LEVEL II

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

AN EXPERIMENTAL COMPARISON OF
PUMPED SUPERLUMINAL ELECTROMAGNETIC RADIATION
TO CERENKOV RADIATION.

by

Jerry Lee Graham

December 1980

Thesis Advisor: F. R. Buskirk

Approved for public release; distribution unlimited.

81 4 09 116

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. $AD-AC47571$	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) An Experimental Comparison of Pumped Superluminal Electromagnetic Radiation To Cerenkov Radiation		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; December 1980
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Jerry Lee Graham		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE December 1980
		13. NUMBER OF PAGES 66
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Pumped Superluminal Electromagnetic Radiation (PSER)
Cerenkov Radiation
Stimulated Electromagnetic Shock Radiation (SESR)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Experiments were conducted to measure the intensity of radiation emitted by a superluminal 100 MeV electron moving through a static, periodic, plane polarized magnetic field oriented perpendicular to the electron's trajectory. Such radiation is known as pumped superluminal electromagnetic radiation (PSER). Comparison was then made with the intensity of Cerenkov radiation emitted by a superluminal 100 MeV electron

DD $_{1\ JAN\ 73}^{FORM}$ 1473   EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601 |

(20. ABSTRACT Continued)

without a pump field. It was found that the PSER
was 12.78% ± 0.75% more intense than the Cerenkov
radiation.

Accession For

NTIS GRA&I	☑
DTIC TAB	☐
Unannounced	☐
Justification	

By
Distribution/
Availability Codes
Avail and/or
Dist   Special

A

An Experimental Comparison of
Pumped Superluminal Electromagnetic Radiation
to Cerenkov Radiation

by

Jerry Lee Graham
Lieutenant, United States Navy
B.S., United States Naval Academy, 1975

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN PHYSICS

from the

NAVAL POSTGRADUATE SCHOOL
December 1980

Author _____

Approved by: _____
                                    Thesis Advisor

            _____
                                     Second Reader

            _____
Chairman, Department of Physics and Chemistry

            _____
                    Dean of Science and Engineering

3

ABSTRACT

Experiments were conducted to measure the intensity
of radiation emitted by a superluminal 100 MeV electron
moving through a static, periodic, plane polarized magnetic
field oriented perpendicular to the electron's trajectory.
Such radiation is known as pumped superluminal electro-
magnetic radiation (PSER). Comparison was then made with
the intensity of Cerenkov radiation emitted by a superluminal
100 MeV electron without a pump field. It was found that
the PSER was 12.78% ± 0.75% more intense than the Cerenkov
radiation.

4

TABLE OF CONTENTS

ACKNOWLEDGMENT

I. INTRODUCTION

Schneider and Spitzer [Ref. 1] have investigated the interaction of electrons and pump fields at superluminal electron velocities. They have found a new radiation process, which they termed stimulated electromagnetic shock radiation (SESR) that may lead to some enhancement of radiation over both Cerenkov radiation and the free electron laser. Many physicists were upset with the name SESR because of the word stimulated. Reference two has renamed the radiation pumped superluminal electromagnetic radiation (PSER).

Pumped superluminal electromagnetic radiation is defined as that radiation produced when an electron moves in the presence of a pump field through a polarizable dielectric medium at speeds greater than the speed of light (superluminal) in that medium. The pump field produces a periodic deviation of the electron's trajectory from a straight line as it moves through the medium. Considering only a single electron under these conditions, Schneider's and Spitzer's investigation has predicted that there should be two frequency bands, vice the one found in Cerenkov radiation, for each medium response. Each band would terminate on the lower end at a frequency related to the frequency of the pump field. The total energy contained in the two bands would also be greater than the energy in Cerenkov radiation

produced by an electron under the same conditions but without a pump field. Other features of PSER would be identical to Cerenkov radiation.

An investigation of PSER was later conducted by Kroll [Ref. 3]. He examined the radiation due to a single electron under the same conditions as Schneider and Spitzer but arrived at different conclusions. He found the only major differences between PSER and Cerenkov radiation to be; 1) a broadening of the angular distribution of the radiation produced by the electron's deviation about a straight line trajectory; and 2) a discontinuity in the power spectrum at the threshold of the anomalous Compton backscattering effect in the forward direction. There was no evidence in his investigation to suggest a significant increase in the energy transformed into PSER over that transformed into Cerenkov radiation.

A slightly different approach, developed by Buskirk[1] will illustrate the physical considerations involved with PSER and highlight the differences in the results obtained by different investigators. Buskirk considers the kinematic relations of the interaction between a superluminal electron, a pump wave traveling in a direction opposite to that of the electron, and the radiation emitted at an angle θ to the electron's trajectory. Figure 1 illustrates the interaction.

---

[1]Concept developed by Professor F.R. Buskirk, U.S. Naval Postgraduate School, 1979.

The incoming wave can be described in the standard manner by .

$$E_1 = E_{10} \cos(k_1 x + \omega_1 t)$$

and

$$B_1 = B_{10} \cos(k_1 x + \omega_1 t).$$

Then the electron motion, allowing only negligible deviations from a linear path, becomes

$$X_{el} = \beta c t + x_0$$

and

$$Y_{el} = A E_{10} \cos(k_1 x_{el} + \omega_1 t)$$

where

$$\beta = V_{el}/c$$

and

$$c = \text{speed of light in vacuum.}$$

Substituting x_{el} into y_{el} one obtains

$$Y_{el} = A E_{10} \cos(k_1 x_0 + \omega_e t)$$

where

$$\omega_e \equiv k_1 \beta c + \omega_1.$$

Radiation emitted by the electron, written in a standard form is

$$E_2 \;=\; E_{20}\; \cos(\vec{k}_2 \cdot \vec{r} - \omega_2 t + \phi_2').$$

Again substituting the electron's position one obtains

$$E_2 \;=\; E_{20}\; \cos(\phi_2 + \Omega t)$$

where

$$\phi_2 \;\equiv\; k_2 x_0 \; \cos(\theta) + \phi_2'$$

and

$$\Omega \;\equiv\; k_2 \beta c \; \cos(\theta) - \omega_2 .$$

At the electron's position an emitted wave must be in phase with the electron's oscillations.

$$\text{phase of electron} \;=\; \pm \text{ phase of wave 2}$$

Substituting the definitions of ω_e and Ω this condition becomes

$$(1) \quad k_2 (\beta c \; \cos(\theta) - V_2) \;=\; \pm\, k_1 (\beta c + V_1)$$

and

10

$$(2) \quad k_1 x_0 = \pm \phi_2$$

where

$$V_1 = \omega_1/k_1 \quad \text{and} \quad V_2 = \omega_2/k_2.$$

Equation (2) can be described as the requirements for electron bunching to produce coherent radiation. Equation (1) is the relation between the electron's velocity, the pump wave's velocity and frequency, and the emitted radiation's frequency, velocity, and emission angle. This becomes more apparent when equation (1) is solved for the ratio of k_2 to k_1.

$$\frac{k_2}{k_1} = \frac{1 + V_1/\beta c}{\pm (\cos \theta - V_2/\beta c)} .$$

Substituting

$$k_1 = \omega_1/V_1 , \quad k_2 = \omega_2/V_2 ,$$

$$V_1 = c/n_1 , \quad \text{and} \quad V_2 = c/n_2$$

equation (1) becomes

$$\frac{\omega_2}{\omega_1} = \frac{n_1/n_2 + 1/n_2\beta}{\pm (\cos \theta - 1/n_2\beta)} .$$

11

This equation shows a continuous distribution of mono-chromatic radiation, a unique ω_2 for each value of θ, except at the Cerenkov angle, $\cos \theta_c = 1/n_2\beta$, where all frequencies are allowed by the discontinuity in equation (1). Therefore there are effectively two frequency bands which overlap in frequency but exist at different values of θ. The two lowest frequencies of the bands are

$$\omega_+ = \frac{(1 + 1/n\beta)}{(1 - 1/n\beta)} \omega_1 \qquad (\theta = 0°)$$

for the band emitted in the range $0° \leq \theta < \theta_c$, and

$$\omega_- = \omega_1 \qquad (\theta = 180°)$$

for the band emitted in the range $\theta_c < 0 \leq 180°$.

Similar results for the relations between the incident pump wave and the emitted wave have been obtained by others. Zachary [Ref. 4] and Walsh [Ref. 5] obtain precisely the same result in a more general form. They allow the pump wave to move at an angle to the electron trajectory. Kroll [Ref. 3] finds a discontinuity in the PSER power spectrum at a frequency which is equivalent to Buskirk's ω_+, but it is radiated at the Cerenkov angle $\cos \theta_c = 1/n\beta$. Kroll mentions nothing about a second frequency band. Schneider and Spitzer [Ref. 1] also find two radiation bands with equivalent ω_+ and ω_-, but both bands are radiated into the range $0 \leq \theta \leq \theta_c$.

II. EXPERIMENTAL INVESTIGATION OF PSER

This experimental investigation of PSER has focused on
the detection of a proposed difference in radiated energy
between PSER and Cerenkov radiation. It was decided to use
a direct current plane polarized magnetic field as the pump-
ing mechanism [Ref. 2]. This configuration was able to
maintain a steady sinusoidal magnetic field with a maximum
amplitude of about 1100 gauss (current of 10 amps and a
period of 7 cm) along the electron beam trajectory. Initial
experiments directed the electron beam along the axis of the
magnetic undulator through the atmosphere and attempted to
measure quantitatively the intensity of the resulting radia-
tion using a photodiode. Several problems arose which pro-
hibited a definitive measurement of the PSER and the Cerenkov
radiation. Two of the more significant problems were exces-
sive detector noise and expansion of the electron beam due
to scattering by the linear accelerator exit window. The
preliminary results obtained with these early experiments
[Ref. 2] supported the claims of Schneider and Spitzer but
could not eliminate other theories.

The experiments reported in this paper consist of a
series of refinements to experimental technique and apparatus.
Figure 2 is a schematic showing the relation between the
electron beam, the undulator, the Cerenkov mirror, and

13

the beam current monitor which was used as a basis for the following experiment setups.

A. SETUP-1

1. Description

In setup one the entire basic arrangement, except for the secondary emission monitor (SEM), was enclosed within a gas-box constructed of sealed plywood and plexiglass to contain the desired gas, helium, between the undulator pole tips yet allow the Cerenkov radiation cone to expand the full width of the gap between pole tips. Mirror one was a thin piece of highly polished aluminum which directed the Cerenkov or PSER up onto the face of a photomultiplier tube (RCA 6810-A). The electron beam current was measured by the SEM.

2. Experimental Technique

Measurements were made by filling the gas-box with helium and displaying the photomultiplier tube (PMT) signal and the SEM signal on a dual trace oscilloscope. For record purposes photographs were taken of the oscilloscope.

3. Results

It was found that the PMT was fast enough to present a detailed picture of the light intensity on a pulse-by-pulse basis (the LINAC operates at a pulse rate of 60 Hz and a pulse duration of about 1 μsec). But, no pulse could be discerned in the SEM signal. Thus, no correlation could

be made between light intensity and beam intensity. Also, because the light intensity fluctuated greatly from pulse to pulse and within the same pulse no comparison could be made between PSER and Cerenkov radiation.

B. SETUP-2

1. Description

Setup two was the same as setup one except the SEM was replaced by a toroid.

2. Experimental Technique

The same measurement method was used with, however, the toroid signal substituted for the SEM signal.

3. Results

The toroid had a fast enough response to display the beam current on a pulse-to-pulse basis but its shape differed from the PMT pulse enough that a meaningful comparison was not possible. Again accurate measurements of PSER and Cerenkov radiation could not be made. These data did, however, suggest that integration of the PMT signal and integration of a beam monitor signal might provide useful data.

C. SETUP-3

1. Description

In setup three the toroid of setup two was replaced by the SEM and the aluminum mirror was covered with a clean sheet of white paper which served as a diffuse reflector.

2. Experimental Technique

It was found that when the PMT anode was connected directly to a CARY 401 vibrating reed electrometer in the charge measuring mode, the PMT signal was integrated. The SEM was also connected to a CARY which then integrated the beam current. Knowing both that the PMT signal would be proportional to the intensity of the light incident on its active surface and the time of integration, an average PMT signal current was calculated. The ratio of average PMT current to average beam current was indicative of the amount of PMT illumination for a given beam current. Comparison was then made between the values of this ratio when the undulator was off (Cerenkov radiation) and the values of this ratio when the undulator was on (PSER).

3. Results

This method of measurement showed great promise in that the measurement accuracy was reduced to about one percent. It was observed, however, that when the magnet was turned on, the illumination of the PMT decreased with time. This indicated that the gas was heating, expanding, and escaping from the gas-box. Measurements taken of the gas temperature in a corner of the gas-box remote from the magnet showed a rise in temperature of eleven degrees centigrade in twenty minutes. Therefore a means of containing the gas within the magnetic field, yet isolated from heating effects of the magnet had to be found.

D. SETUP-4

1. Description

A gas-tube was constructed from thin walled stain-
less steel tubing which fit tightly in the gap between poles
of the undulator. The undulator was reduced to five periods
vice the eleven periods used previously to ensure that the
complete Cerenkov radiation cone could emerge from the down-
stream end of the gas tube. A gas-tube was used in one of
the initial experiments [Ref. 2] but scattering of the elec-
tron beam by the LINAC exit window was such that the beam
quickly exceeded the size of the gas tube. Test of a material
called Kapton, a very strong yellow plastic, indicated that
it could be used as a LINAC exit window with a thickness of
1.0 mil. It was desired to evacuate the gas-tube before
injecting helium to help maintain the purity of the helium.
Therefore each end of the gas-tube was fitted with a two-
part flange which held the Kapton in place and provided a
vacuum seal. One end of the gas-tube was fastened to the
open LINAC drift tube in place of the normal aluminum exit
window. The gas-tube location is illustrated in figure four.
Figure three, showing the transmission spectrum of the Kapton
and the relative response of the photomultiplier tube, indi-
cates the wavelengths for which these measurements were
valid.

2. Experimental Technique

Setup four was aligned by remotely viewing the
Cerenkov radiation at various loctions along the desired

path. The Cerenkov radiation appeared as a ring and seemed
to be entirely contained on the PMT's active surface.
Measurements were taken in the same manner used with setup
three. A cooling fan directed air over the magnet structure
for cooling and the integrations were done alternately with
the magnet on or off. Further, measurements were taken with
the gas-tube evacuated and with the gas-tube filled with
helium at room temperature and atmospheric pressure.

3. Results

a. Gas-Tube Evacuated

A comparison of fifteen integrations (duration
of about forty seconds each) with the magnet onto a like
number with the magnet off showed an increase in the observed
Cerenkov radiation intensity of 7.53 % when the magnet was
on. The standard error of the mean in each case was on the
order of 2.5%.

b. Gas-Tube Filled with Helium

A comparison of twenty integrations (duration
of about forty seconds each) with the magnet on to a like
number with the magnet off showed no change in the observed
Cerenkov radiation intensity. The standard error of the
mean was again on the order of 2.5%.

c. Noise Measurement

A further test was conducted to determine the
quantity of noise being measured. The PMT was shielded
from the Cerenkov radiation by a sheet of paper thick enough

to block the light. Integration performed with this arrange-
ment indicated a great deal of noise (about 10% of desired
signal) due apparently to the electron beam striking the
aluminum mirror.

E. SETUP-5

1. Description

Figure 4 diagrams setup 5. The PMT has been sur-
rounded by approximately four inches of lead brick and moved
away from the electron beam axis. The Cerenkov radiation
is directed vertically to mirror 2 from the electron beam
axis by mirror 1. Mirror 2 then directs the Cerenkov radia-
tion horizontally to the face of the PMT. In this setup
mirror 2 is actually a sheet of white paper which serves as
a diffuse reflector.

2. Experimental Technique

Measurements were taken in the magnet on and off
conditions with the gas-tube evacuated, and with the helium,
at approximately room temperature and atmospheric pressure,
slowly flowing through the gas-tube. Also in each case
measurements were taken with the PMT shielded from all light
in an attempt to obtain a noise figure to be used for data
correction.

3. Results

The results summarized below seemed to indicate that
the illumination of the PMT was independent of the medium

contained within the gas-tube (no medium or helium). Also, the magnet showed an effect on the illumination of the PMT when the gas-tube was evacuated. This suggested that the magnet shifted the Cerenkov radiation pattern in some fashion. Noise in the PMT signal was determined to be about 0.33%.

a. Gas-Tube Evacuated

Comparison of five integrations under each of the two magnet conditions (on at 10 amps or off) showed a decrease in the PMT illumination of 4.6% when the magnet was energized.

b. Gas-Tubed Filled with Flowing Helium

Two sets of data taken in this condition are listed below. Each listing gives the number of integrations measured in each of the magnet on and off conditions and the effect observed when the magnet was energized.

(1) Five integrations; increase of 1.6%

(2) Twenty integrations; decrease of 2.4%

c. Gas-Tube Filled with Static Helium

Two sets of data taken in this condition are listed below. Each listing gives the number of integrations measured in each of the magnet on and off conditions and the effect observed when the magnet was energized.

(1) Twenty integrations; decrease of 2.8%

(2) Twenty integrations; decrease of 1.5%

F. SETUP-6

   1. Description

      Setup six was the same as setup five except for
two changes. First, to correct for any wandering of the
Cerenkov pattern, the cardboard light shield was replaced
by a polished copper tube which served as a light pipe.
Secondly, the diffuse reflector was replaced by a front
surface mirror. It was hoped that these two changes would
eliminate the problems found in setup five.

   2. Experimental Technique

      The same methods of measurement and analysis used
with setup five were used with setup six.

   3. Results

      Three runs were made with setup six. All three runs
had the gas-tube filled with helium but a different filling
procedure was used for run three. Each run involved the
measurement of fifteen integrations in each of the two magnet
conditions. The first two runs showed an increase in the
PMT illumination when the magnet was energized of 6.07% and
10.71% respectively. During the third run the intensity of
PMT illumination for a given beam current increased with
each successive measurement. The only explanation which
seemed conceivable was that the helium was being contaminated
by the surrounding atmosphere. Runs one and two did not show
the effect because of the different filling procedures used.
For the first two runs the gas-tube was filled with helium,

and then sealed. Apparently the contamination of the helium had already occurred when measurements were taken in the first two runs. Further testing was not done to determine the exact process by which the helium was contaminated. Instead, prior to each day's run, the gas-tube was flushed with a rapid flow of helium. The helium flow was then reduced to a point which provided a slight overpressure within the gas-tube. Using this procedure, the increasing radiation effect was not observed again.

G. SETUP-7

1. Description

Setup seven was the same as setup six except the SEM was replaced by an arrangement utilizing a photomultiplier tube. The beam PMT, as it was called, was situated so that it was illuminated by the Cerenkov radiation generated by the electron beam passing through about two inches of air. It provided a signal which was proportional to the instantaneous electron beam current.

2. Experimental Technique

In order to observe a more direct correlation between the electron beam current and the illumination of the photomultiplier tube which measured the Cerenkov radiation or PSER generated in the gas-tube (this PMT will hereafter be referred to as the Cerenkov PMT), it was decided to adopt a measuring system which would measure the beam current and

radiation intensity on a pulse basis. Also, since the
LINAC is pulsed at a sixty hertz rate, a much greater
number of data points would be recorded. The measuring
system, described in Appendix A, went through several
stages of evolution. In its final form the Cerenkov PMT
signal was assigned to channel A and the beam PMT signal
was assigned to channel B. Signal pulses were first
amplified, then a pulse was generated which was propor-
tional to the integrated signal pulse. The new pulse was
converted to a binary number and stored on a computer's
disk memory with its companion pulse. After a predeter-
mined number of pulse pairs had been measured and recorded,
data reduction was done by several programs which developed
a pulse-height spectrum of each channel, a pulse-height
spectrum of the ratio of the channels, and a least-squares
fit of the pulse pairs. These programs are further des-
cribed in Appendix B.

3. Results

The results obtained with setup seven are listed
in table 1. Examination of these data indicated no signi-
ficant increase in the light intensity when the evacuated
gas-tube was filled with helium. The light intensity con-
sisted of Cerenkov radiation generated by the electron beam
passing through the two Kapton windows, the fourteen inches
of helium contained within the gas-tube, and approximately
two inches of atmosphere between the last Kapton window and

23

TABLE 1

Gas Tube Condition	Magnet Current (amp)	Mean Cerenkov PMT	Mean Beam PMT	Mean Ratio*
evacuated	0.0	53.0	67.0	126.0
evacuated	10.0	40.9	45.6	110.2
evacuated	10.0	49.9	77.5	155.2
flow of He	0.0	47.3	60.9	127.7
flow of He	10.0	50.4	77.5	152.9
flow of He	10.0	52.1	70.7	135.0

*Ratio = 100 (beam PMT/Cerenkov PMT)

the first aluminum mirror. Calculations, enclosed in Appendix C, approximating the Cerenkov intensity due to the helium and atmosphere showed those two intensities to be the same order of magnitude. Since no significant change in the light intensity was observed when helium replaced a vacuum in the gas-tube, it was concluded that the intensity due to the Kapton windows must be much stronger than that due to helium and air combined. For this reason it is believed that the above results contain the desired signal information but it is completely overshadowed by the undesired signal from the Kapton windows.

H. SETUP-8

   1. Description

      Setup eight is essentially the same as setup seven. In an attempt to eliminate the Cerenkov signal due to the

24

Kapton windows two changes, illustrated in figure 5, were made. The gas-tube was extended by means of a larger gas-cell, which enclosed the first aluminum mirror and moved the second Kapton window out of the electron beam path. Cerenkov radiation from the first Kapton window was blocked by an aluminum plug placed in the gas-tube near that window. The plug was bored along the beam axis to pass the electron beam but block the Cerenkov from the window which would have expanded to a diameter greater than the beam's diameter.

2. Experimental Technique

No change was made to the experimental technique used with setup seven.

3. Results

Regrettably, due to problems with the LINAC and time limitations, only 2 sets of data were obtained. Results are shown in table 2. A specific test to determine the presence of Cerenkov radiation from the Kapton window was not conducted. However, to obtain a usable signal the high voltage on the Cerenkov PMT was increased by 130 volts over the voltage used on setups prior to setup eight. Therefore it is believed that most of the Cerenkov radiation due to the Kapton window was eliminated from the measured signal.

TABLE 2

DATE	GAS-TUBE CONDITION	MAGNET CURRENT (AMP)	MEAN CERENKOV PMT	MEAN BEAM PMT	SLOPE OF LEAST SQUARES FIT*	MEAN RATIO**	NUMBER OF DATA POINTS
9 OCT	He FLOW	0.0	71.98	101.92	1.499	143.27 ± 0.49	5000
	He FLOW	10.0	79.11	99.29	1.698	127.03 ± 0.46	5000
10 OCT	He FLOW	0.0	12.57	81.27	0.164	-----	5000
	He FLOW	10.0	11.38	64.55	0.211	-----	5000

* CERENKOV PMT = SLOPE × BEAM PMT

** RATIO = 100 (BEAM PMT/CERENKOV PMT)

26

III. CONCLUSIONS

Experimental setup eight represents the best effort of
this investigation. Unlike the previous setups, it measured
a signal due primarily to the Cerenkov radiation or PSER
emitted by the electron as it passed through helium. Pre-
vious setups measured a signal which consisted mostly of
Cerenkov radiation from the Kapton windows or was contaminated
by other undesirable elements. Data collected on 10 October
1980 was taken with very erratic LINAC operation and low
beam current. A mean ratio of beam current to Cerenkov
radiation intensity could not be calculated because indi-
vidual ratios exceeded the program capacity. Further, a
least squares fit to the data showed a relatively poor
linear fit. For these reasons these data were considered
unreliable. Data collected on 09 October 1980 showed an
increase of (12.78 ± 0.75)% in the mean ratio of beam current
to Cerenkov radiation intensity when the magnet was on
over the mean ratio when the magnet was off. Based on the
5000 data points obtained to date with setup eight, this
experimental investigation must support those theoretical
investigations which calculate a marked increase in the
energy radiated under PSER conditions over that radiated
as Cerenkov radiation.

Also of particular interest is the effect noticed on
setup three when the magnet heated the gas. Only a slight

change in the gas density resulted in a seemingly significant reduction in the conversion of electron energy to radiation. It seems very conceivable that an intense pump field other than a static magnetic field might induce local density variations in the dielectric medium which could significantly, and adversely affect the energy conversion efficiency.

28

APPENDIX A

PULSE ANALOG TO DIGITAL CONVERTER

The pulse analog to digital conversion system was constructed using readily available parts. A block diagram of the system is shown in figure 6, and a schematic diagram is shown in figures 7 and 8. The circuits used, with the exception of the pulse stretcher, were taken from the manufacturer's engineering product handbook as described in figure 6. A pulse stretcher was needed to integrate the photomultiplier tube pulses and generate a pulse, proportional to the integrated input pulse, that was long enough (greater than five microseconds) for the sample and hold to acquire the signal. This was accomplished with the pulse stretcher, a modified common source circuit, shown in figure 8.

The pulse stretcher's operation can be described as follows. Capacitor C_1, in the input side of the pulse stretcher, in combination with the diode performed the pulse integration. A positive going pulse which was strong enough to forward bias the diode, charged the capacitor. Resistance and capacitance values were chosen so that the capacitor's charging curve was reasonably linear for the duration and magnitude of expected data pulses. The voltage across the capacitor controlled the field effect transistor's (FET) junction resistance which in turn determined the source-to-drain current and the output voltage appearing across the

load resistor, R_4. Duration of the integrated signal was greatly lengthened because of the diode's high resistance to reverse current flow which increased the time constant for capacitor discharge many times over that for charging. Resistors R_3 and R_5 permitted biasing the FET so that its amplification was also reasonably linear and approximately equal to that of the FET used in the other channel. Input pulses from the photomultiplier tube were characteristically one microsecond long and about one volt after amplification. With this input, the pulse stretcher generated an output voltage which was on the order of 0.75 volts. The voltage decayed like a capacitor's voltage would if it had a time constant of about three milliseconds. But for the duration of the sample and hold's acquisition time, the stretchers output was essentially constant. Tests of the stretcher with simulated pulses showed it to be reasonably linear when the input pulses were varied in magnitude. No tests were conducted to determine if the stretcher's integration was independent of the pulse shape.

The sample and hold circuit was activated by a multivibrator timing circuit to sample the pulse stretcher's output. When the sample window was closed the A/D converter began its conversion. At the end of the conversion, a data valid signal was sent from the A/D converter to the computer. When the computer detected the data valid signal it read the eight-bit binary number and began its processing.

APPENDIX B

PULSE HEIGHT ANALYSIS PROGRAM DESCRIPTION

A series of subroutines, listed at the end of this paper,
were written for an IMSAI 8080 microcomputer using Microsoft
Basic. A control program, PHA3, allowed the operator to
select a subroutine based on the desired operation to be
performed. New data, in the form of 2 numbers which repre-
sented Cerenkov radiation intensity and beam intensity respec-
tively, were recorded as pulse pairs on a floppy disk by the
WRITE-CD subroutine. Previously recorded data was read
into a file(s) in the computer memory by the subroutines
READ-CD or READ-B. READ-CD stored the data in 2 files, one
of which represented the Cerenkov radiation intensity pulse
height spectrum, and the other represented the beam intensity
pulse height spectrum. Each file contained 256 elements.
An element, identified by the number representing the desired
pulse, was the total number of pulses which corresponded to
that element number. For example, if the file A represented
the Cerenkov radiation intensity pulses and the element
$A(162)=493$, this meant that there were 493 pulses in that
particular run which had a measured pulse height of 162.
READ-B read previously recorded pulse pairs from a floppy
disk, calculated a ratio of beam current to Cerenkov radiation
intensity, multiplied the ratio by 100 and stored the result

31

in a manner similar to that used by READ-CD. Finally, for
output and record purposes, the subroutines PHA, PHA1, PHA4,
PHA5, PHA6, and PHA7 were used to provide teletype print-
outs or television display of the pulse height spectrum.

A separate program, LST SQR (also listed at the end
of this paper), was used to read the data from a floppy
disk and perform a least squares fit. The standard rela-
tions, shown below, were used to calculate the slope, m,
and the intercept, b, for the linear equation $y = mx + b$.

$$m = \frac{N\Sigma x_i y_i - (\Sigma x_i)(\Sigma y_i)}{N\Sigma x_i^2 - (\Sigma x_i)^2}$$

$$b = \frac{(\Sigma y_i)(\Sigma x_i^2) - (\Sigma x_i y_i)(\Sigma x_i)}{N\Sigma x_i^2 - (\Sigma x_i)^2}$$

APPENDIX C

CERENKOV RADIATION INTENSITY CALCULATIONS

Calculations were made to estimate the intensity of Cerenkov radiation from helium and from air. The basic equation used was the well known expression for energy loss per unit length experienced by an electron passing through a medium of index n.

$$\frac{dE}{dx} = \int (1 - \frac{1}{n^2 \beta^2}) \frac{1}{\lambda^3} \, d\lambda$$

This equation was integrated numerically by dividing the wavelength range measured by the PMT (4000 A to 8000 A) into small elements $\Delta\lambda$, calculating the index of refraction (n) at a wavelength within each interval, calculating dE/dx for the interval using

$$\frac{dE}{dx_i} = (1.457 \times 10^{13} \, \frac{eV}{m} \, \overset{\circ}{A}^2) c \Delta\lambda (1 - \frac{1}{n^2 \beta^2}) \, \frac{1}{\lambda^3} \, ,$$

and then summing the dE/dx_i to get the total energy loss per meter experienced by the electron.

Helium's index of refraction was calculated using the Sellmeir dispersion relation

$$n^2 = 1 + \frac{A \, \lambda^2}{\lambda^2 - \lambda_0^2}$$

where

$$\lambda_0 = 584.4 \text{ Å}$$

and A was determined to be 7.102×10^{-5} by substituting
helium's tabulated index of refraction of 1.000036 at
$\lambda = 5000$ Å. The resulting electron energy loss for a 100
Mev electron was 10.344 eV. For a path length of 14 inches
this is a total loss of 3.678 eV into the wavelength range
of interest.

An equation of the *form*

$$1 + a + b \frac{1}{\lambda} + c \frac{1}{\lambda^2}$$

was fit to the measured values of air's index of refraction
[Ref. 6]. Using three measured values spaced over the
wavelength range of interest the coefficients of the above
equation were: $a = 2.5704 \times 10^{-4}$; $b = -2.5308 \times 10^{-2}$ Å; and
$c = 224.62$ Å^2. The resulting energy loss for a 100 Mev
electron in air was 127.49 eV/m. For a path length of
2 inches this is a total loss of 6.477 eV which is approxi-
mately twice the energy lost in the transit of 14 inches of
helium.

APPENDIX D

FIGURES
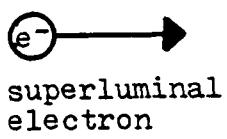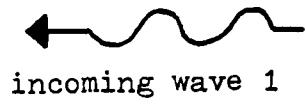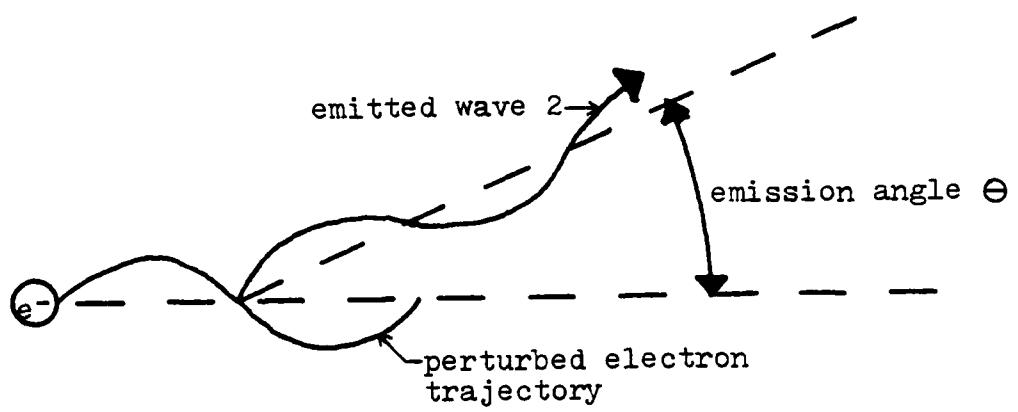
FIGURE 1.   The 3-agent interaction process
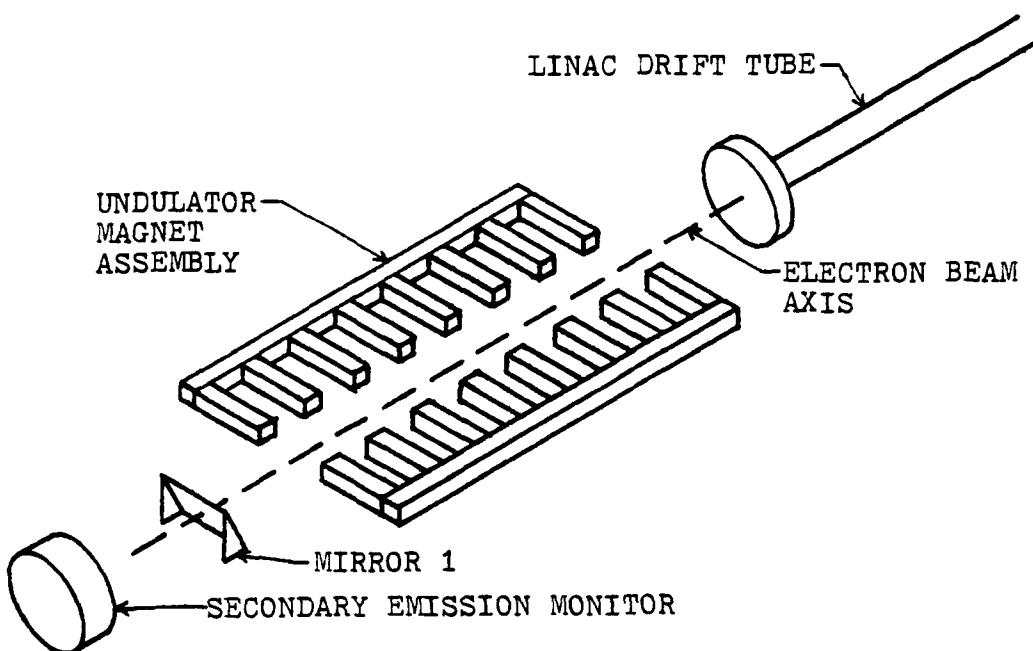
FIGURE 2. Basic arrangement of apparatus.
The undulator consists of 22 pole pieces which
comprise 11 periods with a 7 cm. wavelength.
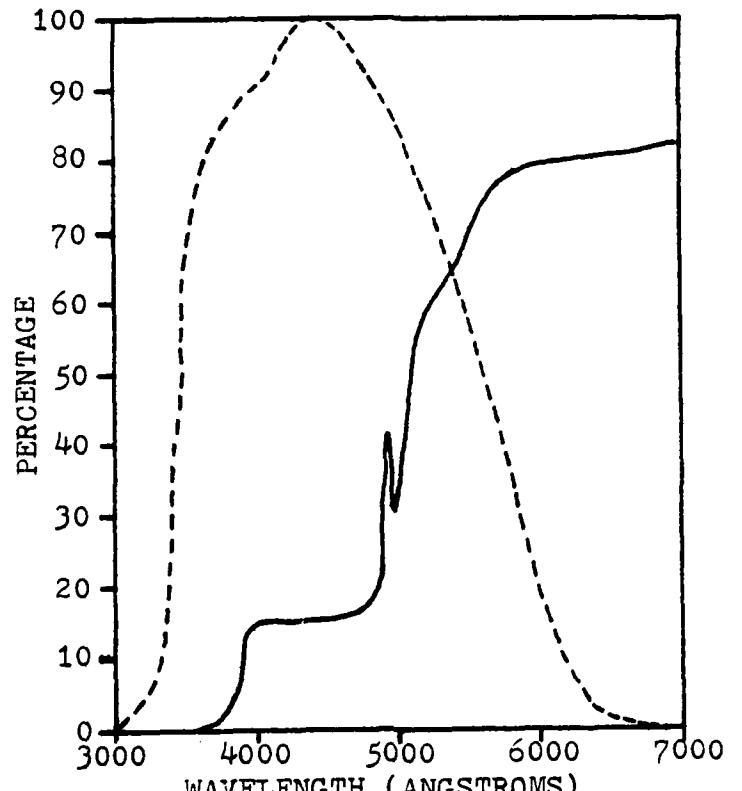
Percent transmission of 1 mil. Kapton

Normalized spectral sensitivity of RCA 6810-A photomultiplier tube

FIGURE 3.
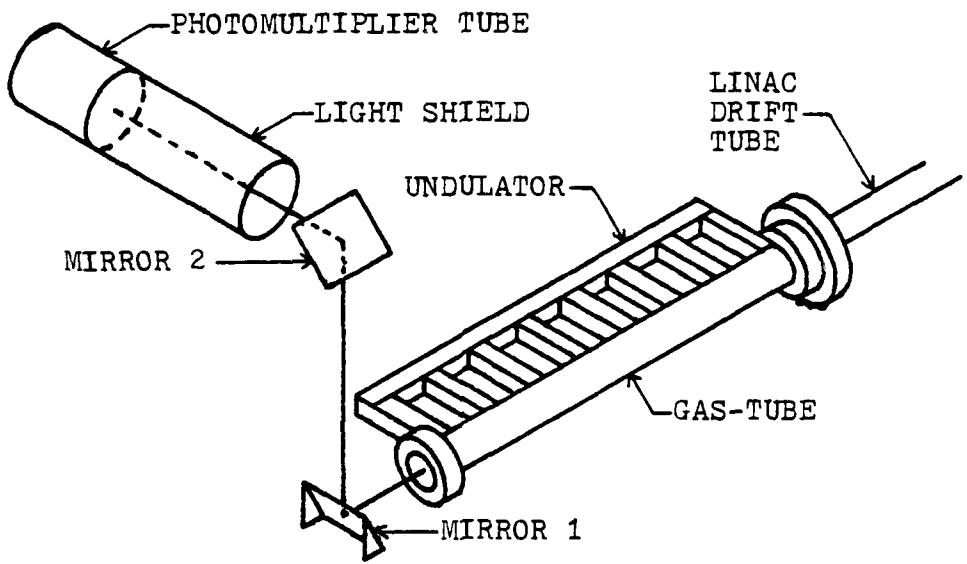
FIGURE 4. Setup-5. For clarity the lead shielding
and part of the undulator are not shown.

38
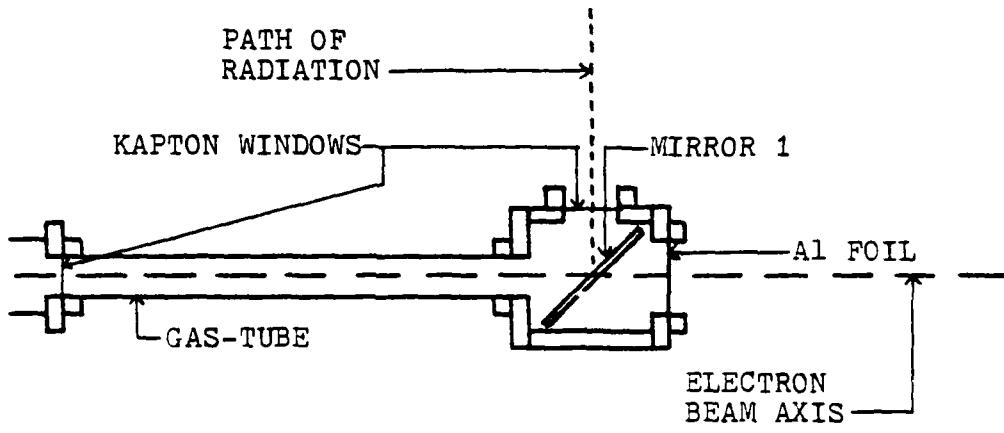
FIGURE 5. Details of setup-8 showing the alterations
made to setup-7.
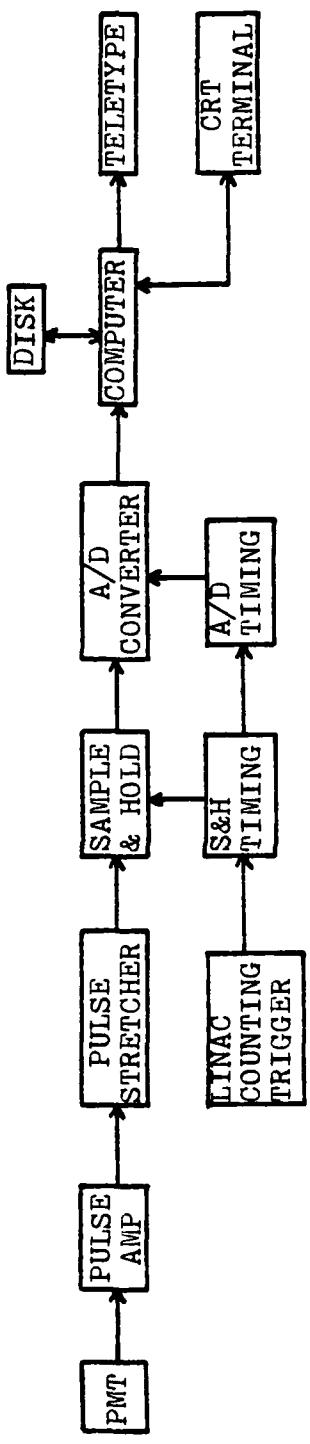
FIGURE 6. Block diagram of the pulse data collection system and Reference data.

Pulse Amp: ORTEC Quad Amplifier, Model AN302/N.

Pulse Stretcher: Circuit based on HEPF 2005 (see figure 7).

Sample & Hold: Circuit based on SHM-LM2 found in Datel Systems INC. Engineering Product Handbook, page 192. The circuit was modified by the addition of a reed relay which discharged the holding capacitor prior to each sample.

A/D Converter: Circuit based on ADC-ET8BC found in Datel Systems INC. Engineering Product Handbook, pages 20 and 21 for unipolar operation.

Timing Circuitry: Circuitry based on SN74121 used as a monostable multivibrator.

40
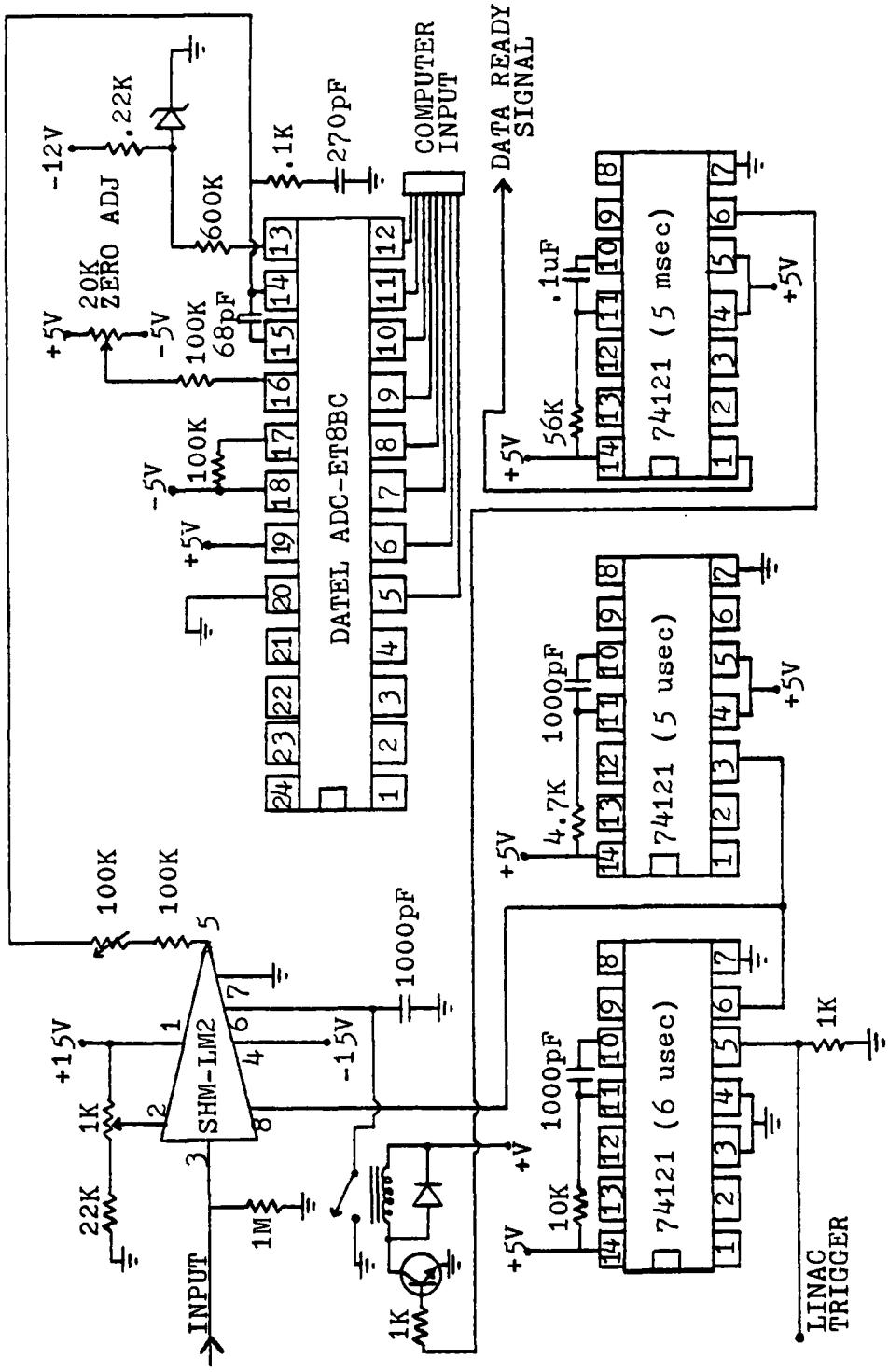
FIGURE 7.

PULSE ANALOG TO DIGITAL CONVERTER
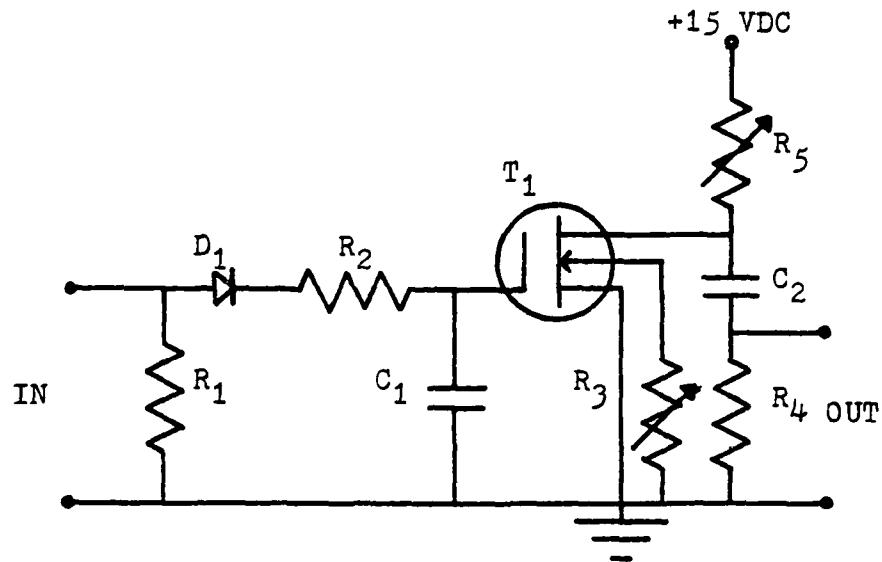
41

$R_1 =$	47 ohm	$C_1 =$	1100 pF MICA
$R_2 =$	1000 ohm	$C_2 =$	0.1 uF CERAMIC
$R_3 =$	5000 ohm	$T_1 =$	HEPF 2005
$R_4 =$	1×10^6 ohm	$D_1 =$	TRANSITRON TYPE S495G
$R_5 =$	20,000 ohm		

FIGURE 8.

PULSE STRETCHER

PULSE HEIGHT ANALYSIS SUBROUTINES

```
4 REM    PHA3: PULSE HEIGHT ANALYSIS CONTROL PROGRAM
5 REM DATA STATEMENT 10 IS IN FOLLOWING ORDER
6 REM MAX COUNT PER BIN
7 REM START BIN FOR PRINTOUT
8 REM STOP BIN FOR PRINTOUT
9 REM SCALE COMPRESSION FACTOR FOR PRINTOUT
10 DATA 250,0,600,30
20 DATA 01 OCTOBER 1980
21 GOTO 120
30 CLEAR
40 READ N,BP,SP,SCALE,DATE$
50 RESET
60 DIM A(256),B(256)
70 WAIT 0,16
72 C=INP(2)
74 D=INP(3)
80 A(C)=A(C)+1
90 B(D)=B(D)+1
100 IF A(C)>N OR B(D)>N THEN 120
110 GOTO 70
120 READ N,BP,SP,SCALE,DATE$
121 RESET
125 WAIT 0,128
```

```
130 OUT 1,7
140 PRINT "READY FOR OUTPUT ACCORDING TO FOLLOWING CODE:"
150 PRINT "     1 FOR CRT DISPLAY OF DUAL CHANNELS"
160 PRINT "     2 FOR TTY DISPLAY OF DUAL CHANNELS"
170 PRINT "     3 FOR NEW DATA"
180 PRINT "     4 FOR END OF PROGRAM"
190 PRINT "     5 TO WRITE DATA TO DISC"
191 PRINT "     6 TO READ DUAL CHANNEL DATA FROM DISC"
192 PRINT "     7 TO READ RATIO FROM DISC"
193 PRINT "     8 FOR CRT DISPLAY OF RATIO"
194 PRINT "     9 FOR TTY DISPLAY OF RATIO"
200 INPUT " ENTER YOUR CHOICE-";Z
210 ON Z GOTO 220,230,240,250,235,236,237,238,239
220 CHAIN MERGE "PHA1",300,ALL,DELETE 5-250
230 CHAIN MERGE "PHA4",300, ALL,DELETE 5-250
235 CHAIN MERGE "WFILE-CD",300,ALL,DELETE 5-250
236 CHAIN MERGE "RFILE-CD",300,ALL,DELETE 5-250
237 CHAIN MERGE "RFILE-B",300,ALL,DELETE 5-250
238 CHAIN MERGE "PHA5",300,ALL,DELETE 5-250
239 CHAIN MERGE "PHA6",300,ALL,DELETE 5-250
240 GOTO 30
250 END
```

```
295 REM    PHA1: CRT DISPLAY OF DUAL CHANNEL PHA

300 FOR I=0 TO 256

310 ASUM=A(I)*I+ASUM

320 BSUM=B(I)*I+BSUM

330 AN=AN+A(I)

340 BN=BN+B(I)

350 ASQR=ASQR+A(I)*I↑2

360 BSQR=BSQR+B(I)*I↑2

370 PA=FIX(A(I)/SCALE)

380 PB=FIX(B(I)/SCALE)

390 IF PA>PB GOTO 470

400 IF PA=PB GOTO 580

410 IF PA=0  GOTO 690

420 F=PA

430 S=PB-PA

440 A$="A"

450 B$="B"

460 GOTO 730

470 IF PB=0 GOTO 530

480 F=PB

490 S=PA-PB

500 A$="B"

510 B$="A"

520 GOTO 730

530 F=PA

540 S=0
```

```
550 A$="A"
560 B$=""
570 GOTO 730
580 IF PA=0 GOTO 640
590 F=PA
600 S=0
610 A$="C"
620 B$=""
630 GOTO 730
640 F=0
650 S=0
660 A$=""
670 B$=""
680 GOTO 730
690 F=PB
700 S=0
710 A$="B"
720 B$=""
730 X$=SPACE$(F)
740 Y$=SPACE$(S)
750 PRINT I TAB(10)
760 PRINT "0";X$;A$;Y$;B$ TAB(45) A(I);B(I)
770 NEXT I
780  PRINT
790 PRINT
800 PRINT
```

```
810 AMEAN=ASUM/AN

820 BMEAN=BSUM/BN

830 ASIG=SQR (ASQR/AN-(ASUM/AN)↑2)

840 BSIG=SQR (BSQR/BN-(BSUM/BN)↑2)

850 ASIGM=ASIG/SQR(AN)

860 BSIGM=BSIG/SQR(BN)

870 PRINT "DATE OF THIS RUN:"DATE$

880 PRINT

890 PRINT "QUANTITY"TAB(15)"CHANNEL A"TAB(30)"CHANNEL B"

900 PRINT " MEAN"TAB(15) AMEAN TAB(30) BMEAN

910 PRINT "VARIANCE"TAB(15) ASIG TAB(30) BSIG

920 PRINT "VAR OF MEAN"TAB(15) ASIGM TAB(30) BSIGM

930 PRINT "# OF PULSES"TAB(15) AN TAB(30) BN

940 CHAIN MERGE "PHA3",120,ALL,DELETE 295-950

950 END
```

```
295 REM    PHA4: TTY DISPLAY OF DUAL CHANNEL PHA
300 WAIT 0,128
310 OUT 1,13
315 T$="RUN (MO-DAY-RUN#) "+FILE$
316GOSUB 930
320 FOR I=1TO5
330 WAIT 0,128
340 OUT 1,10
350 NEXT I
360 INPUT "PRINT LIMITS";BP,SP
365 INPUT "SCALE FACTOR";SCALE
366 AN=0: ASUM=0: ASQR=0
367 BN=0: BSUM=0: BSQR=0
370 FOR I=0 TO 256
380 ASUM=A(I)*I+ASUM
390 BSUM=B(I)*I+BSUM
400 AN=AN+A(I)
410 BN=BN+B(I)
420 ASQR=ASQR+A(I)*I↑2
430 BSQR=BSQR+B(I)*I↑2
435 IF I<BP OR I>SP GOTO 770
440 PA=FIX(A(I)/SCALE)
450 PB=FIX(B(I)/SCALE)
460 WAIT 0,128
470 OUT 1,48
480 IF PA=0 GOTO 570
```

```
490 WAIT 0,128
500 OUT 1,13
510 FOR J=0 TO PA
520 WAIT 0,128
530 OUT 1,32
540 NEXT J
550 WAIT 0,128
560 OUT 1,65
570 IF PB=0 GOTO 660
580 WAIT 0,128
590 OUT 1,13
600 FOR J=0 TO PB
610 WAIT 0,128
620 OUT 1, 32
630 NEXT J
640 WAIT 0,128
650 OUT 1,66
660 WAIT 0,128
670 OUT 1,13
680 A$=SPACE$(7)
690 B$=SPACE$(7)
700 C$=SPACE$(7)
710 LSET A$=STR$(I)
720 LSET B$=STR$(A(I))
730 LSET C$=STR$(B(I))
740 D$=SPACE$(50)
```

```
750 T$=D$+A$+B$+C$
760 GOSUB 930
770 NEXT I
780 AMEAN=ASUM/AN
790 BMEAN=BSUM/BN
800 ASIG=SQR (ASQR/AN-(ASUM/AN)↑2)
810 BSIG=SQR (BSQR/BN-(BSUM/BN)↑2)
820 ASIGM=ASIG/SQR(AN)
830 BSIGM=BSIG/SQR(BN)
840 FOR J=1 TO 3
850 WAIT 0,128
860 OUT 1,10
870 NEXT J
900 WAIT 0,128
910 OUT 1,10
920 CHAIN MERGE "PHA",300,ALL,DELETE 295-1050
930 L=LEN(T$)
940 FOR J=1 TO L
950 P$=MID$(T$,J,1)
960 P=ASC(P$)
970 WAIT 0,128
980 OUT 1,P
990 NEXT J
1000 WAIT 0,128
1010 OUT 1,10
1020 RETURN
1030 END
```

```basic
295 REM    PHA: SUBPROGRAM OF PHA4 FOR DUAL CHANNEL DISPLAY
300 A$=SPACE$(15)
310 B$=SPACE$(15)
320 C$=SPACE$(15)
330 LSET A$="QUANTITY"
340 LSET B$="CHANNEL A"
350 LSET C$="CHANNEL B"
360 T$=A$+B$+C$
370 GOSUB 590
380 LSET A$="MEAN"
390 LSET B$=STR$(AMEAN)
400 LSET C$=STR$(BMEAN)
410 T$=A$+B$+C$
420 GOSUB 590
430 LSET A$="VARIATION"
440 LSET B$=STR$(ASIG)
450 LSET C$=STR$(BSIG)
460 T$=A$+B$+C$
470 GOSUB 590
480 LSET A$="VAR OF MEAN"
490 LSET B$=STR$(ASIGM)
500 LSET C$=STR$(BSIGM)
510 T$=A$+B$+C$
520 GOSUB 590
530 LSET A$="# OF PULSES"
540 LSET B$=STR$(AN)
```

```
550  LSET C$=STR$(BN)

560  T$=A$+B$+C$

570  GOSUB 590

580  CHAIN MERGE "PHA3",120,ALL,DELETE 295-710

590  L=LEN(T$)

600  FOR J=1 TO L

610  P$=MID$(T$,J,1)

620  P=ASC(P$)

630  WAIT 0,128

640  OUT 1,P

650  NEXT J

660  WAIT 0,128

670  OUT 1,10

680  WAIT 0,128

690  OUT 1,13

700  RETURN

710  END
```

```
295 REM    PHA5: CRT DISPLAY OF RATIO PHA
300 FOR I=BP TO SP
310 BSUM=B(I)*I+BSUM
320 BN=BN+B(I)
330 BSQR=BSQR+B(I)*I↑2
340 PB=FIX(B(I)/SCALE)
350 F=PB
360 S=0
370 A$="B"
380 B$=""
390 X$=SPACE$(F)
400 Y$=SPACE$(S)
410 PRINT I TAB(10);
420 PRINT "0";X$;A$;Y$;B$ TAB(45) B(I)
430 NEXT I
440 PRINT
450 PRINT
460 PRINT
470 BMEAN=BSUM/BN
480 BSIG=SQR (BSQR/BN-(BSUM/BN)↑2)
490 BSIGM=BSIG/SQR(BN)
500 PRINT " DATE OF THIS RUN:"DATE$
510 PRINT
520 PRINT "QUANTITY" TAB(15) "CHANNEL B"
530 PRINT "MEAN" TAB(15) BMEAN
```

```
540 PRINT "VARIANCE" TAB(15) BSIGM
550 PRINT "VAR OF MEAN" TAB(15) BSIGM
560 PRINT "# OF PULSES" TAB(15) BN
570 CHAIN MERGE "PHA3",120,ALL,DELETE 295-580
580 END
```

```
295 REM    PHA6: TTY DISPLAY OF RATIO PHA
300 WAIT 0,128
310 OUT 1,13
315 T$="RUN (MO-DAY-RUN#)"+ FILE$
316 GOSUB 770
320 FOR I=1 TO 5
330 WAIT 0,128
340 OUT 1,10
350 NEXT I
360 INPUT "PRINT LIMITS";BP,SP
365 INPUT "SCALE FACTOR";Q
366 BN=0: BSUM=0: BSQR=0
370 FOR I=0 TO 600
380 BSUM=B(I)*I+BSUM
390 BN=BN+B(I)
400 BSQR=BSQR+B(I)*I↑2
410 IF I<BP OR I>SP GOTO 640
420 PB=FIX(B(I)/Q)
430 WAIT 0,128
440 OUT 1,48
450 IF PB=0 GOTO 540
460 WAIT 0,128
470 OUT 1,13
480 FOR J=0 TO PB
490 WAIT 0,128
500 OUT 1,32
```

```
510 NEXT J
520 WAIT 0,128
530 OUT 1,82
540 WAIT 0,128
550 OUT 1,13
560 A$=SPACE$(7)
570 B$=SPACE$(7)
580 C$=SPACE$(7)
590 LSET A$=STR$(I)
600 LSET C$=STR$(B(I))
610 D$=SPACE$(50)
620 T$=D$+A$+C$
630 GOSUB 770
640 NEXT I
650 BMEAN=BSUM/BN
660 BSIG=SQR (BSQR/BN-(BSUM/BN)↑2)
670 BSIGM=BSIG/SQR(BN)
680 FOR J=1 TO 3
690 WAIT 0,128
700 OUT 1,10
710 NEXT J
740 WAIT 0,128
750 OUT 1,10
760 CHAIN MERGE "PHA7",300,ALL,DELETE 295-890
770 L=LEN(T$)
780 FOR J=1 TO 1
```

```
790 P$=MID$(T$,J,1)
800 P=ASC(P$)
810 WAIT 0,128
820 OUT 1,P
830 NEXT J
840 WAIT 0,128
850 OUT 1,10
860 WAIT 0,128
870 OUT 1,13
880 RETURN
890 END
```

```
295 REM    PHA7: SUBPROGRAM OF PHA6 FOR DISPLAY OF RATIO
300 A$=SPACE$(15)
310 B$=SPACE$(15)
320 C$=SPACE$(15)
330 LSET A$="QUANTITY"
340 LSET C$="CHANNEL B"
350 T$=A$+C$
360 GOSUB 540
370 LSET A$="MEAN"
380 LSET C$=STR$(BMEAN)
390 T$=A$+C$
400 GOSUB 540
410 LSET A$="VARIATION"
420 LSET C$=STR$(BSIG)
430 T$ =A$+C$
440 GOSUB 540
450 LSET A$="VAR OF MEAN"
460 LSET C$=STR$(BSIGM)
470 T$=A$+C$
480 GOSUB 540
490 LSET A$="# OF PULSES"
500 LSET C$=STR$(BN)
510 T$=A$+B$
520 GOSUB 540
530 CHAIN MERGE "PHA3",120,ALL,DELETE 295-660
540 L=LEN(T$)
```

```
550 FOR J=1 TO L
560 P$=MID$(T$,J,1)
570 P=ASC(P$)
580 WAIT 0,128
590 OUT 1,P
600 NEXT J
610 WAIT 0,128
620 OUT 1,10
630 WAIT 0, 128
640 OUT 1,13
650 RETURN
660 END
```

```
295 REM    WFILE-CD: WRITES DATA FROM PORTS 2&3 TO DISK FILE
300 INPUT "FILENAME (MO-DAY-RUN#)";FILE$
305 INPUT "MAX COUNT";MAX
310 OPEN "O",#1,"B:"+FILE$
320 N=0
330 WAIT 0,16
335 C=INP(2)
340 D=INP(3)
345 PRINT#1,C;D
350 N=N+1
355 IF N MAX GOTO 330
360 CLOSE#1
370 CHAIN MERGE "PHA3",120,ALL,DELETE 295-380
380 END
```

```
295 REM    RFILE-CD: READS DUAL CHANNEL DATA FROM DISC FILE
296 REM                AND PERFORMS A PULSE HEIGHT ANALYSIS
300 CLEAR
305 DIM A(256),B(256)
310 INPUT "FILENAME (MO-DAY-RUN#)";FILE$
320 OPEN "I",#1,"B:"+FILE$
330 IF EOF(1) THEN 380
335 INPUT#1,C,D
340 A(C)=A(C)+1
345 B(D)=B(D)+1
350 GOTO 330
380 CLOSE#1
390 CHAIN MERGE "PHA3",120,ALL,DELETE 295-400
400 END
```

```
295 REM    RFILE-B: READS DUAL CHANNEL DATA FROM DISC,
296 REM              CALCULATES A RATIO, AND PERFORMS A
297 REM              PULSE HEIGHT ANALYSIS OF THE RATIO
300 CLEAR
305 DIM B(600)
310 INPUT "FILENAME (MO-DAY-RUN#)";FILE$
320 OPEN "I",#1,"B:"+FILE$
330 IF EOF(1) THEN 380
335 INPUT#1,C,D
336 IF C=0 GOTO 330
340 D=CINT(100*D/C)
345 B(D)=B(D)+1
350 GOTO 330
380 CLOSE#1
390 CHAIN MERGE "PHA3",120,ALL,DELETE 295-400
400 END
```

```
1 REM    LST SQR: READS DUAL CHANNEL DATA FROM DISC FILE
2 REM              AND COMPUTES A LEAST SQUARE FIT OF THE
3 REM              DATA PAIRS.
10 DATA "B:10-09-1"
50 READ FILE$
60 OPEN "I",#1,FILE$
70 X=0: Y=0: XY=0: X2=0: Y2=0: N=0
80 IF EOF(1) THEN 130
90 INPUT#1,C,D
100 X=X+D:Y=Y+C: XY=XY+C*D: N=N+1
110 X2=X2+D↑2: Y2=Y2+C↑2
120 GOTO 80
130 B=(XY-X*Y/N)/(X2-X↑2/N)
140 A=Y/N-B*X/N
150 R=(XY-X*Y/N)↑2/((X2-X↑2/N)*(Y2-Y↑2/N))
160 PRINT
170 PRINT FILE$
180 PRINT "CERENKOV="A" + "B" X BEAM"
190 PRINT "R 2= "R
200 PRINT "NUMBER OF POINTS= "N
210 A$=STR$(A)
220 B$=STR$(B)
230 C$=STR$(R)
240 WAIT 0,128
250 OUT 1,10
260 T$=FILE$
```

```
270 GOSUB 370
280 T$="CERENKOV= "+A$+" + "+B$+" X BEAM"
290 GOSUB 370
300 T$="R↑2= "+C$
310 GOSUB 370
320 A$=STR$(N)
330 T$="NUMBER OF POINTS= "+A$
340 GOSUB 370
350 CLOSE #1
360 GOTO 50
370 L=LEN(T$)
380 FOR J=1 TO L
390 P$=MID$(T$,J,1)
400 P=ASC(P$)
410 WAIT 0,128
420 OUT 1,P
430 NEXT J
440 WAIT 0,128
450 OUT 1,10
460 WAIT 0,128
470 OUT 1,13
480 RETURN
490 END
```

LIST OF REFERENCES

1. Schneider, S., and Spitzer, R., "Interaction of Electromagnetic Shock Radiation," _Physics of Quantum Electronics_, v. 7, Addison-Wesley, 1980.

2. Decker, W. M., and Mackin, J. P., _Measurement of Pumped Superluminal Electromagnetic Radiation_, Master's Thesis, U. S. Naval Postgraduate School, Monterey, 1980.

3. Kroll, N. M., "Relativistic Synchrotron Radiation in a Medium and Its Implications for SESR," _Physics of Quantum Electronics_, v. 7, Addison-Wesley, 1980.

4. Zachary, W. W., "Stimulated Electromagnetic Shock Radiation (SESR) When the Angle Between the Electron Velocity and the External Field Direction is Arbitrary," _Physics of Quantum Electronics_, v. 7, Addison-Wesley, 1980.

5. Walsh, J. E., "Cerenkov and Cerenkov-Raman Radiation Sources," _Physics of Quantum Electronics_, v. 7, Addison-Wesley, 1980.

6. McCartney, E. J., _Optics of the Atmosphere_, p. 348-349, John Wiley and Sons, Inc., 1976.

INITIAL DISTRIBUTION LIST

No. Copies

1. Defense Technical Information Center   2
   Cameron Station
   Alexandria, Virginia   22314

2. Library, Code 0142   2
   Naval Postgraduate School
   Monterey, California   93940

3. Physics Library, Code 61   2
   Department of Physics and Chemistry
   Naval Postgraduate School
   Monterey, California   93940

4. Professor F. R. Buskirk, Code 61Bs   4
   Department of Physics and Chemistry
   Naval Postgraduate School
   Monterey, California   93940

5. Lt. Jerry L. Graham   2
   Baldwin Mill Road
   Baldwin, Maryland   21013