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CAN THE HORN SYSTEM BE MODIFIED TO ACCOMMODATE A 1 MSEC SPILL?

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During the past few months it has become clear that a 1 msec good focusing period of the neutrino horn system would be desirable for the counter neutrino experiments. The design specifications of the original horn system were to provide good focusing over a time period of 20 μsec to 60 μsec. With considerable modification of the existing system it may be possible to provide good focusing for a 1 msec spill. The system modifications and the advantages and disadvantages of the modified system will be discussed.

The present system is schematically shown on Figure 1 along with the related equations. The system is a lightly damped LRC circuit and the current waveform is approximately a sin wave with a quarter cycle ($\tau_{1/4}$) proportional to the square root of the load inductance and the bank capacitance. To provide good focusing over a longer time period one could just increase the quarter cycle by increasing either the load inductance or the bank capacitance. This however is impractical because of the poor energy transfer to the horn.

The energy transfer can be improved by inserting an impedance matching transformer between the power supply polarity reversal switch and the load. This type of circuit is shown on Figure 2 with the related equations. From the equations which are for a perfect transformer, we see that the quarter cycle can be increased by the ratio of turns ($\frac{N_1}{N_2}$) of the transformer. The price one pays is that a larger fraction of the energy is lost to Joule heating of the feeding system to the horns. We can see this in the expression for i_2' because δ is relatively frequency independent (R_t varies only because of the skin depth) but $\tau_{\frac{1}{4}}$ increases from 150 μsec to 2.5 msec. The numerical values are given for these simple cases in Table I.

For the simple case of a perfect matching transformer, the proper quarter cycle and current in the horn can be achieved for a transformer with a turns ration $\frac{N_1}{N_2} = 16$.

The advantages of the transformer system over the present system are:

1. Allows use of a 1 msec spill,
2. Reduces the operating voltage on the horns and transmission lines which are on the secondary side of the transformer. This could result in somewhat improved reliability of the horns and transmission lines.
3. Ignitron switching system could possibly be simplified.

The disadvantages of the transformer system over the present system are:

1. The power supply must operate near its maximum design rating which will probably result in more ignitron and cooling problems.
2. The transformer of unknown reliability must be introduced in the system.
3. The increased Joule heat load in the horns requires that Horn 2 be water cooled. Cooling of Horn 1 may have to be

increased. New cooling systems will probably have to be developed.

4. The reliability working ignitron switching system will probably have to be modified to accommodate the lower di/dt.

5. The transformer will have to be located in Neuhall and will take up valuable space and be susceptible to radiation damage and inaccessibility during operation.

In conclusion it appears that a good 1 msec horn system can probably be built from the present system with considerable modification. The new system during its early operation would probably be less reliable than the present system because of the increased voltage of the power supply, increased heat load in the horns, additional water cooling of Horn 2 (which is presently air cooled), the extensive modifications to the electronics and the addition of the transformer. These problems can however all be solved in principle.

Transformer systems of this general design are in operation or in various design stages at ANL, Serpukhov and CERN II.

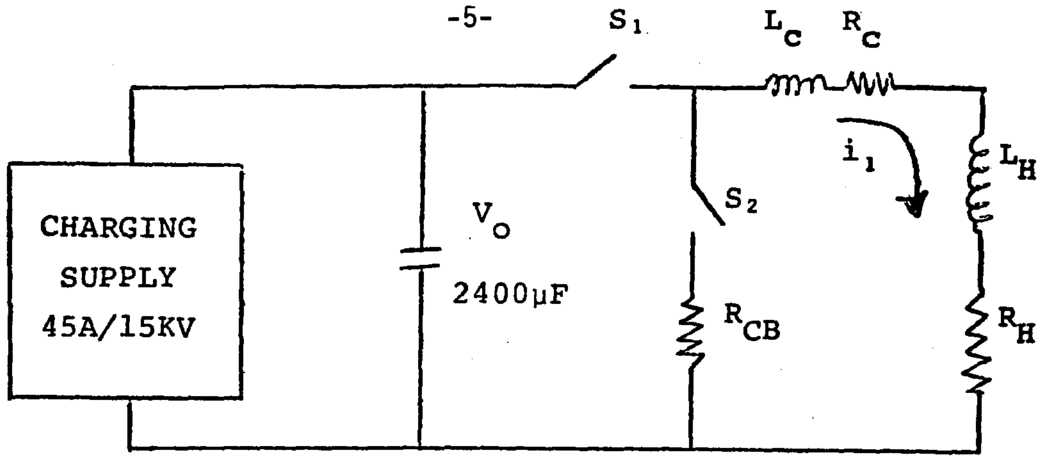
TABLE I

COMPARISON OF THE PRESENT SYSTEM WITH THE TRANSFORMER SYSTEM

	PRESENT SYSTEM	TRANSFORMER SYSTEM*
C(μF)	2400	2400
Peak horn current (KA)	150	150
Peak primary current (KA)	150	9.4
$\tau_{1/4}$ (μsec)	160	2500
Useful spill length for $\frac{\Delta I}{I} \leq \pm 2.5\%$ (μsec)	60	1000
N_1/N_2	-	16
$\delta = \frac{R_t}{4L_t}$	680**	280
$e^{\tau_{1/4}\delta}$	1.12	2.01
Approximate bank voltage (KV)	6.5	>12
Voltage on transmission lines and horns (KV)	6-3	0.75-0.38
Relative heat load in horns from I^2R	1	15

* Calculations based on perfect transformer

** Skin effect in transmission lines



where: S_1, S_2 - ignitrons

R_{CB} - crowbar resistor

L_H - Load inductance (Horn 1 + Horn 2 + transmission line)

R_H - Load resistance (Horn 1 + Horn 2 + transmission line)

L_c - cable inductance to Neuhall

R_c - cable resistance to Neuhall

R_t - $R_H + R_c$

L_t - $L_H + L_c$

For the lightly damped case:

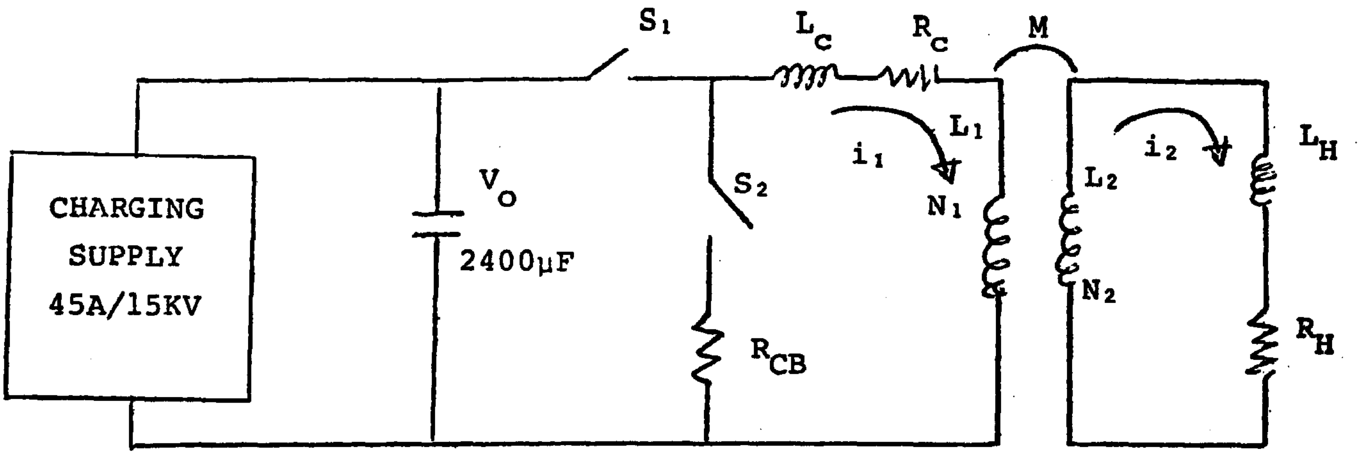
For the current peak $i_1 = V_o \sqrt{\frac{C}{L_t}} \; e^{-\tau_{1/4}\delta}$

where $\delta = \frac{R_t}{4L_t}$

and the current quarter cycle $\tau_{1/4} = \frac{\pi}{2}\sqrt{L_t C}$.

FIGURE 1

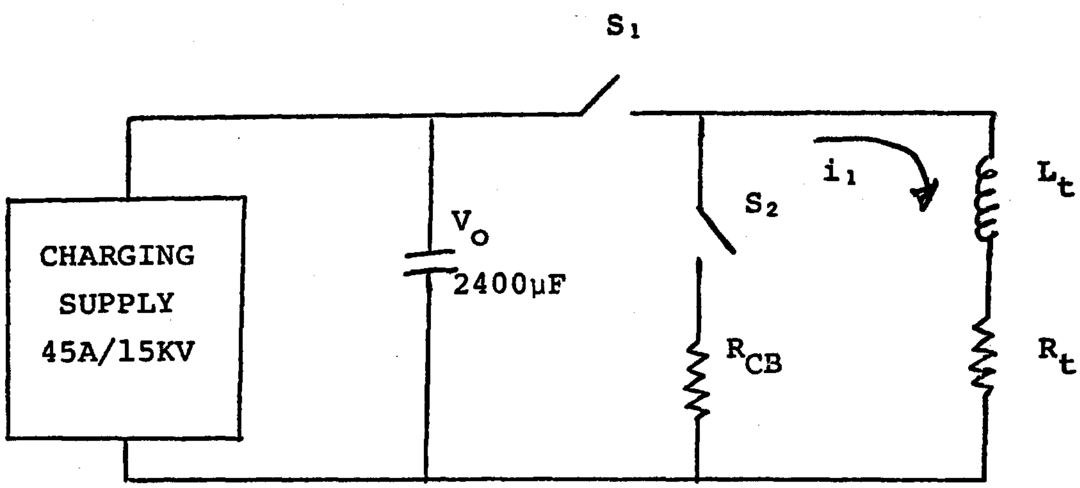
SCHEMATIC OF PRESENT HORN SYSTEM
AND THE RELATED EQUATIONS



where the terms are as in Figure 1 except:

- i_1 - current in the primary circuit
- i_2 - current in the secondary circuit
- L_1, N_1 - inductance and turns for the transformer primary coil
- L_2, N_2 - inductance and turns for the transformer secondary coil
- M - the mutual inductance of the transformer

For a perfect transformer we can make the equivalent circuit:



where: $i_1 = i_2 \frac{N_1}{N_2}$

$$R_t = R_c + \left(\frac{N_1}{N_2}\right)^2 R_H$$

$$L_t = L_c + \left(\frac{N_1}{N_2}\right)^2 L_H$$

For the peak current in load $\quad i_2' \simeq V_o\sqrt{\frac{C}{L_H}} \quad e^{-\tau_{1/4}\delta}$

where $\quad \delta = \frac{R_t}{4L_t}$

and the current quarter cycle

$$\tau_{1/4}' \simeq \frac{\pi}{2}\left(\frac{N_1}{N_2}\right)\sqrt{L_H C}$$

FIGURE 2

SCHEMATIC OF THE HORN SYSTEM USING AN IMPEDANCE MATCHING TRANSFORMER AND THE RELATED EQUATIONS