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INSTRUMENTS

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**PULSE AMPLIFIERS USING TRANSISTOR
CIRCUITS**

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ABSTRACT

Transistor circuits simplify the design of pulse amplifiers because of their essentially linear gain characteristics. The low heat dissipation of such circuits permits small packages. The variations in transistor gain and leakage can be minimized by converting the high single stage gain to stability through the use of emitter feedback. Linearity and response to fast rise pulses is shown for specific scintillation amplifier circuits.

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I. Introduction

Some radiation detectors produce a wide range of pulse amplitudes. Pulses above a maximum voltage level will become distorted due to the overload characteristics of the amplifiers in the system. For optimum performance, the distorted pulse should not produce a spurious response, nor should it affect the pulses which follow. An amplifier which is used to reproduce a wide dynamic range of pulse amplitudes usually must have a high degree of gain stability and a linear response over its operating range. The output usually will feed a discriminator system to eliminate small noise pulses, and the pulses may be sorted into amplitude categories, e.g. for gamma spectroscopy. Reproduction of fast rise time pulse shapes requires a relatively wide frequency band-pass characteristic in the amplifier. The high frequency response remains important even when pulse shaping is introduced. Pulse shaping is used to improve the time resolution of the system, to minimize overload distortion, or to facilitate the action of discriminating and recording circuits. The amplifier response may be optimized by such shaping, but in general the overall characteristics will be fixed by the particular detector system.

II. Design Considerations

Transistor circuits simplify design and construction since filament power is not required. Moreover, both transistors and printed circuit wiring are inherently non-microphonic. However, transistors have

certain variable characteristics which must be considered in the design of pulse amplifiers. Most important of these are the variation of leakage current (I_{co}) and the changes in the grounded-emitter current gain (β). Both are temperature dependent and will vary from transistor to transistor; with aging, the variation may become significant.

DC Stability

The cutoff current, I_{co} , appears as a constant current generator¹ in the base collector circuit, Figure 1a, and is amplified by the effective DC gain. The cutoff current is a temperature variable, and may be considered to double its magnitude for each 7° to 10° C. of increase in temperature for most types of transistors. Thus, a temperature change "at the transistor" from 25° to 55° C. will increase the cutoff current by a factor of between 8 and 18. As illustrated on the collector characteristic, Figure 1b, this is amplified by the effective DC gain, S , and appears as a shift in the operating point. The effective DC gain may be controlled by emitter resistance in conjunction with the external base resistance, Figure 1c. The supply voltage must be sufficient to allow for the voltage drop across the emitter stabilization.

AC Stability

The β varies approximately 20% over a temperature range from 0° to 55° C. Multistage feedback to secure stabilization is complicated because of the phase delay characteristic of transistors. Since large voltage amplification is feasible within a single stage, single

1. Report HASL-4, "Transistorization of Nuclear Counting Circuits" by R. T. Graveson and H. Sadowski

TRANSISTOR STABILIZATION

(a)

(b)

$$A = gm R_L$$

$$G = \frac{A}{1 - AF}$$

$$F = \frac{R_2}{R_L}$$

$$R = \frac{R_3 R_4}{R_3 + R_4}$$

$$S = 1 + \frac{R_1}{R_B} \frac{(1 - \alpha) + R_1}{R_b}$$

(c)

D.C. STABILIZATION

A.C. STABILIZATION

FIGURE 1

stage feedback is satisfactory for most applications, Figure 1d. The designs are based on a voltage gain around 150 in the single stage without feedback. Beta variation of 20% can be reduced to an overall gain variation of about $\frac{1}{2}\%$, when the voltage gain is reduced to 4 by feedback. Emitter feedback also reduces the input time constant and improves the rise time capability of the stage.

Interstage Coupling

The drift transistors are particularly suitable for amplifiers because of their good frequency response, small collector to base capacitance, moderately high beta and low cost. However, when one attempts direct RC coupling, the high input capacitance of the transistor appears across the load of the previous stage. While this is satisfactory for low frequency amplifiers, some means of isolating the high input capacitance from the previous load is required to achieve the high frequency response. The addition of an emitter follower stage as a buffer between amplifying stages fills the need for a unity voltage gain, impedance transformer. The capacitance presented by the input of an emitter follower connection is degenerated to a fraction of its original value. Referring to Figure 2 which is an equivalent circuit for the RCA 2N247², it is possible with feedback to degenerate the base emitter capacitance to about 5% of its original value.

The emitter followers are used in the amplifier design as buffers between stages, as a power amplifier between the last amplifier stage

2. Giacoletto, L. J., "Study of PNP Alloy Junction Transistors from DC through Medium Frequencies," RCA Review, Vol. 15, No. 4. pp. 506-562, December, 1954

<u>TRANSISTOR</u>	<u>f_{α}</u>
RCA 2N247	30 MC
RCA 2N247	100 MC
RAYTHEON 2N417	20 MC

TRANSISTOR
 EQUIVALENT CIRCUIT

FIGURE 2

and the external loading of a cable, and as an input impedance transformer between the detector and the first amplifier stage. As an input impedance transformer, it is usually not possible to use the drift type of transistor. Drift transistors require over one milliamperes emitter current and at least 4 volts between collector and emitter, in order to maintain the drift field, otherwise their frequency response is seriously impaired. When considering a high impedance input stage, the input impedance of the transistor in emitter follower connection is approximately beta times the emitter load. In addition, the base biasing resistors appear in parallel with the transistor input impedance. The high emitter resistance, the low base current required by the high bias resistors, and the voltage limits of the transistor combine to impose the limit on the operating current. High frequency transistors which do not employ the drift principle usually show a somewhat smaller base-emitter capacitance. Also, they have a higher extrinsic base resistance, and a much higher base-collector capacitance. However, they can be operated at relatively low emitter currents while preserving their frequency response. When operated in emitter follower connection, their input capacitance is highly degenerated and their frequency response can be very good.

The input stages of the preamplifier designs are based on the use of a conventional high frequency transistor in emitter follower connection. Succeeding amplifier stages are each buffered by emitter follower stages to isolate amplifier input capacitance from the load

of a previous stage. An emitter follower is used at the output of each amplifier block to provide power amplification and isolation between the load of the last amplifier and the external cable.

III. Amplifier Circuits

The TA-12-A preamplifier, Figure 3, consists of a double emitter follower circuit. The input impedance of each emitter follower stage is BR_e , and for the 2N417, the emitter load will be increased by a factor between 100 and 200. The double connection gives an amplification of the cable load impedance by a factor somewhat over 200,000. When feeding a 50 ohm matched cable the input impedance of the complete circuit is approximately 250K. The gain of this preamplifier is approximately 1.

The TA-5-B preamplifier, Figure 4, has a gain of 10, and consists of two amplifying stages with these emitter follower stages as isolation. The first amplifier stage, which has a 1.1K load is designed to match a delay line for pulse clipping. The input impedance has been measured as approximately 100K.

The output amplifier, TA-6-B, Figure 5, was designed for a gain of 20. The maximum output pulse is slightly over 10 volts, and a fine gain control is included so that the overall gain may be adjusted between 5 and 20. This also has two amplifying stages with three emitter follower buffers. The input impedance was designed to operate with minimal loading on the matching resistors of cables and is 10-15K.

SCINTILLATION PRE-AMP TA-12-A

FIGURE 3

MAX. OUT= 3V
GAIN= 10

NOTE:

1. TRANSISTORS RCA 2N247 UNLESS OTHERWISE SPECIFIED
2. OPTIONAL DELAY LINE SHAPING ($1/2 U_S, Z_C = 1100 \Omega$)

SCINTILLATION PRE-AMPLIFIER HASL TYPE TA-5-B

FIGURE 4

ALL TRANSISTORS RCA 2N247

AMP T A-6

GAIN=20 MAX. OUT=10.5V.

FIGURE 5

The convenience of printed circuit construction and packaging allows addition or removal of amplifier gain blocks depending on the application. To facilitate this, each amplifier, Figure 6, is constructed on 2" wide board, the plug connections are identical and both input and output are negative pulses.

IV. Results

Each amplifier was tested with a 200 millimicrosecond wide, 5 μ s rise pulse, Figure 7. The TA-12-A has a rise response of approximately 10 μ s, the TA-5-B approximately 60 μ s and the TA-6-B approximately 100 μ s. The fall time of each is similar and is approximately 100 μ s. Overload pulses do not introduce distortion or spurious response.

The preamplifier and amplifiers were designed for Gamma Spectrometers which use Sodium Iodide scintillation detectors. A completely transistorized single channel system is shown in Figure 8. The head contains the scintillation detector, the high voltage supply and the preamplifiers. An output amplifier is packaged with the discriminators in the pulse height analyzer. The linearity and maximum output pulse were determined by the PHA discriminator and are indicated by the curves in Figure 9.

The design of linear pulse amplifiers is simplified by the use of transistor circuits. The transistor gain characteristic is essentially linear over a wide operating range. In addition, transistor circuits allow the use of simple single-voltage power supplies, which can be well filtered to minimize noise pickup. The low power consumption results in low heat dissipation even in small packages,

TA-6-B

TA-5-B

TA-12-A

Figure 6--Amplifier Printed Circuits

IN - 200ms/cm

CUT - 200ms/cm

IN AND OUT

10ms/cm

50ms/cm

50ms/cm

TA-12-A

TA-6-B

TA-5-B

Pulse Response of Amplifiers

Figure 7

Figure 8--Single Channel Gamma Spectrometer

AMPLIFIER LINEARITY

FIGURE 9

and it may be expected that the stability and life of all components will be enhanced. Transistors do have instability problems, primarily due to temperature. However, the high single stage gain which is feasible may be converted to stability through the use of emitter feedback. This type of feedback avoids the complications inherent in multistage degeneration, because of the transistor phase characteristics. The emitter follower connection provides a convenient unity voltage gain, impedance transformer, and is useful both for input and output coupling and for interstage coupling between amplifier stages.

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