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Design of an Instrument to Detect High Energy Photons at High Altitudes

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AN INSTRUMENT TO DETECT HIGH ENERGY PHOTONS · EVANS

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Date

DESIGN OF AN INSTRUMENT TO DETECT HIGH ENERGY PHOTONS AT HIGH ALTITUDES

by

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INTRODUCTION

A. BACKGROUND TO THE PROBLEM

The earth's atmosphere is under continual bombardment by high energy particles that show negligible variation in rate of occurrence with the exception of certain variations that can be traced to solar disturbances. Most of these particles, particularly those of very high energy, are assumed to come from outer space. These are the primary cosmic rays, and investigations have shown that they consist of protons, alpha particles, and to a small extent, nuclei of heavier atoms. Indirect evidence that primaries attain energies as high as 10^{17} ev has been observed.[1]

The primary radiation reacts with the nuclei of the atmosphere giving rise to secondary radiations which in turn may also react, and eventually a shower of various particles is formed. These secondary particles in the shower are the cosmic rays usually observed beneath the top of the earth's atmosphere.

Low energy charged primaries are prevented from striking the atmosphere by the earth's magnetic field. This deflection is a function of the geomagnetic latitude. As an example, the low energy cut-off for a proton primary, incident from the zenith,

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[1]Rossi, _High Energy Particles_ (New York: Prentice-Hall Inc., 1956), p. 8.

CHAPTER I

INTRODUCTION

A. BACKGROUND TO THE PROBLEM

The earth's atmosphere is under continual bombardment by high energy particles that show no definite variation in rate of occurrence with the exception of certain variations that can be traced to solar disturbances. Most of these particles, particularly those of very high energy, are assumed to come from outer space. These are the primary cosmic rays, and investigations have shown that they consist of protons, alpha particles, and to a small extent, nuclei of heavier atoms. Indirect evidence that primaries attain energies as high as 10^{17} ev has been obtained.[1]

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[1]Rossi, *High Energy Particles* (New York: Prentice-Hall, Inc., 1952), p. 4.

is 1.5 Bev at 50° geomagnetic latitude and 14 Bev at the geomagnetic equator.[2]

In the case of photon primaries, there is no magnetic deflection, and it might be expected that photons of extremely high energy might be observed. To date, no such observation has been made. Russian investigators, during a flight of an earth satellite, determined that the incidence of photons of energy greater than 1 Bev at an altitude of 250 Km. was less than 0.1 per cm.^{2} per second.[3] From this and similar investigations it is indicated that there are few photons in the primary radiation.[4] Millikan, however, suggested that cosmic rays may originate by complete transformation of mass into energy somewhere in galactic space. This would give rise to primary photons in the energy range of 2-5 Bev.[5] There has been no experimental evidence to support this theory, and this method for the formation of primaries is generally disregarded.

Although photons may be a small fraction of the primary radiation, they are one of the most prevalent components of the secondary radiation. High energy protons and complex nuclei

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[2]Rossi, *op. cit.*, p. 6.

[3]S. N. Vernov, and A. E. Chudakov, "Investigations of Cosmic Radiation," *Usp. Fiz. Nauk.*, 70 585.619, April 1960, p. 230.

[4]K. Greisen, *Progress in Cosmic Ray Physics* (New York: Interscience Publisher's Inc., 1956), vol. III, p. 8.

[5]Louis LePrince-Ringuet, *Cosmic Rays* (New York: Prentice-Hall Inc., 1950), p. 236.

is 1.5 Bev at 50° geomagnetic latitude and higher at the geo-magnetic equator.[2]

In the case of photon primaries, there is no magnetic deflection, and it might be expected that [illegible] high energy might be [illegible] been made. Russian investigations, [illegible] satellite, determined [illegible] of energy greater than 1 Bev [illegible] per cm.^{2} per second.[3] From this and similar investigations it is indicated that there are [illegible] the primary radiation.[4] Millikan, however, [illegible] nate by complete transformation [illegible] galactic space. This would [illegible] energy range of 2-5 Bev. [illegible] to support this theory, [illegible] primaries is generally disregarded.

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[3]S. N. Vernov, and A. E. Chudakov, "[illegible] Cosmic Radiation," [illegible] p. 230.

[4]K. Greisen, Progress in Cosmic Ray Physics (New York: Interscience Publisher's Inc., [illegible]

[5]Louis LePrince-Ringuet, Cosmic Rays (New York: Prentice-Hall Inc., 1950), p. 236.

undergo nuclear collisions in the atmosphere, and produce secondary protons, neutrons, and both charged and neutral pions. The neutral pions disintegrate into photons which can react with matter, and form electrons and positrons by pair production. This pair production process occurs in the presence of the strong electric field of the nucleus, and requires a photon energy of at least 1 Bev. The electrons, in turn, produce more photons by "bremsstrahlung", and the process is repeated until an electromagnetic cascade shower results. The number of particles in a shower increases as the atmospheric depth increases until the partition of energy of the original primary is so great that the individual particles are below the threshold energy for electron pair production by photons, and radiation loss by electrons. At this point the number of particles begins to decrease. The electron energy is further degraded by ionization; and the photons, after losing additional energy due to Compton scattering, are absorbed by the photoelectric effect. The shower then dies out. Another contribution to the formation of particles in the shower is a process whereby charged pions disintegrate into muons and neutrinos, and the muons decay with a rest lifetime of approximately 2×10^{-6} sec. into electrons and neutrinos.

Although the shower radiation is composed mainly of electrons and photons, the relative composition is a function of altitude and energy of the primary. Between sea level and 13 Km., muons compose about half of the radiation, and electrons and photons are about equally divided in the other half. From 13 Km.

undergo nuclear collisions in the atmosphere, the primary secondary protons, neutrons, and both charged and neutral pions. The neutral pions directly fall into two photons with the atoms of matter, and form electrons and positrons by pair production. This pair production process occurs in the presence of the strong electric field of the nucleus, and requires a photon energy of at least 1 Bev. The electrons, in turn, give off more photons by "bremsstrahlung", and the process is repeated until an electromagnetic cascade shower results. The number of particles in the shower increases as the atmospheric depth increases until the partition of energy of the original primary is so great that the individual particles are below the critical energy for electron pair production by photons, and radiation loss by electrons. At this point the number of particles begins to decrease. The electron energy is further degraded by ionization, and the photons, after losing additional energy due to Compton scattering, are absorbed by the photoelectric effect. The shower then dies out. Another contribution to the formation of particles in the shower is a process whereby charged pions disintegrate into muons and neutrinos, and the muons decay with a mean lifetime of approximately $2x10^{-6}$ sec. into electrons and neutrinos.

Although the shower radiation is composed mainly of electrons and photons, the relative concentration is a function of altitude and energy of the primary. At around sea level and 12 km, muons compose about half of the radiation, and electrons and photons are about equally divided in the other half. From 12 km.

to 20 Km., the radiation is almost entirely composed of electrons and photons, and it is in this region that the shower normally attains its largest size. Above 20 Km., the radiation is almost entirely composed of primaries.[6] The higher the energy of the primary, the longer the cascade process can continue, and it is possible for extremely energetic primaries to produce cascades whose maximum development is reached at sea level.

At an altitude of approximately 30 Km., it would be interesting to search for the presence of energetic photons, both in the zenith and in the albedo radiation. Isolated occurrences of such albedo radiation have been reported. O. B. Young and T. S. Yoon observed emulsion tracks that originated from a high energy photon jet. The tracks were caused by incident photons with energies up to 3.6 Bev, and originating from an identical source which was calculated to be at a zenith angle of 98° to the balloon-borne detector, and consequently was an albedo radiation.[7]

The purpose of this thesis is to design a high altitude instrument which will detect photons with an energy greater than 1 Bev, and which will discriminate between zenith and albedo radiation.

B. INSTRUMENT DESIGN

Detection of an incoming photon is accomplished by causing the photon to produce an electron-photon cascade in a heavy

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[6]Rossi, op. cit., p. 6.

[7]O. B. Young, and T. S. Yoon, "Rare High Energy Photon Jet in Cosmic Rays," Phy. Rev., vol. 108, pp. 908-09, 1957.

to 20 Km., the radiation is almost entirely composed of electrons and photons, and it is in this region that the soft component attains its largest size. Above 20 Km., the radiation is almost entirely composed of primaries.[6] The higher the energy of the primary, the longer the primary persists in the atmosphere; thus it is possible for extremely energetic primaries to produce cascades whose maximum development is reached at sea level.

At an altitude of approximately 32 Km., it would be interesting to search for the presence of energetic photons, both in the zenith and in the albedo radiation. Evidence of the existence of such albedo radiation has been reported.[7] E. R. Young and T. S. Yoon observed an emulsion event that originated from a high energy photon jet. The characteristics caused by incident showers with energies up to 3.5 Bev, all originating from an identical source which was calculated to be at a zenith angle of 96° to the balloon-borne detector, and consequently are albedo radiation.

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Detection of an incoming photon is accomplished by causing the photon to produce an electron-positron pair in a

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absorber such as lead. At various points in the development of the cascade, plastic scintillators are used to measure the number of electrons that are present. Scintillators convert a portion of the energy of the electrons which are produced in the cascade into a luminescence which is detected and amplified by a photomultiplier tube.

In order to eliminate the recording of incoming charged particles, four plastic scintillators are stacked with a layer of lead between each. (see Fig. 1). Lead is used since the cross-section for pair production is an increasing function of Z, and also because the high density of lead allows the thickness of the plates to be small even for several radiation lengths. Since it has no charge, an incident photon causes no light pulse in the first scintillator. However, when the photon passes through the first lead plate, pair production results, and a number of electrons are formed. These electrons pass through the second scintillator where they are observed by a phototube. By a cascade process, these electrons multiply in the second layer of lead and a larger pulse is observed in the third scintillator. Similarly, an even larger pulse may be observed in the fourth scintillator. It is necessary, of course, that the incident photon originally possess sufficient energy to cause the cascade to proceed as far as the fourth scintillator.

According to investigations by Belenk'ii[8] and Ivanenko[9], a 1 Bev incident photon produces a maximum number of approximately

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[8]Rossi, op. cit., pp. 287-88.

[9]I. P. Ivanenko, "Doklady," Soviet Physics, vol. I, 1956, p. 234.

absorber such as lead. At various points in the development of the cascade, plastic scintillators are used to measure the number of electrons that are present. A scintillator converts a portion of the energy of the particle which was produced in the cascade into a light signal which is then detected by a photomultiplier tube.

In order to minimize the detection of incoming charged particles, four plastic scintillators are arranged with a layer of lead between each. (See Fig. 3). Lead is used since the cross-section for pair production is an increasing function of Z, and also because the high density of lead allows the thickness of the plates to be small even for several radiation lengths. Since it has no charge, an incident photon passes without interaction in the first scintillator. However, when the photon passes through the first lead plate, pair production results, and a number of electrons are produced. These electrons pass through the second scintillator where they are observed by a phototube. By a cascade process, these electrons multiply in the second layer of lead and a larger pulse is observed in the third scintillator. Similarly, an even larger pulse may be observed in the fourth scintillator. It is necessary, of course, that the incident photon originally possess sufficient energy to cause the cascade to proceed as far as the fourth scintillator.

According to investigations by Rossi[8] and Ivanenko[9], a 1 Bev incident photon produces a maximum number of approximately

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[8]Rossi, op. cit., pp. 255-258.

[9]I. P. Ivanenko, "Cascade", Soviet J. Atomic Energy, Vol. 3, 1957, p. 234.

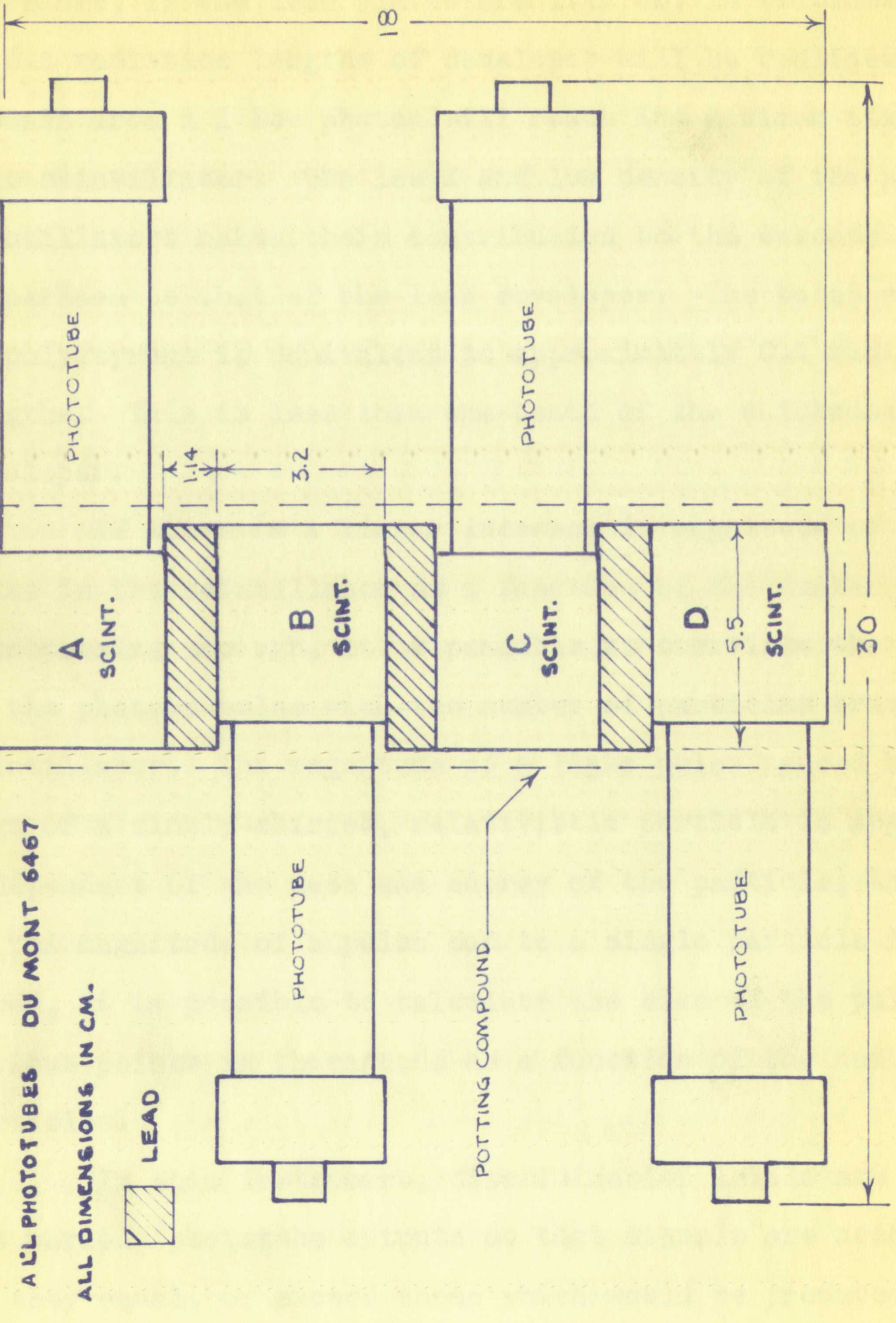

FIG. 1
DETECTOR TELESCOPE

nine charged particles after traversing 6.6 radiation lengths of lead. One radiation length is equal to 0.52 cm. in lead; therefore, if the lead plates are 1.14 cm. in thickness, a total of 6.6 radiation lengths of developer will be realized, and the cascade from a 1 Bev photon will reach its maximum size in the last scintillator. The low Z and low density of the plastic scintillators makes their contribution to the cascade small in comparison to that of the lead developer. The total of 12.8 cm. of polystyrene is equivalent to approximately 0.4 radiation lengths. This is less than one-tenth of the thickness of lead developer.

If there is a linear increase in magnitude of the light pulse in the scintillator as a function of the number of particles passing through, it is possible to correlate the voltage of the photube pulse with the number of particles traversing the scintillator. The magnitude of a light pulse caused by the passage of a singly-charged, relativistic particle is approximately independent of the mass and energy of the particle; therefore, if the magnitude of a pulse due to a single particle is determined, it is possible to calculate the size of the pulse at various points in the cascade as a function of the number of particles.

In this instrument, discrimination levels are set for the various phototube outputs so that signals are accepted only if they equal, or exceed those which would be produced by a single particle in the first scintillator, two particles in the

nine charged particles after traversing 6.6 radiation lengths of lead. One radiation length is equal to 0.52 cm. of lead; therefore, if the lead plates are 0.5 cm. thick and there is a total of 6.6 radiation lengths of developer, it will be realized, that the cascade from a 1 Bev photon will reach its maximum size in the last scintillator. The low Z and low density of the plastic scintillators makes their contribution to the cascade small in comparison to that of the lead developer. The total of 12.8 cm. of polystyrene is equivalent to approximately 0.3 radiation lengths. This is less than one-tenth of the thickness of lead developer.

If there is a linear increase in magnitude of the light pulse in the scintillator as a function of the number of particles passing through, it is possible to correlate the voltage of the phototube pulse with the number of particles traversing the scintillator. The magnitude of a light pulse caused by the passage of a singly-charged, relativistic particle is approximately independent of the mass and energy of the particle; therefore, if the magnitude of a pulse due to a single particle is determined, it is possible to calculate the size of the pulse at various points in the cascade as a function of the number of particles.

In this instrument, discrimination levels are set for the various phototube outputs so that signals are accepted only if they equal, or exceed those which would be produced by a single particle in the first scintillator, two particles in the

second, four in the third, and nine in the fourth. This corresponds to the cascade development caused by a photon whose energy is 1 Bev.

Signals from the last three tubes are routed through a coincidence circuit (Fig. 2). If the inputs to the coincidence circuit are simultaneous, a signal appears at the coincidence circuit output. This signal is fed to one input of the anti-coincidence circuit. Since it is desired to eliminate events that are caused by charged particles striking the first scintillator, the output of the first phototube is fed to the other input of the anti-coincidence circuit. If a pulse occurs here at the same time as a pulse is received from the coincidence network, it shorts the coincidence signal to ground so that no signal appears at the output of the anti-coincidence circuit. If the observed cascade is caused by a neutral particle, the coincidence is allowed to pass through the output of the anti-coincidence circuit. This signal is then fed to a gate which activates a sub-carrier oscillator which in turn modulates the main carrier of the transmitter.

A standard U.S.A.F. Radiosonde transmitter is used. This instrument also transmits information on barometric pressure and atmospheric temperature. The signal is received at the recording station by a U.S.A.F. Ground Meterological Data Receiver. The F.M. output of this receiver is fed to a special demodulator unit in order to recover the photon counting data. The temperature and pressure data are recorded on a continuous graph, and totalizing counters are used to record the photon counts.

second, four in the third, and eight in the fourth. This pattern responds to the cascade development caused by a gamma whose energy is 1 Bev.

Signals from the last three tubes are presented to a coincidence circuit (Fig. 6). If the inputs to the coincidence circuit are simultaneous, a signal appears at the coincidence circuit output. This signal is fed as one input of the anti-coincidence circuit. This unit is designed to eliminate events that are caused by charged particles striking the first scintillator, the output of the first phototube is fed as the other input of the anti-coincidence circuit. If a pulse occurs here at the same time as a pulse is received from the coincidence network, it shorts the coincidence signal to ground so that no signal appears at the output of the anti-coincidence circuit. If the observed cascade is caused by a neutral particle, the coincidence is allowed to pass through the output of the anti-coincidence circuit. This signal is then fed to a gate which activates a sub-carrier oscillator which in turn modulates the main carrier of the transmitter.

A standard F.M.-F.M. telemetering transmitter is used. This instrument also transmits the data on gas pressure and atmospheric temperature. The signal is received at the ground station by a U.S.A.F. [illegible] employed [illegible]. The F.M. output of this receiver is fed to a special discriminator unit in order to recover the pulses and the data. The temperature and pressure data are recorded on a continuous chart, and scaling counters are used to record the gamma counts.

LEDGEND

A SCINTILLATOR
B "
C "
D "
E TUBE H.V. SUPPLY
F PHOTOTUBE
G AMPLIFIER
H INVERTER
J DISCRIMINATOR
K ANTI-COINCIDENCE
L COINCIDENCE
M GATE
N SUB-CARRIER OSC.
P TRANSMITTER
S DIPOLE ANTENNA
——— CHANNEL 1
- - - - - CHANNEL 2

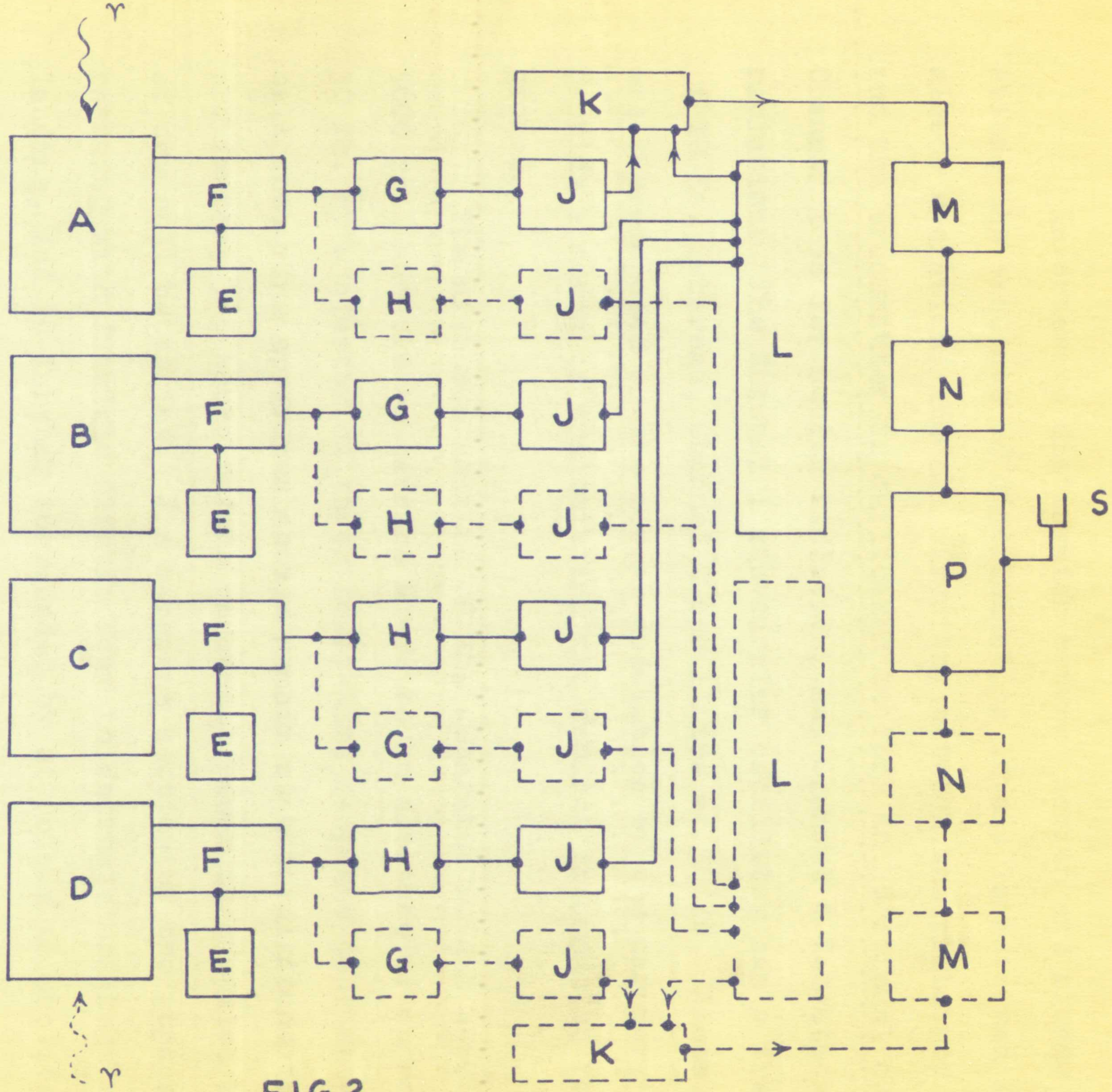

FIG. 2

BLOCK DIAGRAM OF AIRBORNE CIRCUITRY

In order to distinguish between zenith and albedo radiation, the sequence of discrimination levels is reversed for albedo radiation, and all circuitry between the phototube output and the transmitter is duplicated to form an additional channel. Channel 1 is for zenith radiation, and Channel 2 detects albedo radiation. The Channel 1 sub-carrier oscillator has a frequency of 10 Kc.; whereas, Channel 2 oscillates at 30 Kc. These signals are superimposed on the normal modulation of the carrier, and provide a means of transmitting the desired information to the ground.

The airborne section of the apparatus weighs approximately 5600 gm., and can be carried aloft to an altitude of approximately 30 Km. by a cluster of three Dewey-Almy neoprene constant-level balloons. The apparatus should remain at this altitude for approximately 3-5 hours before descent. Power is supplied by means of dry cell batteries. The airborne section of the apparatus is packaged with flexible plastic foam to decrease breakage upon landing, and is further surrounded by styrofoam to provide thermal insulation.

In order to distinguish between zenith and albedo radiation, the sequence of discrimination levels is reversed for albedo radiation, and all circuitry beyond the scintillation counter and the transmitter is duplicated to form an additional channel. Channel 1 is for zenith radiation and Channel 2 for albedo radiation. The Channel 1 sub-carrier oscillator has a frequency of 10 Kc.; whereas, Channel 2 oscillates at 30 Kc. These signals are superimposed on the normal modulation of the carrier and provide a means of transmitting the desired information to the ground.

The airborne section of the apparatus weighs approximately 5600 gm., and can be carried aloft to an altitude of approximately 30 Km. by a cluster of three heavy-duty rubber meteorological balloons. The apparatus should remain at that altitude for approximately 3-5 hours before descent. Power is supplied by means of dry cell batteries. The airborne section of the apparatus is packaged with flexible plastic foam to decrease breakage upon landing, and is further surrounded by styrofoam to provide thermal insulation.

CHAPTER II

APPARATUS

A. SCINTILLATOR

For this detector, a scintillator consisting of p-terphenyl in a solid solution of polystyrene is used. A plastic scintillator has the advantages of light weight (density is approximately 1.1 gm/cm^3), easy machinability to desired shape, and ruggedness.

In the p-terphenyl-polystyrene solution, a charged particle excites the polystyrene during its passage through the scintillator. The polystyrene then transmits the energy to the p-terphenyl solute, which is a phosphor that produces a light flash that can be detected by a photomultiplier tube.[1] The frequency of this radiation is a property of the phosphor, and the transfer of energy to the photomultiplier may be increased by the addition to the plastic of a wave length shifter which shifts the phosphor radiation to a wave length that more closely matches the highest spectral sensitivity region of the photomultiplier. The scintillators used in this detector, used such a wave length shifter to change some of the light produced from the ultraviolet to the blue region.

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[1]Rossi, <u>op</u>. <u>cit</u>., p. 143.

CHAPTER III

APPARATUS

A. SCINTILLATORS

For this detector, a scintillator consisting of p-terphenyl in a solid solution of polystyrene was used. This plastic scintillator has the advantages of light weight (density approximately 1.1 gm/cm³), easy machinability to desired shapes, and ruggedness.

In the p-terphenyl-polystyrene solution, a charged particle excites the polystyrene during its passage through the scintillator. The polystyrene then transfers the energy to the p-terphenyl solute, which is a phosphor that produces a light flash that can be detected by a photomultiplier tube.[1] The frequency of this radiation is a property of the phosphor, and the transfer of energy to the photomultiplier may be improved by the addition to the plastic of a wave length shifter which shifts the phosphor radiation to a wave length that more nearly matches the highest spectral sensitivity region of the photomultiplier. The scintillators used in this detector had such a wave length shifter to change the light emitted from the ultraviolet to the blue region.

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[1]Rossi, op. cit., p. [illegible]

In order to insure that the frequency of chance coincidences is negligible, and to insure that the circuitry can accurately accommodate the scintillation pulses, it is necessary to know the speed and time resolution of the photomultiplier-scintillator combination. The r.m.s. error in the time of occurrence of the pulse is approximately:[2]

$$t\ \text{r.m.s.} = \frac{\alpha BA}{Nc}$$

where α is the fluorescent time decay of the phosphor

B is the transit time spread per stage of the photomultiplier

Nc is the total charge released by the cathode

A is a constant of magnitude unity

values for the above are[2, 3, 4]

$\alpha \sim 5 \times 10^{-8}$ sec. $\quad$ $Nc \sim 5 \times 10^{-6}$ amp.

$B \sim 1 \times 10^{-8}$ sec. $\quad$ $A \sim 1$ amp/sec. ;

therefore,

$$t\ \text{r.m.s.} \quad 1 \times 10^{-10}\ \text{sec.}$$

Since the voltage pulses in the circuitry following the phototube are approximately 5μ sec. in duration, the time spread in the phosphor and phototube sections is negligible in its contribution to the possibility of chance coincidences.

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[2] G. A. Morton, "Time Resolution of Scintillation Counters," Nucleonics, Vol. X, p. 39, March 1952.

[3] Du Mont Photomultiplier Tubes (Technical Sales Dept., Allen B. Du Mont Laboratories, Clifton, New Jersey, 1955), p. 11.

[4] Rossi, loc. cit.

In order to insure that the frequency of spurious co-incidences is negligible, and to insure that the circuits are accurately accomodated the [illegible] requirements, it is necessary to know the speed and rise time of the photomultiplier-scintillator combination. The r.m.s. error in the time of occurrence of the pulse is approximately:

$$t_{r.m.s.} = \sqrt{\frac{\alpha B}{N_c A}}$$

where α is the fluorescence decay time of the crystal

B is the transit time spread of the photo-multiplier

N_c is the total charge released at the cathode

A is a constant of magnitude unity

values for the above are:[2, 3, 4]

$\alpha \sim 5 \times 10^{-8}$ sec. (NaI(Tl)) [illegible] 10^{-8} sec.

$B \sim 1 \times 10^{-9}$ sec. [illegible] $A \sim 1$ [illegible].

therefore,

$t_{r.m.s.} \sim 1 \times 10^{-11}$ sec.

Since the voltage pulses at the electrodes following the phototube are approximately [illegible] transformation, the time spread in the phosphor and photomultiplier is negligible as a contribution to the resolving time of [illegible] coincidence.

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[2]O. A. [illegible], [illegible] Nucleonics, Vol. [illegible]

[3]Du Mont Photomultiplier Tubes ([illegible]), Allen B. Du Mont Laboratories, Clifton, New Jersey, [illegible]

[4]Rossi, loc. cit.

For this detector the plastic scintillator is machined into a cylinder 5.5 cm. in diameter, 3.2 cm. thick, and with a 3.2 cm. flat face on the cylindrical wall to accommodate the window of the phototube. For optical bonding of the tube to the scintillator, mineral oil is used. This has a refractive index of 1.5 and matches that of the phototube window. For permanent bonding, it is suggested that a cement with a refractive index of 1.5 be used since mineral oil, after long contact with polystyrene, will cause crazing of the interface.

The cylinder is polished with cerium oxide and then painted on all surfaces except for that surface in contact with the window of the phototube. A high reflectivity rubber base paint is used to increase internal reflection. The scintillator is mechanically attached to the phototube with a plastic tape and is covered with opaque plastic tape to exclude incident light.

B. THE PHOTOTUBE

A Du Mont type 6467 multiplier phototube is used; its general characteristics are listed below:[5]

Maximum spectral response	4400Å
Down 10% spectral band width.	3250-6125Å
Number of dynodes	10
Current amplification at 135 volts/stage	1.1×10^6
Tube diameter	1.25 in.
Tube length	4.5 in.

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[5]Du Mont, op. cit., pp. 37-38.

For this detector the plastic scintillator is machined into a cylinder 3.5 cm. in diameter, 5.2 cm. long, and with a 3.2 cm. flat face on the cylindrical wall to accommodate the window of the phototube. For optical bonding between the scintillator, mineral oil is used. This has a refractive index of 1.5 and matches that of the phototube window. For permanent bonding, it is suggested that a cement with a refractive index of 1.5 be used since mineral oil, after long contact with poly-styrene, will cause crazing of the interface.

The cylinder is polished with [illegible] and then painted on all surfaces except for that surface in contact with the window of the phototube. A high reflectivity rubber base paint is used to increase internal reflection. The scintillator is mechanically attached to the phototube with a plastic tape and is covered with opaque plastic tape to exclude incident light.

B. THE PROTOTYPE

A Du Mont type 6467 multiplier phototube is used; its general characteristics are listed below:[5]

Maximum spectral response . . . . [illegible]

Down 10% spectral response . . . . [illegible]

Number of dynodes 10

Current amplification at
135 volts/stage . . . . [illegible]

Tube diameter . . . . [illegible]

Tube length . . . . [illegible]

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[5]Du Mont; [illegible]

Maximum ratings:

Peak anode current	25 mA
Anode-Cathode voltage.	1800 V
Last dynode-anode voltage.	200 V
First dynode-cathode voltage	400 V

The overall current amplification is a logarithmic function of the voltage per stage. An anode-cathode potential change of only one per cent will cause a seven per cent in anode current. For this reason it is necessary to keep the supply voltage to the dynodes as constant as possible. The signal to noise ratio S/N decreases as the voltage increases so it is necessary to compromise between high voltage for amplification, and low voltage for large S/N ratio. The photo tube in this apparatus is operated at an anode to cathode potential of 1555 volts; this gives a current amplification of approximately 1.1×10^6 and a dark current noise level less then .02 volts.

Dark current is the current that flows in the tube without external light source excitation.[6] It is a statistically random process, and it is desirable to keep its value as low as possible to avoid noise. Its sources are

a. Thermionic emission: although the materials used in the tube have low emission rates, this effect is of importance at room temperatures. Since thermionic emission is strongly temperature-dependent, the effect can be reduced by cooling the tube. It is probable that at the temperatures encountered in the upper atmosphere the effect will be reduced.

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[6] Du Mont, op. cit., p. 8.

Maximum ratings:

Peak anode current . . . . [illegible]

Anode-cathode voltage . . . . [illegible]

Last dynode-anode voltage . . . . [illegible]

First dynode-cathode voltage . . . . [illegible]

The overall current amplification is a very critical function of the voltage per stage. An anode-cathode potential change of only one per cent will cause a [illegible] per cent change in anode current. For this reason it is necessary to [illegible] the supply voltages to the dynodes as constant as possible. [illegible] to note [illegible] ratio S/N decreases as the voltage increases so that it is [illegible] to compromise between high voltage for amplification and low voltage for large S/N ratio. The [illegible] is operated at an anode to cathode potential [illegible] which gives a current amplification of approximately [illegible] and a current noise level [illegible].

Dark current is the current flowing through the tube without external light [illegible]. [illegible] is statistically a random process, and it is desirable to keep it as low as possible to avoid noise. The sources are:

a. Thermionic emission [illegible] the tube have low emission values [illegible] at room temperature. [illegible] temperature-dependency [illegible] cooling the tube. It is probable [illegible] upper atmosphere [illegible] will be reduced.

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[6] Du Mont, [illegible]

b. Ionization of residual gas: electrons passing through residual gas in the tube have enough energy to ionize the gas. These ions, mainly positive, are attracted to the cathode where they strike and cause emission of secondary electrons. These secondary electrons give rise to a spurious pulse at the anode. There is some evidence that these pulses may be the cause of "afterpulses" which are observed to occur shortly after a genuine pulse occurs. The effect may be lessened by cooling the tube and by lowering the voltage.

c. Ohmic leakage: this noise is caused by a potential leak across terminals, and may be minimized by potting the terminals in a silicone or similar potting compound.

d. Charging of glass envelope: if the envelope shield is at anode potential and in contact with the tube, spurious pulses of large magnitude will occur. This is avoided by wrapping the envelope in aluminum foil, and connecting the foil to the cathode.

e. Bleeder supplies: high resistance bleeder supplies to the dynodes tend to produce noise. This is minimized by using neon tubes in the voltage divider. At the same time the neon tubes act to regulate the potentials.

"Noise in signal" is a random fluctuation in the output pulse that occurs only when a signal is present and may be the main factor in the signal to noise ratio.[7] The S/N ratio can be calculated from the formula:

$$\frac{S}{N} = \sqrt{\frac{\bar{i}}{2e\,\Delta f}} \quad ,$$

[7]Du Mont, op. cit., p. 9.

b. Ionization of residual gas: [illegible] residual gas in the tube have enough energy to ionize the gas. These ions, mainly positive, are attracted to the cathode where they strike and cause emission of secondary electrons. These secondary electrons give rise to a spurious pulse at the anode. There is some evidence that these pulses may be the cause of "afterpulses" which are observed to occur shortly after a genuine pulse occurs. The effect may be decreased by cooling the tube and by lowering the voltage.

c. Ohmic leakage: this noise is caused by a potential leak across terminals, and may be eliminated by putting the terminals in a silicone or similar protective compound.

d. Charging of glass envelope: if the envelope of glass is at anode potential and in contact with the cathode, spurious pulses of large magnitude will occur. This is avoided by wrapping the envelope in aluminum foil, and connecting the foil to the cathode.

e. Bleeder supplies: high resistance bleeder supplies to the dynodes tend to produce noise. This is minimized by using neon tubes in the voltage divider. At the same time the neon tubes act to regulate the potential.

"Noise level and signal/noise ratio: The fluctuation in the output pulse that occurs only when a signal is present and may be the main factor in the signal to noise ratio. The S/N ratio can be calculated from the formula:

$$\frac{S}{N} = \sqrt{\frac{I}{2e\Delta f}}$$

7Du Mont, [illegible]

where $\bar{i}$ = average signal current

Δf = frequency bandwidth of the system

e = electronic charge

From this equation it can be seen that S/N will improve if the average current is made as high as possible. This can be done by matching the phosphor luminescence to the spectral peak of the tube, and by keeping the collection efficiency of the first dynode as high as possible. Good results are obtained if the cathode to first dynode potential is approximately twice that of the subsequent steps.

In order to increase the frequency response of the system, the leads coupling to the load should be kept as short as possible. This is necessary to avoid having the lead capacitance produce oscillations in the neon tube regulator circuit.

C. ELECTRONIC CIRCUITRY

1. HIGH VOLTAGE POWER SUPPLY

In order to operate the photomultiplier at constant anode-cathode potential of 1555 volts and to keep the power drain on the batteries low, it is necessary to use a transistorized, regulated, high voltage supply (see Fig. 3). This power supply is a modification of a design used by Dr. Victor H. Regener of the University of New Mexico in high-altitude ozone research.

A six-volt battery powers a transistorized oscillator, the output of which is fed through a step-up transformer into a four-stage voltage doubler and then to a neon string which acts

where $\bar{i}$ = average signal current

Δf = frequency bandwidth of the system

e = electronic charge

From this equation it may be seen that S/N will improve as the average current is made as high as possible. This can be done by matching the phosphor luminescence to the spectral peak of the tube, and by keeping the collection efficiency of the first dynode as high as possible. Good results are obtained if the cathode to first dynode potential is approximately twice that of the subsequent steps.

In order to increase the frequency response of the system, the leads coupling to the load should be kept as short as possible. This is necessary to avoid having stray inductances produce oscillations in the leads, tube socket or circuit.

C. ELECTRONIC CIRCUITRY

1. HIGH VOLTAGE POWER SUPPLY

In order to operate the scintillation counter at constant anode-cathode potential of 1250 volts and to keep the power drain on the batteries low, it is necessary to use a transistorized, regulated high voltage supply (see Fig. 5). This power supply is a modification of a design used by Dr. Victor H. Regener of the University of New Mexico in high-altitude cosmic ray research.

A six-volt battery powers a transistorized oscillator the output of which is fed through a step-up transformer into a four-stage voltage doubler and then to a [illegible]

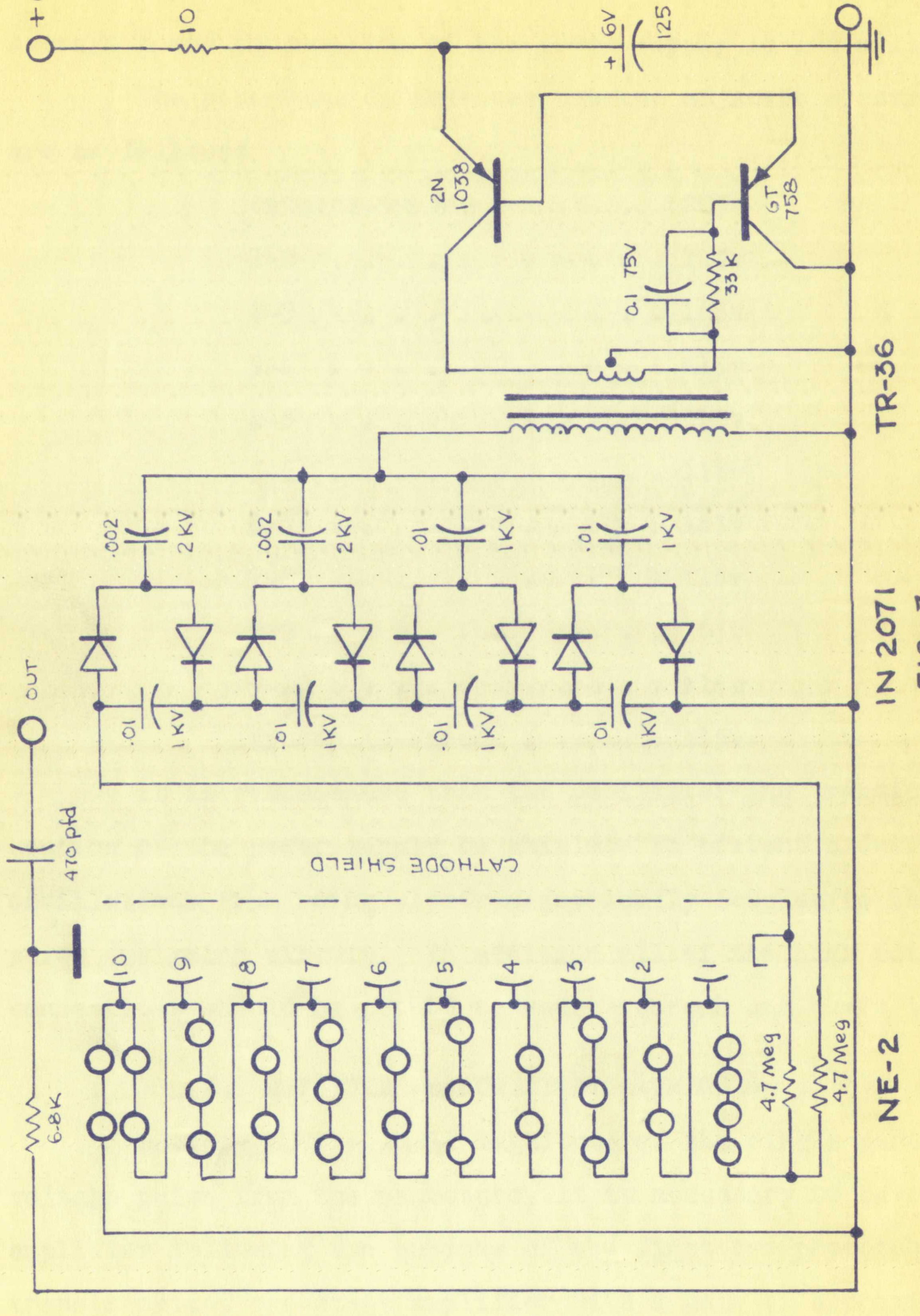

FIG. 3

POWER SUPPLY

as a voltage regulator and divider for the various dynodes. Average power consumption of the power supply is 166 milliwatts.

The potential differences between adjacent electrodes are as follows:

cathode-dynode 1	205v
1-2	115v
2-3	165v
3-4	115v
4-5	165v
5-6	115v
6-7	165v
7-8	115v
8-9	165v
9-10	115v
dynode 10--anode	115v

It is recommended that the oscillator and transformer section of the power supply be shielded to prevent undesirable oscillations from being electromagnetically coupled to the pulse analyzing circuit. In addition all of the high potential connections should be potted to reduce corona and ohmic leakage.

2. AMPLIFIER-DISCRIMINATOR-TRIGGER

Because of the small magnitude of the single particle voltage pulse from the phototube, it is necessary to have an amplifier following the outputs of the first two phototubes. A transistorized one-stage amplifier with a gain of approximately two is used. Amplification is not necessary for the pulses from

as a voltage regulator and divider for the various dynodes. Average power consumption of the divider circuit is [illegible].

The potential differences between the various electrodes are as follows:

cathode—dynode 1 . . . . [illegible]
1-2 . . . . [illegible]
2-3 . . . . [illegible]
3-4 . . . . [illegible]
4-5 . . . . [illegible]
5-6 . . . . [illegible]
6-7 . . . . [illegible]
7-8 . . . . [illegible]
8-9 . . . . [illegible]
9-10 . . . . [illegible]
dynode 10—anode . . . . . [illegible]

It is recommended that the oscillator and the primary section of the power supply be shielded to prevent undesirable oscillations from being electrostatically coupled to the pulse analyzing circuits. In addition all of the high voltage connections should be potted to reduce corona and high voltage leakage.

2. AMPLIFIER-PREAMPLIFICATION SYSTEM

Because of the small magnitude of the initial negative voltage pulse from the phototube, it is necessary to have an amplifier following the output of the photomultiplier. A transistorized two-stage amplifier with a gain of approximately two is used. Amplification is not necessary for the [illegible]

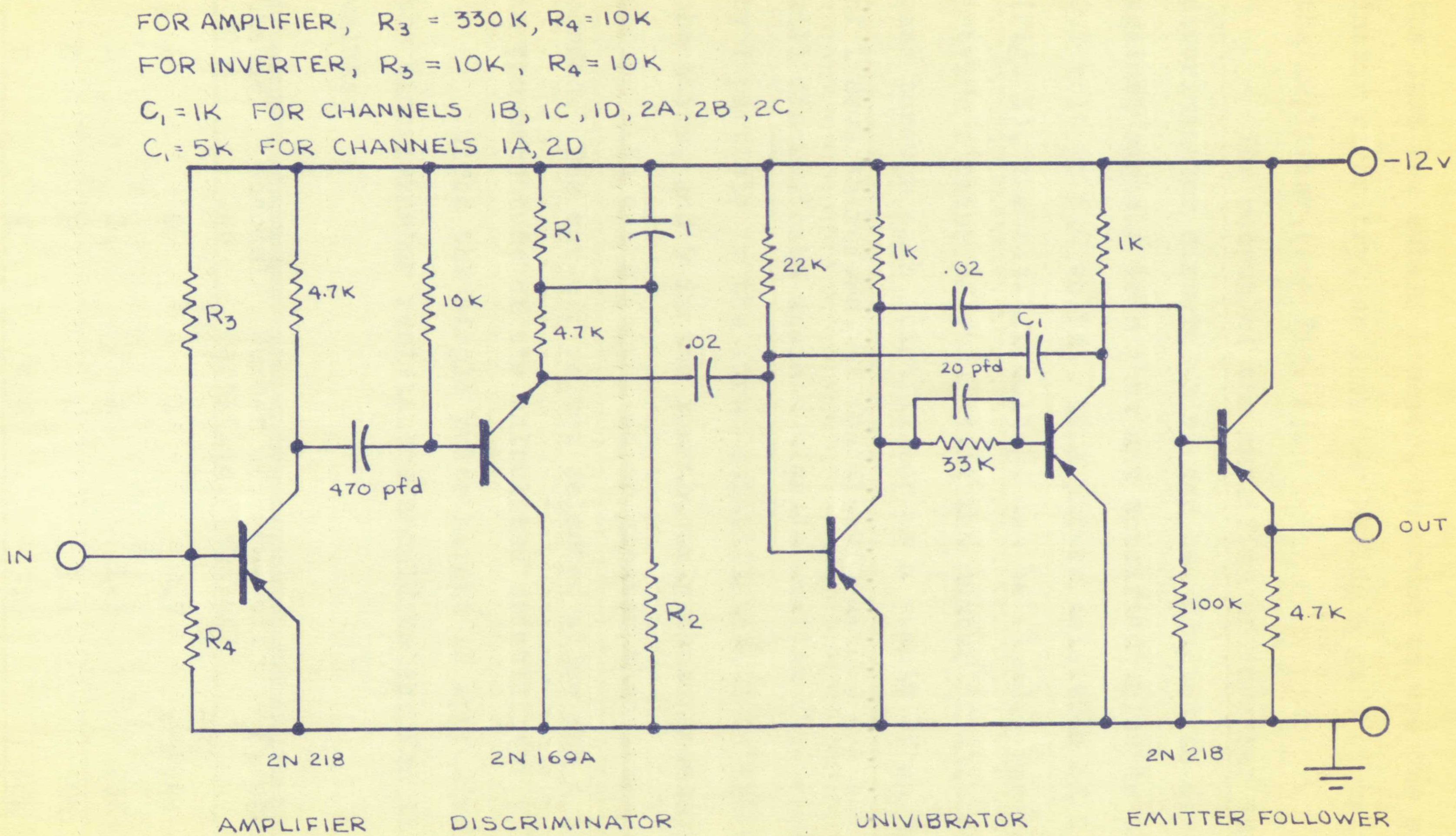

FIG. 4

AMPLIFIER DISCRIMINATOR CIRCUIT

the last two tubes; however, in order to use the same discriminator circuitry, an inverter having a gain of unity replaces the amplifier (see Fig. 4).

The output of the amplifier or inverter is fed into a discriminator circuit which can be adjusted to discriminate against signals less than any specified value in the range from 0.1 volt to 8.0 volts. By a proper selection of R_1 and R_2 (Fig. 5), the cut-off voltage can be fixed. The cascade curves provide a means of predicting the number of electrons that will pass through each scintillator as a result of an initial photon of 1 Bev; therefore, if the discriminators are set so that they will discriminate against signals smaller than those produced by 1 particle in the first scintillator, 2 in the second, 4 in the third, and 9 in the fourth, only those events produced by a photon with energy equal to or greater than 1 Bev will be recorded. The cut-off values selected allow for a small decrease in the magnitude of the calculated scintillator pulse.

Since the single pulse height is approximately 0.8 volts,[8] the discriminator resistances should be set for the following values:

Channel One	Channel Two	Number of Particles	Cut-off Voltage	R_1 ohms	R_2 ohms
A	D	1	0.7	10K	47K
B	C	2	1.5	25K	47K
C	B	4	3.1	50K	47K
D	A	9	7.0	50K	1.5K

[8]See Chapter III for determination of this value.

the last two tubes, however, in circuits and discriminator circuitry, an invert [illegible] with [illegible] the amplifier (see Fig. 4).

The output of the amplifier [illegible] is the [illegible] discriminator circuit which can be adjusted to discriminate against signals lower than any specified value in the range from 0.1 volt to 8.0 volts. By a proper selection of [illegible] (Fig. 5), the cut-off values can be fixed; the calibration curves provide a means of predicting the number of [illegible] that will pass through each scintillator as a result of [illegible] of 1 Bev; therefore, if the discriminators are set so that they will discriminate against signals smaller than those produced by 1 particle in the first scintillator, 2 in the second, 4 in the third, and 9 in the fourth, only showers produced by a photon with energy equal to or greater than 1 Bev will be recorded. The cut-off [illegible] for a small change in the magnitude of the calibrated [illegible] values.

Since the [illegible], the discriminator [illegible] values:

Channel One	Channel Two	Number of Particles	Cut-off [illegible]	[illegible]
A	D	1	[illegible]	[illegible]
B	C	2	[illegible]	[illegible]
C	B	[illegible]	[illegible]	[illegible]
D	A	[illegible]	[illegible]	[illegible]

[3] See Chapter III [illegible] determination of [illegible] values.

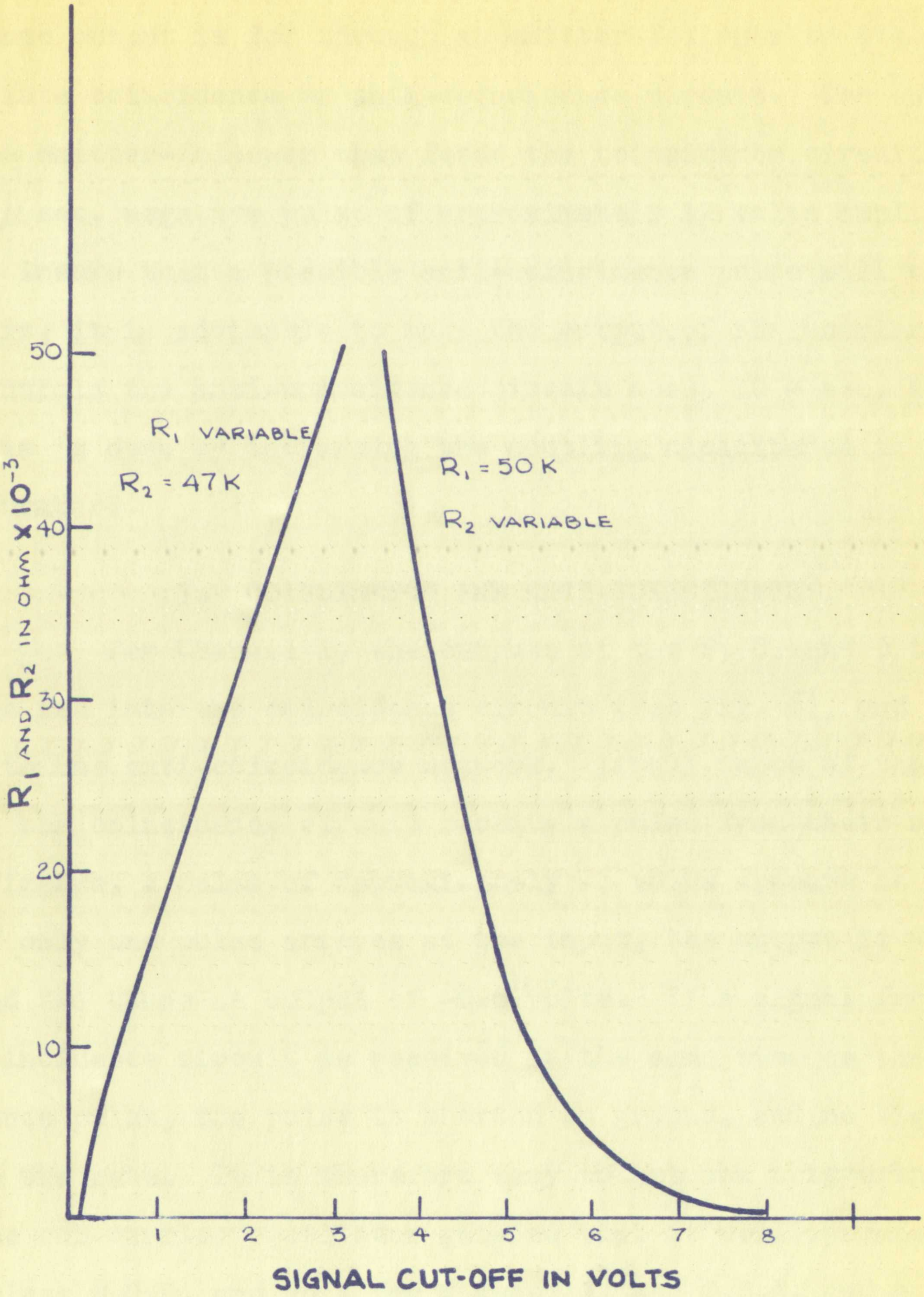

FIG. 5

DISCRIMINATOR RESISTANCE VALUES

The output of the discriminator triggers a univibrator whose output is fed through an emitter-follower to its appropriate coincidence or anti-coincidence circuit. The output of the emitter-follower that feeds the coincidence circuit is a 5 μ sec. negative pulse of approximately 12 volts amplitude. To insure that a possible anti-coincidence pulse will cancel this, it is advisable to make the output of the univibrator that controls the anti-coincidence circuit about 10 μ sec. in duration. This is done by increasing the coupling capacitance in the univibrator.

3. COINCIDENCE AND ANTI-COINCIDENCE

For Channel 1, the outputs of the B, C, and D triggers are fed into the coincidence circuit (see Fig. 6), and A is fed into the anti-coincidence network. If all three of the inputs to the coincidence circuit receive a pulse from their respective triggers, a pulse of approximately -6 volts appears at the output. If only one pulse arrives at the input, the output is -0.3 volts, and two cause an output of -0.6 volts. If a signal from the anti-coincidence circuit is received at the same time as the coincidence pulse, the pulse is shorted to ground, and no signal appears at the gate. It is therefore easy to set the triggering level of the sub-carrier oscillator gate so that it will operate only on pulses B,C,D, and no A for Channel 1, and C,B,A, and no D for Channel 2.

There is a possibility of a chance coincidence caused by different randomly occurring particles if they arrive at the three

The output of one discriminator triggers a multivibrator

whose output is fed through an emitter-follower to the appro-
priate coincidence or anti-coincidence circuit. The output of
the emitter-follower that feeds the coincidence circuit is a
5 μsec. negative pulse of approximately 12 volts amplitude.
To insure that a possible anti-coincidence pulse will cancel
this, it is advisable to make the output of the multivibrator that
controls the anti-coincidence circuit about 10 μsec. in duration.
This is done by increasing the coupling capacitance in the multi-
vibrator.

4. COINCIDENCE AND ANTI-COINCIDENCE

For Channel 1, the outputs of the B, C, and D telescopes
are fed into the coincidence circuit (see Fig. 7), and A is fed
into the anti-coincidence network. If all three of the inputs
to the coincidence circuit receive a pulse from their respective
triggers, a pulse of approximately -4 volts appears at the output.
If only one pulse arrives at the input, the output is [illegible] volts,
and two cause an output of -2.5 volts. If a signal from the anti-
coincidence circuit is received at the same time as the coinci-
dence pulse, the pulse is cancelled, and no signal appears
at the gate. [illegible]
the sub-carrier oscillator [illegible] counts only the
pulses B,C,D, and no A [illegible]
Channel 2.

There is a possibility that [illegible]
different randomly occurring [illegible]

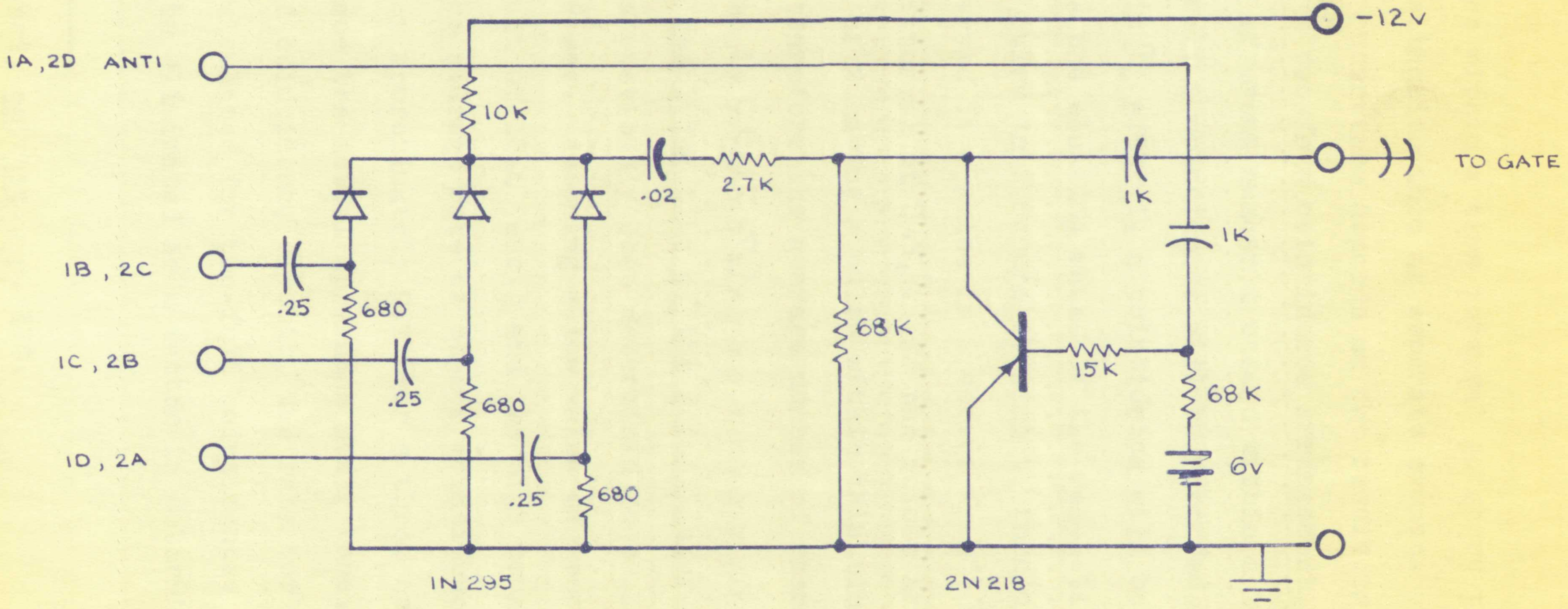

FIG. 6

ANTI-COINCIDENCE CIRCUIT

scintillators within a time interval so short that the apparatus does not distinguish them as separate events. The probability of a chance occurrence depends on the resolving time of the circuit.[9] For a two-fold coincidence arrangement, define a quantity τ_1 so that if event number 2 occurs within a time τ_1 later than event number 1, a coincidence will be recorded. Similarly, if 2 occurs within τ_2 after 1, a coincidence will be recorded. Let C_1 and C_2 be the counting rates of the respective detectors. Suppose the pulse in 2 occurs at time t, then a chance coincidence will be observed if a pulse in 1 occurs from $t-\tau_2$ to $t+\tau_1$, or in total time interval of $\tau_1+\tau_2$. If the pulses are unrelated, the probability of 2 having a pulse within this time period is $C_2(\tau_1+\tau_2)$, therefore the average number of chance coincidences per unit time is $C_1C_2(\tau_1+\tau_2)$.

The resolving time of the scintillator-phototube combination has previously been determined to be in the neighborhood of 10^{-8} sec. Assuming a low value of resolution of the entire circuit of 10μ sec., and the high counting rate of 1 per sec., the average rate of chance coincidence would be 2×10^{-5} per second or approximately 0.2 over a three hour observation period. Since the actual apparatus under consideration contains a three-fold coincidence circuit, the rate would be far lower than that calculated for two-fold coincidences and chance coincidences can be eliminated as a factor in determing the counting rate.

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[9]Rossi, op. cit., p. 110.

scintillators within a time interval too short for the [illegible] does not distinguish them as separate events. The probability of a chance occurrence depends upon the resolving time of the circuit.[9] For a two-fold coincidence circuit, [illegible] τ_1, so that if event number 2 occurs within a time τ_1 after event number 1, a coincidence will be recorded. Similarly, if 1 occurs within τ_2 after 2, a coincidence will be recorded. Let C_1 and C_2 be the counting rates of the respective detectors. Suppose the pulse in 2 occurs at time t, then a chance coincidence will be observed if a pulse in 1 occurs from $t-\tau_1$ to $t+\tau_2$, or in a total time interval of $(\tau_1+\tau_2)$. As the pulses are unrelated, the probability of 2 having a pulse during this time period is $C_2(\tau_1+\tau_2)$, therefore the average number of chance coincidences per unit time is $C_1C_2(\tau_1+\tau_2)$.

The resolving time of the scintillator-phototube combination has previously been determined to be in the neighborhood of 10^{-8} sec. Assuming a low value of resolution of the entire circuit of 10 μ sec., and the high counting rate of 1 per sec., the average rate of chance coincidences would be [illegible] per second or approximately [illegible] over a three hour observation period. Since the actual apparatus under consideration contains a three-fold coincidence circuit, the rate would be far less than that calculated for two-fold coincidences and chance coincidences can be eliminated as a factor in affecting the counting rate.

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[9]Rossi, op. cit., p. 10.

The eight amplifier-discriminator-triggers plus two coincidence-anti-coincidence circuits have an average power consumption of approximately 900 milliwatts.

4. GATE AND SUB-CARRIER OSCILLATOR

There are two separate gate and sub-carrier oscillator circuits. The frequency of oscillation is controlled by the value of C_1 (see Fig. 7). An adequate separation in the frequencies between channels will insure positive discrimination by the receiver demodulator. Frequencies of 10 Kc. and 30 Kc. have been found to be adequate for this purpose. The output from the sub-carrier oscillator is then fed through an emitter-follower to the grid of the transmitter oscillator.

5. MODULATOR AND TRANSMITTER

The modulator and transmitter is a standard Radiosonde AN/AMT-4A. For details of operation, consult the standard Army and Air Force Technical Manual.[10] The radiosonde transmits on a carrier frequency of 1680 mc. The modulator unit which contains the sensing elements for pressure and temperature, samples the meteorlogical information as well as a standard reference signal. These signals are received at the ground station by a Rawin Set AN/GMD-1 and are recorded by a Radiosonde Recorder AN/TMQ-5. Total weight of the transmitter, modulator, including battery pack is 1156 gm.

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[10] TN 11-2432A/T.O. 16-30 ANT4-5, Radiosonde, (Wash: U. S. Gov't. Printing Office, 1951).

The eight amplifier-driving tubes and the [illegible] coincidence-anti-coincidence circuits [illegible] an average power consumption of approximately [illegible] watts.

4. DATA SUB-CARRIER OSCILLATOR

There are two separate data sub-carrier oscillator circuits. The frequency of oscillation is controlled by the value of C_1 (see Fig. 17). A difference [illegible] in the frequencies between channels will insure positive discrimination by the receiver [illegible]. Frequencies [illegible] kc. and [illegible] kc. have been found to be adequate for this purpose. The output from the sub-carrier oscillator is then fed through a cathode-follower to the grid of the transmitter oscillator.

5. MODULATOR AND TRANSMITTER

The modulator and transmitter is a standard radiosonde AN/AMT-4A. For details of operation, one can be referred to Army and Air Force Technical Manual.[10] The radiosonde transmitter has a carrier frequency of 1680 mc. The modulator unit contains the sensing elements for pressure and temperature, supplies the meteorological information as well as a standard reference signal. These signals are received at the ground station by a Rawin Set AN/GMD-1 and are recorded by a Radiosonde recorder AN/TMQ-5. Total weight of the telemetering assembly, including battery pack is 1150 gm.

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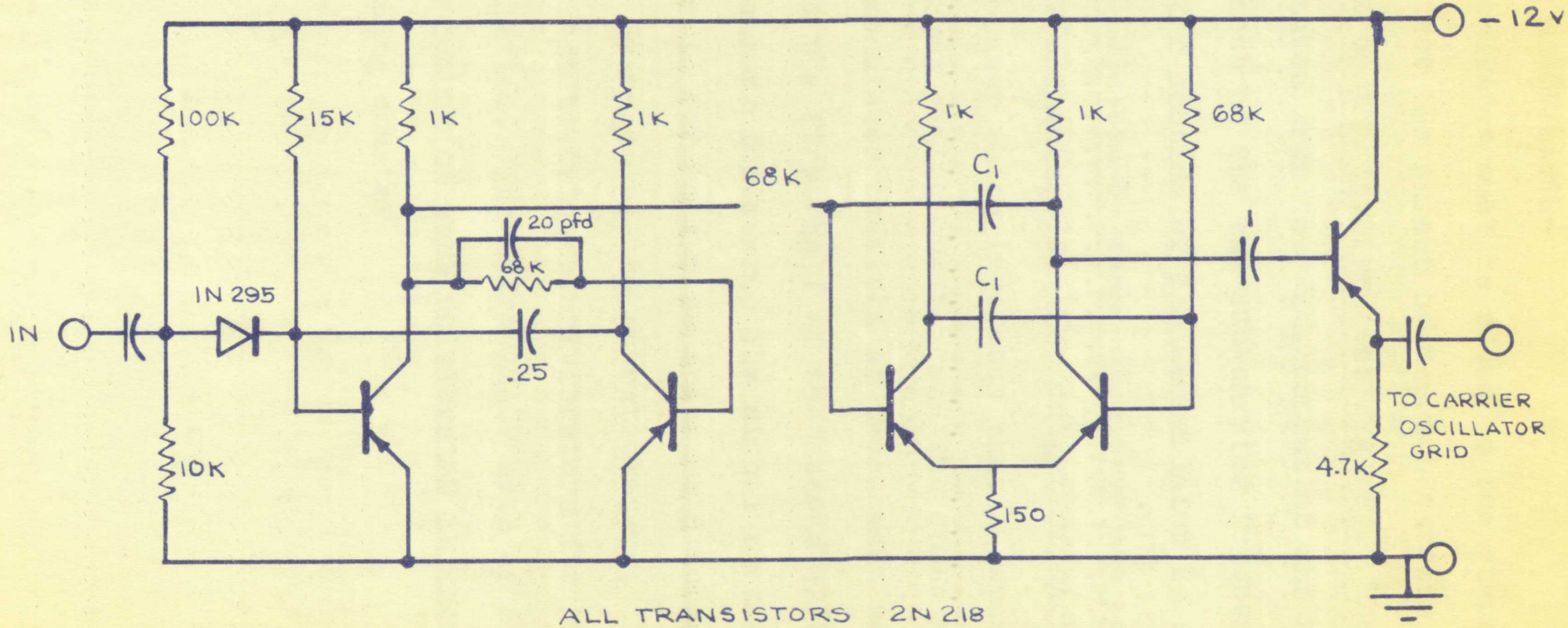
[10]TM 11-2432A/T.O. 16-30 AMT4-2, Radiosondes ([illegible] U. S. Gov't. Printing Office, 1952).



ALL TRANSISTORS 2N 218

CHANNEL 1, C_1 = 1K
CHANNEL 2, C_1 = 220 pfd

FIG. 7

SUB-CARRIER OSCILLATOR

6. DEMODULATOR

The demodulator must be added to the standard receiving equipment to detect the pulses of the sub-carrier frequency that have been placed on the carrier (see Fig. 8). The input to the demodulator is taken from the F.M. output of the receiver. It detects one or both of the two sub-carrier frequencies; therefore, the detector section of the demodulator is duplicated and each section is adjusted by means of a separate potentiometer to detect one of the channels. The output of each detector is then fed to a counter which indicates that an event has occurred. One counter records zenith events, and the other records albedo events. The demodulator consists of three main sections. The first 12AU7, and the first half of the second 12AU7 provide an amplifier and cathode follower. The signal on the grid of the cathode follower is fed to two separate 6AL5 tubes which act as step counters. By means of the potentiometers, these step counters can be set to trigger univibrators for the 10 Kc. or the 30 Kc. modulation. The third 12AU7 acts as a univibrator in each case. The output of each univibrator is then fed into a separate totalizing counter.

6. DEMODULATOR

The demodulator must be added to the standard receiving equipment to detect the pulses of the two sub-carrier frequencies that have been placed on the carrier (see Fig. ..). The input to the demodulator is taken from the F.M. output of the receiver. It detects one or both of the two sub-carrier frequencies; therefore, the detector section of the demodulator is duplicated and each section is adjusted by means of a separate potentiometer to detect one of the channels. The output of each detector is then fed to a counter which indicates that an event has occurred. One counter records zenith events, and the other records nadir events. The demodulator consists of three main sections. The first 12AU7, and the first half of the second 12AU7 provide an amplifier and cathode follower. The signal from the grid of the cathode follower is fed to two separate 6J5 tubes which act as step counters. By means of the potentiometers, these step counters can be set to trigger at the proper levels for the 70 Kc. or the 30 Kc. modulation. The other 12AU7 acts as a univibrator in each case. The output of each univibrator is then fed to a separate totalizing counter.

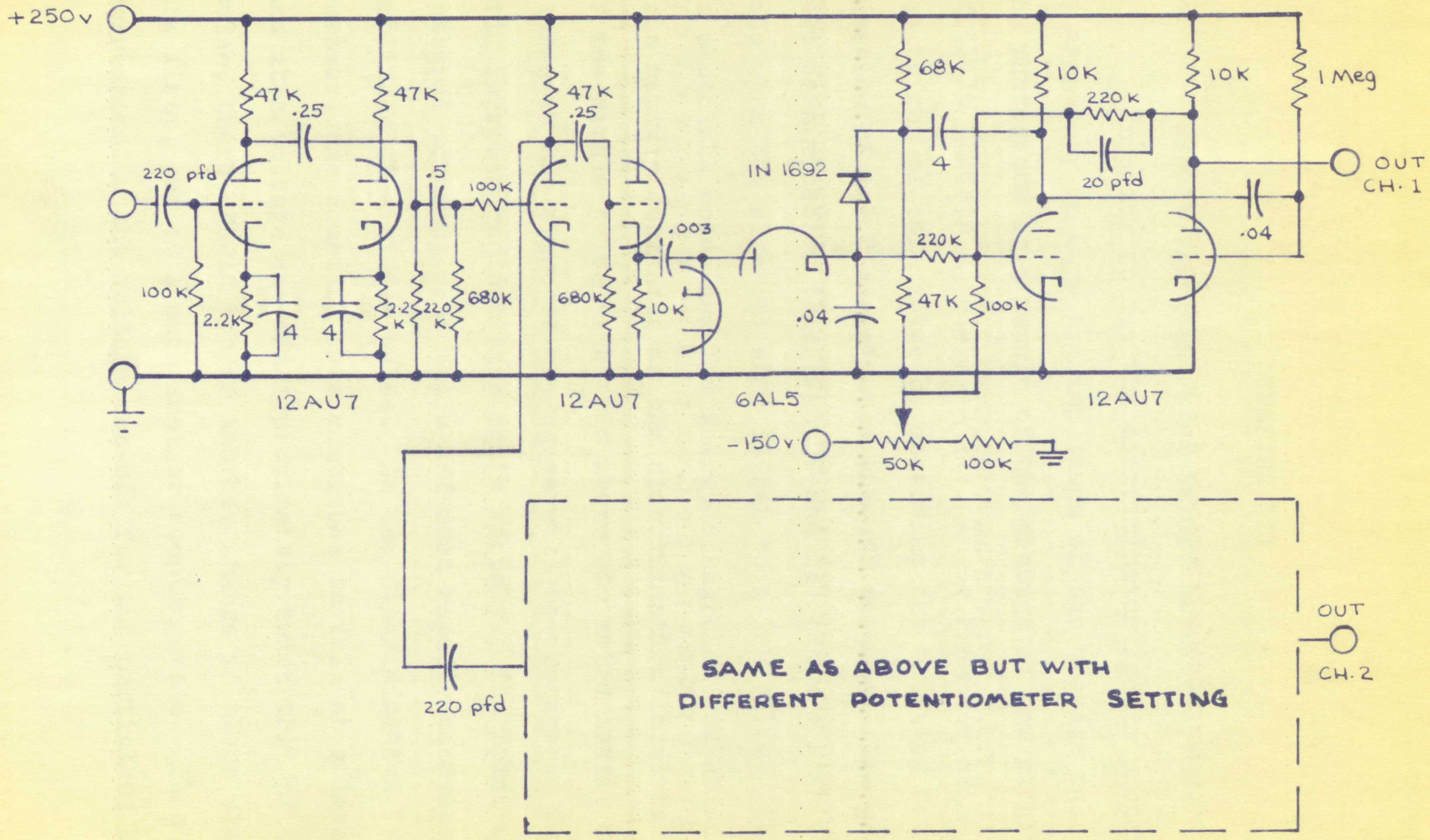


FIG. 8

RECEIVER DEMODULATOR

CHAPTER III

SINGLE PARTICLE PULSE HEIGHT DETERMINATION

In order to set the discriminator levels properly, it is necessary to know the amplitude of the voltage pulse seen at the photoanode as a result of the passage of one singly charged particle through a scintillator. It is possible to determine the height of this pulse by observing the counting rate as a function of the discriminator cut-off voltage. The graph of this determination (see Figs. 9 and 11) shows a high counting rate when the discriminator is set to a low value. This is due to phototube noise and low energy background radiation. The rate rapidly decreases as the discrimination level is increased. If the single pulse height is above the noise level, a distinct change in the slope of the curve will be observed. The slope will increase and decrease again rapidly. The point where the integral counting rate falls off most rapidly corresponds to the amplitude of a single pulse. As the discrimination is increased further, the counting rate continues to fall at a lesser rate, and at a voltage cut-off approximately twice that of the single pulse, there should appear another change in slope similar to the first, but at a much smaller counting rate. This would correspond to the voltage cut-off for two particles; however,

SINGLE PARTICLE PULSE HEIGHT DETERMINATION

In order to set the discriminator levels properly, it is necessary to know the amplitude of the voltage pulse seen at the photoanode as a result of the passage of one singly charged particle through a scintillator. It is possible to determine the height of this pulse by observing the counting rate as a function of the discriminator cut-off voltage. The graphs of this determination (see figs. 9 and 10) show a high counting rate when the discriminator is set at a few volts. This is due to phototube noise and low energy background radiation. The rate rapidly decreases as the discrimination level is increased. If the single pulse height is above the noise level, a distinct change in the slope of the curve will be observed. The rate will increase and decrease again rapidly. The point where the integral counting rate falls off most rapidly corresponds to the amplitude of a single pulse. As the discrimination is increased further, the counting rate continues to fall at a lower rate, and at a voltage cut-off approximately twice that of the single pulse, there should appear another change in slope similar to the first, but at a much smaller counting rate. This would correspond to the voltage cut-off for two particles in coincidence.

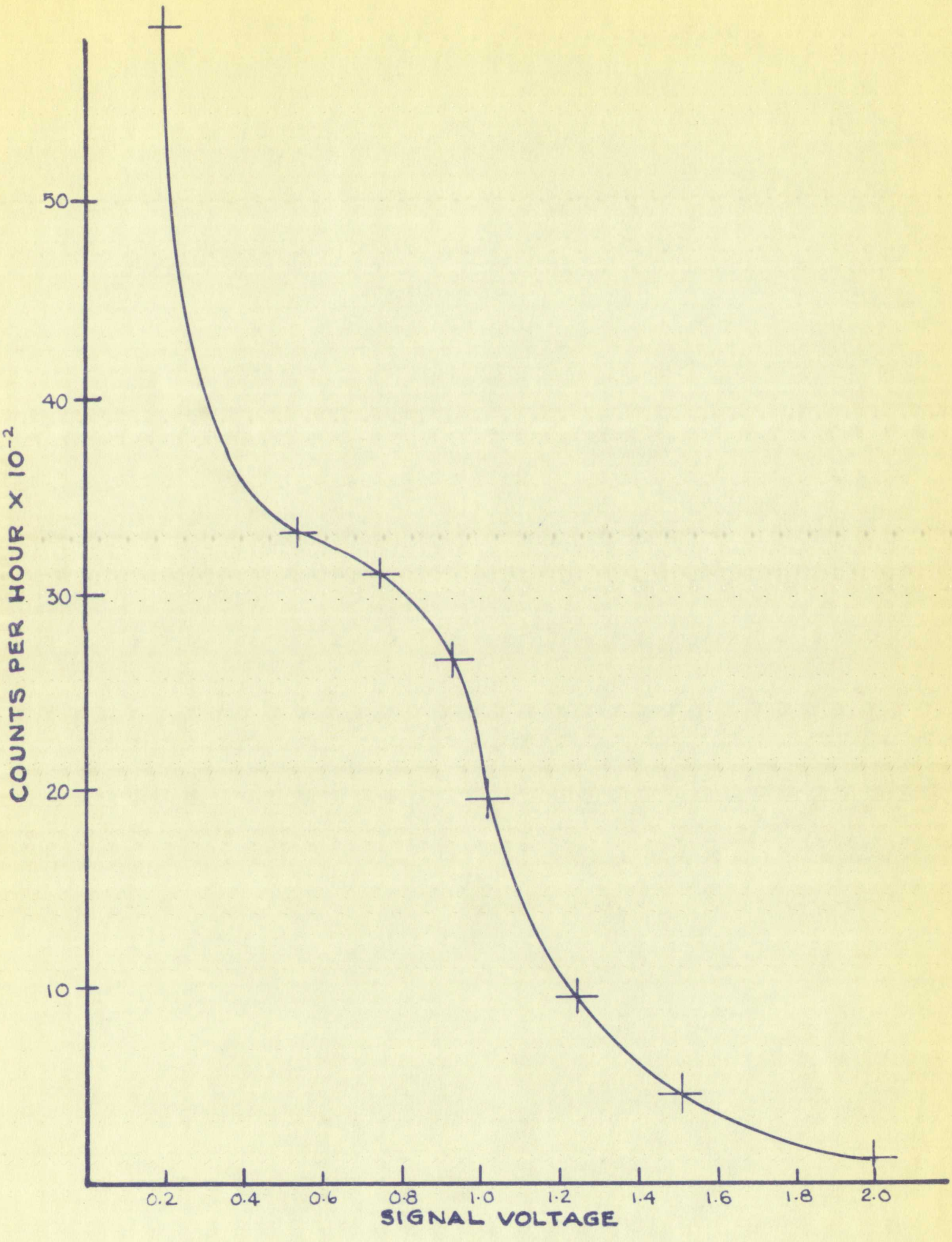


FIG. 9

INTEGRAL COUNTING RATE

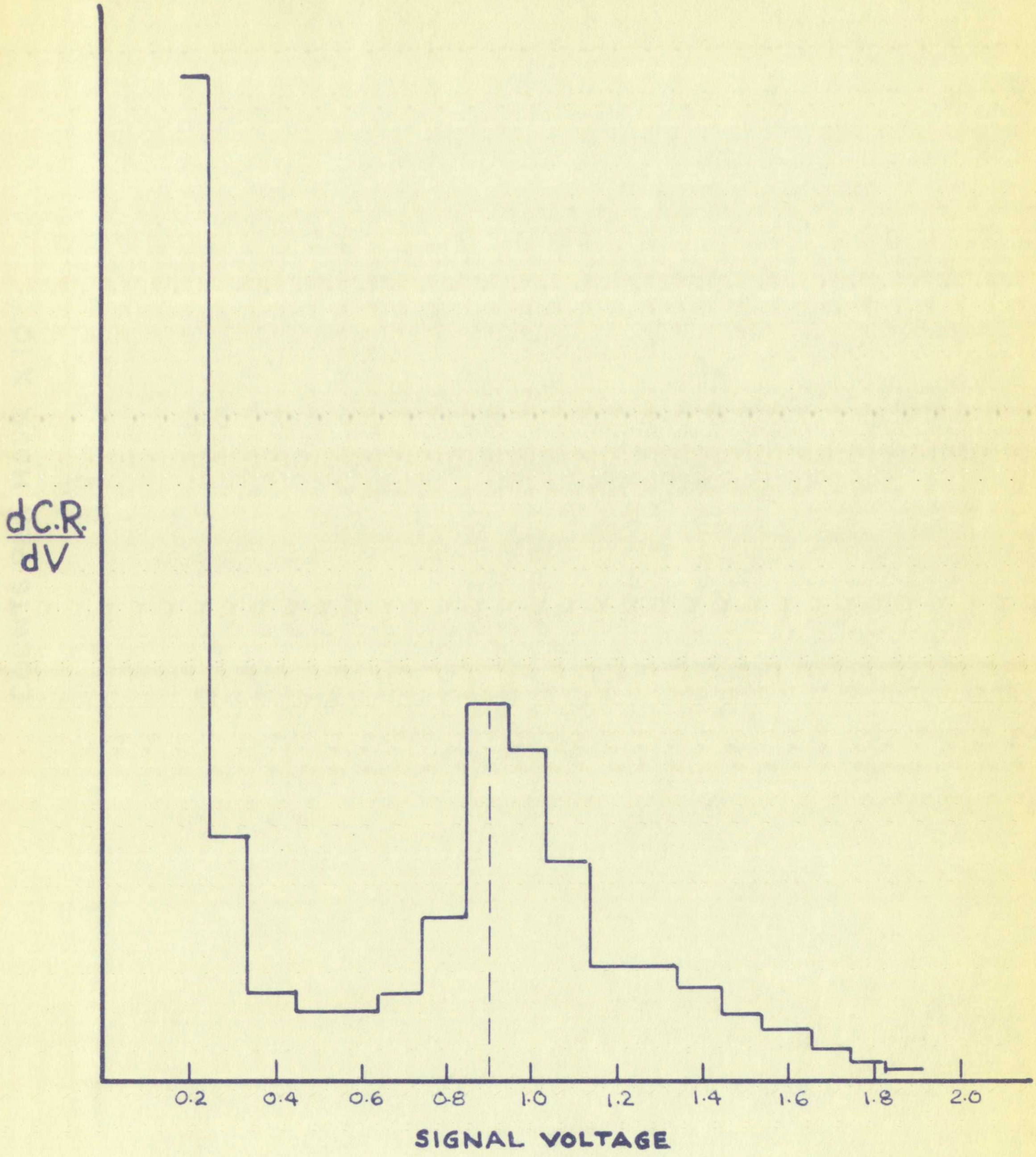


FIG. 10

DIFFERENTIAL COUNTING RATE

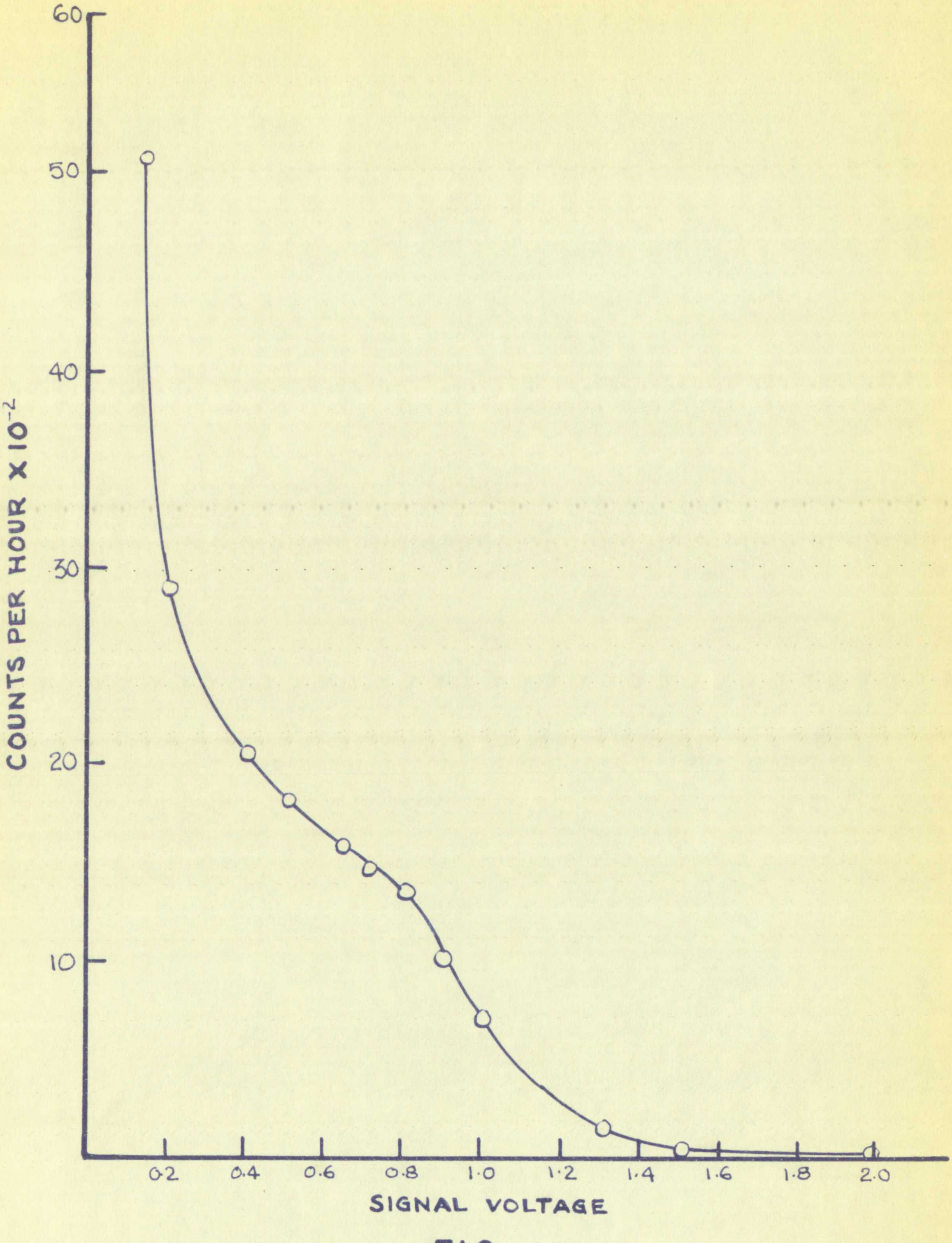


FIG. 11

INTEGRAL COUNTING RATE, SHIELDED

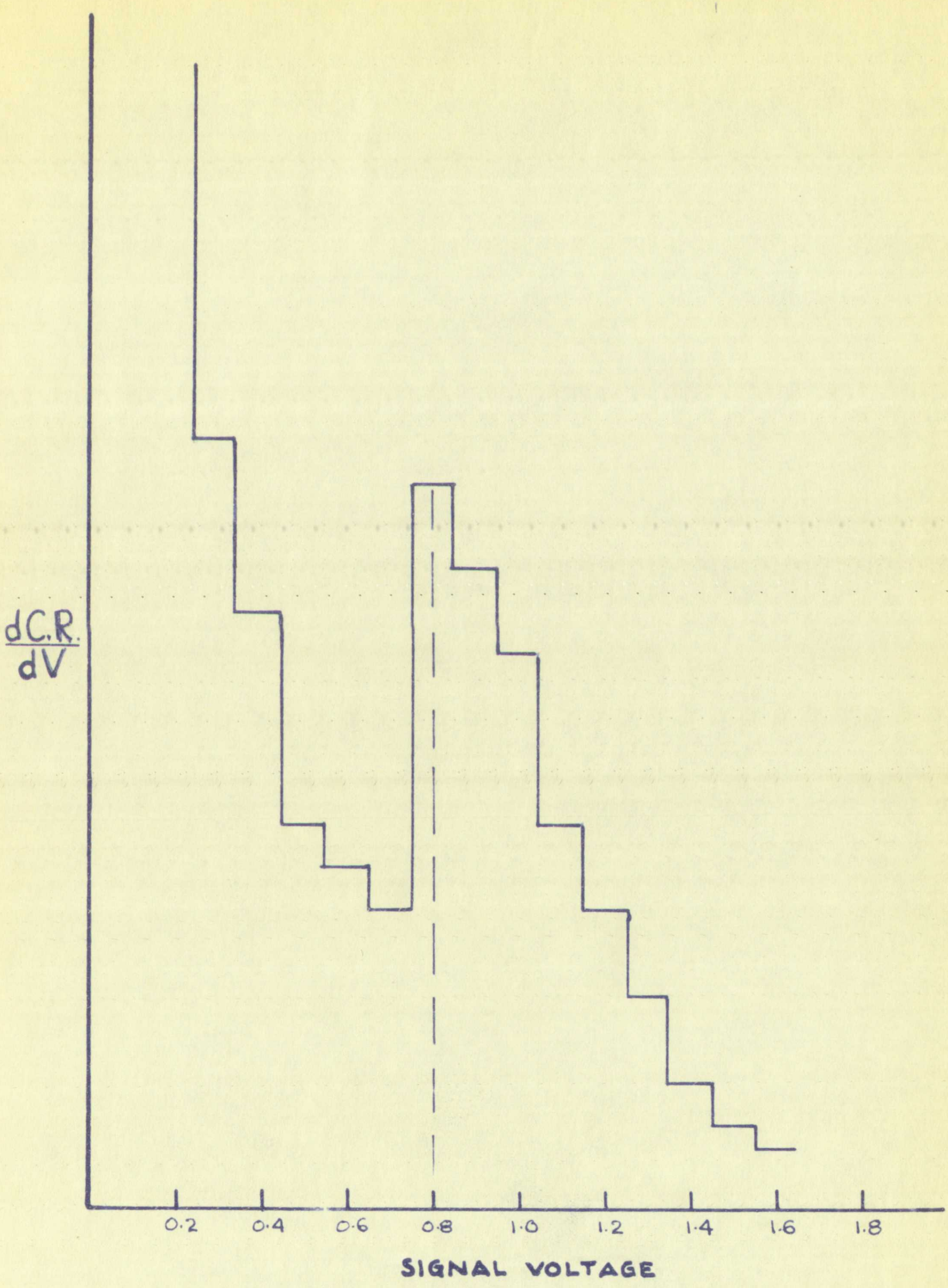


FIG. 12

DIFFERENTIAL COUNTING RATE, SHIELDED

this was not observed in this determination. In order to determine the voltage for which the counting rate for singles is a maximum, it is advantageous to plot the differential counting rate (see Figs. 10 and 12). These graphs show a distinct peak due to single particles, at the point where the counting rate decreases rapidly.

The average number of single particles which occur at this altitude is known. From this information it is possible to calculate the approximate counting rate for single particles for a scintillator of known area. For the scintillators used in this determination, the counting rate is calculated to be approximately 0.3 per second for the shielded determination. This result agrees closely to the observed counting rate for what is assumed to be singles. Therefore it is probable that the magnitude of a pulse due to a single particle has been determined correctly.

The determination was carried out twice, once with two inches of lead surrounding the scintillator, and once with no shielding. The purpose of the shield was to eliminate a large part of the low energy component, whose incident direction, due to scattering, could be at large angles to the zenith. With shielding, muons are the most abundant component of the radiation, and the incident direction is mainly vertical. The zenith angle distribution is approximately a cosine squared function. Cutting out the sideways electron component by shielding decreases the spread in the magnitude of pulses due to single particles, and

this was not observed in this determination. In order to determine the voltage for which the counting rate for singles is a maximum, it is advantageous to plot the differential counting rate (see Figs. 20 and 21). These graphs show a maximum, as due to single particles, at the point where the counting rate decreases rapidly.

The average number of single particles which occur at this altitude is known. From this information it is possible to calculate the approximate counting rate for single particles for a scintillator of known area. For the scintillator used in this determination, the counting rate is calculated to be approximately 0.3 per second for the singles determination. This result agrees closely to the observed counting rate for what is assumed to be singles. Therefore it is probable that the magnitude of a pulse due to a single particle has been determined correctly.

The determination was carried out twice, once with two inches of lead surrounding the scintillator, and once without shielding. The purpose of the shield was to eliminate a large part of the low energy component, whose maximum direction, due to scattering, could be anything. Under the conditions of no shielding, mesons are the predominant accessory part of the radiation, and the incident direction is mainly vertical. The zenith angle distribution is approximately a cosine squared function. Cutting out the electron component by means of the lead thus minimizes the spread in the magnitude of pulses due to single particles, and

decreases the probability of error in the determination of the signal magnitude due to single particles.

In both determinations, the single pulse height was determined to be between 0.8 and 0.9 volts. This agrees with a visual estimate made by observing oscilloscope pulses at the output of the phototube.

CHAPTER IV

SUMMARY

It is desirable to have an instrument which is capable of selectively detecting high energy photons at an altitude of approximately 30 Km. in the presence of a much larger flux of charged incident particles, and which will have enough directional sensitivity to distinguish between zenith incident radiation and albedo radiation. In addition, it is necessary to have a system which will collect and record this information for further analysis.

This investigation has completed the preliminary design for a system with the above capabilities. It is anticipated that further design refinements will be needed as a result of tests to determine temperature and altitude stability, optimum packaging, and the possibility of increased data determination requirements that were beyond the scope of this investigation.

The author would like to express his appreciation to Dr. John R. Green for suggesting this problem and his help in the preparation of this thesis, to Dr. James R. Barcus for his many hours of valuable guidance throughout this investigation, and to Dr. Victor H. Regener who graciously allowed the author to make use of his Radiosonde equipment, and who provided many of the elctronic components that were essential to the completion of this investigation.

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