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Fujieda, I.

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Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Physics Division

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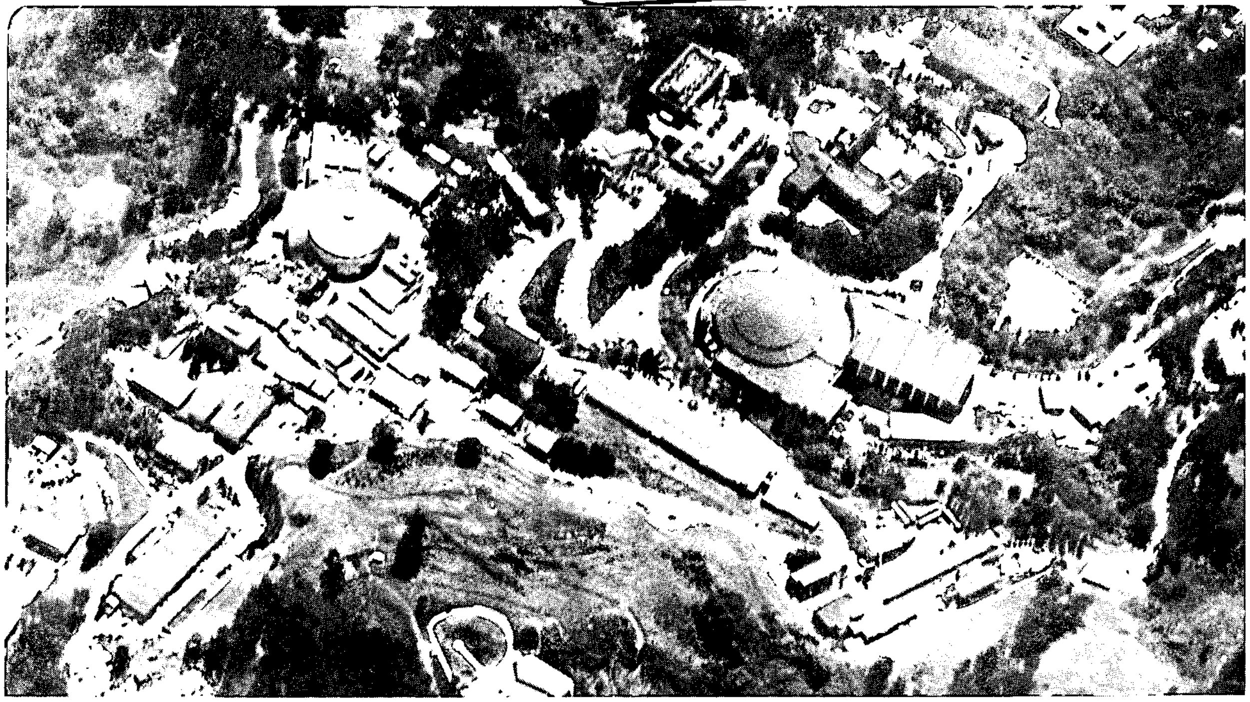

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I. Fujieda[†], T.A. Mulera[‡], V. Perez-Mendez

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

and

A. del Guerra

Istituto di Fisica
Pisa I - 56100, Italy

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[†] Present address: Shimadzu Corporation, Kyoto, Japan

[‡] Present address: Perkin-Elmer Electron Beam Technology Division, Hayward, CA 94545

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I. Fujieda†, T.A. Mulera‡, V. Perez-Mendez
Lawrence Berkeley Laboratory, Berkeley, CA 94720
and
A. del Guerra
Istituto di Fisica, Pisa I - 56100, Italy

Abstract

Measurements of electron transmission and multiplication in lead glass tube arrays, in which a resistive field shaping electrode is provided by reduction of a surface layer of lead oxide, have been continued. The transmission losses have been successfully modeled allowing the true avalanche gains to be extracted. Gains of up to 100 have been observed. Applications as a photon shield in Cherenkov imaging detectors are discussed.

Introduction

We have previously reported some preliminary measurements of electron transmission and multiplication in arrays of narrow lead glass tubing(1). These arrays were originally developed as combined gamma ray converters and electron drifting structures for our work in positron emission tomography (PET)(2). A resistive metallic layer which acts as a continuous voltage divider for drift field shaping is made by reducing a surface layer of the lead oxide in the glass to metallic lead by heating in a hydrogen atmosphere. Typical layers have surface resistivities of 50-200 MΩ/Square. This chemical reduction of PbO on the glass surface is a convenient method of providing a uniform resistive layer to define the potential everywhere on the surface of the drift structure. It is particularly convenient for small diameter tubes where such methods as coating uniformly with resistive inks would prove difficult. The use of such continuous electrodes to avoid field distortions due to the edge of discrete electrodes and the presence of nearby conductors has been shown to be of great importance in drifting electrons, without loss, in narrow aspect ratio geometries(3). As well as employing these arrays in PET we have proposed their use as a combined radiator and field shaping structure in a drift collection calorimeter(4). The possibility of improving their performance in PET and a possible new application in the suppression of photon feed back in photo ionization detectors, such as Ring Imaging Cherenkov (RICH) counters, has lead us to investigate the achievability of modest amounts of electron multiplication inside the tube arrays.

In our initial measurements we reported transmission with 50% efficiency through arrays having a geometrical transparency of 63%. At higher electric fields, an effective multiplication of 2 was observed. We were unable at that time to decompose this effective multiplication factor into its component factors of entrance and exit losses, diffusion losses to the walls, and avalanche gain(1).

We have extended these measurements to investigate the effects of electric field ratios, and various gas mixtures at different pressures, with the aim of maximizing transmission and avalanche gain. By modifying the conformal representation analysis of Bunemann et al.(5), we have modeled the transmission of electrons through wire grids, with square and round holes. This enables us to estimate the entrance and exit losses in the tube arrays. The diffusion loss to the tube walls was estimated using a Monte Carlo simulation. We were then able to extract the tube avalanche gain from the measured effective multiplication.

Analysis of Electron Transmission and Multiplication

Consider a grid of wires with the geometry shown in Figure 1 and electric fields E_1 and E_2 on either side.

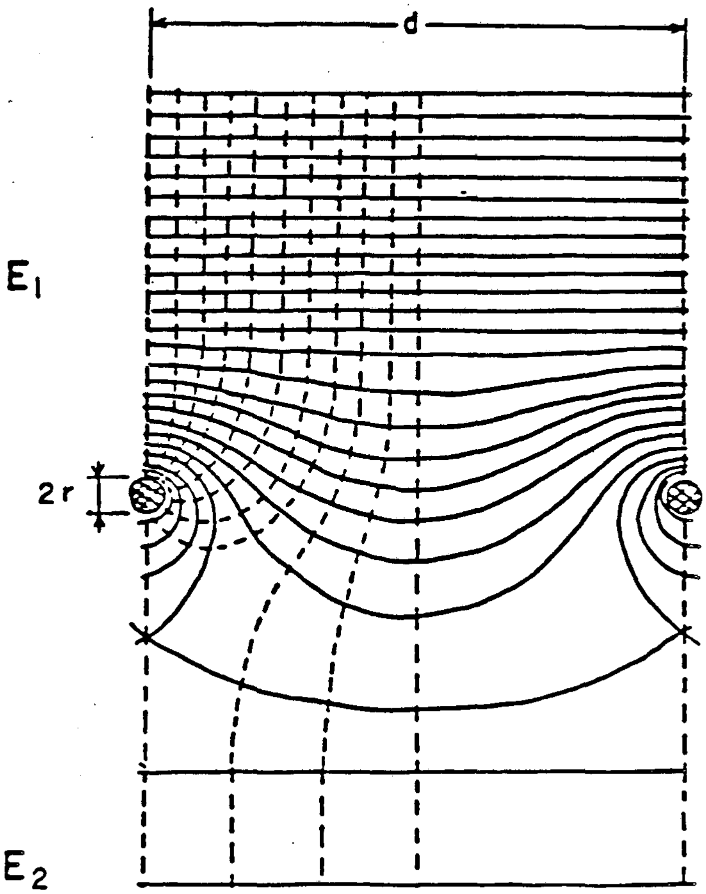

Fig. 1. Electric field lines and equipotentials across a wire grid for $E_2/E_1 = 0.2$

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† Present address: Shimadzu Corporation, Kyoto, Japan

‡ Present address: Perkin-Elmer Electron Beam Technology Division, Hayward, CA 94545

According to Bunemann et al.(5) the transmission of electrons through the grid as a function of $R = \frac{E_2}{E_1}$ and of $\rho = \frac{2\pi r}{d}$ is given by

$$T(R) = R \text{ for } R < \frac{1-\rho}{1+\rho}$$

$$= R - \frac{|R-1|}{\pi}\left\{\left[\left(\frac{R+1}{R-1}\cdot\rho\right)^2 -1\right]^{1/2} - \cos^{-1}\left(\frac{|R-1|}{R+1}\cdot\frac{1}{\rho}\right)\right\}$$

$$\text{for } \frac{1-\rho}{1+\rho} < R < 1$$

$$= 1 - \frac{R-1}{\pi}\left\{\left[\left(\frac{R+1}{R-1}\cdot\rho\right)^2 -1\right]^{1/2} - \cos^{-1}\left(\frac{R-1}{R+1}\cdot\frac{1}{\rho}\right)\right\}$$

$$\text{for } 1 < R < \frac{1+\rho}{1-\rho}$$

$$= 1 \text{ for } \frac{1+\rho}{1-\rho} < R.$$

Here $\rho = \frac{2\pi r}{d}$ is a measure of the optical transparency of the grid.

This model overpredicts the transmission for grids of less than perfect optical transparency by neglecting the effects of induced charges on neighboring wires. Our previous measurements(1) indicate that the effects of these induced charges are not negligible even for optical transparencies as high as 94%.

Rather than performing an exact electrostatic calculation of the effects of these charges we chose to parameterize them by choosing an effective value for ρ as shown in the appendix. The validity of this approach was checked using grids in the experimental arrangement described below.

The grid model enables the calculation of electron losses at the entrance and exit of a tube array. An additional cause of transmission loss is diffusion of electrons to the tube walls. This loss was calculated by a Monte Carlo program using the diffusion coefficients given by Sauli(6).

Experimental Arrangement

Measurements were made as before(1), using the combination of multistep avalanche chamber and multiwire proportional chamber shown in Figure 2. The wire meshes were interchangeable with lead glass arrays 1 cm or 0.5 cm thick composed of tubes having an inner diameter of 0.91mm and a wall thickness of 0.01mm. Electron transmission and effective multiplication was determined by comparison of the pulse heights from the internal and external ^{55}Fe sources, where the electrons from the internal source are attenuated by the transmission through the grids. Photons from the external source convert in the E_4 region and avalanche at the anode wire without grid transmission losses. Pulse height analysis was performed using a LeCroy model 3001 qVt multichannel analyzer or by direct observation of the signals on an oscilloscope.

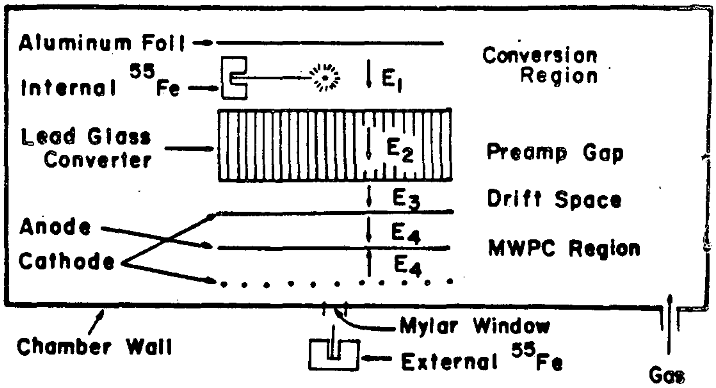

Fig. 2. Cross section of a two step avalanche chamber. Avalanche gain was measured in the E_2 region for wire grids and lead glass tube matrix. Internal and external ^{55}Fe sources produce conversion electrons in E_1 and Esib4 regions respectively.

Results

Figure 3 shows the variation in electron transmission using wire meshes as a function of the electric field ratio E_3/E_2 when the ratio E_2/E_1 is fixed at 2.3. The dashed curves show the modified Bunemann model's prediction for two values of the effective optical transparency parameter ρ. This measurement was done with the chamber filled with 70% Ar + 30% CO_2 at atmospheric pressure. The agreement between the measured and calculated transmissions justifies our adoption of the concept of an equivalent value for ρ.

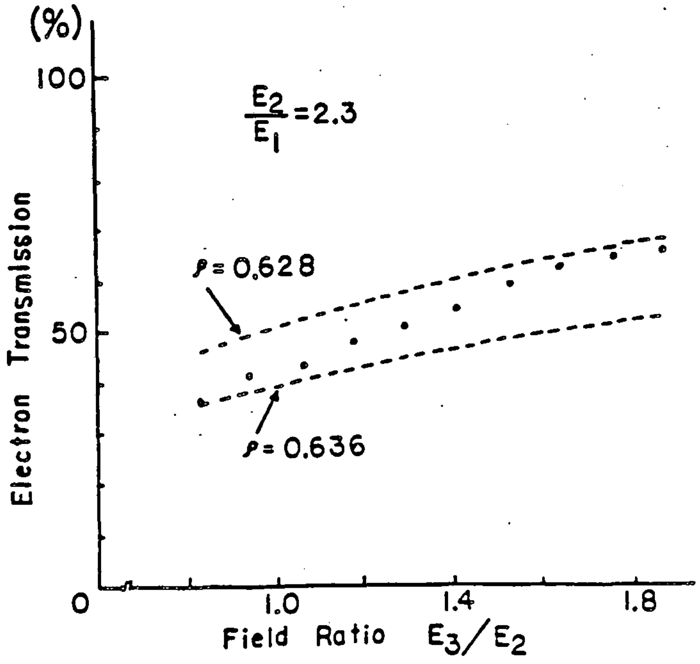

Fig. 3. Measured electron transmission through two meshes as a function of E_3/E_2 for the fixed value of E_1 = 0.58 kV/cm and E_2 = 1.3 kV/cm. The dashed curves are the calculated transmission for two different values of the parameter ρ.

The wire meshes were then replaced with the 0.5cm drift length lead glass tube array. Electrical breakdown along surfaces of the tubes required operation at fairly low values of E_2. Since neon has a larger first Townsend coefficient than argon at low reduced fields (E/p), we chose a gas filling of 96% spark chamber neon (90% Ne + 10% He) + 4% C_2H_6 at atmospheric pressure. Using the internal and external ^{55}Fe sources the effective electron multiplication factor was calculated as follows.

Let n be the typical number of initial electrons produced by converting a 5.9 KeV x-ray photon, M_1 and M_2 be the multiplication factors of the preamplification region and the MWPC respectively, T_1 and T_2 be the entrance and exit transmissions in the lead glass array and (1-D) be the diffusion loss to the tube walls. Then the pulse height from the internal source is proportional to $nT_1M_1DT_2M_2$ and that from the external source is proportional to nM_2. Comparison of the two pulse heights thus allows one to obtain the effective multiplication factor, $T_1M_1DT_2$, for the lead glass preamplification region. Obtaining T_1 and T_2 from the modified Bunemann model and D from a Monte Carlo calculation of the diffusion then allows extraction of the true preamplifier gain M_1.

Figure 4 shows a plot of this true multiplication as a function of the electric field in the preamplifier region for Ne-He quenched with 4% C_2H_6 at atmospheric pressure. A gain of 10 is achieved before electrical breakdown sets in.

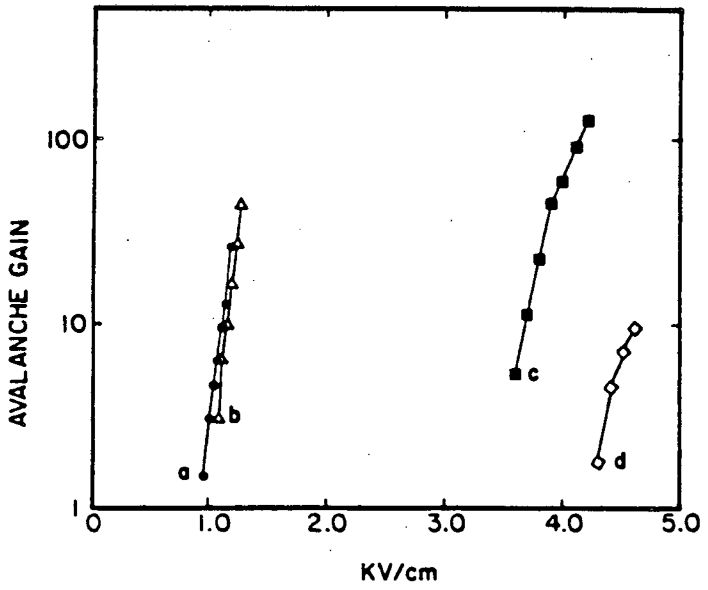

Fig. 4. Avalanche multiplication as a function of gas mixture, pressure and electric field corrected for transmission losses. (a) Ne + He + 10% C_2H_6(40 torr), (b) Ne + He + 10% C_2H_6(70 torr), (c) Isobutane(40 torr), (d) He + Ne + 4% C_2H_6(760 torr).

Reports of very high gains at fairly low electric fields (in parallel plate avalanche chambers)$^{(7)}$ achieved using hydrocarbon gas fillings at low pressure lead us to investigate the effect of reducing the gas pressure on the gain of our lead glass preamplifier as shown in Figure 4.

Application Photoionization RICH Detectors

A typical configuration for a Ring Imaging Cherenkov detector is shown in Figure 5. The UV component of the Cherenkov radiation from the charged particle produces a number of electron ion pairs distributed in a circle. The positions of these electrons are determined by a combination of drift time measurement with position sensing electronics along the anode wires after avalanche multiplication. The avalanche gain has to be greater than 10^5 for high accuracy position sensing starting with single electrons. In High Energy and Relativistic Heavy Ion Physics many tens of particles are capable of producing Cherenkov rings in the gas. Consequently large amounts of UV light are produced in the avalanches along the anode wires which can feed back and produce spurious secondary discharges. To minimize this possibility some RICH detector designs incorporate optical baffles placed around the anode wires. The transmission of UV light through more conventional baffles is around 25%$^{(8)}$.

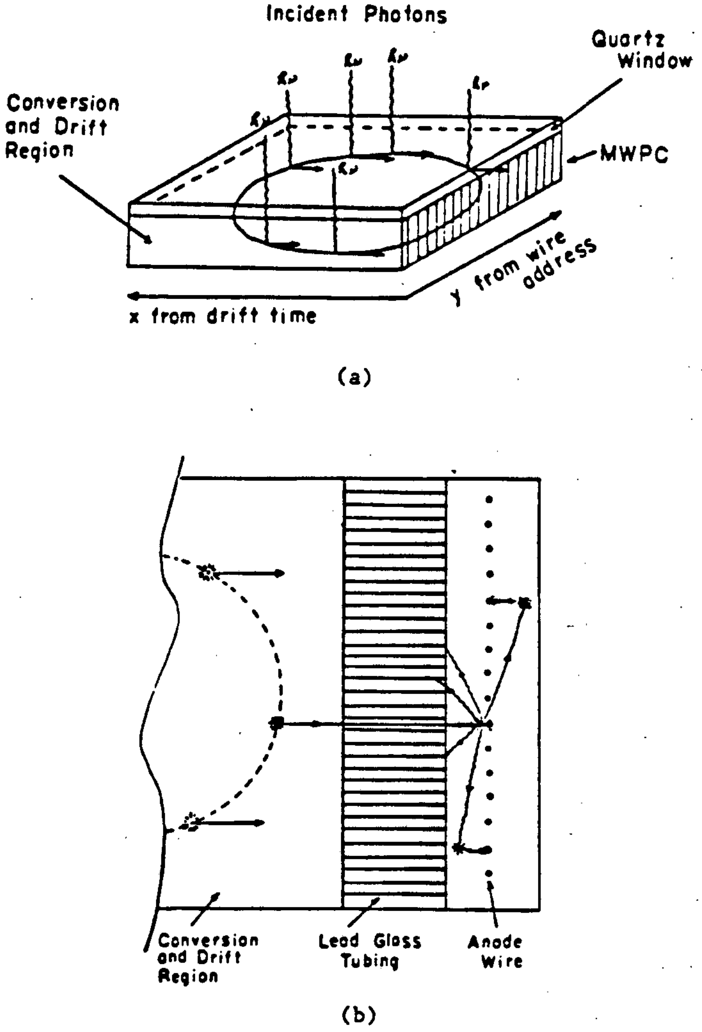

Fig. 5. Tubing matrix as UV shield for RICH detectors
(a) Section of RICH detector showing drift direction of electrons
(b) Second view of RICH detector showing UV shielding capability of tubing matrix

The present lead glass tube matrices would baffle more than 99% of the UV light produced 1.5 cm from the center of the array. A better compromise is to make the electronic transmission greater by increasing the inner diameter of the tubes. An array composed of 2.1 mm glass tubes with wall thickness 0.1 mm would have almost perfect electron transmission, when the ratios of the successive fields are 3:1 and still block more than 98.8% of the UV feedback.

Summary and Conclusions

We have successfully modeled entrance and exit loss as well as diffusion loss to the walls of electrons drifting through narrow lead glass tube arrays. This has allowed the extraction of the true avalanche gains achieved in the tubes.

Modest gains (~10) were observed with gas fillings at atmospheric pressure; while decreasing the gas pressure leads to gains of up to 100. Still higher gains might be achieved by combining low pressures with a gas having a large first Townsend coefficient at high values of E/p. Argon quenched with a hydrocarbon, especially isobutane, is a possibility which comes to mind.

It should be pointed out that the lead glass arrays used in these measurements were originally manufactured for different purposes. There has been no attempt to optimize the geometry to minimize entrance, exit, and diffusion losses i.e. maximizing electron transmission, while maximizing the photon shielding properties. Such an optimization would result in a considerable improvement in performance of these arrays as UV baffles in RICH detectors.

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Appendix

Effective values of "ρ" from Bunemann's formula for the cases (a) Mesh and (b) Lead Glass Counter:

(a) Mesh

Fig. 6. shows the cross section of the wire mesh together with its dimensions. Two kinds of identification were made;

(1) take r (the radius of the grid) to be equal to a half of the longer segment.

(2) take r to be equal to a half of the diagonal. The parameter ρ in each case is (1) 0.628 and (2) 0.636.

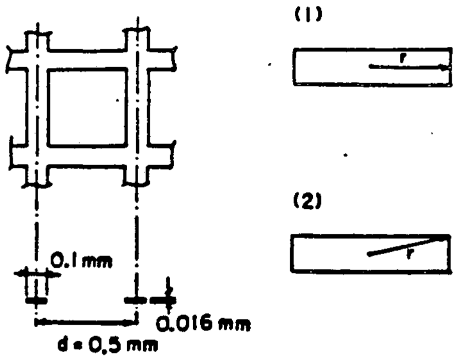

Fig. 6. Cross section of wire mesh.

The equivalent ρ for a lead glass converter is derived by equating the optical transparency of the converter and that of a grid. Figure 7 shows the top views of a converter (1) and a grid (2). The resultant ρ for a 0.91mm inner diameter, 0.1mm wall thickness tube array is 0.934.

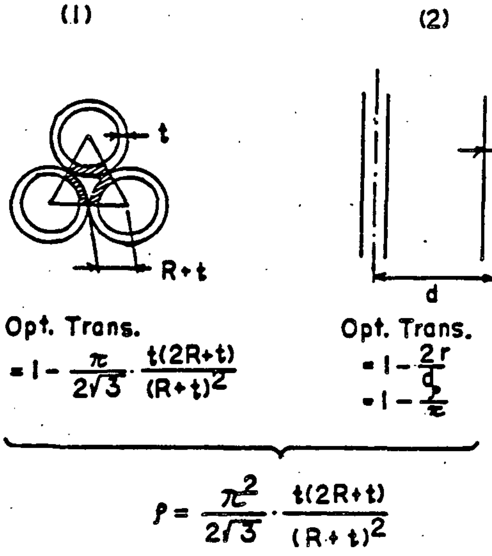

Fig. 7. Equivalent value of ρ for tube matrix.

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