1 SYSTEM FOR DATA ACCUMULATION AND PRESENTATION

The elements that are generally considered to be a part of a counting system are depicted in Fig. 1.1. Selection of the individual components depends on the type of detector to be used, the complexity of the counting problem, and the mode of data display. The electrical characteristics of each part of the system must be carefully considered in order to avoid mismatching and the resultant distortion of the data.

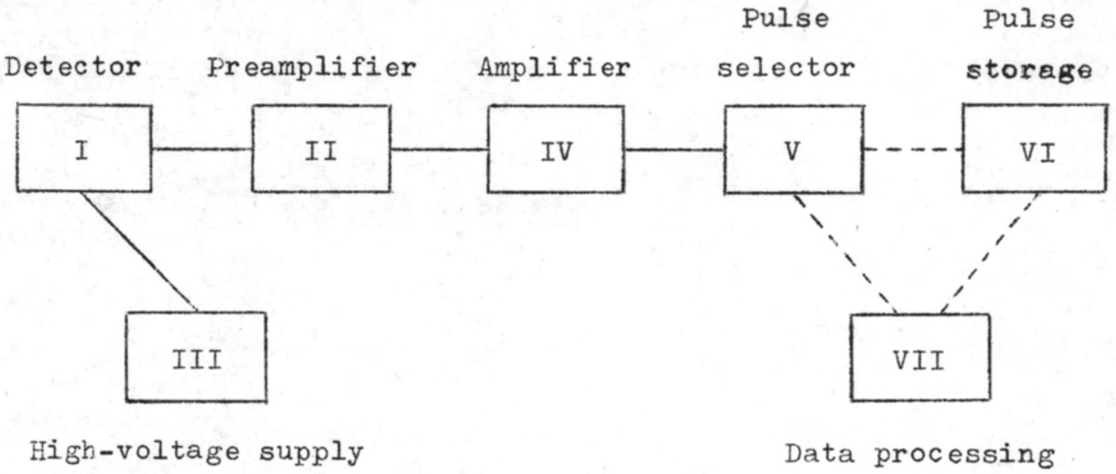

Fig. 1.1 Block diagram of components constituting a general counting system.

Several of the elements in Fig. 1.1 may be combined into one unit in simple systems. For instance, the scaler for a conventional Geiger Müller (G-M) counter includes elements III, IV and VII with II and VI being omitted. Scintillation and solid state detectors, however, usually demand a careful consideration of each of these elements and their relationship to each other. The characteristics of an output of the detector in terms of amplitude, pulse duration, and risetime are quite different for various kinds of detectors and, in some cases, even for different types of incident radiations. Examples of these differences may be seen in Table I.

TABLE I

Output Characteristics of Various Detectors

Transducer	Charge (picocoulombs)	Pulse duration (microseconds)
Solid state detector	10^{-3} - 10^{-1}	10^{-2}
Proportional counter	10^{-2} - 1	1
Organic scintillator	10^{-2} - 10	10^{-2}
Sodium iodide scintillator	10^{-1} - 10^{2}	0.25
Organic Geiger-Müller tube	10	50-300
Halogen Geiger-Müller tube	10^{3}	50-300

1.1 Preamplifier

Radiation transducers are characteristically low-capacitance high-impedance devices. The capacitance introduced by a signal cable running from the radiation detector to the amplifier will in many cases significantly attenuate or distort the transmitted electrical impulses. Preamplifiers placed near the detector will minimize this input capacity and may be designed to provide impedance matching at their output so that cables many feet long may be used.

Preamplifiers are frequently omitted for detectors producing more than 10 pC per pulse when used with signal cables not more than 1 meter long. This situation pertains to most end-window G-M counters and also some NaI (Tl) scintillators when used to measure medium-and high energy γ-ray emitters in conjunction with high gain multiplier phototubes.

1.1.1 Types of preamplifiers

The simplest type of preamplifier is called an emitter follower. This widely used device principally provides impedance matching between detector and amplifier, since its gain is usually slightly less than one. Figure 1.2 shows a npn transistor operated as an emitter follower.

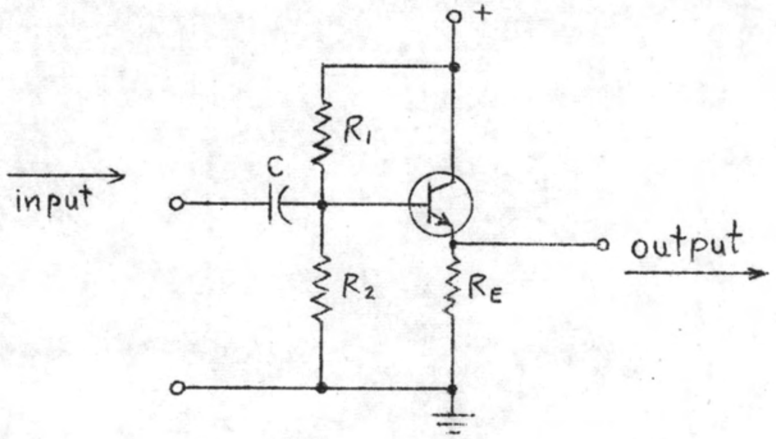

Fig. 1.2 Emitter follower. Impedance matching for signal transmission.

The charge pulse produced by the detector as the result of a radiation interaction is impressed upon capacitor C in Fig. 1.2 and will have an amplitude and duration of the order of magnitude shown in Table I. Resistance R_2 in parallel with R_1 provide a leakage path for this charge. The resultant change of the current from the emitter to the collector passing through R_E constitutes the output pulse. The emitter follower (sometimes called "cathode follower") will drive long cables at its output with little capacitance loading on the input. The decay characteristics of the pulse are controlled by the values of C and R_1, R_2,which constitute the RC time constant. Serious mismatching in a counting system can occur if the preamplifier pulse shape is not compatible with the amplifier requirements. Likewise, components designed for optimum pulse shape for use with liquid or plastic scintillators must sometimes be modified when substituting the slower NaI (Tl) detectors.

Current (and therefore power) gains of over 1,000 are possible. The gain is a direct function of total input capacity of the preamplifier and radiation detector. Usually, however, one does not speak of the "gain" of a charge-sensitive preamplifier, but rather of the "charge sensitivity", which refers to the voltage output obtained when a given charge is produced in a high-impedance nuclear detector. Units may be millivolts per picocoulomb, or millivolts per million electron volts.

Although some charge-sensitive preamplifiers are completely transistorized and others use only vacuum tubes, many are hybrids; that is, one or more vacuum tubes are used in the input, followed by transistors in later stages. The reason for this is that transistors have an inherently low input impedance, some temperature instability, and noise levels that are too high if good signal-to-preamplifier noise ratios are desired.[1]

Field-effect transistors (FET) are also being increasingly used for this purpose and are making fully transistorized systems more popular. Noise in a conventional transistor is principally caused by carrier recombination in the base region. The field-effect transistor has no p-n junction so that its noise figure is quite low.

1.2 Amplifiers

Nuclear pulse amplifiers are used to convert a low-amplitude pulse from a radiation detector (or preamplifier) to one with sufficient amplitude and the proper pulse shape to drive the pulse-selecting elements of the counting system. The amplifier must have enough gain to drive the pulse selector while still enabling the detector to operate in its most favorable operating range. Its gain must be stable against fluctuations in power supply, ambient temperature, and other factors that might contribute to either long-term drift or transient changes. It should have the proper rise time so that information from the detector is not lost. On the other hand, the rise time may not be so fast that unnecessary noise is introduced into the system.

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[1] Noise levels that are usually due to carrier recombination in the transistor base region are a function of input capacitance.

1.2.1 Pulse shaping

The characteristics of the amplifier system determine the shape of the output pulse that it produces. The shape of a typical pulse may be seen in Fig. 1.3, where the amplitude, plotted as percentage of the maximum value, is shown as it changes with time. The units of amplitude are arbitrary; they may be output voltage or may represent instantaneous values of output current.

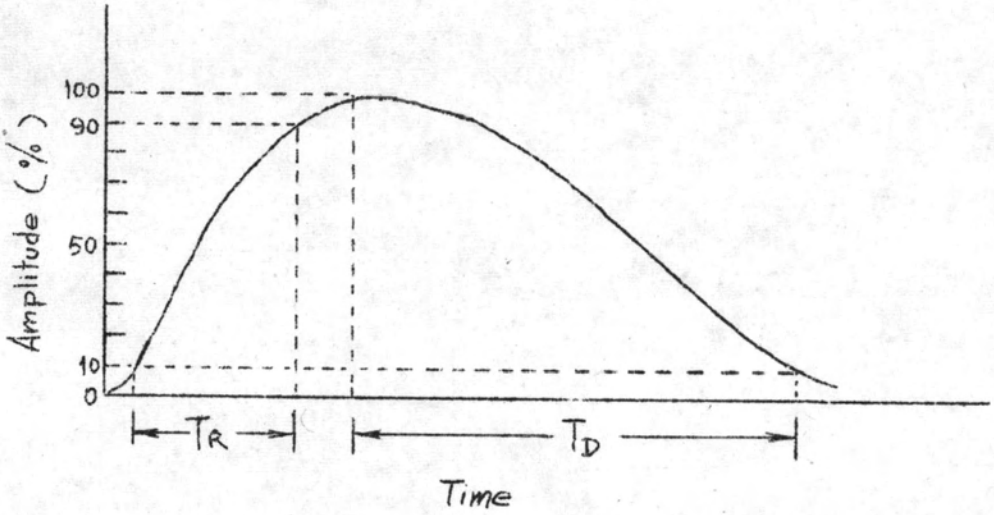

Fig. 1.3 Pulse shape. Variation of pulse amplitude with time.

The most convenient definitions of "rise time" (T_R) and "decay time" (T_D) are illustrated in the figure. Risetime is defined as the time interval during which the pulse amplitude goes from 10 % to 90 % of its maximum value. The decay time is taken to be the time necessary for the pulse to fall from maximum to 10 % of maximum. Other characteristics that are sometimes of interest are "delay time", the time required for the pulse to rise to 50 % of maximum, and pulse duration. "Pulse duration" does not have an obvious definition for those pulses which decay exponentially, but for practical purposes may be measured from the beginning of the pulse to the time when it has decayed to 10 % of the maximum.

The useful information in a detector pulse is contained in its leading edge and its top. The long tail that follows contains little (if anything) of interest and, if accurately reproduced, makes the system subject to pile-up errors at high counting rates. In addition, the low-frequency response required of the amplifier makes it susceptible to the effects of hum, microphonics, and flicker noise. The use of a clipping network[2] which in its simplest form is an interstage RC coupling network whose time constant is much smaller than any of the others, simultaneously clips the tail of the pulse and degrades the low-frequency response of the amplifier.

The choice of the optimum clipping time depends upon the time constant associated with the amplifier rise, which in turn depends upon the collection time in the detector and upon the type of measurement being made.

In ion chambers the collection time is dependent on the orientation of the initial track of ionized gas particles with respect to the collecting electrode. Unless collimation is used,

[2] Also known as a "differentiating network" because the resulting output signal approximates the mathematical derivative of the input signal. The "clipping network" refers to time clipping and should not be confused with a voltage clipping network.

the orientation, hence the collection time, varies from pulse to pulse. If the amplifier rise and clipping times are made comparable with the collection time, variations in orientation of incoming events will produce variations in measured pulse height. If spectral measurements are being made, these variations may limit the attainable energy resolution. If the time constants which control the amplifier rise and fall are made equal and if these time constants are at least twice as great as the longest collection time that can occur, then variations in pulse height due to variations in track orientation will be less than 1 %.

If the pulse-amplitude measurements are unimportant, the amplifier time constants can be reduced to the average detector time constant with no appreciable loss in S/N and with a considerable increase in permissible counting rate.

The same condition applies to scintillation counters, whether or not energy measurements are made, because there is no rise-time dependence upon the direction of the incoming radiation.

1.2.2 Location of the clipping network

The performance of an amplifier is strongly dependent on the location of the clipping circuit. If it is located at the input, the full amplifier gain is available to amplify the noise level of the input transistor. If it is placed near the output, the section preceding the clipper will be subject to overload from pile-up. It is evidently necessary to balance one effect against the other in deciding the location.

1.2.3 RC clipping network

It was stated earlier that clipping may be accomplished by giving one RC coupling network in the amplifier a shorter time constant than any of the others.

The clipping network plus one additional interstage coupling networks which are separated by an isolating stage is

$$v(t) = \frac{1}{1-\frac{T_1}{T_2}} \left(e^{-t/T_1} - \frac{T_1}{T_2} e^{-t/T_2}\right) \qquad (1.1)$$

where $v(t)$ = time response of the system,

T_1 = RC product in ohms x farads (= seconds) of the clipping network,

T_2 = RC product in ohms x farads (= seconds) of the coupling network.

If $T_1 = T_2 \equiv T$, the response becomes

$$v(t) = e^{-t/T} (1-t/T) \qquad (1.2)$$

Equation (1.1) is graphed in Fig. (1.4) for $T_1/T_2 = 1$ and $T_1/T_2 = 0.1$.

The base line crossing occurs at

$$t_1 = \frac{T_1 T_2}{T_2 - T_1} \ln \frac{T_2}{T_1} \qquad (1.3)$$

which yields

$$t_1 = T, \quad \text{if } T_1 = T_2 \equiv T \qquad (1.4)$$

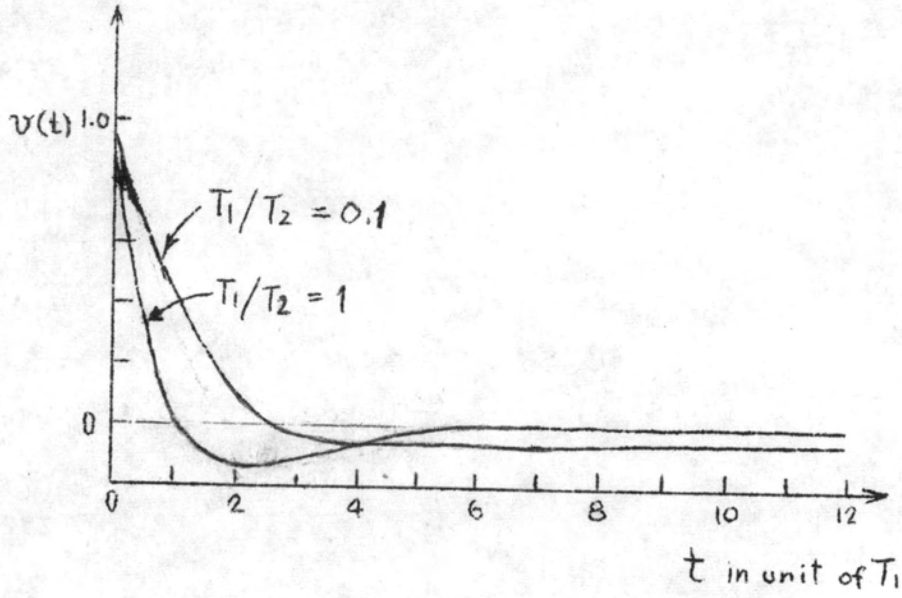

Fig. 1.4 Response of two cascaded RC coupling networks to a unit step.

The peak of the undershoot occurs at

$$t_2 = 2t_1 \qquad (1.5)$$

and has a magnitude of

$$\left|v(t_2)\right| = \left(\frac{T_1}{T_2}\right)^{\frac{T_2+T_1}{T_2-T_1}} \qquad (1.6)$$

which yields

$$\left|v(t_2)\right| = e^{-2}, \text{ if } T_1 = T_2 \qquad (1.7)$$

Examination of (1.6) shows that the ratio of the peak of the undershoot to the peak of the primary pulse approaches T_1/T_2 as T_1/T_2 approaches zero.

It follows that the area of the primary pulse is equal to the area of the undershoot. Pulses with a small undershoot will have a long recovery time and vice versa. When three interstage coupling networks are used, it is found that an overshoot follows the undershoot. Since the overshoot has the same sign as the primary pulse, it will be counted as a second pulse under adverse conditions. Fortunately, the magnitude of the overshoot compared with the magnitude of the primary pulse is small under ordinary conditions.

However, under overload conditions the undershoot is often sufficiently large to saturate the amplifier during a considerable portion of the undershoot, causing excessive deadtime. This effect can be reduced by increasing the preamplifier pulse decay time (which generally reduces the counting rate capabilities of the preamplifier) or compensating for the undershoot by using pole-zero cancellation.*

1.2.4 Feedback amplifiers

Feedback amplifiers can be used to improve many areas of circuit performance. Nagative feedback applied to an amplifier always reduces the gain of the amplifier, but it increases the bandwidth, change input and output impedances and lower distortion in the output-signal due to nonlinearities or noise introduced by

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*See Appendix.

the amplifier. Generally speaking, the performance of a feedback amplifier can be made to depend entirely on circuit element values rather than the active devices of the amplifier.

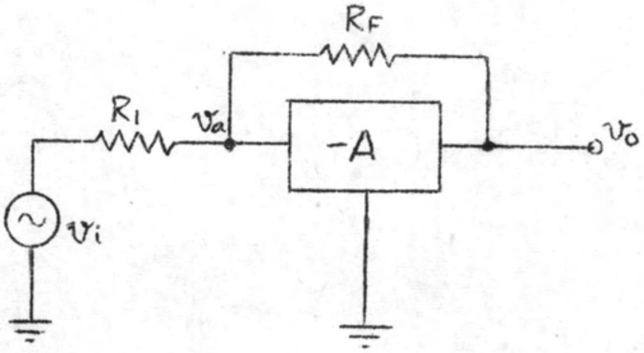


Fig. 1.5 Simple adder used with ideal feedback amplifier.
(Rin = ∞ , Rout = 0)

The circuit in Fig. 1.5 demonstrates the use of a single resistive adder in feedback amplifier design. This is a voltage-feedback stage using a shunt-feedback configuration. Note that A (the magnitude of open-loop gain) is a positive number.

The voltage at the amplifier input v_a, can be found by noting that R_1 and R_F form a simple voltage divider, as shown in Fig. 1.6.

$$v_a = v_i-(v_i-v_o)\frac{R_1}{R_1 + R_F} = \frac{v_i R_F}{R_1+R_F} + \frac{v_o R_1}{R_1+R_F} \quad (1.8)$$

The output voltage is equal to $-Av_a$ or

$$v_o = - A\,\frac{v_i R_F}{R_1+R_F} - A\,\frac{V_o R_1}{R_1+R_F} \quad (1.9)$$

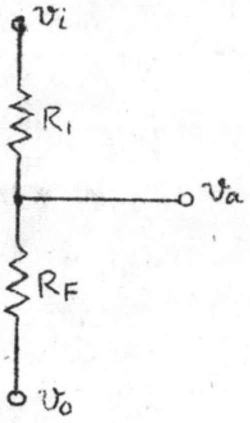


Fig. 1.6 Circuit for calculating v_a.

Solving for the output voltage gives

$$v_o = -\frac{Av_i}{1+AR_1/(R_1+R_F)} \cdot \frac{R_F}{R_1+R_F} \tag{1.10}$$

It is obvious that the portion of the output voltage fedback to the input is

$$F = \frac{R_1}{R_1+R_F} \tag{1.11}$$

Hence the output voltage is

$$v_o = \frac{-Av_i}{1+AF} \cdot \frac{R_F}{R_1+R_F} \tag{1.12}$$

or the closed loop gain

$$A_f = \frac{v_o}{v_i} = \frac{-A}{1+AF} \cdot \frac{R_F}{R_1+R_F} \tag{1.13}$$

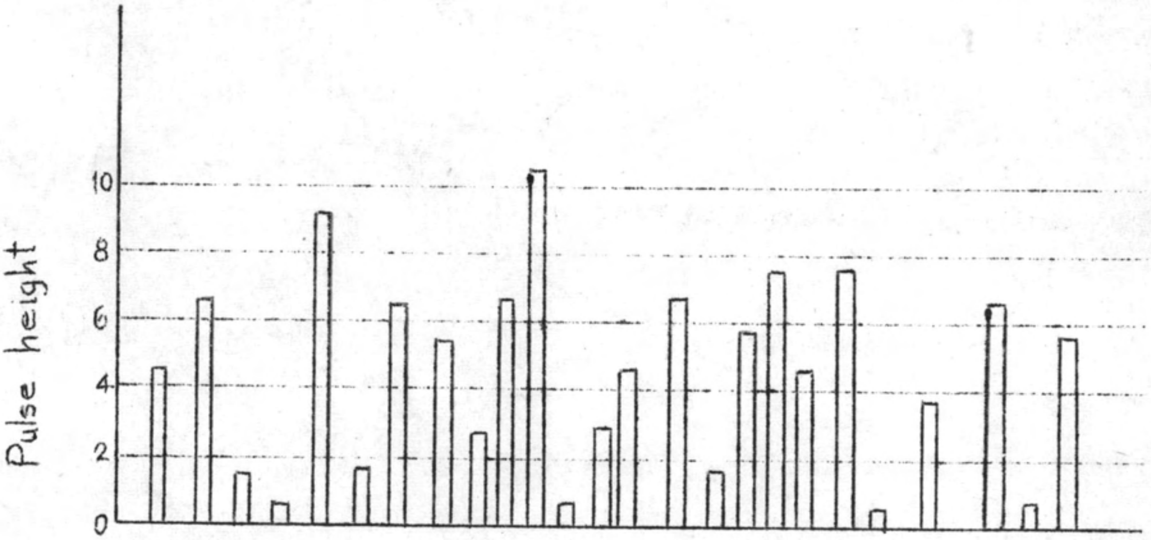
If $AF \gg 1$, then

$$A_f = \frac{v_o}{v_i} \simeq -\frac{1}{F} \cdot \frac{R_F}{R_1+R_F} = -\frac{R_1+R_F}{R_1} \cdot \frac{R_F}{R_1+R_F}$$

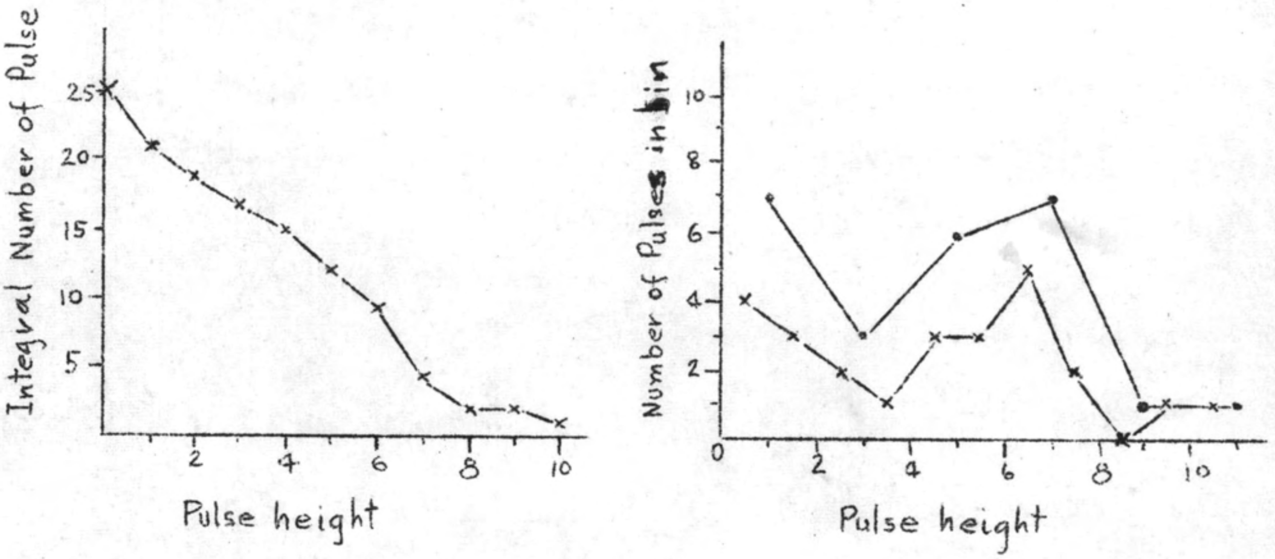
$$A_f \approx -\frac{R_F}{R_1} \tag{1.14}$$

1.3 Pulse Selector

Emerging from the detector output and, subsequently, from amplifier output is a train of pulses, randomly spaced with respect to time and varying in amplitude according to characteristics of the detecting system and of the incident radiations. Such a sequence of pulses is represented in Fig. 1.7 a. An integral plot of this pulse amplitude distribution is shown in Fig. 1.7 b.



(a)



(b)

(c)

Fig. 1.7 Representation of a pulse spectrum

a) Amplifier output showing time of occurence and amplitude of individual pulses in the group to be analyzed.

b) Integral plot of pulse amplitude spectrum.

c) Differential plot of the same pulse amplitude distribution ; x Bin, 1 unit of pulse height; . Bin, 2 units of pulse height.

The number of pulses having heights greater than a particular amplitude is plotted as a function of the amplitude value. Thus, inspection of Fig. 1.7a reveals that there are 25 pulses having amplitudes greater than 0, 21 pulses with amplitude greater than 1, 18 pulses with amplitudes greater than 2, and so on, and these are the coordinates of the points plotted in the integral spectrum.

Inspection of the pulse train reveals that there are four pulses with amplitudes greater than 0 but less than 1, three pulses with amplitudes between 1 and 2, two pulses with amplitudes greater than 2 and less than 3, and so on. This plot of the data (bin size equal to one unit of amplitude) gives the differential spectrum of Fig. 1.7c. The effect of using a larger bin when plotting the data is also shown; it yields more events per bin but reduces the resolution.

The integral and differential plots are merely two different ways of presenting the same data. Indeed, either curve may be derived from the other. Ordinate values for points above a certain value on the differential curve may be added to obtain the integral ordinate value, or successive integral ordinates may be subtracted from each other to supply the co-ordinates of the points on the differential curve. This is why peaks on the differential curve always correspond to regions of maximum slope on the integral curve.

A classical and widely used discriminator circuit is the Schmitt trigger. Tunnel diode also proves to be a good counter-part to form a discriminator with remarkable reliability, linearity and sensitivity. With some slight modifications, lower level and upper level discriminator can be developed from tunnel diodes. It has shown itself to be good lower level discriminator as well as upper level discriminator because of its simplicity, smallness, high speed operation, low noise in low level detection and low power consumption. The disadvantage of the tunnel diode discriminator lies in the fact that an extremely stable power supply is required to stabilize the operating point of the tunnel diode since the performance of the discriminator depends entirely on the operating point.

1.4 Pulse Storage

The fundamental information in a counting experiment relates to the time interval between successive events and the energy transfer associated with each event. Conventional counting devices lump a number of events together and provide the data as events per unit time. This process is destructive in the sense that information relating to shorter averaging times is lost. Magnetic tape provides a means of preserving the time relationship between individual pulses so that the data may be run and re-run with different averaging times in order to provide the best analysis in any situation. Most experiments do not require this degree of sophistication, however, and ordinary counting, whether the measuring time be milliseconds or minutes and hours, will suffice.

1.5 Data Processing

1.5.1 Scalers

The term "scaler" has often been used to denote the single box containing high-voltage supply, amplifier, discriminator, binary flip-flop circuits, and mechanical register that is connected to a detector. Present usage, however, restricts the term to a mechanical or electrical device which is used to count the pulses applied to it by a radiation detecting and analyzing systems. Scalers might therefore be classified as data-storing devices.

Scalers are also data processers, since they accept a series of randomly spaced pulses and produce a number. There are many kinds of scalers offering different degrees of convenience of readout, reliability, pulse-pair resolution, size, and power consumption.

One of the first methods by which electrical pulses were counted involved the use of an electromagnetic register. This type of register consists of a relay mechanism and a drum on which the digits 0 to 9 are painted. Only one of these digits is visible through the viewing aperture at any time. When a suitable pulse of current is passed through the magnetizing coil, an armature is attracted and the drum is moved so that the succeeding digit is indicated. The maximum speed at which an ordinary electromagnetic register can operate is about 10 to 25 pulses per second. This is much too slow for many applications.

The first electronic scalers consisted of a set of binary (scale of two) elements connected in series to provide a scaling factor of 2^n, where n represents the number of binary stages. These scale-of-two units (flip-flops) are symmetrical circuits which can be characterized by either one of two conducting states, designated 0 and 1. Such a circuit is shown in Fig. 1.8 .

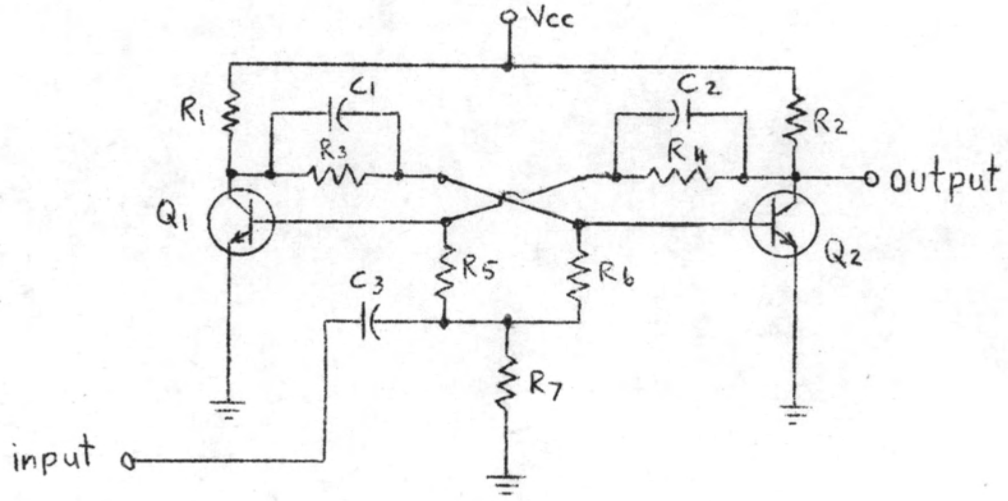


Fig. 1.8 Scale-of-two circuit. One output pulse for each two input pulses; called a "flip-flop" circuit.

Suppose that transistor Q_2 is in its conducting state. The d.c. connection insures that transistor Q_1 will not be conducting at the same time. This we shall call the "O" state. When a signal is impressed upon the input, it will pass a pulse of one sign only, causing a transfer of the conduction. With Q_1 conducting and Q_2 off the system is in the binary state "1". The next pulse at the input will transfer the system back to state "O" and a pulse will appear at the output when this transition occurs. This output pulse may be used to trigger either a mechanical register or another flip-flop circuit. Because of the dependence upon conduction, flip-flop circuits are ideally suited for transistorization. Reliable and inexpensive transistor binary scalers are commonly available.

A chain of integrated circuit JK flip-flops used as a counter is shown in Fig. 1.9. The truth tables for the JK flip-flop are shown in Fig. 1.10.

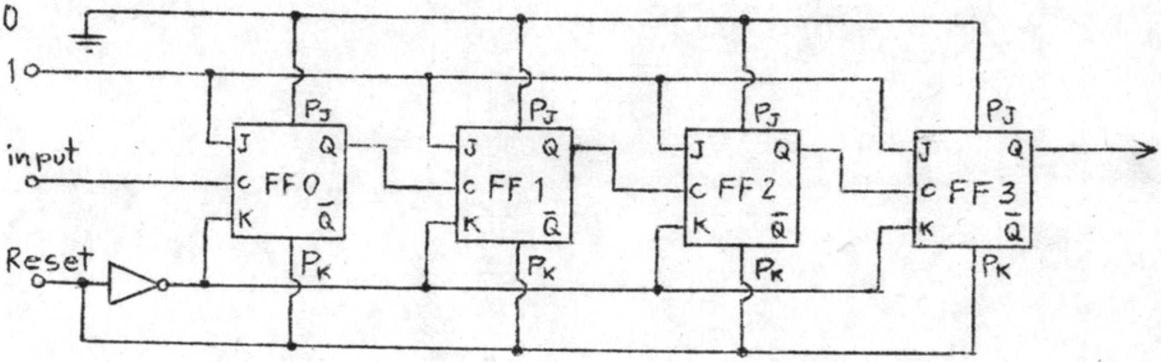


Fig. 1.9 Binary Ripple-Through Counter.

J	K	Q_{n+1}
0	0	Q_n
0	1	0
1	0	1
1	1	$\overline{Q_n}$

Synchronous Inputs at Clock Time

P_J	P_K	Q_{n+1}
0	0	Q_n
0	1	0
1	0	1
1	1	*

Asynchronous Inputs

Fig. 1.10 Truth Tables for the JK Flip-Flop.

The J and K terminals, with the connections shown, are at the 1 level when counting; and therefore each circuit with the input at terminal C is a toggle flip-flop. This is the simplest method of counting that employs an asynchronous technique known as ripple carry, or simply called a ripple-through counter.

The basic flip-flop circuit changes state with each input pulse and returns to the same state after every second pulse. Each output waveform, therefore, is a square wave at one-half the frequency of its input. By using the output of one stage as the input to the next, the frequency is successively halved. The pertinent waveforms are shown in Fig. 1.11, illustrating the successive frequency division.

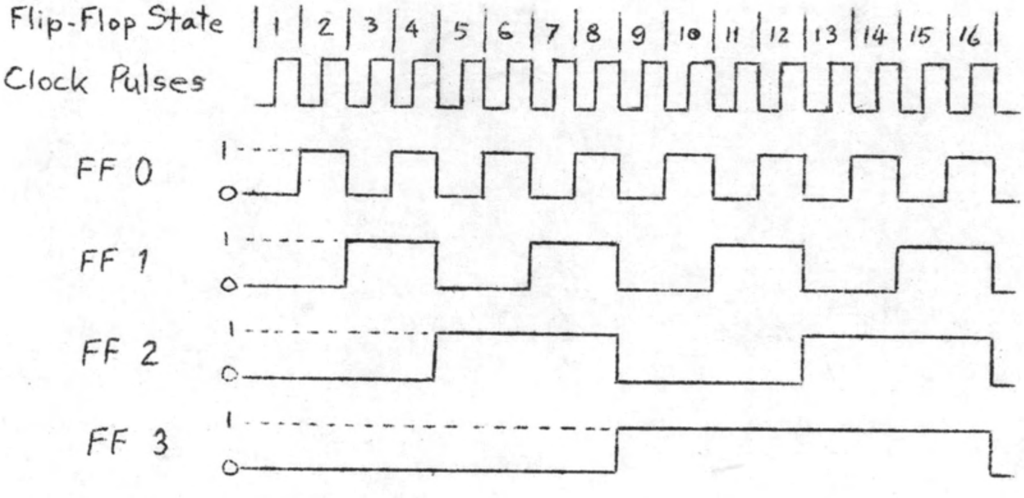


Fig. 1.11 Waveforms in Four-Stage Binary Counter.

These waveforms may be verified by applying the following rules :

1. Flip-flop FFO changes state with each external input pulse.
2. Each of the other flip-flops changes state when and only when the preceding flip-flop makes a transition from state 1 to state 0.

A counter that can be made to count in either a forward or reverse direction is called an "UP-DOWN" or "REVERSIBLE" counter. Forward counting is accomplished, as discussed above, when the toggle input of a succeeding flip-flop is coupled to the Q output of a preceding flip-flop. The count will proceed in the reverse direction if the coupling is made instead to the $\bar{Q}$ output.

If a flip-flop changes from state 0 to 1, then the $\bar{Q}$ output will change from 1 to 0. The negative-going transition at $\bar{Q}$ will cause the succeeding flip-flop to change state. For reverse binary counting the following rules will apply :

1. Flipflop FFO changes state with each external input pulse.
2. Each of the other flip-flops changes state when and only when the preceding flip-flop makes a transition from state 0 to state 1.

1.5.2 Binary-coded-decimal (BCD)

The process of converting binary information into decimal units is particularly time consuming and has been largely obviated by the so-called binary-coded-decimal systems. Binary stages may be programmed to read in decimal units in one of a number of ways. Two of the most common ones are the 16-6 and 8+2 systems. In the former, four flip-flop units in series (scale factor $2^4 = 16$) are made to receive false counts of 2 and 4 in the second and third stages (by the proper use of feedback), so that 10 input pulses (16-6) are required for one output pulse. Four scale-of-two circuits are also used in the 8+2 system, but an inhibit gate is included which prevents the second stage from responding to the tenth pulse but, rather, triggers the fourth stage. Thus, 8 counts are required to change the conduction state of the fourth binary elements, but it reverts back to the 0 state with the addition of only 2 more counts.

BCD systems employing vacuum tube or transistor flip-flop require proportionately more complex circuitry than simple binary systems. Integrated circuit technology has now dramatically changed this situation. One integrated circuit decade scaler (Texas Instrument SN 74190 UP/DOWN decade counters) is quite inexpensive, is very fast (20 MHz), is small ($\frac{7}{8}$ inch maximum dimension, 1.2 gm weight) and only consume 0.325 W of power.

1.5.3 Readout

Readout is the means by which the quantity which the equipment has counted is displayed for observers to see. Some of the devices used for the switching operations in counting equipment are inherently self indicating. For example, digits are displayed by electromagnetic registers, the glowing gas in trigger and polycathode tubes shows the state of the count. In general, however, such self indicating devices cannot count at the highest possible speeds.

The switching operation of the fastest counting circuits (such as vacuum tube, transistor, integrated circuit, beam switching tube and tunnel diode circuits) does not cause any visible change which can be interpreted as a change in the number of counts. If visual readout is required, some additional components are employed with such circuits to convert the electrical readout from the counting circuit into visual readout.

There are two basic types of readout which can be used to display the state of the count, namely digital and analog. When a digital readout system is employed, the number of counts is displayed as actual digits. Analog readout systems show the number of counts in terms of the movement of a meter needle, the movement of a spot of light on the screen of a cathode ray tube or some other physical change in which the actual number of counts is not shown directly.

Digital readout, the direct display of characters or coded equivalents, offers the following advantages as compared to analog readout, and digital printout (where input is converted to printed characters, as in a teletypewritter).

Immediate comprehensibility: An in-line digital display requires no translation. It presents information conventionally whereas meter readings frequently involve verniers, multiple scales, logarithmic calibration, and other complications.

Dependability : Digital displays reduce chances of mechanical and human error. Electromechanical readouts sometimes malfunction, but electronic digital displays, on the whole, are as accurate as the information fed to them. They require no instrument calibration.

Speed : Many digital readouts register data as fast as the human eye can follow (about 2 counts per second). Furthermore, the characters snap into position, to prevent blurring. This is an obvious advantage over a rapidly fluctuating meter, or a slow printout device. And if faster presentation rates are necessary, there are readouts available which operate in milliseconds and microseconds, although these must be "stopped" by photography or special timing pulses.

Flexibility : Many digital readouts can be used as either counters or indicators, depending upon external switching arrangements. In addition to digits (0 to 9), some readouts display letters of the alphabet, full messages, and special characters. Many incorporate dynamic alarms, and some accept with slight modifications, a variety of inputs-pulses, parallel or serial binary codes, or straight "decimal" selection switching.

Usually meters handle only one or two closely related units. But with proper switching, the same digital readouts can register widely differing units and symbols, for example, time, temperature, and nuclear pulses.

Appearance: Many of these devices are quite handsome, with the strong, clean lines of good modern architecture.

A very common form of readout system involves the use of one additional cold cathode gas filled numerical indicator tube for each decade in the scaler. The indication is given as a glow in the gas contained in the indicator tube. In some types of tube the glow is of such a shape that it forms the digit which is to be indicated. This type of display is particularly useful, but milliammeters graduated from zero to nine are often used in transistor scalers, since they consume no appreciable power. Other possible forms of readout include the use of tungsten filament bulbs, cathode ray or "magic eye" indicators, neon bulbs, light emitting diode (LED) and luminescent display panels.

1.6 High-Voltage Power Supplies

Because of the dependence of the output pulse amplitude of the various detectors on the value of the high-voltage bias applied to them, the high voltage power supply is an important part of the complete electronics system for pulse amplification and analysis.

Whereas the high voltage has little effect on the output in the case of G-M counters and solid state detectors, changes of only 1 % in the bias of a scintillation detector will change the output pulse amplitude by 10 % or more. Stability of modern high-voltage power supplies depends on a number of factors such as time, temperature, input supply voltage, and output load.

Transistorized power supplies find applications where small size, light weight and high efficiencies are required. In addition the service life of the converter is long since transistor power supplies contain no moving parts.

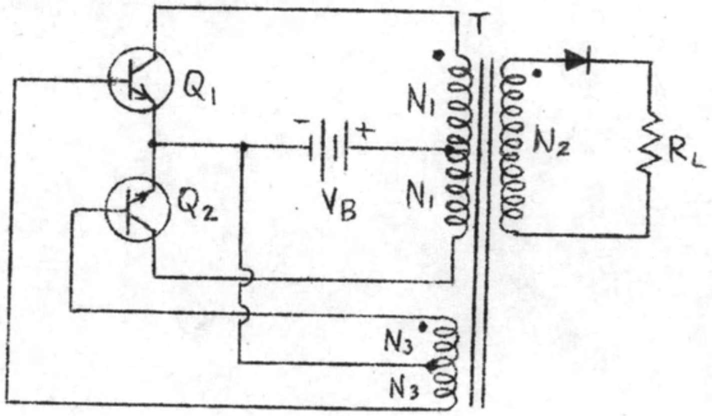


Fig. 1.12 Simplified schematic of transistorized dc-dc converter.

Fig. 1.12 shows a simplified circuit of the transistor dc-dc converter. The transistor acts as an ON-OFF switch to obtain a square wave ac output voltage from a dc source. This square wave can be stepped up or down by transformer T for a desired output level and rectified to give a dc output voltage. The transistors are switched ON or OFF by a feedback winding on the transformer, one transistor going ON while the other transistor goes OFF.

The d.c. output may be multiplied up by the voltage multiplier to give higher d.c. output voltage which can be regulated by gas-discharge regulator tube. The output voltage across the regulator tube is usually stable enough to use with the scintillation detector or any detectors which the maximum detector sensitivity is to be realized.

1.7 Timer

The assay of radioactivity requires not only the tabulation of the number of counts produced in a detector but also a measurement of the time interval during which the counts were collected. The count rate may then be calculated and related to the radioactivity. Timing therefore plays as important a role as scaling in nuclear measurements.

The widely used electromechanical timers are driven by synchronous electric motors. Elapsed time and preset time models are available. The limitations on accuracy imposed by the clutch mechanism and by reading the smallest graduation on the dial are of a fixed nature, independent of the length of the time interval measured. Although fixed uncertainties of 0.1 to 0.2 s are most common, errors as large as 1 s exist with some preset timers. Therefore 100 s may be required for 1 % precision even though the count-rate exceeds 100 counts per second.

Electronic timers consist essentially of a fast decimal scaler, as described before, pulsed by a standard oscillator. Crystal controlled oscillators are used in some timing units. The output of the timer may be visual or may be printed automatically.

Most scalers measure the number of counts that appear in a fixed, preset time interval. The length of time may be chosen (1 min, 100 s, and so forth) so that the calculation of count-rate is simplified. Replicate determinations may be made and averaged directly. Sometimes, however, the preset count mode of operation is to be preferred. The scaler measures the amount of time required to accumulate a specified number of counts.

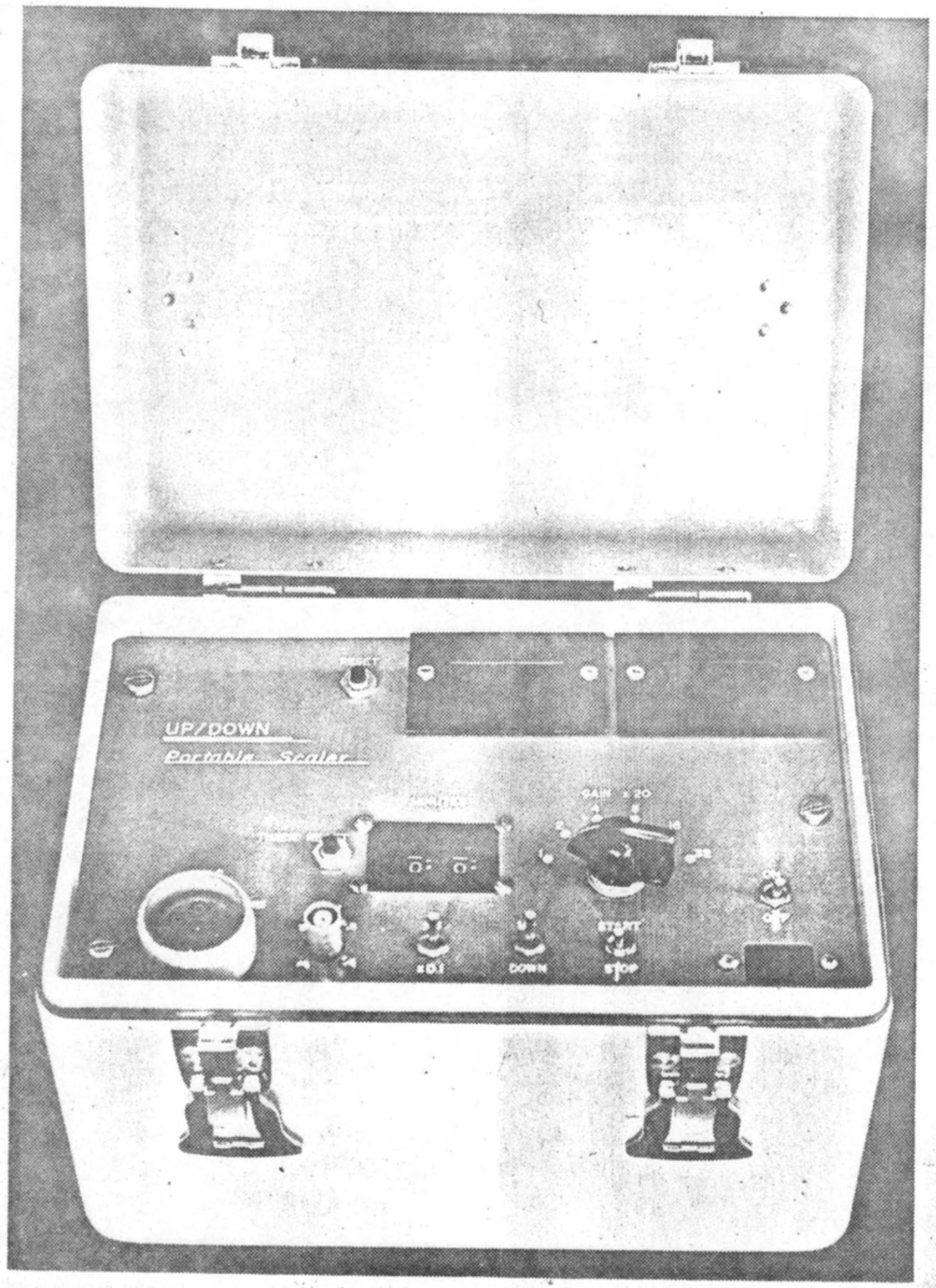


Fig. 2.1 The UP/DOWN Portable Scaler.