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DESIGN OF A MATCHED FAST KICKER SYSTEM*

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1. INTRODUCTION

At the time when the first damping ring was under construction one of us (F. B.) was asked to look into the design of the SLC damping-rings pulsed kickers. The SLC requires two rings one each for e^+, e^- operating at an energy of 1.2 GeV. The period of revolution in the ring is $\simeq 116\ ns$. During the steady state operation each ring contains two bunches circulating diametrically opposite. Therefore the time separation of the two bunches in each ring is $\simeq 58\ ns$. However the injection and ejection of the bunches is different for the two rings.

For the e^- ring, two bunches from the same LINAC pulse separated by 58 ns are injected into the ring together and after damping for 5.6 ms are also ejected together. All through they remain separated in time by 58 ns. Therefore each of the injection and the ejection kicker pulses must either have two points of equal amplitudes separated exactly by 58 ns, or have a flat top $\geq 58\ ns$. One additional requirement remains for which the injection pulse differs from that for ejection. In principle the injection pulse can be started at anytime between LINAC pulses provided it reaches maximum when the first bunch is at the kicker. 58 ns later the second bunch has arrived at the kicker while the first bunch is half way around the ring and will take 58 ns to reach the kicker again.

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If this bunch is not to be disturbed the kicker pulse must fall to zero (after the injection of second bunch) in 58 ns. Hence for injection the rise time is not critical but the fall time must be $\leq$ 58 ns. After one LINAC period the e^- bunches are fully damped and are ready for ejection. The optimum time to start the ejection pulse is when one of the circulating bunches has just passed through the kicker. Therefore the pulse must take ≤ 58 ns to rise to maximum when the next bunch, the first to be ejected, is at the kicker. With a pulse shape as stated above both bunches can them be correctly ejected. We see that, contrary to the injection requirement, the rise time of the pulse is crucial while the fall time is of no importance.

In the case of the e^+ ring the two bunches are injected from two successive LINAC pulses, and damping requires two LINAC periods. In the steady state one bunch is injected/ejected at a time but always in the presence of a second bunch circulating in the ring. The optimum time to start the injection of the "new" LINAC bunch is when the "old" circulating bunch has just cleared the kicker, and will pass through it again after 116 ns. If this bunch is not to be disturbed by the kicker, the injection pulse must rise from 0 $\rightarrow$ maximum and fall back to zero in a total time $\leq$ 116 ns. This time can be divided between rise and fall at will. It is easy to see that the same requirement applies to the ejection kicker.

The ring's design is very compact, and space is at a premium. Approximately 40 cms of straight section is available for any one kicker. One cannot waste space by hanging high power loads directly on the magnet. Furthermore the tolerances on the stability of magnetic kick and the shape of its leading and trailing edges are very stringent. To minimize the clutter around the magnet and to eliminate reflections and ringing it was decided to design a matched system which includes a pulser of impedence Z feeding a magnet of the same impedence via matching cables. Matching cables also transmit the pulse from the magnet output to a cooled resistive termination.

The first magnet considered was a transmission line in vacuum which would have cleanly fulfilled all our requirements above. In such a magnet half of the kick is provided by the electric field and the other half by the magnetic field. The damping rings design calls for a kick of 7.2 mr at 1.2 GeV/c. The maximum magnetic length L available is 40 cms as mentioned before, and a safe beam stay clear region of $\approx$ 2.5 cm is required. Let us calculate the voltage required for a simple parallel plate transmission line kicker. We use the electric field which supplies half of the kick. The transverse change of beam momentum Δp required is

$$\frac{\Delta p}{p} = \frac{1}{2} \times 7.2 = 3.6\ mr \quad .$$

and

$$\Delta p = \text{the transverse impulse} = \text{Transverse force} \times \text{time.}$$

Then

$$\frac{eV \times 10^{-9}}{g} \times \frac{L}{c} \times \frac{1}{p} = 3.6 \times 10^{-3} \quad ,$$

where e is the particle charge = 1, V the voltage required in volts, g the plate separation ($\geq$ beam stay clear = 2.5 cms), L the line magnet length = 40 cms maximum, and p the particle momentum in GeV/c = 1.2 (note that c cancels).

The minimum required voltage is then = 270 kV. It is interesting to note that the impedence of the line kicker (i.e the plates width for a given g) does not enter the calculation and it is left for the reader to verify that, for any impedence chosen, the magnetic kick equals the electric kick. This voltage is very difficult to handle and transmit, and the pulse stability requirement demands a highly regulated power supply which at such a voltage would be prohibitively expensive. This type of kicker, suitable as it may be, was ruled out.

It was decided to put a limit on pulse voltage of $\leq$ 50 kV and use ferrite to obtain the required magnetic field. Since the matched system design remained attractive a study was started to learn how to build ferrite loaded transmission line magnets of a given impedence, which resulted in the general principles of design summarized by F. Bulos in CN-72.[1,2]

To save power supply voltage the pulser chosen was a Blumlein[3] resonantly charged by the power supply.

Because of the unavoidable jitter in the switch of the pulsing system it is desirable to have a magnetic pulse with a flat top τ_f where $\tau_f >$ the jitter. This will remove the contribution of the jitter to pulse amplitude variation. To achieve such a flat top the following relation must be fulfilled:

$$E.P.W = t(\text{rise}) + t(\text{transit}) + t(\text{flat top}) \quad . \tag{1.1}$$

where E.P.W is the electric pulse width from 0 to beginning of the pulse fall; t(rise) is the rise time of pulse from 0 → maximum; t(transit) is the time required for the electric pulse maximum to travel from the magnet beginning to its end, it includes slewing due to lossiness and high frequency response of the ferrite; t(flat top) is the desired flat top duration.

The fall time of the electric pulse is usually about one and a half times the rise in most pulsers, this should be kept in mind.

The first set of kickers built and installed and now operating were intended for the e^+ ring. The times involved, required an electric pulse width E.P.W $\leq$ 40 ns (quite short). It was possible to obtain this with a Blumlein built from 3 coaxial cylinders using castor oil as a dielectric. The overall physical line length was $\simeq 10'$ allowing it to fit standing up in the damping ring vault.

The design aimed at a magnetic pulse with a flat top of $\simeq 2$ ns. However, the shortness of the electric pulse dictated by timing requirements, and the high frequency response of the available (in House) ferrite (Phillips 4C4) did not allow it. The importance of relation (1.1) is demonstrated in Fig. 1(a,b) using the same ferrite in an experimental magnet of impedence 50 Ω driven by a mercury switch pulser. The input pulse rise time was ≈ 1 ns. Figure 1(a) shows the electric pulse at the end of the magnet (top trace) and the magnetic pulse integrated over the magnet length (bottom trace) with E.P.W = 40 ns; Fig. 1(b) is the same except for E.P.W = 65 ns. Generally the 4C4 ferrite which we had, needed $\simeq$ 40 ns to fill for a magnet of length $\simeq$ 40 cms using an E.P. of negligible rise time. The magnetic pulse shape of Fig. 1(a) is almost identical to that obtained in the installed kickers.

The figure indicates that the electric pulse has deteriorated substantially by travelling through the short magnet. This is due to the lossiness of the ferrite at high frequencies. It is clear that a ferrite of better frequency response is needed. A brief discussion of ferrite quality appears below in Chapter 3.

We will now procede with the main topic namely the design of a capacitively loaded Blumlein and a capacitively loaded transmission line ferrite magnet. In each case the motivation for the design, its advantages and disadvantages are briefly discussed.

2. A CAPACITIVELY LOADED BLUMLEIN

The pulse width/unit length obtained from a Blumlein or a single cable pulser is $= 2\sqrt{LC}$ where L, C are respectively the inductance and capacitance per unit length of line. For pulse widths $\leq$ 50 ns (such as in the case of the e^+ kicker above) it was possible to obtain adequate L, C from a triaxial Blumlein of managable length and cross-section filled with castor oil (dielectric constant ≈ 6). In principle one can manage any length of a single line pulser using a commercial cable, but unlike the Blumlein its pulse amplitude is only 1/2 the charging voltage. A Blumlein can be constructed from commercial cables but its geometry is messy and its performance is inferior.

For large pulse widths ($> 500\,ns$) one is forced to increase both L and C in order to keep the line length managable, hence the use of lumped L, C lines. For this type, several sections of lumped L and C are used. C is fixed and L

is tuned to optimise the pulse shape. The geometry is not coaxial and hardly compact. The performance is sensitively dependent on the lay-out, and tuning the inductance is somewhat cumbersome.

For intermediate pulse widths (a few hundred ns), the design described here is very suitable for Blumlein construction, has superior geometry, it is compact and easier to tune.

In this type, as explained in the design example below, one depends on the natural inductance of strip line sections obtaining the desired pulse width and line impedence by appropriate capacitive loading. Such a Blumlein pulser is shown schematically in Fig. 3. It consists of a double strip line folded once upon itself making 4 strip lines of equal impedence sharing a common central plate. These lines are then loaded with discrete capacitors. When high voltage ($> 20\,kV$) is required, the lines are immersed in a grounded jacket containing transformer oil.

The design calculations are illustrated in the following example.

The impedence Z of a parallel strip-line is given to a good approximation by

$$Z(\text{ohms}) = \frac{1}{\sqrt{k}} \times 377 \times \frac{G}{G+w} \tag{2.1}$$

where $k =$ the relative dielectric constant of the material between the plates, 377 is the impedence of the vacuum in ohms, G the plate separation (or gap), w the plate width.

Let the final desired impedence be $Z_f = 16.7\ \Omega$ (You can verify that the final single strip line impedence is also $16.7\ \Omega$), and let the pulse width be $= 125\ ns$.

1. Start with a strip line of impedence (unloaded) $= 100 \rightarrow 125\ \Omega$ (here we will use $125\ \Omega$). The choice of the initial impedence is usually a compromise. Generally, the higher the initial impedence the shorter is the final line but the cross-section is larger. The separation and the width of the plates in

each of the two inner strip lines are given by (2.1)

$$\frac{1}{\sqrt{k}} \times 377 \frac{G_1}{G_1 + w_1} = Z = 125 \text{ (here)}$$

k is the dielectric constant of oil used (for transformer oil $k = 2.25$). We have two unknowns w_1, G_1 the width of the plates and the gap between them. For simple and practical loading with capacitances (as we shall see), G_1 is determined by the available good quality $H.V$ capacitances of the door knob type. We have chosen TDK capacitances because they are of rugged construction, good tolerances, and the capacitance is mildly dependent on the charging voltage. The length of two such capacitances in series (for $H.V$ holding power and smaller capacitance) is slightly less than $2\frac{3}{4}''$. We choose $G_1 = 2.75''$. This gives $w_1 = 2.78''$.

2. Calculate the inductance and capacitance per unit length (say meters) of the unloaded strip line:

$$\sqrt{L/C} = Z(\text{in oil}) = 125\Omega \tag{2.2}$$

$$\tau/M = \sqrt{LC} = \sqrt{k} \times 3.3\ ns \tag{2.3}$$

τ/M is the travel time *one way*/meter, 3.3 ns is the travel time/M in air. (2.2), (2.3) give the values of the inductance L/M and the unloaded capacitance C/M. In this example:

$$L = 625\ nH\ /M \quad ; \quad C = 40\ pf/M\ .$$

3. Leave the width of the central plate unchanged but increase the widths of the second plates on each side by at least 1/2 gap width to shield the inner strip lines from the following outer ones reducing the leakage and hence coupling between them. The widths of these plates w_2 is then =

$2.75'' + 2.78'' = 5.53''$. This determines G_2 (the 2^{nd} gap) which yields the same impedence of 125 Ω. The shielding criteria we used here increases the widths of the outer plates (w_3) to $w_2 + G_2$. The final gaps and widths, and the oil jacket dimensions (chosen for practicality only) we arrive at in this examples are (see Fig. 3): $w_1 = 2.78'', G_1 = 2.75''; w_2 = 5.53'', G_2 = 5.47'', w_3 = 11''$ and the jacket $\approx 18'' \times 15''$ in cross section.

4. Leave the inductance as it is and load with additional capacity/M to drop the impedence to its final value

$$\sqrt{\frac{L}{C_f}} = Z_f = 16.7\Omega \tag{2.4}$$

with $L = 625\ nH/M$, $C_f = 2240\ pf/M$. Hence we need to add:

$$C(\text{added}) = C_f - C(\text{unloaded}) = 2240 - 40 = 2200\ pf/M \quad .$$

5. Calculate the effective length of the line which gives the required pulse length. Remember that in Blumleins and cable pulsers the electric pulse length is given by 2τ where τ is the travel time one way along the line. For our example

$$PL = 2\tau = (2C_f/M)Z_f \times \ell \text{ (meters)}.$$

$$125 \times 10^{-9} = 2 \times 2240 \times 10^{-12} \times 16.7\Omega \times \ell$$

$$\therefore \quad \ell = 1.67 \text{ meters } \approx 5.6ft$$

This design with graded widths approaches the performance of the slightly superior coaxial cylinders geometry mentioned before, however its length is $\approx 6'$ instead of $35'$ for a pulse width of 125 ns.

6. For good rise time, the added capacitance must be distributed along the line's length over as many sections as practically possible to approximate

the usual continuously-distributed-elements cables. The number of sections is dictated by the value of available capacitances. The smallest capacitance available from TDK is 560 pf although they will accept orders for nonstandard values at additional cost. With two in series the unit capacitance is 280 pf.

The separation between units is:

$$S = \frac{280}{C_{\text{added}}/M} \times 100\ cms = \frac{280 \times 100}{2200} = 12.73\ cms = 5''$$

And the maximum number of sections then is

$$\frac{\ell(cms)}{12.73} = \frac{167}{12.73} = 13 \quad .$$

A similar design was used to build a line of 12.5 Ω impedence feeding 2 sections of ferrite loaded magnet each of impedence 25 Ω. Each section was 30 cms long and was fed from the line via $2 \times 50\ \Omega$ H.V cables and terminated with a 25 Ω resistive load. Figure 4 shows the electric pulse ($\approx$ 120 ns width) and resulting magnetic pulse integrated over the entire length. Intentionally no particular care was taken to measure and match the loading units or to insure that the separations of the line plates were constant along the line. The plates were $1/16''$ $A\ell$ (though copper would be preferable). A minimum amount of tuning was performed for learning purposes. The electric pulse was measured with a home-made uncompensated resistive divider probe with a rise-time of $\approx$ 25 ns. The thyratron contribution to rise time of the pulse (L/R) was $\approx$ 15 ns.

3. A CAPACITIVELY LOADED FERRITE TRANSMISSION-LINE MAGNET

Two different schemes can be used to build ferrite transmission line magnets of a desired impedence:

a) Without adding any capacity, the desired impedence is obtained from the electromagnetic properties of the ferrite chosen as indicated in Ref. CN-72.

b) Use less ferrite resulting in higher impedence then load the magnet capacitively to obtain the final desired impedence.

b) was the type first considered and prototyped at the start of the kicker project. The prototype was loaded with the smallest door knob capacities available (50 pf 7.5 kV). The capacitances were installed in gaps between the ferrite blocks distributed along the magnet length. Even for these small size capacitances the loss in magnetic length was substantial. Loading with available commercial units that can stand the required voltage ($\approx$ 45 kV) would be impossible because of their physical size. Designs placing the capacitances outside the magnet are very cumbersome. At that time the design was rejected although the magnet tested very well. A more elegant method was contemplated and also rejected because it would have required extensive research to be carried out by ferrite manufacturers.

Recently F. Villa[4] suggested using moderately high dielectric plastic or ceramic wafers sandwiched between the ferrite blocks. We could not find such dielectric materials. Instead we considered the very high dielectric ceramics (Barium or Zinc titnate) used in making the H.V door knob capacitances. These materials have dielectric constants in the thousands $5 - 10 \times 10^3$. A rectangular block of such material $\simeq 1/8''$ thick by $.4''$ wide and a height equal to the ferrite thickness ($\approx 1''$) has a capacity of $\simeq 150$ pf which is very suitable for distributed loading in the magnets required for the SLC kickers. A design was developed to use such units for loading without losing any magnetic length or disturbing the magnetic property of the ferrite (see later).

A practical design of such loaded magnets is as follows:

1. Choose a practical width of the H.V plate (the central electrode Fig. 2) which allows enough space to accommodate the H.V drive cables; 3 → 4 inches in most cases is sufficient.

2. The desired gap height and width, and the ferrite thickness will determine the average ferrite cross-sectional length. From this the effective permeability and dielectric constant of the geometry, μ_e, ϵ_e can then be calculated using the manufacturers μ and ϵ of the ferrite, and hence the unloaded impedence and transit time/M as indicated in CN-72.

3. From here on, the final desired impedence, the total added capacitance, the frequency of loading, number of sections and the optimum values of the loading units are all calculated in an identical way as in the case of loaded line describe above. To accommodate the loading units, in several sections along the line magnet without losing magnetic length notches are ground in the ferrite with thickness equal to the unit capacitance thickness, a width slightly larger, and height equal to the ferrite thickness. The larger width will allow small increases in the loading capacitance if needed by using slightly wider blocks. (see Fig. 6).

The magnet is assembled without joining the ferrite blocks or potting the loading units. The magnet is energized at reduced voltage to avoid breakdown in the untreated cracks, and tuning is accomplished by trying different value capacitances. This is a learning process and one soon finds various shortcuts. For example experience has indicated to us that the major tuning for the loaded line is accomplished by overloading the switch end of the Blumlein. For the magnet, one overloads the output.

When the tuning is accomplished the ferrites are joined with a silastic potting compound and the capacitance blocks are also potted in place with the same compound.

In Fig. 6 we show tests made on a unloaded magnet. The unloaded impedence was 50 Ω. The magnet was then capacitively loaded to drop its impedence to 16.7 Ω. Figure 5(a) shows the magnetic pulse of the unloaded magnet driven by a 50 Ω cable from a mercury switch pulser. Figure 5(b) is the magnetic pulse of loaded magnet driven by 3×50 Ω cables through a 3 way split from the same pulser. The magnet was terminated by 50, 16.7 Ω respectively.

The advantage of tunability should be weighed against the added mechanical complexity moderate as it may be. However there are additional advantages and disadvantages which are not so obvious and which should be evaluated carefully. The main disadvantage is a slight increase in the transit time of the loaded magnet over that of the unloaded magnet of the same *final impedence*. This increase is larger when the magnet to be loaded starts with a higher impedence. One has to go through the calculations of transit times for both magnets to obtain the answer, and we have mentioned a similar increase in the transit time through the loaded line when the starting unloaded impedence is increased.

The most important gain with this design is the sizable reduction in the cross-sectional length of the ferrite and hence its volume. To evaluate this we make use of the magnetic circuit equation which is analogous to ohms law in electrical circuits:

$$\frac{I}{R_m} = \phi \quad , \quad R_m = \sum_i \frac{\ell_i}{\mu_i \mu_o A_i} \tag{3.1}$$

where I is the current, R_m the magnetic reluctance along the flux lines, ϕ the flux, ℓ_i is the length of the magnetic material with relative permeability μ_i and a cross sectional area A_i, all the materials are assumed in series. In our magnet these are the ferrite of length ℓ_f and thickness t_f and the air gap of length ℓ_g and width w_g. Equation (3.1) for our magnet can then be written:

$$\phi \left(\frac{\ell_f}{\mu_f t_f L} + \frac{\ell_g}{w_g L} \right) = \mu_0 \, I \quad , \quad L \text{ is the magnet length}$$

Since we are interested in the B-field (B_g) in the gap which is ϕ / A_g, the equation can be simplified further:

$$B_g \left(\frac{\ell_f}{\mu_f \; (t_f/w_g)} \; + \; \ell_g \right) \; = \; \mu_0 \, I \tag{3.2}$$

when μ is very high as in the case of iron the first term inside the bracket is negligible and the gap completely dominates. But for $\mu \sim 100$ which is typical of high frequency ferrite, this term contributes significantly. It is clear that its contribution is proportional to ℓ_f and one can obtain B_g with less current as ℓ_f is shortened. In addition the volume of the ferrite decreases and hence volume losses also decrease (see general remarks below).

As an example we consider the contemplated e^- damping ring kicker with $t_f/w_g = 1$, $\ell_g = 2.5$ cms and $Z = 16.7\Omega$. Compare an unloaded magnet of this impedence with a magnet starting with $\approx 45\ \Omega$ and loaded down to 16.7Ω. Calculations show that using a $\mu = 70$ the $\langle \ell_f \rangle$ is $\simeq 90$ and 35 cms respectively. The bracketed term is then .038, .03 respectively. Calculations also show that the transit time for a magnetic length of 33 cms increases by $\simeq 5$ ns. The disadvantage of this increase should be carefully weighed against the 20% *decrease* in the required current and the 60% *reduction* in the ferrite volume.

To summarize, one should weigh the advantages and disadvantages of loading for each geometry, ferrite type, and application before choosing the loaded design.

4. GENERAL REMARKS

a. In choosing the ferrite thickness one should consider the effect of the ratio t_f/w_g. From Eq. (3.2) one can easily see that for a desired gap width w_g, gap length ℓ_g, and gap field B_g (these are dictated usually by beam size, momentum and kick angle), the first term in brackets increases as t_f/w_g decreases resulting in a higher required current.

b. Ferrite losses[5]: The magnetic behaviour of the ferrite is contained in its μ. In general μ is complex

$$\mu = \mu_1 + i\,\mu_2$$

The losses are due to the imaginary part and are described by a quantity $\tan\delta = 1/Q$ where $\tan\delta = \mu_2/\mu_1 = 1/Q$ and Q is called the quality factor in analogy to electrical circuitry. The higher $\tan\delta$ the lossier is the ferrite.

The energy density in the ferrite is B^2/μ and the total energy is

$$\int B^2/\mu \; dV$$

combining the energy in the ferrite and the losses, one arrives at the customary "Merit Factor" MF:

$$MF \;=\; \mu Q \;=\; \frac{\mu}{\tan\delta}$$

that is the larger μQ the smaller are the losses. The product μQ is frequency dependent. Sometimes the frequency dependence of μ and $Q = 1/\tan\delta$ are given separately and sometimes the product μQ or $\mu/\tan\delta$ is plotted as a function of frequency. In general the higher the μ the poorer the frequency response. Most of the available ferrites which have a frequency response flat beyond 1 MHz have a $\mu < 100$ (for example Phillip 4C4 has a $\mu \simeq 100$ and is flat up to 5 MHz. TDK series $K5A$, $K6A$, $K7A$ and $K8A$ have μ's $\simeq$ 300, 70, 25, 18 and a frequency response flat up to 3, 30, 70, 100 Mc respectively). Therefore the choice of ferrite for fast kickers is usually a compromise between a high μ (for high fields) and a good frequency response. Such a compromise led us recently to choose $K6A$ for the SLC kickers. The loss factor $\tan\delta/\mu$ for $k6A$ is a factor 3 smaller than that for 4C4 up to 5 MHz where a steep rise occurs for 4C4. The steep rise for $K6A$ occurs after 30 MHz.

5. CONCLUSIONS

1. Relation (1.1) tells us that in designing fast ferrite - kickers:

   a) The pulser rise time must be as fast as possible.

   b) The ferrite must have good high frequency response to avoid pulse deterioration on travelling the magnet length.

   c) A flat top is possible only when $E.P.W > \text{t(rise)} + \text{t(transit)}$ as defined previously.

2. The loss in the ferrite is proportional to $\tan\delta/\mu = 1/\mu Q$; the μQ product must remain large up to frequencies $> 25\ MH$. The volume of the ferrite should be kept as small as practical. The capacitively loaded design is a simple method effective in reducing the ferrite volume.

3. The capacitively loaded Blumlein is a suitable pulser for pulse lengths in the range $100 \rightarrow 500\ ns$. It is well shielded and is capable of giving an adequately fast rise time and is fairly compact in comparison to the unloaded line.

4. There are advantages and disadvantages to the loaded magnet design which should be carefully considered for each application individually; they are not intuitively obvious.

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mechanical design of the prototype loaded Blumlein and component procurement and his continued involvement in the mechanical design of the various kickers required for the SLC.

REFERENCES

1. F. Bulos, SLAC Linear Collider (SLC) Note CN-72 December, 1980.

2. The work on the e^+ damping ring kickers was carried out independently without searching the literature on fast kickers. Since then many references were accumulated by us or brought to our notice. Most of the kickers except for one (the Cornell kicker), had different pulse length requirements ($> 1\,\mu s$) but the rise time required was not superfast. None of them was designed as a transmission line. The space limitations were less stringent. We provide here a sample of references arranged in a chronological order:

   a) On the design of "Fast Kicker" Magnets, by B. Kuiper, A. Messina and H. Riege, MT-3 (1970) CERN.

   b) "High Voltage Pulse Generators For Kicker Magnet Excitation," by D. C. Fiander, D. Grier, K. D. Metmacher, and P. Pearce, "Eleventh Modular Symposium" September 1973.

   c) The "SPS Fast Pulsed Magnet System," by P. E. Fangeras, E. Frick, C. G. Harrison, H. Kuhn, V. Rödel, G. H. Schröder, and J. P. Zanasco, 12^{th} Modular Symposium, February 4-5, 1976.

   d) "Ultrafast Pulsed Magnets For Beam Manipulation In An Electron Storage Ring," by R. Dixon, F. Messing, D. Morse, and A. Sadoff, Laboratory of Nuclear Studies, Cornell University. Published in IEEE Tran. On Nuclear Science, Vol. ns-24, number 3.

   e) "Travelling Wave Kicker Magnet With Sharp Rise And Less Overshoot," by G. Nassibian, CERN/PS/BR 79-5. Preprint to be presented at the 1979 Particle Accelerator Conference in San Francisco March 12-14, 1979.

   f) "Rapid cycling synchotron (RSC) Single Stage Kicker Magnet," by D. E. Suddeth, and G. J. Volk, 14^{th} Modular Symposium, June 3-5, 1980.

3. a) Blumlein "voltage-doubler circuits" are discussed by O. L. Ratsey, J. Inst. Elect. Engrs. 93, 245 (1946); by K. J. R. Wilkinson, J. Inst. Elect. Engrs. 93, 1090 (1946); and by Craggs and Meek. See also J. L. Brewster, F. M. Charbonnier, L. F. Garrett, K. W. Riegelmann, and J. K. Trolan, "Design Studies for Ultra-Fast, Low-Impedance, High-Peak-Power Pulsed Systems," Technical Report No. AFWL-TR-65-21, Air Force Weapons Laboratory, Kirkland Air Force Base, N. M. (1965).

   b) "Computer Simulation of the Blumlein Pulse Forming Network," by C. B. Edwards, Rutherford Laboratory Print RL-81-029, March 1981.

4. F. Villa, SLAC, private communications.

5. The best place to obtain information on ferrite types and properties is the manufacturers catalogue. We have used mainly the catalogues of the following companies:

   a) Ferroxcube Corporation, A northe Americans Phillips Company.

   b) TDK Corporation of America, catalogues from both *L* and *A* division.

FIGURE CAPTIONS

1. Comparison of the performance of a ferrite transmission line magnet with: a) 40 ns input pulse. b) 65 ns input pulse. The input pulse rise time $\approx 1\,ns$. The magnetic pulse is obtained with a single turn loop spanning the magnet length. The loop output is integrated with an RC integrator.

2. Schematics of magnet assembly.

3. Schematic of loaded strip-lines Blumlein.

4. A capacitively loaded Blumlein feeding a 125 ns pulse into a 25 Ω ferrite loaded magnet. The Blumlein Impedence is 12.5 Ω feeding two sections of such magnet each via $2 \times 50\,\Omega$ H.V cable.

   a) Top and bottom traces are the electric pulse from a loaded Blumlein pulse width $\approx$ 125 ns and the integrated B-field from a 25 Ω ferrite loaded transmission line magnet.

   b) Same as above except for the magnetic pulse which is not integrated.

5. Performance of a 50 Ω ferrite line magnet, and the same magnet capacitively load down to 16.7 Ω

   a) Top: Electric pulse from a mercury switch pulser. Rise time degraded artificially. Pulse length $\approx$ 125 ns and monitored between pulser and magnet. Ripple on pulse is mostly due to the degrading scheme. Bottom: Integrated B-field of a 50 Ω magnet.

   b) Same as a) except that magnet was capacitively loaded to drop its Z from 50 Ω to 16.7, and is terminated with 16.7 Ω at output instead of 50 Ω. The two pictures are with two different schemes of splitting the pulse from pulser for matching.

6. Schematic of loaded magnet. Ferrite blocks are shown separated for clarity. The capacitive blocks are shown potted in notches in the enlarged view. Note that notches are somewhat oversize to allow tuning and final potting.

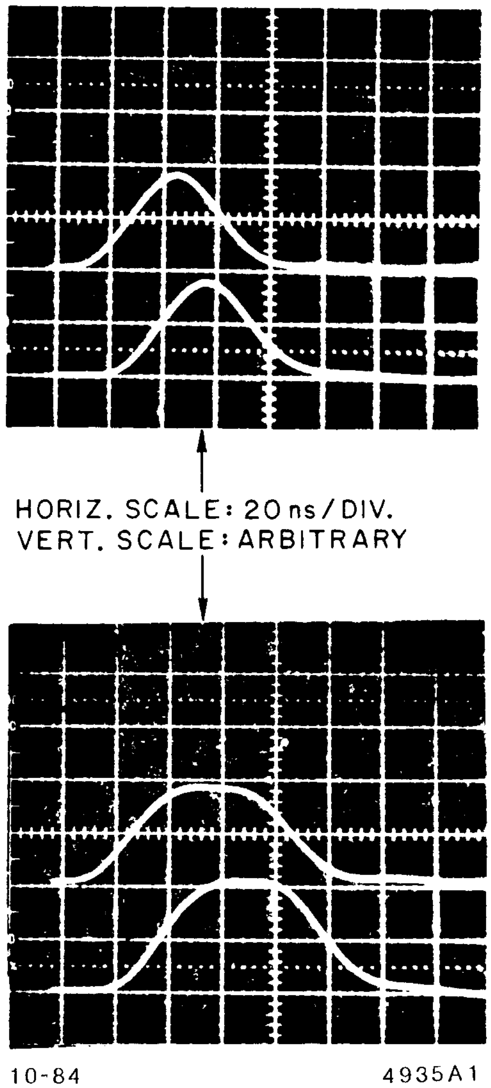
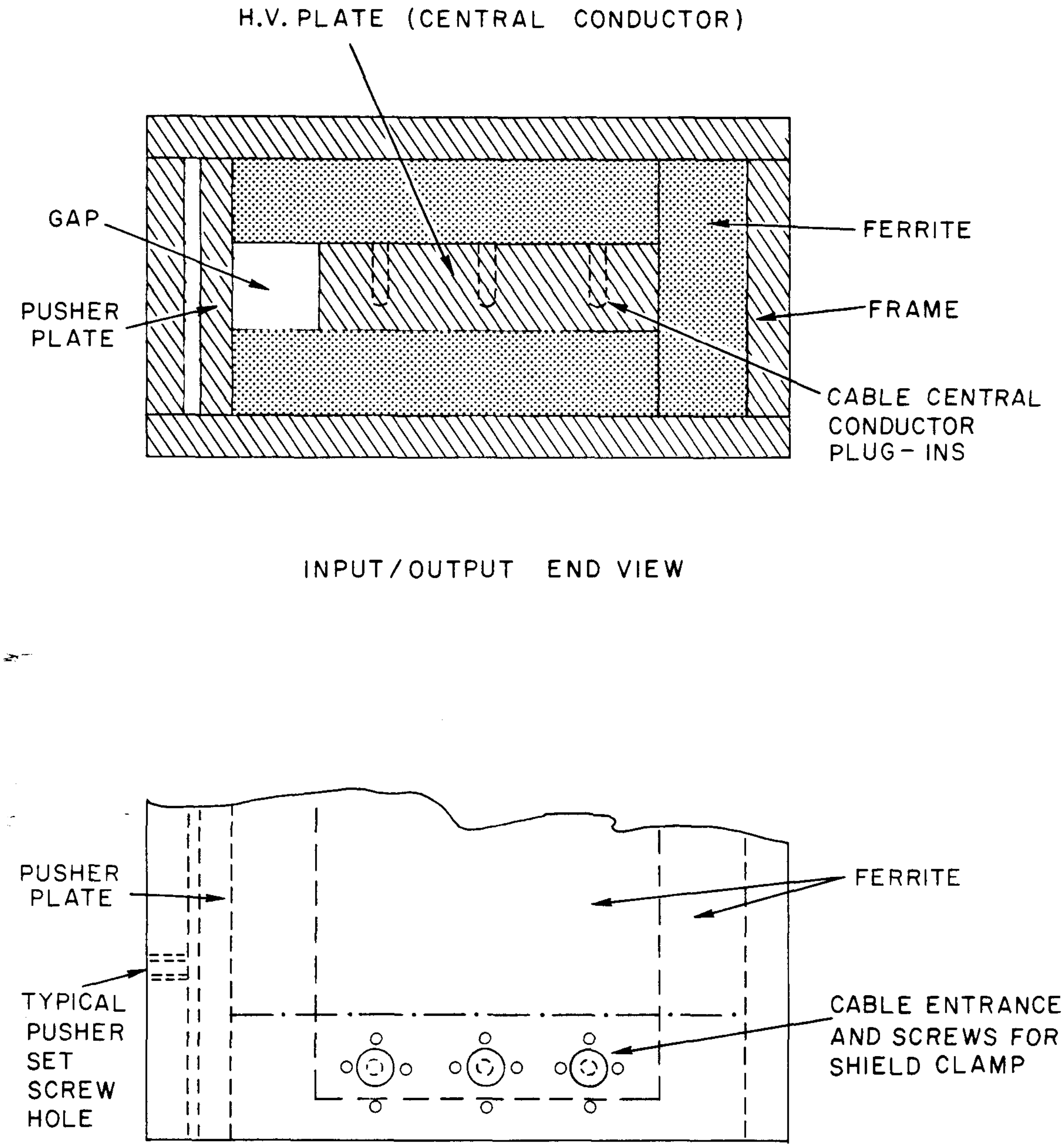


Fig. 1



INPUT/OUTPUT END VIEW

10-84 INPUT/OUT PLAN 4935A2

Fig. 2

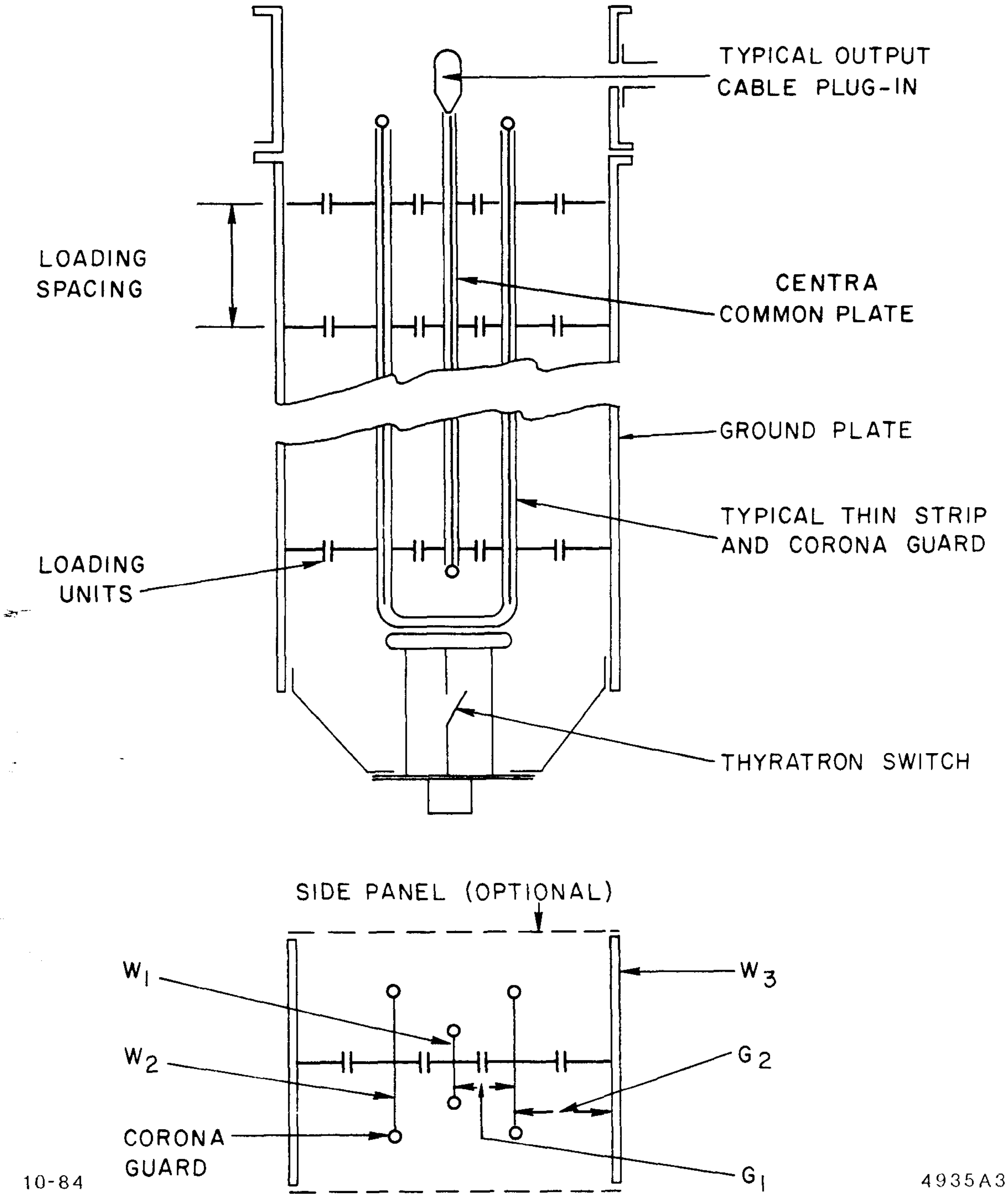

TYPICAL OUTPUT
CABLE PLUG-IN
LOADING
SPACING
CENTRA
COMMON PLATE
GROUND PLATE
TYPICAL THIN STRIP
AND CORONA GUARD
LOADING
UNITS
THYRATRON SWITCH
SIDE PANEL (OPTIONAL)
W1
W3
W2
G2
CORONA
GUARD
G1
10-84
4935A3

Fig. 3

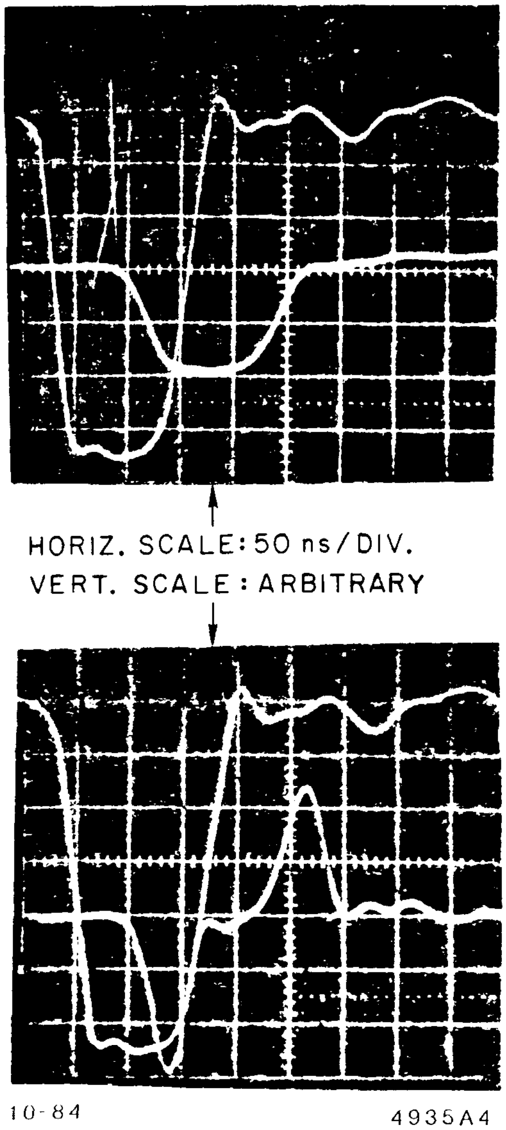


Fig. 4

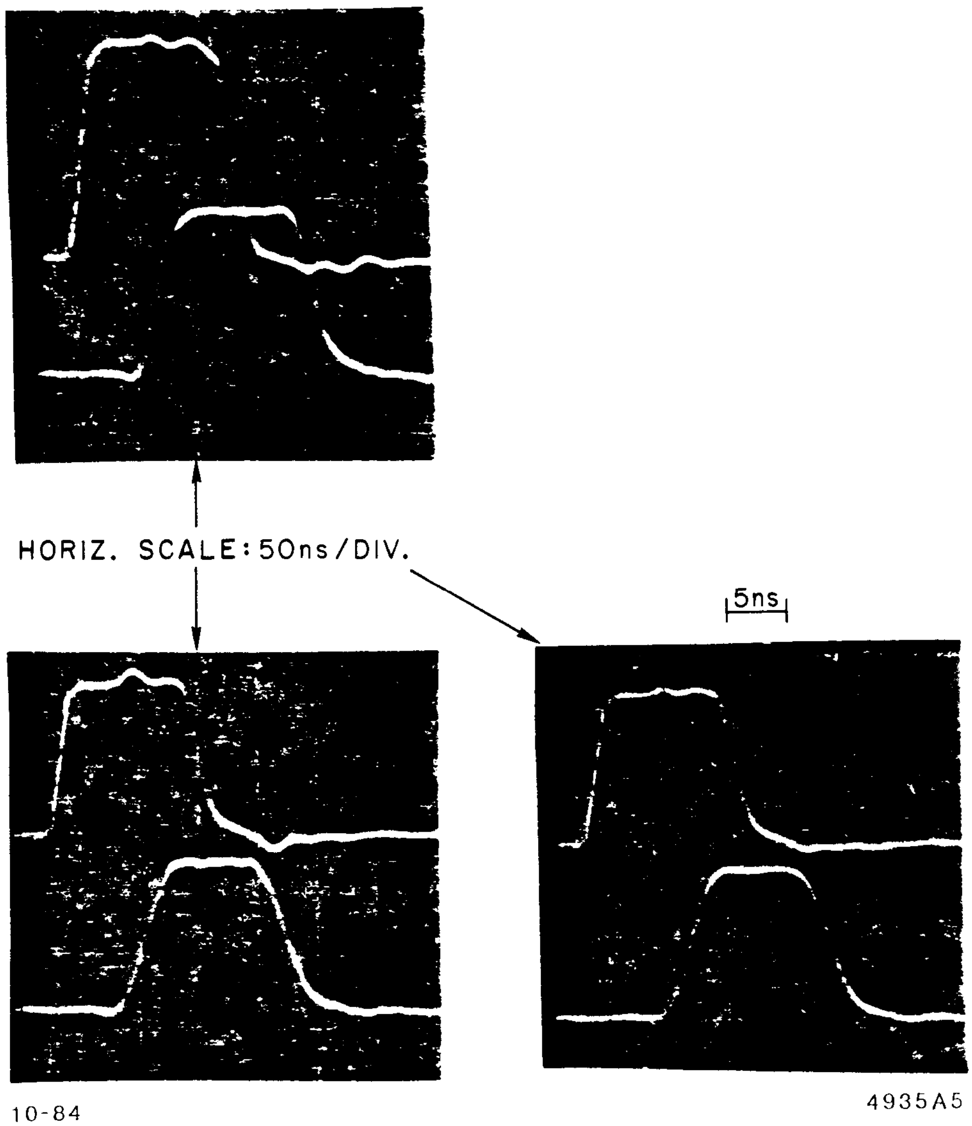
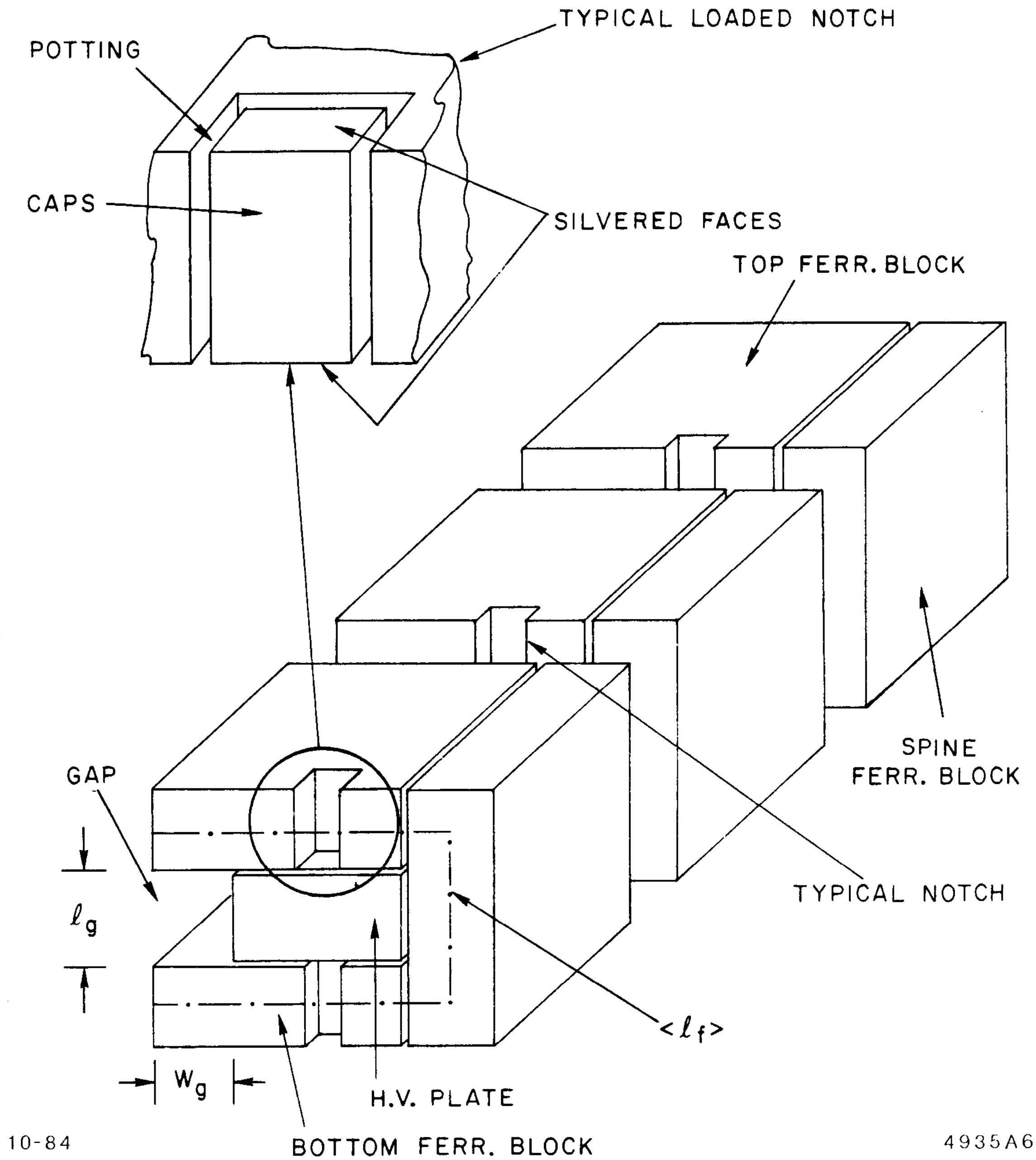


Fig. 5



TYPICAL LOADED NOTCH
POTTING
CAPS
SILVERED FACES
TOP FERR. BLOCK
GAP
SPINE
FERR. BLOCK
TYPICAL NOTCH
ℓ_g
$<\ell_f>$
W_g
H.V. PLATE
BOTTOM FERR. BLOCK
10-84
4935A6

Fig. 6