Applications Bulletin
TELEDYNE PHILBRICK

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V-F's AS LONG-TERM INTEGRATORS

1. Voltage-to-Frequency Converters make good long-term integrators, as shown in Figure 1. Of course it must also be recognized that analog integrators are easy and inexpensive to build for time constants from 1 millisecond to 100 seconds. However, when the time constant approaches 1000 seconds the operational amplifier required becomes expensive and the capacitor becomes very expensive, since a leakage rating of 10^6 Megohm-Microfarads at the temperature of interest is required to achieve an accuracy of 0.1%. To get better accuracy or longer time-constants the analog integrator becomes prohibitively expensive, with the capacitor being the most costly component, and the V-to-F integrator becomes an extremely attractive alternative. Put an analog input signal into a Philbrick Model 4701 (10 kHz) V-F and simply count the output pulses, and you have computed the "area under the curve," or integral, which is a classically useful function. V-F integrators have an inherently digital read-out, which is a very useful feature in some situations. If an analog output is required, it can easily be obtained by using a low-cost Digital-to-Analog Converter (DAC).

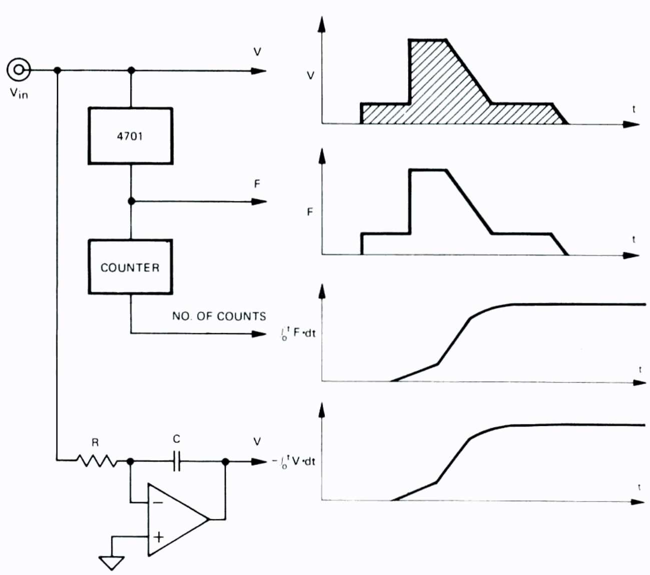

Figure 1. Integrator Using V-F

2. Digital integrators using V-F's have at least 3 other advantages over their analog counterparts:
   (a) You can easily disable the counter to "STOP" the integration and "HOLD" the integrated value indefinitely with absolutely no drift.
   (b) It is also easy to preset the digital counter to any desired level and integrate up (or down).
   (c) There is never a problem of dielectric absorption, often called "soakage," with a V-F integrator.

3. What's the best way to "count"? For most applications, 7400 TTL logic is recommended because it is quite low in cost and is available from many sources. You can get Binary counters such as the SN7493, or BCD counters such as the SN7490, for less than $1.00 to handle 4 binary bits or 1 BCD digit at a cost of approximately 22¢ per binary stage.

   On the other hand, COSMOS logic is easy to run from a 9 volt battery and avoids the problem of volatility of memory when the power goes out. Of course it is also the perfect logic for portable instruments. Although the price of COSMOS counters presently is somewhat higher than TTL types, the difference is not too great and can be expected to narrow in the future. For example, a CD4040AE 12-bit binary counter sells for only $5.10 which is only 43¢ per binary stage.

4. As a typical design example, let's suppose that you wanted to integrate for 1 hour using a 10 kHz Model 4701 V-F. In this case the maximum count will be 36 million, since (10,000 counts/sec) (3600 sec) = 36 (10^6) counts.

   Since 10^3 is approximately equal to 2^{10}, then a pre-scaler consisting of 13 binary stages and a 4-digit output counter will give a full scale count of approximately 3,600. Alternately, using 13 binary stages as pre-scaler, and 12 binary stages as counter will give a full scale count of approximately 3,600 counts out of a maximum counter capacity of 4,000.

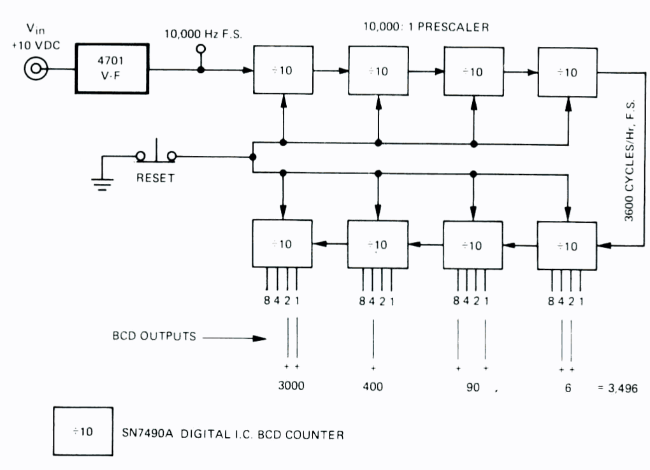

Figure 2. Precision Digital Integrator with 1 hour Integration Time

Unfortunately, this resolution of 1 part in 5,000 is not necessarily usable as real accuracy, because the nonlinearity error of a 4701 can be as large as 0.05% or 2.5 parts in 5,000 especially at input voltages less than or equal to 5 millivolts.

However, in some applications where Vin covers the 1800:1 range between +6 mV and +11 volts, then the accuracy will be very good and the resolution will be excellent.

A 1 hour integrator using a 4701 and BCD counters is shown in Figure 2.

5. The nonlinearity error of the 100 kHz 4703 is only about as good as the 4701, but in integrator applications it can give excellent resolution for input voltages above 20 millivolts. It would require an extra stage of pre-scaler for use as a long-term integrator, but as a short-term integrator it would give 10 times better resolution. For example, in a 10 millisecond period a 4701 can resolve the difference between 98 counts and 99 counts, whereas a 4703 can resolve the difference between 986 and 987 counts.
6. Although the 4705, at 1 MHz F.S., would need several more stages of pre-scaler frequency divider, it has excellent linearity even for small signals, such as 1/10 or 1/100 or 1/1000 of Full Scale. (The typical nonlinearity of the 4705 is ±0.0002% of F.S. plus ±0.01% of signal; refer to the 4705 data sheet.) Excellent linearity over a wide dynamic range makes the 4705 especially suitable for integrating wide-range signals. Such a circuit using the 4705 could cover a 1,000:1 input range with very good accuracy (0.1% typical, 0.5% maximum).
7. If the input to a 4701 is always positive, it will work fine. However, if it goes below 0 Vdc for any significant amount of time, the 4701 can mis-remember the next positive-going signal. For example, a +50 mV signal may not be integrated and recorded accurately and properly if it has a 60 Hz, ± 100 mV peak noise signal riding on it.

If VinDC is always positive, it may be sufficient to add active filtering to it to keep the noise level low, as shown in Figure 3.

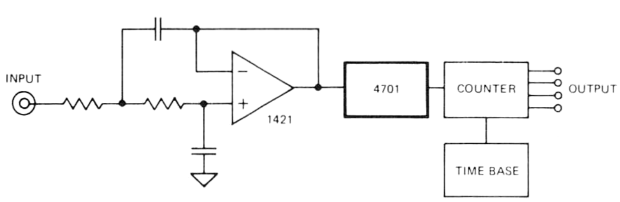

Figure 3. Active Filtering to Reduce Input Noise

However, if the input signal can go negative, an Absolute Value circuit, such as the one shown in the V-F Application Note AN-6, can be used with an up-down counter to provide proper up-down integration. In a Binary System the SN74193 counter can be used to count up or down. The Block diagram of such a system is shown in Figure 4.

Here, using a 4701, Vout is *Low* between pulses. At the point where Vin is approximately equal to 0, when the "Sign" changes, an output pulse from the V-F is

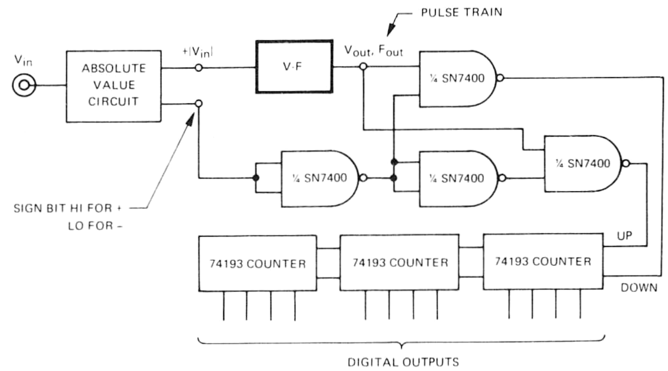

Figure 4. Block Diagram of Bipolar (Up—Down) Digital Integrator

not likely to be produced and false-pulse counting will not occur. When the sign bit is high, pulses will appear only on the *up* line; when the sign bit is low, they appear only on the count *down* line. Counting proceeds accordingly.

8. Digital integrators are easy to reset. A manual push-button or automatic or repetitive signal can be used to "ground" (or pulse "high," as required) the Reset lines of all the digital counters and pre-scalers.
9. To establish a time base, standard analog multivibrators can be used for short integration periods; and counters can be added to make periods of hours or days.
10. Of course, a digital integrator can be used in two modes: (a) it can be used to show the integral of a function over a fixed amount of time, or (b) it can be reset only when the counter becomes "full." In the latter case the time interval between resets is the "output."
11. For man/machine interfaces, standard electro-optical readouts such as "Nixie" tubes, LED's, etc. can of course be used with digital integrators. However, for applications where a pre-scaler changes the maximum output frequency to 1 pulse per second or less, an electro-mechanical counter (such as is made by Victor or Veeder-Root) accomplishes both counting *and* display for only a few dollars.
12. In applications where the analog signal input to a digital integrator is a small voltage or current a suitable "preamp" (voltage amplifier or current-to-voltage converter) will be required to get the full scale analog signal up to the same magnitude as the rated full scale input of the V-to-F. Of course you *can* feed a 100 millivolt signal directly into a 1 MHz 4705 and get 10 kHz out of it, but a much less expensive solution would be to amplify the signal with a gain of 100 preamplifier, and then feed it into a 4701!

TELEDYNE PHILBRICK

Allied Drive at Route 128, Dedham, Massachusetts 02026
Tel: (617)329-1600 TWX: (710)348-6726 Telex:92-4439

In Massachusetts call collect • (617) 329-1600

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