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A 40-CHANNEL PULSE HEIGHT ANALYZER

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SALUTATION

Mr. Chairman, members and friends of the Institute of Radio Engineers:

GENERAL

By the use of ionization chamber and scintillation equipment, radioactive particle energy can be transferred into electrical pulses. The pulse amplitudes in turn are proportional to particle energy. To establish a radioactivity energy spectrum, an instrument for determination of numberical pulse intensity as a function of particle energy is required. Such an instrument is the pulse height analyzer.

A simple but effective single channel pulse height analyzer now in use throughout the United States consists of two electronic discrimination circuits; one set to eliminate all pulses under a predetermined value, and the other set to eliminate all pulses over a predetermined value. All pulses falling within the limits of this "electronic window" will register on the counting equipment for the pulse height analyzer.

For use in radioactivity energy spectrum establishment, it is necessary to stack a number of such single channel units. The electronic complexity, circuit instability, and unreliability rise with the number of channel units, and with present day techniques, a pulse height analyzer of the electronic window type becomes somewhat a problem when more than ten units are stacked.

With the constant improvement of scintillation equipment, it is necessary to provide higher speed pulse height analyzer equipment. In fact, 10^{-3} microsecond pulses are available from present day phototubes, although present

day pulse height analyzer equipment is only capable of handling pulses with a 5 to 10 microsecond resolution time.

Realizing this, over three years ago investigation of a switching tube for use in a pulse height analysis device was instituted at the University of California Radiation Laboratory. Several pulse height analyzers were put into service using this experimental tube. The resulting channel definition and collector output were thought acceptable at that time and several pulse height analyzers are still in operation at the Laboratory using the original switching tube design. The best double resolution time obtainable with this switching tube and associated circuitry was about 25 microseconds. A little over six months ago a meeting was called at the Laboratory to discuss the possibility of building a pulse height analyzer of the switching tube type basically for use with sodium iodide scintillation crystals. The device was to have 40 channels with a double resolution time of 1 microsecond. However, some scientists thought an additional slower double resolution time of 25 microseconds should be incorporated, because use in conjunction with existing equipment might be desirable. Channel definition of the somewhat crude switching tube was to be sharpened, channel width tolerances were to be tightened, and collector output was to be increased. The additional requirement ... the equipment was to be rugged and semi-portable.

SLIDE ONE

This is the first prototype of the Radiation Lab 40 Channel Pulse Height Analyzer. In this view one can see the four K 1059 switching tubes which were handmade by Dumont to Radiation Laboratory specifications. On the neck of each tube may be seen a permanent magnet focus yoke. Closer

scrutiny of the lower chassis will reveal a signal amplifier and a cathode gating circuit. The section above the switching tube is divided into 4 chassis. Each chassis houses ten amplifiers and cathode followers which in turn drive the scaling and register equipment in the lower part of the rack and in the rack to the right. The rack to the left houses the power supply and control equipment. This first prototype was finished several weeks ago, and with the experience gained from this unit, the redesign of the switching tube and circuitry is now in progress. Todays discussion will be limited to the IMPROVED version or SECOND prototype of the Pulse Height Analyzer unit.

SLIDE TWO

THE SWITCHING TUBE

This slide shows a outaway of the improved 10 target switching tube. A non-poisoning computer-type cathode is heated by a 6.3 volt filament. The emitted electrons are brought into focus by use of a special permanent manget focus and centering yoke, and the beam current is controlled by the voltage of the iris grid. The electron gun system is similar to that employed in the magnetic focus television kinescope. The pair of electrostatic deflecting plates following the first anode structure are for signal use, and the next pair of plates in the target direction are for gate use.

The tube anode is composed of 10 1/10 th by 1/10 th inch targets, which are escutcheoned by a phosphor painted shield. The shield prevents electrons from spilling over to the output leads of the tube, and the phosphor paint serves as a facility for rough focus of the beam. Each of the 10 targets is an electron multiplier and has been fashioned in the form of a flat bottomed trough. The axis plane of the trough is parallel to the beam, which in turn is perpendicular to the bottom of the trough. A collector wire is placed on center between the trough sides and parallel to

the bottom. The bottom of the trough below the collector wire is painted with secondary emitting material, and with adequate partition height the electron spillover from trough to trough is negligible. The electron multiplier of this design has a gain of between 3 and 4 under standard operating conditions.

SLIDE THREE

A photograph of the elements of the improved switching tube is shown. This is designated by the Dumont experimental number K-1181 and again because the tube was handmade, rather loose target tolerances have been maintained. When tooling for production has been achieved, an individual trough tolerance of $\pm \frac{1}{2}$ mil can be maintained and an overall trough tolerance of $\pm \frac{1}{2}$ mil can be maintained. This provides for mechanical channel to channel trough accuracy of $\pm \frac{1}{2}\%$ and 10 channel trough accuracy of $\pm$ 0.05%. Aside from these limitations the overall accuracy of the tube is dependent upon trough wall thickness and electron beam size. Great care is taken to assure the ultimate in focus adjustment and long term focus stability. With perfect focus adjustment a beam size of 3 mils is obtainable. A value nearer 5 mils, however, is reached in actual practice. In actual practice an effective wall thickness of 20 mils has been measured.

SLIDE FOUR

THE PULSE HEIGHT ANALYZER SYSTEM

This block diagram shows the essential electronic constituents of the Radiation Laboratory Pulse Height Analyzer. The unit accepting the scintillation tube or ionization chamber output is a high stability, remote feedback amplifier. A delay line tail clipper is incorporated near the amplifier input to prevent inaccuracies arrising from pulse pile-up. The output pulse is then either 1 microsecond or 25 microseconds in length

depending upon the setting of the tail clipper control. Looking at the main analyzer unit, the pulse shaper is a circuit which looks at the peak of the pulse and raises the lower portion for the pulse duration. The resultant output is a flat-top pulse either 1 or 25 microseconds in length which retains its amplitude relation to the input. This pulse is amplified through a high stability feedback amplifier and is feed into the signal plates of four UCRL switching tubes. The beams of the tubes are positioned so as to present a continuous forty channel spectrum. The signal pulse is differentiated, applied to the gate plates of the tubes, and will produce deflection of the beam from the switching tube target. When the pulse reaches a flat-top condition, the beam settles on the target and a count is produced on the switching tube scaling equipment. The output pulse of the scaler accuates the grid of a register drive tube which in turn indicates the number of counts divided by the scaling factor. Each unit shown on the block diagram will now be discussed in detail.

LIGHTS ON

INPUT AMPLIFIER

A sodium iodide crystal and scintillation tube convert radioactivity into pulses of electrical energy. It is necessary to amplify these pulses at the source and bring them to a reasonable output voltage and impedance level before feeding them through a radiofrequency and noise strewn particle accelerator area to the pulse height analyzer and control equipment which is usually located in the accelerator counting area. Failure to follow these precautions would sharply limit the rise time of the pulse height analyzer input system and input cables would undoubtedly pick up random radio frequency, extraneous pulses, and other inherent noises present near particle accelerators.

SLIDE FIVE

This is the schematic of a remote input amplifier developed at the Laboratory for pulse height analyzer application. The system is divided into three three-tube amplifier chains. Switching of the feedback resistors in amplifier chains 1 and 2 by the use of relays 1, 2, 4, and 5 can accomplish a total amplifier gain of 25, 250, or 2500. This method of reducing amplifier gain has the advantage of trading gain for additional amplifier stability. Individual amplifier chain voltage gains from 2 to 25 are obtained, and individual amplifier chain feedback factors from 26 to 1850 are obtained. The 1 microsecond and 25 microsecond pulse tail clipper lines are selected remotely by the actuation of relay 3.

In addition to feedback, for amplifier stability, additional stability is provided by the use of an automatic mutual conductance control for each tube. The screen of a pentode or screen and plate of a triode connected pentode, are supplied from a regulated 1000 volt source through a very large dropping resistor. This essentially provides the tube with a constant current source. A comparitively steady state mutual conductance is obtained over the entire tube life even under emission drop with cathode aging. As emission falls, electrode voltage rises. After a predetermined unsafe voltage value has been reached for the tube and its components, a series of neon bulbs (as shown in this schematic) clamps the voltage and prevents any further rise. This also makes the circuit inoperative in a very positive manner, instead of an intermittant manner, and the circuit that requires a new tube is marked by a glowing neon bulb brought through the chassis next to the tube base as will be shown in the next slide. This circuit is a very simple but effective built-in tube tester.

SLIDE SIX

Great pains have been taken to reduce noise in the input amplifier, Filtered direct current filament and relay systems are used. The unit is placed in two 1/16th inch perforated steel cases which act as magnetic and electrostatic shields. The circulating chassis currents have been reduced to a minimum by intelligent component layout, and the bonding of input circuits. All power leads including filament and control circuits pass through three sets of filters before entering the input amplifier compartment. An additional filter system is provided between the various amplifier compartments. The first two amplifiers are shock mounted from the inner amplifier chassis, and the inner amplifier chassis is shock mounted from the case. Since the amplifier input is mostly capacitive, a very high resistance was employed on the input grid circuit. At higher frequencies the capacitive reactance is predominant, and thermal noise from a large input resistor (22 MEG) is negligible. The amplifier has a rise time of better than 0.2 microsecond and an input level of better than 60 microvolts for the 1.0 microsecond channel. This would permit useful measurements of 6 millivolt pulses with a 1% accuracy. The amplifier output may be feed into a 125 ohm line. The input requirements are 6.3 volts dc filament, 300 volts, and 1 kv, in addition to 24 volts dc on the relays.

SLIDE SEVEN

MAIN ANALYZER UNIT

This is a schematic of the main Pulse Height Analyzer unit. The pulse from the input amplifier is fed into plug 2. Crystal 1 and 2, R 14, R 15, and C 7 constitute the pulse flatener, which functions in the following manner. C 7 is charged to 1/2 the peak voltage value of the input pulse, and maintains this voltage value until the input pulse falls to 1/2 of its

initial value. Then the pulse voltage falls in its usual manner to a value of zero. The pulse is then amplified by a high stability feedback amplifier which in turns feeds the 4 switching tube signal plates. It will be noticed that this amplifier also uses automatic mutual conductance control, and the gain is again controlled by changing a resistor in the feedback network. However instead of changing the gain by switching in fixed resistors as in the input amplifier, the gain may be controlled in a continuous manner by use of a 10 turn precision potentiometer. It is this control that determines the high level discrimination of the Pulse Height Analyzer.

C 16 and R 36 constitute the Pulse differentiating circuit and V 10 and its circuitry constitute a saturating in-phase amplifier to drive the gate plates of the switching tubes. A common 550 volt ± 0.1% accelerating voltage is used for the switching tubes. Stacking of the four 10 channel units is done by setting the beam position control. Setting of the magnetic focus and the beam intensity controls determine a minimum beam size. The low level discriminator is a master beam position control and it determines the point at which the analyzer operates above zero level. The switching tube output amplitude is a master intensity control for the tubes. Condenser dividers are provided to compensate for slight variation in deflection sensitivity of the production switching tube.

The circuitry associated with V 5 and V 6 in the upper left hand corner of the schematic provide for either coincidence or anti-coincidence cathode gate pulses, depending upon the settings of S 1 and S 2. Switches 3 and 4 shown in the upper left hand corner provide for control of the remote amplifier gain and the remote amplifier pulse length.

SLIDE EIGHT

This slide shows the Main Analyzer unit with all tubes removed. The switching tube is shown mounted in its yoke. A mu metal shield may be used to cover the tube when the analyzer is used in large magnetic fields.

SLIDE NINE

Before leaving this schematic, I would like to point out pins 1, 2, 3, 4, 5, 7, 8, 9, 10, 11 on the K-1181 switching tube. These are the electron multiplier outputs and feed into the analyzer scaling equipment.

SLIDE TEN

SCALER AND REGISTER DRIVE UNIT

This is one channel that is typical of 40 in the Pulse Height ANalyzer unit. V 1 is a dual triode amplifier. V 2 is a dual triode, binary scalar and V 3 is an amplifier register drive unit. If the scale of 2 provided by the binary V 2 is not enough additional scales of 8 may be plugged into plug 1.

SLIDE EIEVEN

PLUG IN SCAIE OF 8 UNIT

This unit is a plug in scale of 8 and shows 3 binary dual triodes of the subminiature type connected by germaniam crystals. If channels jam because of an excessive counting rate for the scale of 2 incorporated in the scaler and register drive unit, this unit may be used to scale down to a rate the register will accept.

Scaling factors available are 2, 16, and 128. It is felt that a scaling factor of over 128 will almost never be needed.

The data presentation panel is at the present time just entering our shop so a picture of it is not available, however schmatically it is quite simple. A register is provided for each of the 40 channels and a neon

interpolation light is provided up to a scale of 128 for each of the 40 channels. This makes a total of 280 interpolation lights. With the exception of power supplies which are rather straight forward this just about completes discussion of the improved version of Pulse Height Analyzer unit.

SLIDE TWELVE

PULSE HEIGHT ANALYZER TEST EQUIPMENT

I will now briefly attempt totouch on Pulse Height Analyzer test equipment. The unit in this schematic is designed to test quality of the Pulse Height Analyzer switching tube. Beam current and deflection sensitivity may be measured. A 60 cycle saw-toothed voltage is applied to the signal plates of the tube, sweeping a focused beam past the electron multiplier targets. All even numbered targets are connected together, and all odd numbered targets are connected together. For example targets 2, 4, 6, 8, and 10 and 1, 3, 5, 7, 9. As the beam is swept by the targets five square waves are generated on the respective even and odd targets at a displacement of 180° from each other. By expanding the sweep on the test scope and comparing the square wave rise time with the square wave length, the ratio of target wall width to overall target length can be established. The overall target width is known to be 100 mils and therefore from this ratio the effective wall width, which is dependent upon beam width and actual physical wall width, can be calculated.

SLIDE TWELVE A

This slide shows the oscilloscope trace of an effective wall width measurement. In this case the effective wall width was 20 mil.

SLIDE TWELVE

The target end of the tube is next connected to a scaler unit very similar to the scaler used in the initial Pulse Height Analyzer. The signal deflection plate circuit is then connected through an amplifier to a sweep generator and simulated alpha pulser. The linearity of this sweep is accurate to ±0.15% and a statistical analysis can very quickly be made of each pulse height analyzer target. The accuracy of the analysis can be carried to a point limited by the stability of the tube tester and simulated alpha pulser, merely by extending the time of the analysis.

SLIDE THIRTEEN

THE SIMULATED ALPHA PULSER

This is the schematic of the sweep generator and simulated alpha pulser spoken of previously. The power supply of this unit incorporates a simple but effective regulator. Three OA2 tubes act as current regulators for a 5651 voltage regulator tube which is placed in a constant temperature oven. This voltage is impressed across a network consisting of R 10, R 11 and R 12. R 12 is a precision potentiometer with a linearity of ± 0.15%. The bearings of this potentiometer are good for about 1 million revolutions, and it is driven by a clock motor at 1 revolution per minute. The relay, RE 1, is a Western Electric mercury relay which is driven from a 60 cycle source.

Depending upon whether a 1 microsecond or a 25 microsecond pulse length is needed, the swinger of the mercury relay is connected to the appropriate line. When the relay swinger is in position 4 the line is charged, and when the swinger returns to pins 1 and 2 the line is discharged through the output circuit. A network is provided to shape the square wave from the line into a simulated alpha pulse.

Step attenuator and pulse amplitude controls are provided to select the proper pulse amplitude. With switch 4 in the high position, the pulse amplitude control is adjusted to the desired high level discrimination for the pulse height analyzer. With switch 4 in the low position, R 11 is adjusted to the desired low level discrimination. When both the high and low discrimination levels have been set, then switch 4 is connected to the motor position and R 12 is started sweeping at /rpm. A statistical analysis is started, the accuracy of which depends upon the precision of the pulser power supply (not quite 0.05%), and the linearity of the potentiometer which is good to about ± 0.15%. All registers on the pulse height analyzer unit after a period of operation should read the same. Statistically about 3 minutes is required for a 1% calibration check. Any deviation from identical register readings would indicate an error or non-linearity in the pulse height analyzer electronics.

LIGHTS

CONCLUSION AND ACKNOWLEDGEMENTS

As with most projects of this nature, successful completion is dependent upon the diligent cooperation of many men, and the contribution of their talents. The author wishes to thank the following members of the University of California Radiation Laboratory Staff: The Pulse Height Analyzer Advisory Committee, under the direction of Dr. Burton J. Moyer.

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Mr. Alex Stripeika

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and chief technician of the project Mr. Jim Shand.

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This concludes the design and operation of the University of California Radiation Laboratory 40 channel switching tube Pulse Height Analyzer. Thank you for your attention. If you have any questions, I will certainly try to answer them.

THE END