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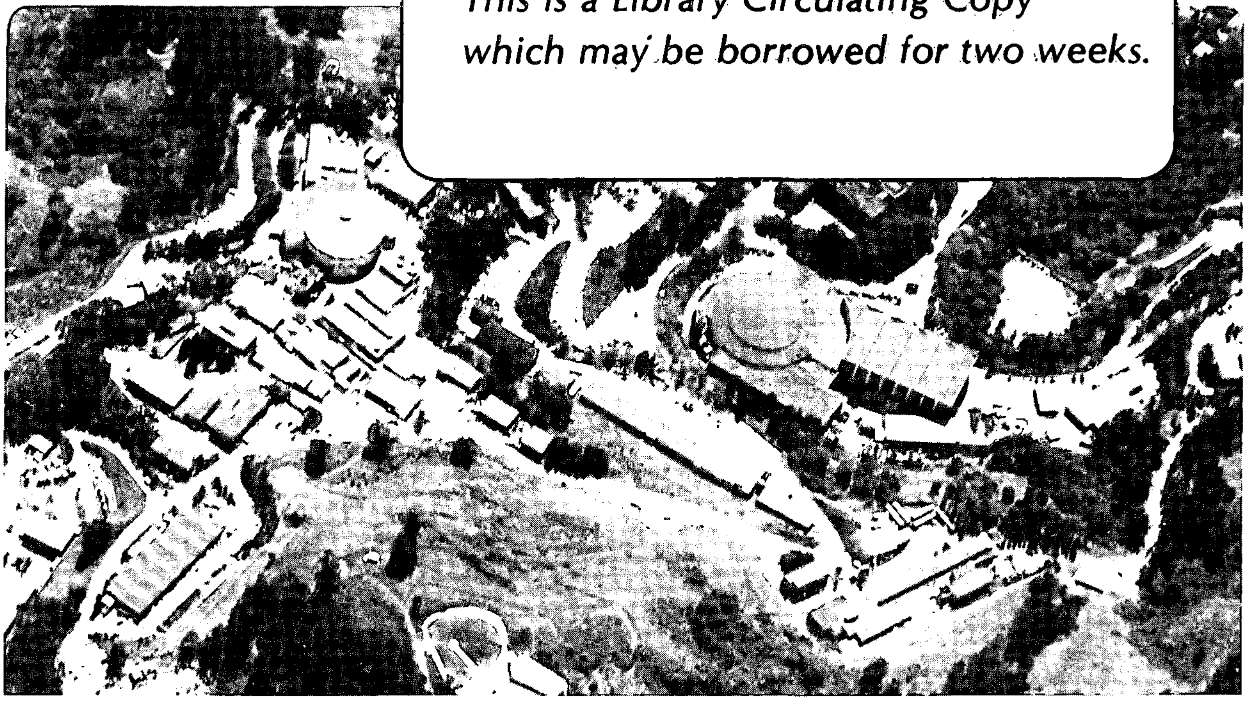

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ELECTROSTATIC TRANSFORMERS FOR LARGE TOWERS[1)]

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Summary

In ion chamber calorimetry a large tower can be matched for fast signal readout to a low noise preamplifier using an electrostatic transformer (EST) as part of the tower structure. This is an attractive alternative to the ferrite core transformer, particularly inside a large magnetic field. The EST is most needed and most effective for the large hadronic towers, where the large ratio of area to perimeter minimizes the loss of spatial resolution from crosstalk with neighboring towers.

The total capacitance in a parallel plate ionization sampling calorimeter is usually very large, tending to produce long charge transfer times to the preamplifiers and large electronic noise[3)] to go with intrinsically small signals. These limitations will be particularly restrictive in SSC applications, where rates are very high and speed is essential. A standard remedy is the ferrite core transformer, which can match the large tower output capacitances to the much smaller input capacitances of the preamps. An alternative is to connect several gaps in series in what we call an electrostatic transformer.

A. GENERAL FEATURES OF ELECTROSTATIC TRANSFORMER (EST)

Figure 1 compares the traditional parallel-connected tower with an EST.

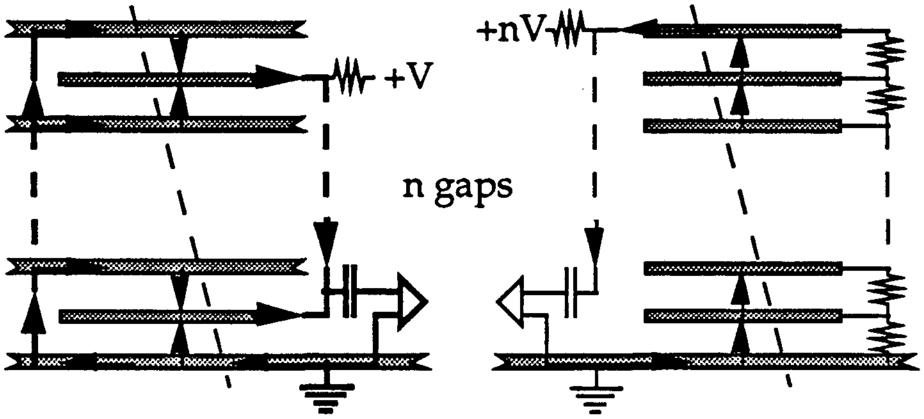

Figure 1. Operation of electrostatic transformer (right) compared with that of conventional parallel-connected tower. The central dashed line indicates the trajectory of an ionizing particle. Arrows show the directions of the signal currents.

For either configuration the gap high voltage is V; but the series resistive divider shown for the EST requires a supply voltage nV, where n is the number of gaps in series. When the gaps are connected in parallel the total signal current in the output is ΣI_m, where I_m is the moving-charge current in the m^{th} gap. The output capacitance C_0 is n times C, the average capacitance per gap. For the EST, in the approximation that the capacitances of all gaps in series are equal, the output capacitance is C/n and the output current is the average gap current $I_o = \Sigma I_m / n = \langle I_m \rangle$. Of the initial charge Q_m, a fraction (n-1)/n remains in the gap of origin until replaced from the high voltage supply.

For a tower with N gaps, each of capacitance C, Figure 2 compares the use of an EST with a ferrite transformer of turns ratio n=3. The latter is connected to the parallel-summed tower pads of total capacitance NC. The capacitance seen from the preamp is $C_o = NC/n^2$. In the EST the pads are internally connected with p parallel sets or cells of n gaps in series, so that $N = pn$, $C_o = pC/n = NC/n^2$. In both cases the output current is $N \langle I_m \rangle / n$. This similarity of performance explains the identification of the series gap connection as an electrostatic transformer.

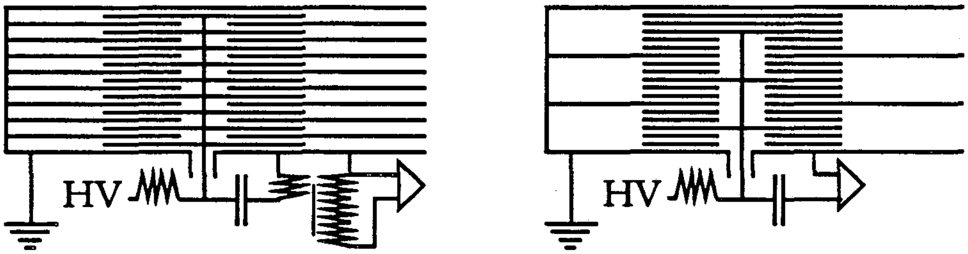

Figure 2. Comparison of n=3 transformers for 18 gap tower. The ferrite transformer (left) with 3/1 turns ratio is applied to the parallel-summed signal from all pads. The internal EST uses six parallel sets or cells of three pads in series.

Like the ferrite transformer the EST is not perfect. Its performance may be compromised by high voltage requirements, stray capacitance, lead inductance and gap to gap nonuniformities. An especially important problem is crosstalk with neighboring towers. Below we consider design features to minimize these limitations. Alternative EST tower designs are shown schematically in Figure 3.

1. High Voltage

If the tiles are all-metal [Figure 3(a)], the total high voltage is proportional to n. Compared with n=1 operation, this requires larger HV cables, feedthroughs, ganging rods, support insulators and signal decoupling capacitors. An alternative which avoids higher voltage is to use divided tiles[4,5)], with different d.c. voltages on opposite sides. [Figure 3(b)]. Then high voltage decoupling is local, signal ganging is at ground potential and the ganging feedthroughs are small. Figure 3(c), using an all metal signal-ganging tile, avoids the risks of virtual leaks from bonding to or cladding the absorber tile. In this case each intermediate tile is insulating, with opposite polarity high voltage pads of large mutual capacitance on the two sides; the voltage across each insulating tile exceeds the gap voltage by a factor n/(n-1).

Assuming that the sampling ratio is fixed (for e/h compensation), Figures 3a and 3b show the maximum possible frequency of sampling. The sampling in Figure 3c is three times coarser. If the signal-ganging tile is thin the sampling is coarser by another factor of two.

2. Stray Capacitance and Ganging Inductance

If the tower output capacitance is greatly reduced by a transformer, the signal is more easily lost to stray capacitance. Internal ganging, as suggested in Figures 2 and 3, minimizes both the stray capacitance and the ganging inductance, which can otherwise delay charge collection and produce uneven sampling from a deep tower. The stray capacitance of the first and last tower pads to the outer walls is eliminated if ground planes terminate the first and last signal gaps. This condition is more easily achieved if the HV decoupling is done internally, as shown in Figures 3(b) and 3(c), rather than with larger, higher voltage capacitors outside the end gaps, as suggested in Figures 1,2 and 3(a). The use of ESTs to lower the output capacitances of large towers minimizes the degradation of the charge transfer by feedthrough inductance; also, the cable impedances are in a convenient range (≈100 ohms)[6].

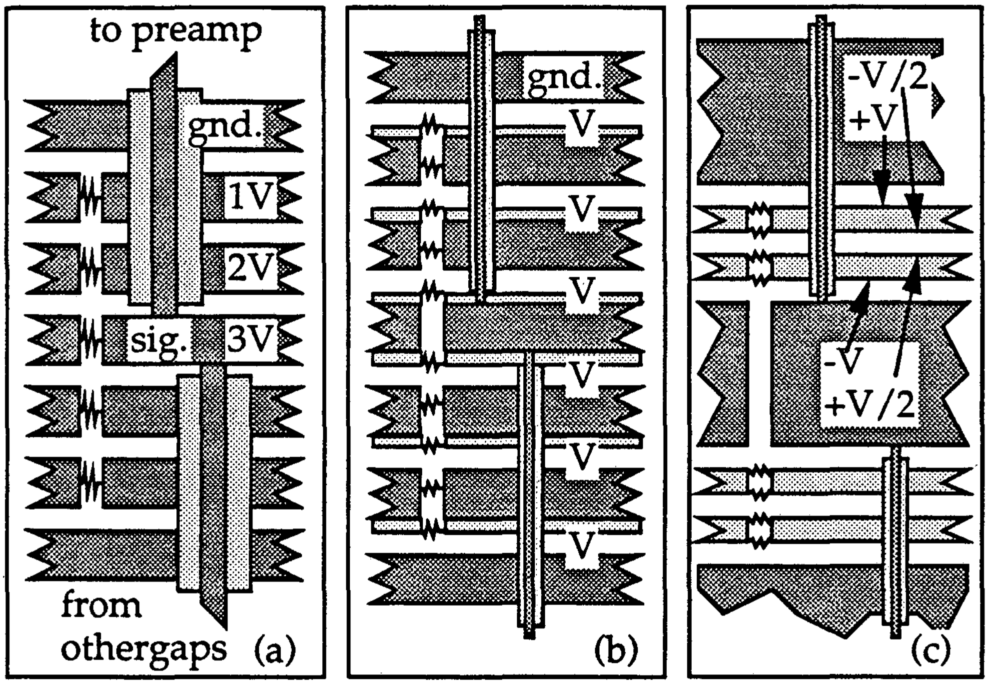

Figure 3. Alternative tile designs for two cells of an EST with n=3. The signal is ganged through holes or at the edges of the absorber plates and intermediate tiles. The high voltages on the latter are horizontally distributed by resistive surfaces on the tile support insulators.

3. Nonuniformity of Capacitance

The performance of the EST described in A above assumes that the individual gap capacitances in each cell are equal. More generally, the output current is $I_o=(C/n)\Sigma I_m/C_m$, where $n/C=\Sigma 1/C_m$. If the gap currents are all equal, I_o is the same as for uniform gaps.

An important random source of capacitance variation is gap width. If the gap is too small, the capacitance is too large, and the output current is less than the average for the cell. This effect augments the direct loss of signal-charge in an undersized gap.

Systematic variations in gap capacitance come from the functional differences of tiles within a cell [see Figures 3b) and 3c)]. Because capacitance is proportional to pad area, in a projective geometry tower the deviation of C_m from the average is proportional to its radial displacement Δr_m from the center of the cell; i.e., $C_m=C(1+2\Delta r_m/r)$, so that $nI_o=\Sigma I_m+2\Sigma I_m\Delta r_m/r$. At $\theta=\pi/2$ for a cell of n gaps of width G, separated by tiles of thickness t, the rms fractional error in output current from a single-gap current source is $\sigma(\Delta I_o/I_o)=[(n-1)(G+t)/r]/(3)^{1/2}$. For $n\approx3$, $r\approx300$ cm, $G+t\approx1$cm, this gives $\sigma\approx0.002$. This error is reduced further by the correlation of the source currents in various gaps of the cell; the error vanishes if all the currents are equal. Because hadronic shower development is gradual with respect to cell length, the effects of all the periodic variations in gap capacitances are negligible.

B. SIGNAL CROSSTALK

1. Capacitance Lattice

Figure 4 shows the coupling of a tower to its neighbors. In addition to the capacitance C between pads within the cell, each pad has coupling capacitance c to the nearest neighbors, which have total internal layer to layer capacitance KC. These are in turn coupled to next nearest neighbors by kc, etc. Values of K and k depend on the shape of the pads; e.g., for rectangles, K=4, k=3; for hexagons, K=6, k=3.

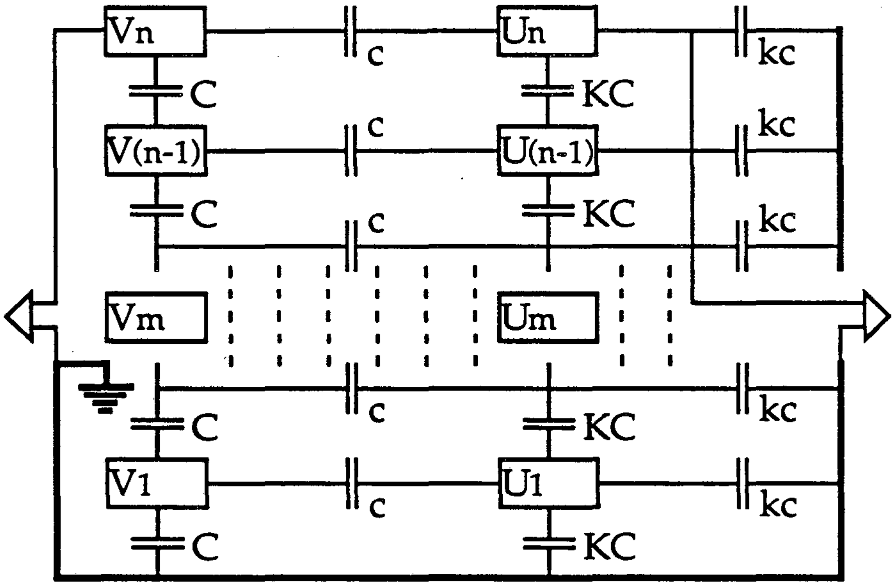

Figure 4. Capacitance lattice for electrostatic transformer of ratio n. V_m and U_m are the signal voltages on the m^{th} pad within a central and neighboring cell, respectively.

2. Crosstalk Amplitude

For the lattice of Figure 4 the fractional crosstalk amplitudes to first order in c/C are $f_{mn}=(c/2C)[n(n+1)-m(m-1)]$, for the m^{th} layer in a cell of

$n \geq m$ gaps. The average fractional crosstalk is $f_n = \langle f_{mn} \rangle = (c/6C)(n+1)(2n+1)$. Note that f_{mn} is smaller for gaps near the output (large m) than for gaps near the ground plate. Also, we expect c to be a function of m, depending on the individual tile parameters; c is reduced for m=1 by the screening of the continuous ground sheet. As with the periodic variations in gap capacitance, this periodicity in the spatial resolution has negligible effect, because hadronic showers develop over distances long compared with the cell length.

3. Dynamic Damping of Crosstalk

f_n is an initial crosstalk amplitude. For each current element the amplitude is damped by the primarily resistive loading of the preamplifiers and cables. This damping is different for the signal and the crosstalk; the crosstalk decreases with time, so that the overall effect depends on the ratio of charge transfer time T to shaping time τ. For values that we have studied for SSC applications, $2 \leq (T/\tau) \leq 3$, the effective crosstalk is suppressed below that given by f_n by a factor in the range 2-4.

4. Values of Coupling Capacitance

In first approximation c/C is determined by the tile thickness t, the pad dimension L, tower gap G, and coupling gap g; i.e., $c/C \approx tKG/Lg$ (see Figure 5). This estimate is reliable only for $t \gg g$.

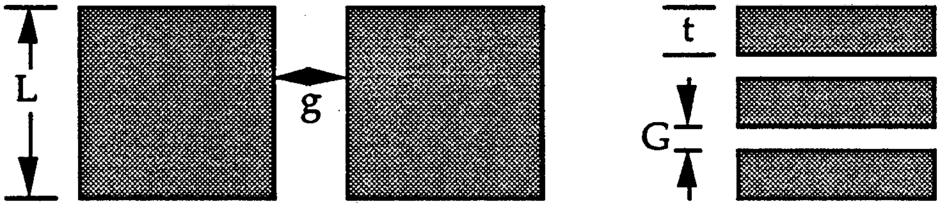

Figure 5. Tile configuration showing crosstalk parameters .

In the Barrel hadronic section, where L is large, relatively large cracks (i.e., large g) are acceptable because the showers are wider than in, say, the EM section. In practice, therefore, c/C is a relatively sensitive function of tower area. For Barrel EM designs, typically, K=4, t=5mm, G=g=2mm, L=50mm (for $\Delta\phi=0.025$), giving $c/C \approx 0.4$. In this case an EST might not work very well, but it probably isn't needed. In the hadronic section, on the other hand, we might have t=10mm, G=2mm, g=8mm, L=150mm (for $\Delta\phi=0.05$), giving $c/C \approx 0.067$, small enough for a useful EST.

5. Scaling the EST with Radius

Assume for simplicity that the composition of the calorimeter is uniform; i.e., the sampling fraction (required for e/h compensation) and the gap thickness are constant. For constant angular tower width, C increases like r^2. For constant tower depth, therefore, the tower output capacitance is independent of r, provided that $n \propto r$. Except for the differences in cable length, this condition is well suited to a radius-independent preamplifier, with the signal to noise ratio decreasing linearly with r. If the towers at large r can have shorter cables, the dependence of signal to noise ratio on radius can also be minimized.

For $n \propto r$ the fractional crosstalk for $3 \leq n \leq 5$ is approximately represented by $f_n \propto r^{1.45} c/C$. Using B.4. above, we note that $L \propto r$ and we let g, the crosstalk coupling gap, grow as $r^{0.45}$. Then the crosstalk also is independent of r.

For the EM part this scaling does not apply, both because the EM towers are relatively shallow and because they will likely have smaller angular width than the hadronic towers. We expect that n=1 will suffice for the EM towers.

C. CONCLUSIONS

The electrostatic transformer can be used to match large (hadronic) tower capacitances to relatively modest preamplifiers. In simplest concept the required high voltage is proportional to the transformer ratio. Voltage correlated limitations on the maximum usable transformer ratio are avoided by using insulators for high voltage decoupling inside the tower. With careful layout large stray capacitances and ganging inductances are avoided.

The most serious limitation on the maximum usable transformer ratio is the degradation of spatial resolution by crosstalk to neighboring towers. The magnitude of this effect depends on the coupling capacitances and also on the ratio of the charge transfer to pulse shaping times. To obtain more accurate estimates we have begun some tests with realistic values for these parameters.

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