from the cadmium lamp used by Michelson, displacement where satisfactory coincidence would be maintained amounts to only a few millimeters, corresponding roughly to several thousand wavelengths.

"Calculations show that the light from a laser could be subjected to displacement of several hundred kilometers without seriously impairing the coincidence between crests and troughs. An experiment performed at the National Bureau of Standards demonstrated that displacement of the wave train by as much as 200 meters resulted in no noticeable lack of coincidence between crests and troughs, even when the light waves were traveling through the atmosphere. In this experiment well-defined interference was obtained with a mirror separation of 100 meters with infrared light with a wavelength of 1 micron."

Single mode He-Ne lasers have now been developed that are highly stable and can be made to operate at or near the center of the red neon spectral line at a wavelength of 6328 Angstrom (25 μ inch) by tuning the laser cavity length. Electronic feedback can be used to lock the wavelength output automatically to the center of the neon line.

The result is a highly coherent light source operating within a basic Michelson interferometer setup producing a very precisely known wavelength of light as the unit of measurement. A mirror moving over distances of hundreds of feet causes interference fringes to pass across a receiving surface, where 1 fringe corresponds to $\lambda/2$ or 12.5 μ inches displacement of

the moveable mirror. What problems arise and what other features are needed?

a. It is almost impossible to manufacture the structure such that the moving mirror always moves in a direction perpendicular to its face except over short distances. If the relationship is not exact at all times, the reflected beam does not interfere properly with its counterpart from the fixed mirror, and the resulting fringes will be obscure.

A corner cube reflector will always reflect light in the required direction and is generally used where displacements of several feet have to be measured. However, it is expensive to make because the alignment of reflecting surfaces has to be very precise.

When a moving corner cube reflector is used, the beam is folded back on itself twice, hence a change in the beam length of one wavelength is equal to a mirror movement of one quarter wavelength. The fringe count now represents units of quarter wavelengths.

To achieve extremely accurate measurements, NBS, in contrast, uses plane mirrors and maintains parallelism by electronic and mechanical means.

b. The eye is obviously an unsatisfactory detector for counting fringes. A suitable sensor consists of a photo-detector, an amplifier, together with an electronic counter capable of operating up to 1 MHz. This high speed is necessary because vibration is an ever present problem, and would otherwise lead to missed counts.

By increasing the number of detectors, the precision of the interferometer can be increased to small fractions of a half wavelength.

c. The eye can detect forward and backward motion of the fringes; a single photo-detector cannot. However, if two detectors monitor two fringe signals that are 90 electrical degrees apart, then their two outputs can be fed to the 5280A operated in the A Quad B mode, and positive and negative displacement will be indicated with a resolution of 12.5 μ inches. The two fringe signals can be generated by coating half the face of one of the reflectors with a phase retarding layer.

d. There are a number of effects which may cause inaccuracy in the measurements. The importance of these effects will depend ultimately upon the accuracy desired. An interferometer system sealed in a vacuum would avoid these causes of inaccuracy, but is impractical for the types of applications with which the reader is likely to be concerned.

First, any perturbation of the air through which the beam travels will lead to an unreliable fringe pattern (perhaps a non-existent one). Secure shielding will prevent this and other unfortunate occurrences such as oil films or fingerprints on the reflecting surfaces.

Next, it should be realized that angular and linear thermal expansion and contraction of the structure is not negligible when accuracies of μinches are contemplated.

Unless the environmental temperature is stable and precisely controlled, the μ inch accuracy one is seeking will be illusory, the measured displacement will be variable.

Thirdly, it is important to note that the wavelength of light varies directly with the refractive index of the medium through which it travels. The refractive index depends upon temperature, pressure and the proportion of other constituents such as CO_2 and water vapor. As explained above, temperature will of necessity be controlled. The wavelength of light changes by three parts in 10^6 for every 1 mm Hg pressure change so pressure effect compensation will generally be necessary. Allowance for polluted shop atmospheres may also have to be taken into consideration. The complication of applying several corrective factors may be avoided by measuring the refractive index directly by interferometric techniques.

It seems obvious that measurements to within a few μ inches or better require substantial care, and attention to every detail. However it should be noted that laser interferometer measurements are also suitable for situations where less extreme accuracy will suffice. The requirements for the laser, the optical setup, and the compensation systems will then be far less severe.

There have been a number of sophisticated approaches to the design of laser interferometer metrology and control systems, and such sophistication is indeed called for; the reader should understand that we have limited ourselves to a discussion of the basic principles involved.

OPTICAL SCALE SYSTEMS. There are several different types of optical systems employing accurately spaced lines on a substrate. One is described that has been widely used for machine control and provides an output very suitable for reversible counting techniques. It is based on the formation and counting of Moire fringes.

Assume that two identically ruled scales are aligned at a small angle to one another and that a light beam is passed through the two scales onto a receiving area. See Figure 12. Now if one scale is moved relative to the other, then a series of fringes will move across the receiving area in a direction at right angles to the motion of the scale and at a rate of one fringe per basic scale interval.

The width of the fringes and the spacing between the fringes will depend on the angle of tilt between the two scales. If this angle is a very small one, then the fringe width will be considerably greater than the spacing between the scale marks and the fringe outline will be perhaps rather indistinct--but observable. If the angle of tilt is relatively larger (greater than ten degrees) the fringes are clearly defined, but the magnification effect is much reduced. This magnification of the behavior of the gratings is important and desirable, because it leads to easy detection and counting of the fringes as they move across the receiving area. Furthermore fringe counting represents integration of the relative movement of the scales

over hundreds of lines; if one line is incorrectly placed or even missing, the effect on the fringe motion is negligible. If n lines are observed, then the effect of one of these lines being out of position is reduced by a factor of n.

According to Loewen (Reference 17):

"There are two different types of continuously ruled scales. The amplitude grating or Ronchi ruling has approximately uniform width lines which are alternately opaque and transparent (for transmitted light applications) or reflecting and non-reflecting (for reflected light applications). Spacing can be as fine as 1000 line pairs per inch and occasionally up to 3000 line pairs/inch. Various photographic processes are used to reproduce a master ruling.

The second type of continuous scale has triangular shaped contiguous grooves. It is known as a prismatic or phase grating. The required three-dimensional shape is not photographically reproducible and must be obtained by high precision resin casting methods from a master ruled in a metallic surface. Groove frequency varies from 2500 to 5000 per inch, although 25,000 groove per inch scales have been used in experimental systems."

There are similarities to the laser interferometer technique. First, the photo electric counting is incremental and zero position is arbitrarily established by clearing the counter. Individual lines are not separately identified, and calibration is significant only in conjunction with a specific read-out system. Secondly two photo detectors are required to produce signals 90° out of phase, and the 5280A reversible counter in the A Quad B mode of operation will keep track of displacement with respect to any arbitrary zero.

The main difference between the two methods lies in the accuracy obtainable. For practical purposes, the unit of measurement for the ruled grating will be about 200 μinch limited by the ability to rule suitable lines as closely as possible on a grating (note however that electronic circuitry can generate and count several pulses per Moire fringe and very elaborate systems have been designed to generate as many as 100 or even 1000 counts per fringe. For the simple interferometer, the unit of measurement is half a wavelength or 12.5 μinch (and this can be further reduced by electronic circuit techniques). However, the optical scale system can be calibrated directly in fractions of an inch; some sort of man or machine computation is necessary to convert units of $\lambda/2$ into convenient units.

The fixed and moveable gratings can be separated by a few thousandths of an inch; this separation can be maintained without risk of contact, hence no wear due to friction results.

INCREMENTAL LINEAR ENCODERS: This type of linear transducer is very similar to the optical rotary device discussed in the section on rotary measurement. A glass scale having a pattern of fine clear and opaque lines passes through a sensing head containing the optical system, a lamp and a photo detector. A scale with 1250 line/apertures per inch gives a resolution of 0.0001 inches when optical and electronic multiplication are employed. Sense-of-direction is obtained by producing two signals in quadrature, and is accomplished by inserting a phasing system in the optical portion of the unit.

This is a no-contact device with no accuracy degradation because of wear. As with other incremental pulses, zero reference can be established anywhere on the scale by resetting the counter.

LINEAR-TO-ANGULAR CONVERSION: One fairly obvious method of measuring linear displacement is to convert the linear motion to angular motion, and then to use a rotary transducer to generate pulses for counting. The advantage here is that the rotary transducer is an inexpensive and simple device, and it would seem that little care is required in the construction of the system.

Thus if a lead-screw controls the work table of a machine tool such that one rotation represents 0.1 inch of table travel, then a rotary transducer providing 1000 pulses per revolution would give a resolution of 0.1/1000 or 0.0001 inches. If step-up gearing between the lead screw and the transducer was employed, even higher resolution could be obtained. However, note that ultimate accuracy is dependent on the accuracy of the entire gearing mechanism, both the gearing between the linear moving work table and the rotary lead-screw, and also the step-up gearing mechanism. The extent of the back lash in the system will limit the resolution obtainable.

4. INCREMENTAL PULSERS

Here the concern is with devices that provide one output pulse every time an object (preferably but infrequently, a specific object) passes nearby the sensor. There are many types of such devices; optical, magnetic and variable reactance units are ones that come readily to mind. The more sophisticated (and expensive) units provide solid state switching; in others the output may be provided by means of a relay.

Only one of these devices, which is interesting for a number of reasons, is discussed.

The device contains a light source and photo detector operated from a single phase 115 volt power supply. A "light wire" made up of flexible optical glass fibers, transmits light from the internal source to the desired location. The light wires flexibility permits it to be threaded over, under or around obstructions, or into small holes and crevices. The light wire (a split bundle) also returns the reflected light (or direct light from an external source) to the photo cell. The light wire can be supplied in a flexible metal cable shield.

The device detects variations in reflected or direct light due to objects passing in front of the opening of the light wire, changes in relative position or location of moving parts or changes of illumination. Optical filters installed internally or in front of the optics allow the device to be color selective.

Note that one commercial device, with relay output, is limited to a minimum count rate of 400 per minute, i.e., only 7 counts per second.

APPENDIX II
FRONT AND REAR VIEWS
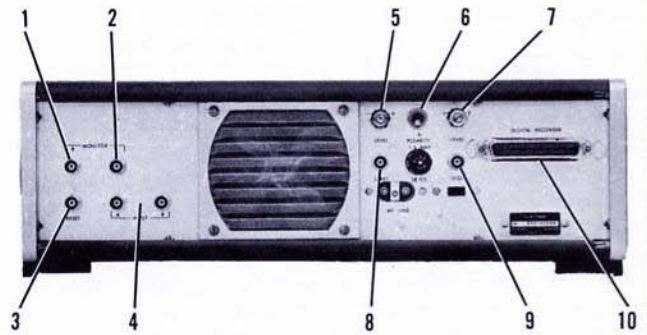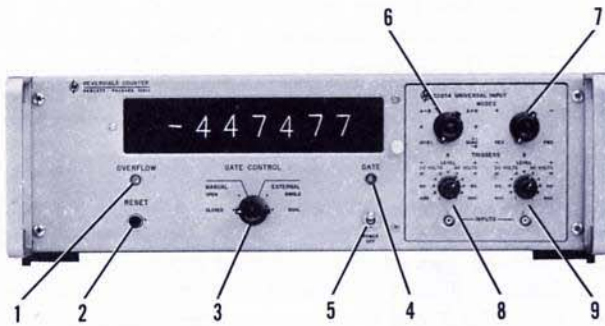
1. Lights when left-most nixie has exceeded the count of 9.

2. Resets the decades to zero.

3. Selects type of control. EXTERNAL SINGLE allows control of the gate by a voltage level connected to the rear START connector. A voltage more positive than the trigger level opens the gate. A voltage less positive than the trigger level closes the gate. EXTERNAL DUAL allows gate control with separate start-stop inputs. The control signal to the start-stop rear input connectors may be either a level change or a pulse.

4. Lights when gate is open.

5. Power Switch.

6. Selects modes of operation.

7. Mode count direction switch selects count direction polarity. For algebraic operation, (A, A± B, or B), the position reverses the signs of the selected mode (i.e., A-B to -A+B, etc). For Af(B) and A QUAD B the REV position reverses the directional control polarity or phase (changes from +voltage for addition to -voltage for addition in REV position).

8. Selects trigger level and polarity for channel A input.

9. Selects trigger level and polarity for channel B input.

1. Channel B trigger waveform for trigger point and symmetry monitoring.

2. Channel A trigger waveform for trigger point and symmetry monitoring.

3. Connector for remote reset by contact closure or saturated NPN transistor to ground.

4. Rear inputs for channel A and B.

5. Trigger level adjust for gate Start. -10v to +10v range, 1v rms sensitivity.

6. Selects gate opening polarity when in GATE CONTROL, SINGLE and triggering slope when in GATE CONTROL, DUAL.

7. Trigger level adjust for gate Stop. -10v to +10v range, 1v rms sensitivity.

8. Gate START input. Also used for GATE CONTROL, SINGLE input.

9. Gate STOP input.

10. DIGITAL RECORDER output. +1248 BCD code.

APPENDIX III
SPECIAL ORDERS AND OPTIONS

The 5280A Reversible Counter with 5285A Universal Input Plug-In is an extremely versatile instrument. A number of features now available on special order will increase this versatility even further. Ask your Hewlett-Packard Field Engineer for further information.

1. An internal time base allows gate times of 0.1 seconds, 1 second or 10 seconds to be selected at the front panel (extension of the range is possible). Alternately the gating period may be set in increments of 10 ms from 10 ms to 1000 seconds by means of thumbwheels on the front panel.

The time between samples is varied from 0.2 seconds to 5 seconds by means of a control on the front panel; the control incorporates a "Hold" provision which allows the most recent count to be displayed indefinitely. Every sample count begins afresh from zero, that is,

automatic resetting occurs. No external inputs are required for gating or resetting purposes.

The addition of a time base makes possible full utilization of the many capabilities of the 5280A without the expense and complication of the provision of external gating signals.

2. A "Readout on the Fly" feature may be built into the 5280A according to special order. This feature enables the count to be transferred into a storage register on command without interrupting counting. The time interval between command pulses may be as short as 10 microseconds. As a result, the 5280A may be used in information or control systems without loss of counts or slowing down the speed of the system.

3. 4-line 1-2-2-4 BCD output with "1" state positive is now available as option 01 in lieu of the standard 1-2-4-8 BCD output.

APPENDIX IV

HEWLETT PACKARD INSTRUMENTS FOR USE
WITH THE 5280A/5285A REVERSIBLE COUNTER

TRANSDUCERS

506A OPTICAL TACHOMETER PICKUP:

A light source and photo-cell for use as a transducer to measure speeds of moving parts. Specially suitable for measuring speed of moving parts which have small energy or, which for other mechanical reasons, cannot be connected mechanically to any measuring device.

The part to be measured is prepared with alternate reflecting and absorbing surfaces. The interrupted reflected light is picked up by the photo-tube, and the electrical impulses generated by the photo tube are transmitted to the counter. Speeds to at least 5000 rps may be measured without amplification. $195.00

508A TACHOMETER GENERATOR

These are a series of transducers that convert rotary motion into electrical impulses, with a low running torque of approximately 0.15 inch-oz; peak starting torque = 4 inch-oz. Because of its arrangement of an Alnico magnet arranged in a closed magnetic loop, a Model 508 may be used in the presence of relatively strong external fields without effect on measurements.

        508A - 60 pulses per revolution
        508B - 100 pulses per revolution
        508C - 120 pulses per revolution
   508D - 360 pulses per revolution

The usable shaft speeds range between 15 to 40,000 rpm; within this range, the output voltage will be sufficient to trigger the 5280A counter. $125.00.
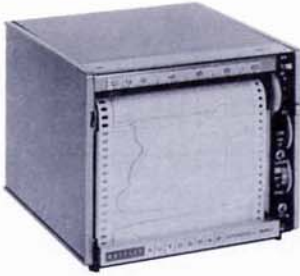
RECORDERS
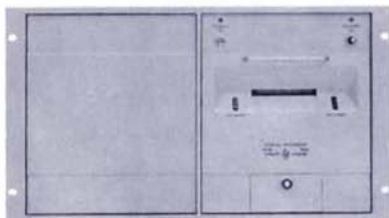
562A DIGITAL RECORDER

A transistorized electro mechanical device providing a printed record of electronic digital information. Parallel entry and low-inertia moving parts allow printing rates as high as 5 lines per second, each line containing up to 11 characters. BCD input data may be transferred to the 562A in 2 msecs; as soon as data transfer is completed, the driving source may be released to gather more information. An analog output suitable for driving either potentiometer or galvanometer recorders is available as an option. This is an extremely versatile and flexible printer. $1600.00 approximately for 6 column BCD input.
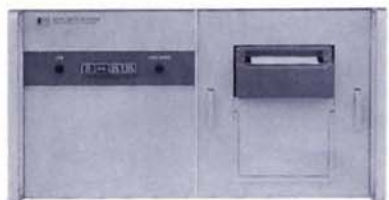
5050A DIGITAL RECORDER

The 5050A Digital Recorder (available Spring 1967) accepts up to 20 columns of 4-line BCD data from 1 or 2 sources and prints up to 18 of these columns on 3 inch wide paper tape at rates up to 20 lines per second (1200 per minute). Mixed code operation is possible.

680A STRIP-CHART RECORDER

This is a precision servo potentiometer instrument with a 5" writing width chart; one each of ten spans and eight speeds may be selected by the user. This instrument features all solid state circuitry, high accuracy, fast response, high common mode rejection, synchronous chart drive, and full view tilting chart magazine. The accuracy is better than 0.2% of full scale with 0.1% of full scale resettablility. Choice of ink, pressure, or electric stylus available. Suitable input devices are the 562A Digital Recorder with analog output option, or the 580A Digital-Analog Converter. $750.00
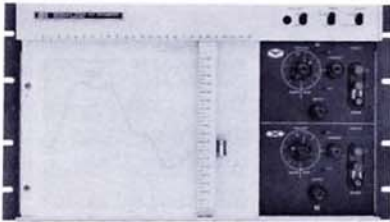
7035A X-Y RECORDER

A high performance, low cost, servo potentiometer X-Y recorder designed for use in applications where high dynamic performance is not required. Metric scaling is optional. Each axis has an independent servo system with no interaction between channels. Features include solid state circuitry, AUTOGRIP electric paper hold-down, guarded input, electric pen lift. Input resistance on 100 mV/inch input is 1 megohm. Floating inputs. Slewing speed 15 inches/sec. Accuracy ± 0.2% at full scale. Linearity ± 0.1% of full scale. Optional external time base available. $895.00. Higher performance X-Y recorders also available.

OSCILLOSCOPES

122A OSCILLOSCOPE (Dual trace: dc to 200 kHz)

Four calibrated vertical ranges, 10 mV/cm to 10 V/cm; 15 calibrated sweeps from 5 μsec/cm to 200 msec/cm, ± 5%; x5 sweep magnifier works on all ranges; horizontal amplifier has 3 calibrated steps 100 mV/cm to 10V/cm. For x-y, phase shift between vertical and horizontal amplifier less than ± 2° to 100 kc. Beam Finder quickly finds trace. $695.00
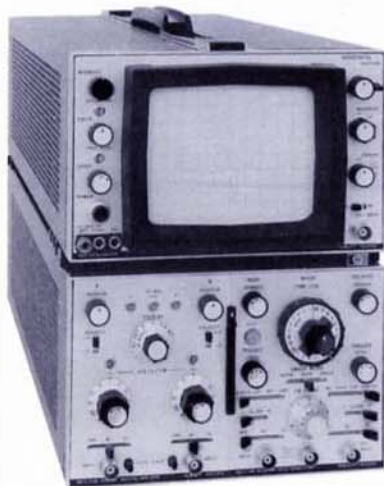
180A OSCILLOSCOPE (Dual trace: dc to 50 MHz)

MAIN FRAME:	8 x 10 cm display in a 17" tube
	Weighs only 30 lbs
	Horizontal amplifier dc to 5 MHz
	Internal graticule, no parallax
	Sweep amplifier x1, x5, x10.
	Beam finder
	All solid state
	"State of the art" Oscilloscope $825.00

VERTICAL PLUG-IN:
1801A   Dual Channel
               Dc to 50 MHz, 7 nsec rise time
               Sensitivity 5 mV/cm to 20V/cm
               Input impedance: 1 megohm shunted by 25 pf. $650.00

HORIZONTAL PLUG-IN:
1820 Time   24 ranges of 0.05 μsec/cm to 2 sec/cm to
    Base   5 nsec/cm with x10 multiplier. $475.00

1821A Time   22 ranges 0.1 μsec/cm to 1 sec/cm to 10 nsec/cm
Base & Delay   with x10 multiplier
Generator   Trace intensification
               Delayed time base sweeps and delay controls 18
               ranges 0.1 μsec/cm to 50 msec/cm
               Delay time - continuously variable from
               0.1 μsec to 10 sec
 $800.00

FREQUENCY SOURCES

The following give some indication of the range of HP
instruments available to provide stable frequencies.

651B TEST OSCILLATOR

This solid state oscillator provides accurate stable test signals for
laboratory or production measurements. Frequency range 10 Hz to
10 MHz, continuously adjustable across 6 bands. A typical indication
of the overall frequency stability for a 22 hour period at 5 MHz is
±0.02%. $590.00
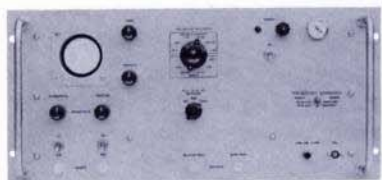
100E FREQUENCY STANDARD

This is a highly stable, relatively inexpensive quartz oscillator, ideal
for test, production and lab use. Output frequencies are 10 Hz, 100
Hz, 1 kHz, 10 kHz, 100 kHz, 1 MHz sinusoidal and 10 Hz, 100 Hz,
1 kHz, 10 kHz pulse. Output pips from the timing comb are at 100,
1000, and 10,000 μsec intervals. Long term stability is better than
5 parts in 10^8/week. $1100.00.
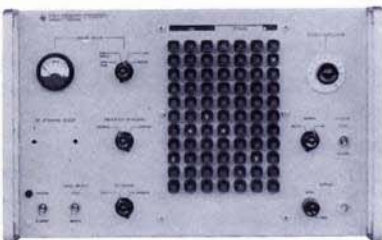
5102A FREQUENCY SYNTHESIZER

Provides any output frequency from 0.1 Hz to 1 MHz selectable in
steps as small as 0.1 Hz, or from 0.01 Hz to 100 kHz in steps as
small as 0.01 Hz, by normal pushbuttons or by remote electrical
signals. Each column can be continuously varied over entire range by
local or remote use of the search oscillator. Retains stability of
internal 1 MHz source ($\pm 3 \times 10^{-9}$ per 24 hours) or external 1 MHz or 5
MHz can be used. Spurious signals $>$ 90 dB down, 100 kHz range; $>$
70 dB down, 1 MHz range. $6500.00

MISCELLANEOUS

580A DIGITAL-ANALOG CONVERTER

Suitable for transforming BCD output from the 5280A Reversible
Counter into output signals for either strip chart or X-Y recorders of
both the potential and galvanometer types. The accuracy is 0.5% of
full scale or better, by selecting the two or three least significant dig-
its for analog output, an analog record with resolution of 1 part in 10^6
can be obtained from the 5280A counter. No polarity indication.

Potentiometer output: 100 mV full scale into 20k ohms
Galvanometer output: 1 mA full scale into 1500 ohms
Transfer time: 1 msec. $525.00

2212A VOLTAGE-FREQUENCY CONVERTER

Produces an output pulse train whose pulse rate is directly propor-
tional to the dc input voltage magnitude. Three standard ranges 10
mV, 100 mV, 1V sensitive to positive and negative inputs with polar-
ity indicating output signal.

Output: 0 to 100 kHz. For a step change in input voltage, the correct
input frequency is reached in less than 100 μsec.

Accuracy of pulse count over 1 second period: ±0.02%

Stability: ±0.01%.

Linearity: ±0.01% of full scale, zero to full scale.

$1080.00 with bench mounting stand.

3300A FUNCTION GENERATOR

This unit may be used to externally gate the 5280A Reversible Counter.

Provides frequencies from 0.01 Hz to 100 kHz in 7 decade ranges.

Sinusoidal, square and triangular output waveforms from two channels.

Rise and fall times less than 250 nanoseconds. The sync pulse may be used with appropriate circuitry to reset the 5280A.

Has plug-in and remote frequency control capabilities.

$645.00 with 3301A Plug-In.

SYSTEMS EQUIPMENT FROM DYMEC DIVISION

HP 2540 COUPLER

The Model 2540 Coupler transfers information from a group of parallel data sources - counters, digital voltmeters, digital clocks, for example - to a wide variety of serial entry recorders.

Printed record: adding machine or electric typewriter.
Wire or radio link: Tape punched in any telegraph code.
Computer input: Tape punch, Flexowriter or card punch.

In many cases, two recording devices can be operated simultaneously. Very versatile; almost any data source, recorder, or computer system can be accommodated.
Price depends upon number of inputs and outputs and features.
Typically $1200.00 to $3000.00.
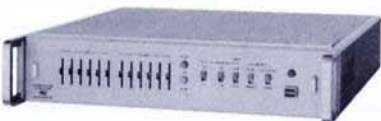
HP 2539A DIGITAL COMPARATOR

Compares BCD information against single or dual preset limits, providing Hi/=Lo or Hi/Go/Lo lamp indications and electrical outputs, respectively. Comparisons are made in less than 3 milliseconds. The instrument can be operated manually, or automatically in a programmed data acquisition system. Completely flexible; with option M3, the instrument can handle 12 different comparison conditions. In basic form, accepts up to 4 digits of external BCD information for comparison against single or dual 4 digit limits - 5 or 6 digits optional. The ability to compare on a basis of sign as well as numerical magnitude can be added as Option M3. $1850.00.

HP 2514A DIGITAL SCANNER

This Digital Scanner scans digital data from multiple sources and transmits this information to one set of recording equipment. The 5280A Reversible Counter is a suitable source while the scanner couples directly to the M45-562AR Digital Recorder, HP-2545-M61 Tape Punch Set, and HP-2546-M15 Magnetic Tape Recorder Set. Accepts data from three sources, six sources with options. The scanner provides 1 BCD digit of source identification. Accuracy identical to data source. Transfer rate up to 20 sources per second. Sequential or random scanning in Manual Step, Single Scan or Continuous Scan operating modes. $2500.00.

The instruments described in this Appendix are representative of the broad line of Hewlett-Packard products which complement the 5280A Reversible Counter. For further details of these and other instruments, please contact your HP Field Office.

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