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Low Cost Integrated Circuit Versatile Pulse and Frequency Counter*

GARY L. SAMUELSON AND DAVID C. AILION
Department of Physics, University of Utah, Salt Lake City, Utah 84112

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In this paper we describe a compact multipurpose counter whose design is based on the use of plastic integrated circuits. The circuit contains about $90 worth of semiconductor components and is very easy to wire; nevertheless, it is extremely versatile. It consists of dual 10^7 and 10^5 counters which can be used separately as two counters, or in series as a single 10^{12} events counter. Frequencies up to 10 MHz can be read to the accuracy of the crystal used (typically better than 0.005%). Time intervals can be measured—either the width of a single pulse or the time interval between the positive (or negative) slopes of two pulses. The circuit can also be used as a digital integrator, since the average count of pulses in a series of numerous pulse train events can be automatically evaluated after 10, 100, 1000, or 10 000 events.

INTRODUCTION

PLASTIC integrated circuits are becoming increasingly more useful in the design and construction of do-it-yourself laboratory equipment where both time and cost are at a premium. Logic, pulse generating, amplifying, and counting circuits fall under this category. This paper describes the operation of an inexpensive, easily constructed counting circuit employing a *single* rotary switch (the function switch) to change the instrument from an events counter to a frequency counter, time interval counter, or integrator. This circuit is ideal for use in conjunction with digital boxcars.[1]

I. CIRCUIT OPERATION (SEE FIG. 1)

The heart of this instrument comprises two decimal counters built from Motorola dual J–K flipflops (MC790P). As seen in Fig. 1(b), each decade consists of four flipflops with the 0-9 output being binary coded on four readout lights. This coding is easy to master and saves the six additional lamps and binary-to-decimal decoding circuitry needed in each decade for full decimal readout.[2]

The "half-moon" devices indicated in the schematic are inverting dual and four-input integrated circuit nor gates. These are simply two or four high speed transistors connected to a common collector load so that if *any* of the transistor inputs is "high" (+3.6 V), the gate output at the collector will then be saturated to near ground potential. If, on the other hand, *all* the inputs are "low" (0 V), the transistors will be cut off thus causing the collector output to be at the supply voltage (+3.6 V). The J–K flipflop will make a transition whenever the input drops from a high positive value (~3.6 V) to a low value (~0 V). Also the $\bar{A}$ output in each decade is always high if the "1" lamp is off.

The two four-input nor gates whose inputs are attached to the function and range switches control the four-input gates on the inputs of the two counters. The range switch can be used in the following manner to limit the number of counts that either counter can accumulate. Since the range switch selects the $\bar{A}$ output of one of the decade counters and connects it to the first four-input gate, the second four-input gate of each counter will be saturated whenever $\bar{A}$ drops. Thus we freeze the counts on one counter (either counter A or B), whenever the other counter reaches a predetermined number (established by the setting of the range switch).

The function switch has five positions. Position 1 turns the power off. Position 2 is labeled "count" and allows the two counters to accumulate pulses independently. Alternately, we can operate the two counters as a *single* extended range counter by connecting the output of counter A to the input of counter B. There is a 1 MHz oscillator associated with counter A which is gated off in the "count" position. In the third or "freq" position of the function switch, counter B accumulates pulses from the B input while the oscillator is gated on and fed into counter A. With the range switch in the **X1** position, and after the reset button has been released, counter A will count to 10^6 (1 sec interval) and then send hold voltages to the two counter input gates. The reading on counter B will then represent the number of input pulses per second. In the X10 position, only 10^5 counts are received from the oscillator before the hold is applied, thereby allowing counting for 0.1 sec. The reading on counter B is now one-tenth the frequency. Thus, the first five significant figures of any frequency up to 10 MHz can be read.

The fourth function, or the "time int" position, allows counter A to receive the 1 MHz oscillator signal for a time determined by the interval between any two successive steps. Counter A now reads the interval directly in micro-

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[1] This circuit has provided the counters required in the digital boxcar described in the previous paper.

[2] If a decimal readout is desired, relatively inexpensive integrated packages containing miniature decimal lamps and binary-to-decimal circuitry can now be purchased. [These are the so-called "Decimal Counting Units" which can be obtained in kit form for $12 each from Southwest Technical Products Corp., 219 West Rhapsody, San Antonio, Texas 78216 and are described in an article by D. Lancaster, Popular Electron. 28, 27 (Feb. 1968).]

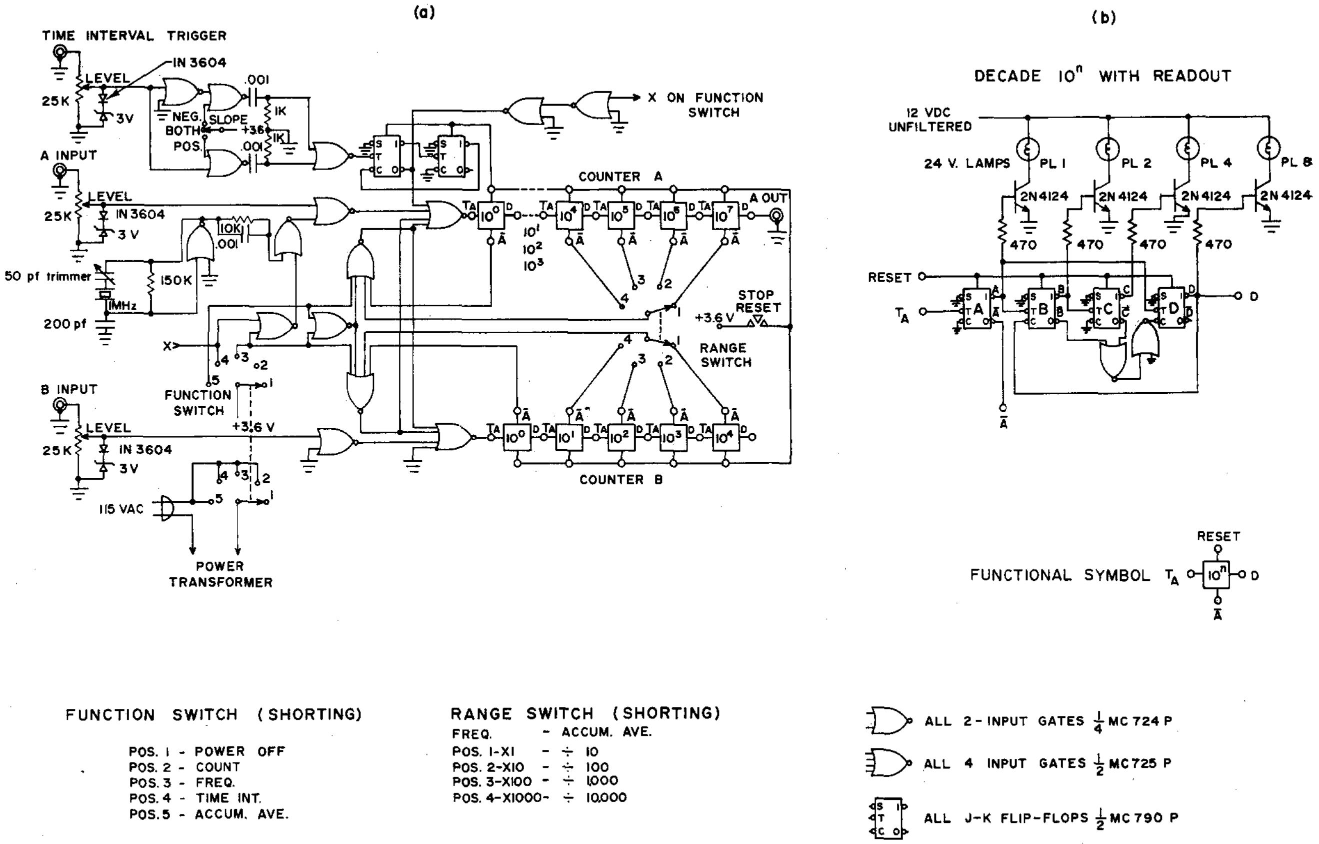

FIG. 1. Circuit diagram. (a) Schematic and (b) basic decade counter. All capacitors are μF unless otherwise noted.

seconds to a precision determined by the precision of the crystal. From the time int trigger input, the pulses to be timed are divided into two channels (one inverting and one noninverting) and then into two differentiators. The SPDT center-off slope switch permits one or the other or both of the differentiators to operate. The outputs are mixed and inverted, then sent to a flipflop which is holding counter A off. The first trigger pulse flips the bistable and starts counter A. The second trigger pulse flips the first bistable back (thus stopping counter A) and also flips the second bistable, the output of which disables the first from responding to any other inputs until the reset is pressed. This feature enables us to read the width of the first pulse in a pulse train without having the reading confused by readings for later pulses. The slope switch setting determines whether the hold circuit will respond to the leading or trailing edge of two pulses or (as on "both") to the leading and trailing edge of a single pulse whose width we desire to measure. Times longer than 10 sec can be measured by connecting the counter A output directly to the counter B input, thereby extending the range to times of the order of 10^6 sec.

The last function position labeled "accum ave" allows counter A to receive bursts of pulses, accumulating them in a running sum while counter B is pulsed once *before* each burst to record the number of such events. The range switch setting determines the number of bursts allowed before both counters are turned off. For instance, in the ÷ 10 setting, the counters are held off after 11 events pulses. Since the first events pulse is registered before the first burst, this allows 10 complete bursts to accumulate on counter A. Dividing this by 10 completes the average. The other range positions allow 100, 1000, or 10 000 events to be averaged.

II. PERFORMANCE AND GENERAL CHARACTERISTICS

Power requirements are easily satisfied by a supply or battery which can provide 1 A at approximately 3.6 V ($\pm 10\%$). Ripple is unimportant (less than 5%).

This counter is limited to inputs of frequency less than 10 MHz, since the flipflops used are 10 MHz flipflops. Nevertheless, the circuit could be used easily on signals faster than 10 MHz with the aid of a frequency converter. Alternatively, the circuit could be built using faster integrated circuits, but these would undoubtedly increase the cost. The circuit requires an input of at least 0.6 V. If this is not available a preamp should be used.

The basic accuracy and precision of this instrument is determined by that of the crystal used in the 1 MHz counter. Accuracy is no problem, since the crystal used can be tuned exactly to 1 MHz by means of the trimmer capacitor shown in the schematic. We used an inexpensive commercial crystal since its temperature and drift stability were adequate for our purposes. (We observed a drift of the order of 3×10^{-6} over a period of several hours and a temperature stability of better than 50×10^{-6} for temperature variations of ±15°C.) Of course better stability can be obtained using a higher quality crystal kept in an oven at constant temperature.

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Thin Lithium Targets Sealed in Nickel for Low Oxygen Contamination[*]

David C. Weisser[†] and Russell K. Hobbie
John H. Williams Laboratory of Nuclear Physics, University of Minnesota, Minneapolis, Minnesota 55455

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A technique is described for making pure lithium targets in the range of $100\ \mu g/cm^2$ by encapsulation in a sputtered nickel film. The oxygen impurity is about 2%.

LITHIUM TARGETS

LITHIUM targets with minimal contamination of carbon and oxygen are required for many experiments. The target preparation technique described here was developed during a search for a state of ^{4}He excited by the ^{6}Li $(d,\alpha)^4$He reaction.[1] The low energy α particles of interest from this reaction would be obscured by large ^{12}C(d,α) and ^{16}O(d,α) yields. The lithium targets produced were also used for studies[2,3] of the reactions ^{6}Li$(p,\alpha)^3$He and ^{6}Li$(^3\text{He},t)^6$Be. Since long duration beam exposures were anticipated in these experiments, the target contamination had to remain low when the target was in a scattering chamber atmosphere of 10^{-5} Torr. We wanted to be able to prepare targets well in advance in order to conserve accelerator time.

Lithium targets are often made in the scattering chamber by evaporation onto backing foils. Thick self-supporting lithium targets can also be made in a separate vacuum system by evaporation onto a substrate from which the foil is later stripped. The foil is then mounted on a target frame and transferred to the scattering chamber. These methods leave at least one face of the target exposed to contamination by the residual gas in the scattering chamber and therefore do not satisfy our requirements.

A target which protects the lithium by encapsulating it in a nonreactive metal meets our needs. The encapsulation is accomplished by evaporating the lithium, under high vacuum, onto a metal backing foil and then covering it with a sealing layer of the same metal. Gold and silver, which are easily evaporated, are the metals one thinks of first for this purpose. Gold cannot be used because it tends to alloy with lithium, thus exposing it to the atmosphere. Silver is eliminated because its large lattice spacing makes it too transparent to the small lithium atoms. It is desirable, therefore, that the encapsulating metal have small atomic size. The metal must have a large atomic number so that its Coulomb barrier will suppress low energy alpha particles that compete with the ^{6}Li(d,α) reaction. Nickel is a satisfactory compromise of atomic size and Coulomb barrier height and is commercially available as thin foils. It cannot easily be evaporated onto the lithium, however, because its evaporation temperature is more than twice that of lithium; the lithium film is destroyed by the radiant heat from the nickel evaporator. The lithium can be successfully coated, however, by a sputtered nickel film, since sputtering is a relatively cool process.

APPARATUS

The vacuum system consists of a 46 cm high by 35.6 cm diam glass bell jar, an aluminum feethrough collar containing 12 ports, and an aluminum baseplate mounted on the throat of a 260 liter/sec Welch Turbo-molecular pump. The L gasket and O-rings are Viton-A. Heater pads are attached to the pump throat, and cooling water may be circulated in channels in the baseplate and collar. A liquid nitrogen cold finger extends over the pump orifice. This apparatus produces a vacuum in the mid 10^{-8} Torr range with little hydrocarbon content.

The lithium is evaporated from a folded tantalum boat supported on water cooled copper rods. The vacuum chamber is shielded from the evaporated lithium by glass and stainless steel baffles.

The sputterer is shown in Fig. 1. Ultrahigh purity argon is fed through a liquid nitrogen cold trap into the sputterer

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[†] Now at California Institute of Technology, Pasadena, California.

[1] D. C. Weisser, Ph.D. thesis, University of Minnesota, 1968 (unpublished); Bull. Am. Phys. Soc. **13**, 82 (1968).

[2] D. K. Olsen and R. E. Brown, Phys. Rev. **176**, (1968).

[3] J. G. Jenkin, D. C. Weisser, and R. E. Brown, J. H. Williams Laboratory Annual Rep., AEC Rep. No. COO-1265-67, 1968, p. 129.