Fermilab

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RESULTS OF HORN TRANSFORMER STUDIES TO PROVIDE A ONE MILLISECOND HORN PULSE

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Introduction

Considerable interest has been shown in expanding the horn current pulse width from the existing 40 microseconds to 1 millisecond. The technique considered here to provide this longer pulse requires the introduction of an high current transformer into the existing horn power supply system.

The Existing Horn System

Figure 1 shows the present short pulse system in simplified schematic form with Figure 2 showing the calculated wave shape for this system and the known circuit component values. The dotted line on Figure 1 represents the dividing line between the power supply enclosure and the target hall.

Due to the complications of the actual component layout and without making extensive system modifications, the only appropriate location for a transformer is in the target hall at the termination of the RG-220 cables and preceding the strip line which is installed on the Neutrino Train. The schematic of this system is shown in Figure 3. Figures 4,5,6, and 7 show the calculated wave-shapes for this system for different turns ratios. The parameters take into account the change in the system natural frequency with its consequent effect on the strip line parameters (largely due to skin effect).

In preparing a specification to procure a transformer for this purpose, estimates and calculations were made to determine the limits of the various circuit parameters. The results of these determinations are covered in detail in the specification prepared for obtaining bids (see Proposal #N1016-752V), the most significant of which are discussed below.

In general, the specification called for an laminated iron core transformer (Silectron or equivalent) that would maintain a six millisecond pulse (square wave equivalent) once each three seconds. Primary taps of A = 24, 28, and 32 are to be available to permit close matching to the circuit requirements. The transformer primary requirements call for a maximum voltage and current of 15 KV and 10 KA respectively to provide a maximum secondary voltage and current of 1 KV and 200 KA (these are absolute maximums). The total stray inductance and resistance referred to the primary was to be limited to 150 microhenries and 75 milliohm. The core size was limited by the space constraints in the target hall. This size limitation coupled with the core characteristics necessitated introducing an inductor for reseting the core between pulses. The exposure to radiation required radiation resistant insulation material through the transformer and reset inductor.

With these basic ideas in mind, the specification was prepared and submitted to a fairly large number of vendors, 33 in total. Of these, only three showed interest and made bids. It was also learned that CERN was attempting to procure a transformer for their horn system. Negotiations were started with their vendor to obtain a bid to procure a transformer of their design. Table 1 is a summary of each of the bids.

SUMMARY

Considerable insight into this entire problem has been gained by information from CERN. CERN has chosen the transformer technique for pulse width increase and has had considerable difficulty in obtaining a transformer based upon their design. Their original vendor failed to deliver and their second vendor has just delivered (some four months later than the original delivery date).

Also, two of the U.S. bids were extremely weak, i.e., no real design effort had been expended and none would be until a firm contract had been placed.

For a transformer of this size to be installed, a large number of other costs would be incurred. These costs include power supply modifications to permit higher voltage, lower current operation, equipment to install the transformer, reset the transformer core, etc. These costs were reviewed two ways; 1) A minimum cost system (CERN type transformer, 12 KV max bank voltage); and 2) A higher voltage system (CERN type transformer, 20 KV max bank voltage, to permit 200 KA operation). This is summarized in Table 2 and 3. Figure 8 is a sketch of the CERN design transformer.

TABLE 1

Vendor	TRANSFORMER Cost of One	TRANSFORMER Cost of Two	Spare Coil Cost	REMARKS
Gauss Control, Inc. Mountain View, California	144,000	98,750	38,900	Very Small Business No detailed design until contract is awarded (6-7 months)
Greensboro Transformer and Machinery Corp. College Point, New York	106,210	87,600	22,950	No detailed design until contract is awarded (9 months)
Magnetic Pulse Technology, Inc. Anaheim, California	237,844.21	217,422.11	107,725	Fairly detailed preliminary design Single turn secondary may be a serious problem (7 months)
Thrige-Titan Odense/DENMARK (See Tables 2 & 3)	54,023 (+)	---	---	Does not include: Isolation inductor ~10 k Shipping, Customs, etc., ~5 k May not include copper ~5 k Based completely upon CERN design turns ratios - N=24, 28, 32 End connections must be modified ~15k →Total Extra ~ 35 k (40 weeks)

TABLE 2

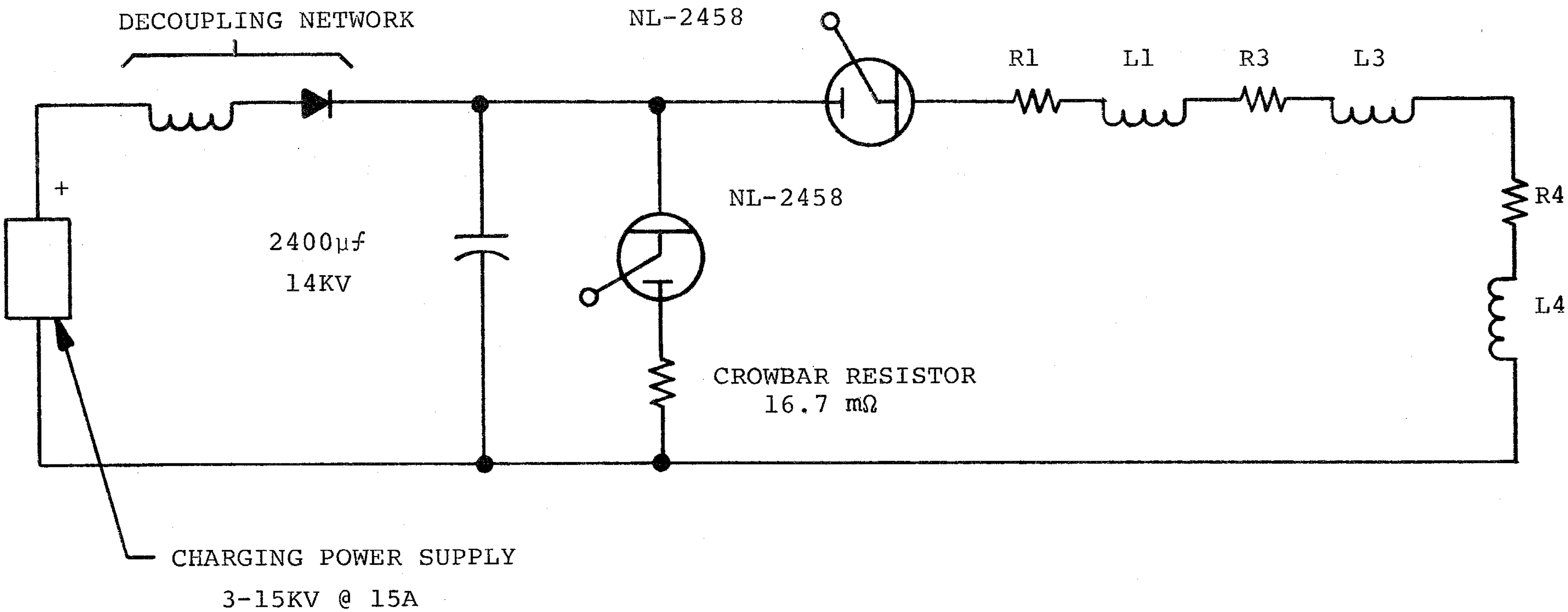
Horn Transformer Summary - Minimum System

Transformer (CERN Design)	
Vendor: Thrige-Titan, Odense/Denmark	55 k
Shipping, Customs, etc.	5 k
Core Reset Inductor	10 k
End Connection Modifications	15 k
Winding Copper (may not be required)	5 k
Interlocks, Protection, etc.	5 k
Total Transformer --------	95 k
Pulsed Power Supply (for $\leq$ 14 KV)	
High Voltage Ignitrons	30 k
New Trigger Transformers	5 k
Miscellaneous Monitoring Equipment	10 k
Ignitron Mounting Modifications	10 k
Total Power Supply --------	55 k
Target Hall	
Transformer Bedplate	7 k
Track/Switches	15 k
Transformer H_2O and Electrical Connections	15 k
Total Target Hall ---------	37 k
Transformer Reset Power Supply, Interlock, Controls, etc.	10 k
GRAND TOTAL	197 k

TABLE 3

Estimated Costs 20 KV Transformer System

Transformer (CERN Design)	
Vendor: Thrige-Titan, Odense/Denmark	55 k
Shipping, Customs, etc.	5 k
End connection Modifications	15 k
Core Reset Inductor	10 k
Winding Copper (may not be required)	5 k
Interlock, Protection, etc.	5 k
Total Transformer -----------	95 k
Pulsed Power Supply (for > 14 KV)	
High Voltage Ignitrons	30 k
High Voltage Capacitors	60 k
20 KV Power Supplies	90 k
Trigger Transformers	5 k
Monitoring Equipment	10 k
Total Power Supply ----------	195 k
Target Hall	
Transformer Bedplate	7 k
Track/Switches	15 k
Transformer H_2O and Electrical Connections	15 k
Total Target Hall	37 k
Transformer Reset Power Supply, Interlocks, Controls, etc.	10 k
GRAND TOTAL	337 k



$R_1 = 9 \times 10^{-4}\ \Omega$ = RG-220 cable resistance

$L_1 = 2 \times 10^{-7}$ H = RG-220 cable inductance

$R_3 = 4 \times 10^{-3}\ \Omega$ = Strip transmission line resistance

$L_3 = 9 \times 10^{-7}$ H = Strip transmission line inductance

$R_4 = 1 \times 10^{-3}\ \Omega$ = Horn load resistance

$L_4 = 2.9 \times 10^{-6}$ H = Horn load inductance

$C = 2.4 \times 10^{-3}$ F = Bank capacitance

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Figure 1

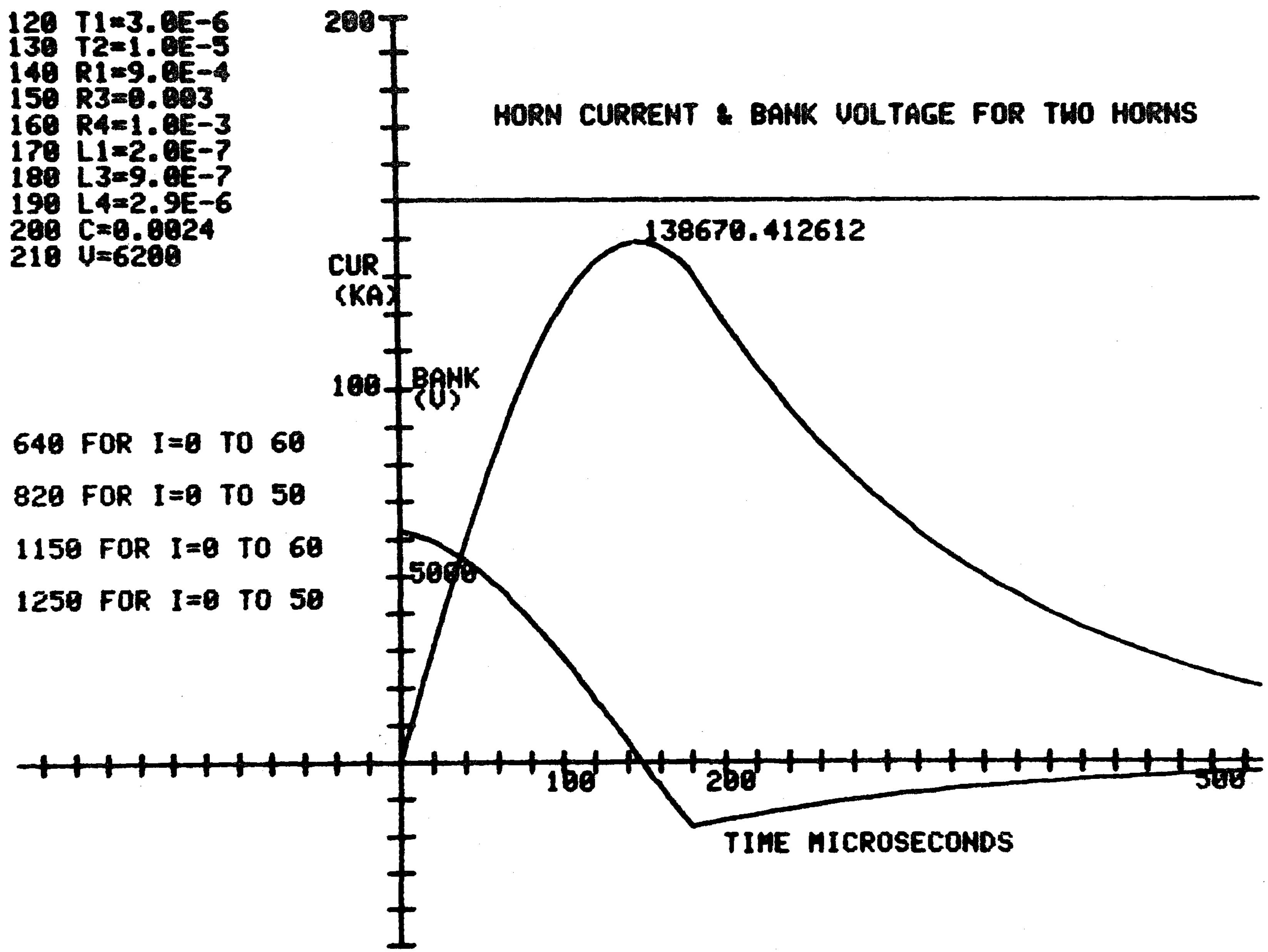

Figure 2

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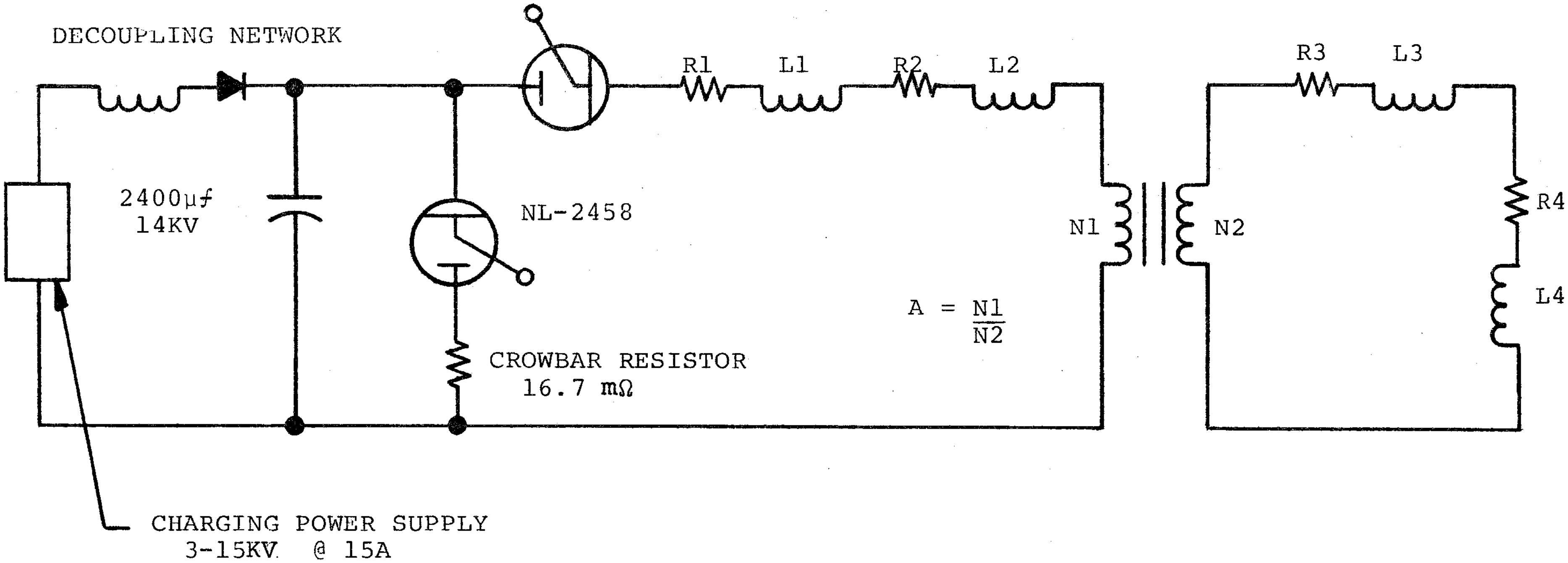

$R_1 = 9 \times 10^{-4}\,\Omega$ = RG 220 cable resistance

$L_1 = 2 \times 10^{-7}$ H = RG 220 cable inductance

$R_2 = Rp + A^2 Rs = 75 \times 10^{-3}\,\Omega$ = transformer resistance

$L_2 = Lp + A^2 Ls = 5 \times 10^{-4}$ H = transformer inductance

$R_3 = 5 \times 10^{-4}\,\Omega$ = strip transmission line resistance

$L_3 = 9 \times 10^{-7}$ H = strip transmission line inductance

$R_4 = 1 \times 10^{-3}\,\Omega$ = Horn load resistance

$L_4 = 2.9 \times 10^{-6}$ H = Horn load inductance

$C = 2.4 \times 10^{-3}$ F = Bank capacitance

$N_1/N_2 = A$ = Transformer turns ratio

Figure 3

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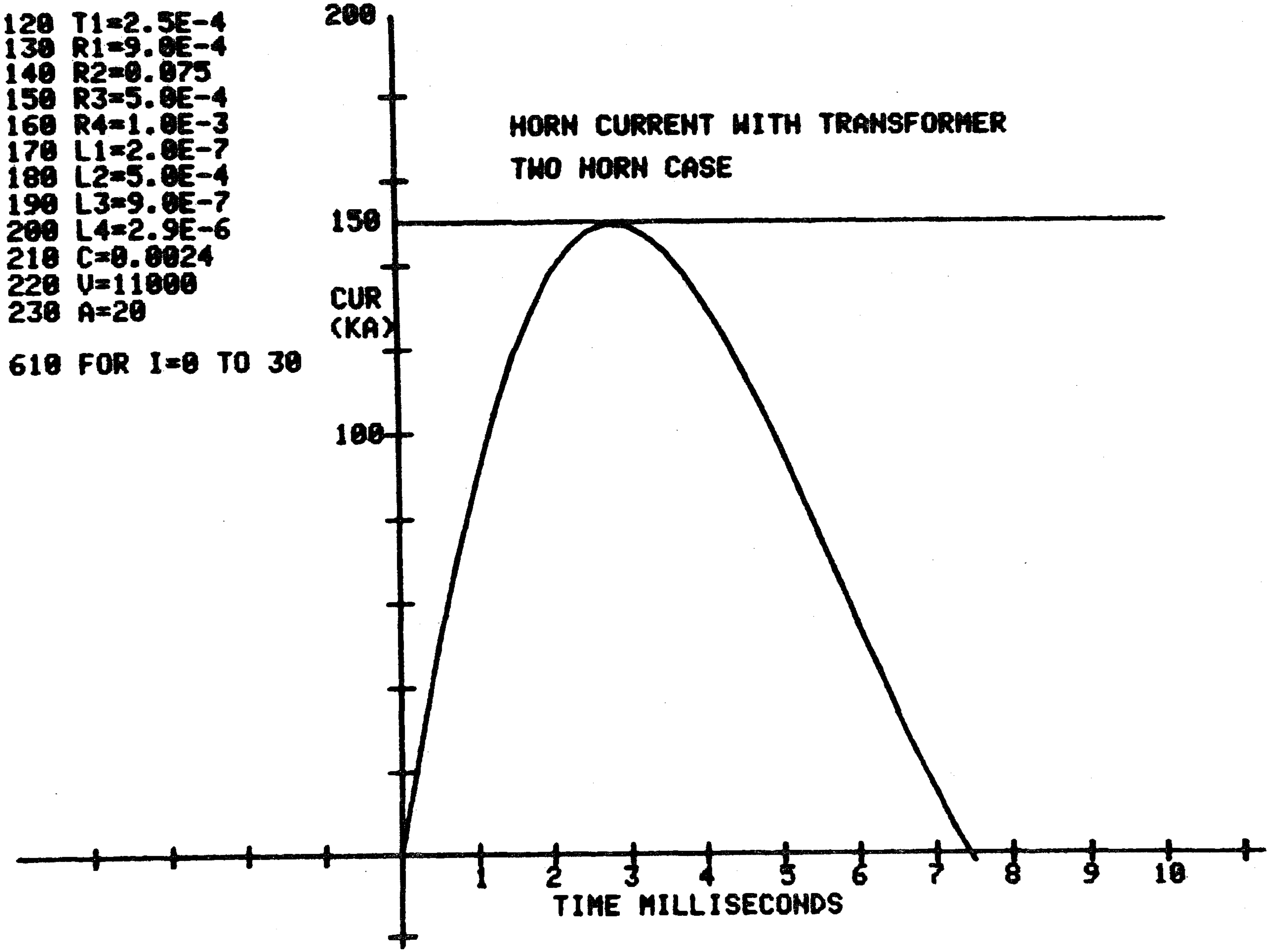

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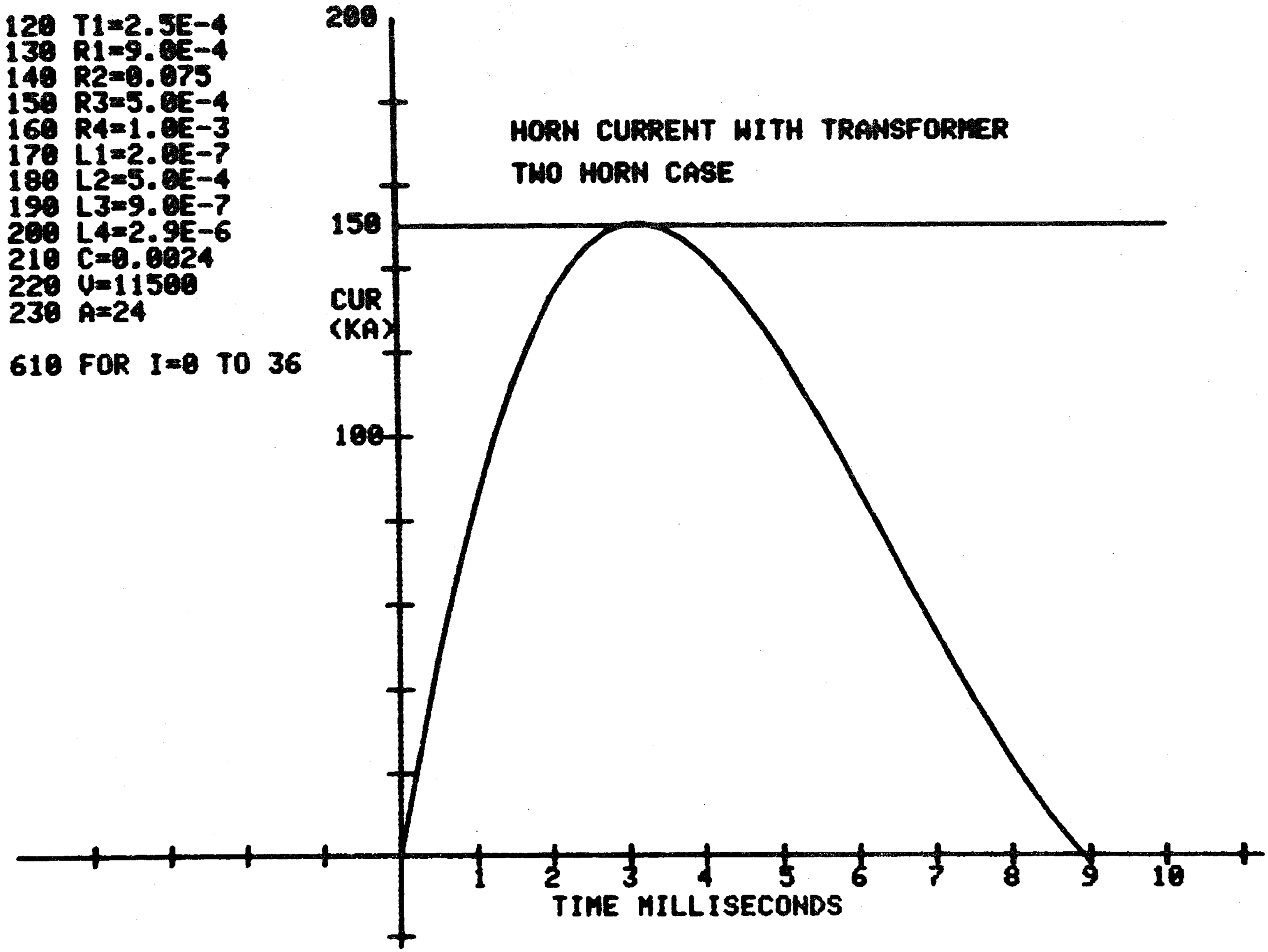
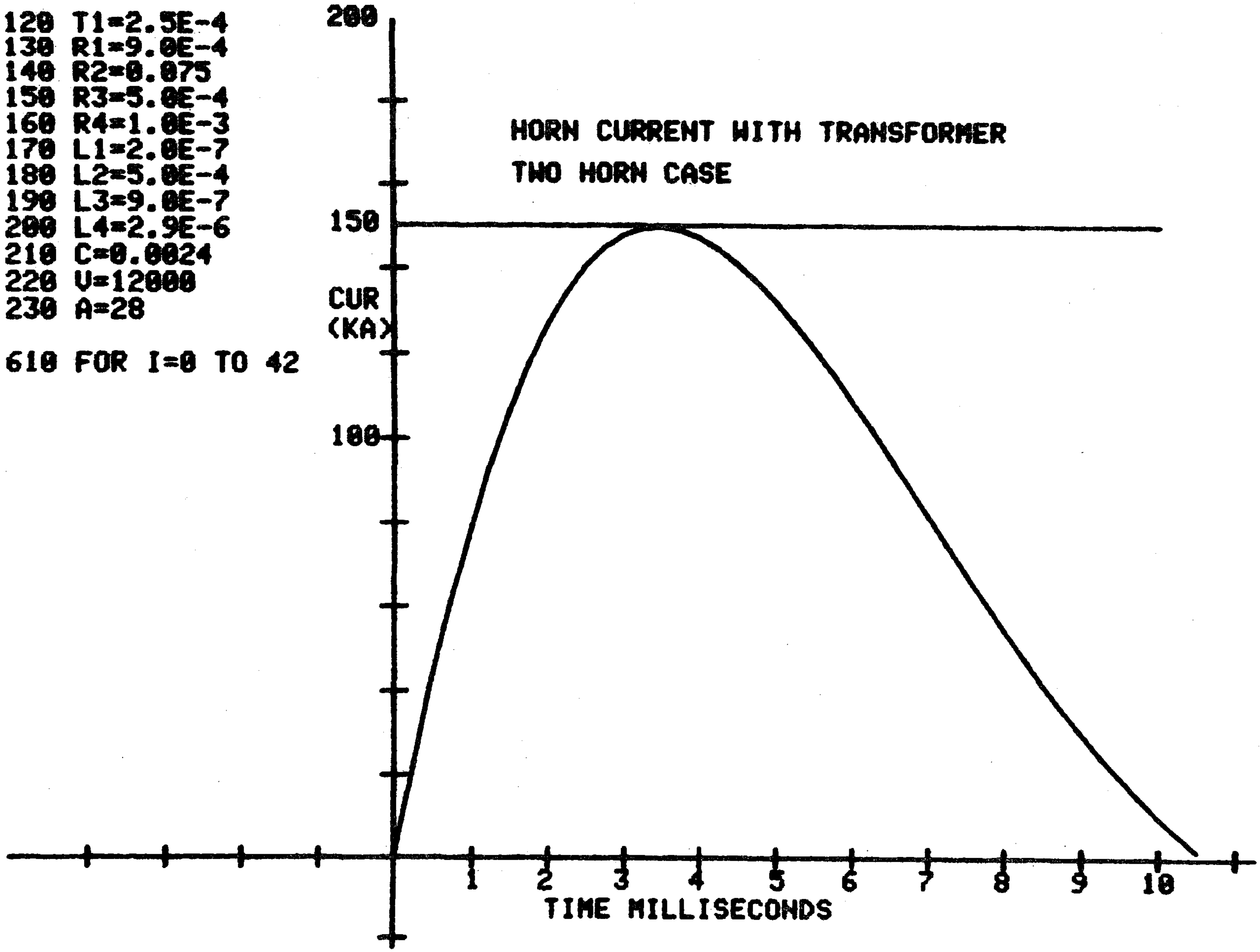

120 T1=2.5E-4
130 R1=9.0E-4
140 R2=0.075
150 R3=5.0E-4
160 R4=1.0E-3
170 L1=2.0E-7
180 L2=5.0E-4
190 L3=9.0E-7
200 L4=2.9E-6
210 C=0.0024
220 V=11500
230 A=24
610 FOR I=0 TO 36
200
150
100
CUR
(KA)
HORN CURRENT WITH TRANSFORMER
TWO HORN CASE
1
2
3
4
5
6
7
8
9
10
TIME MILLISECONDS

Figure 5



Figure

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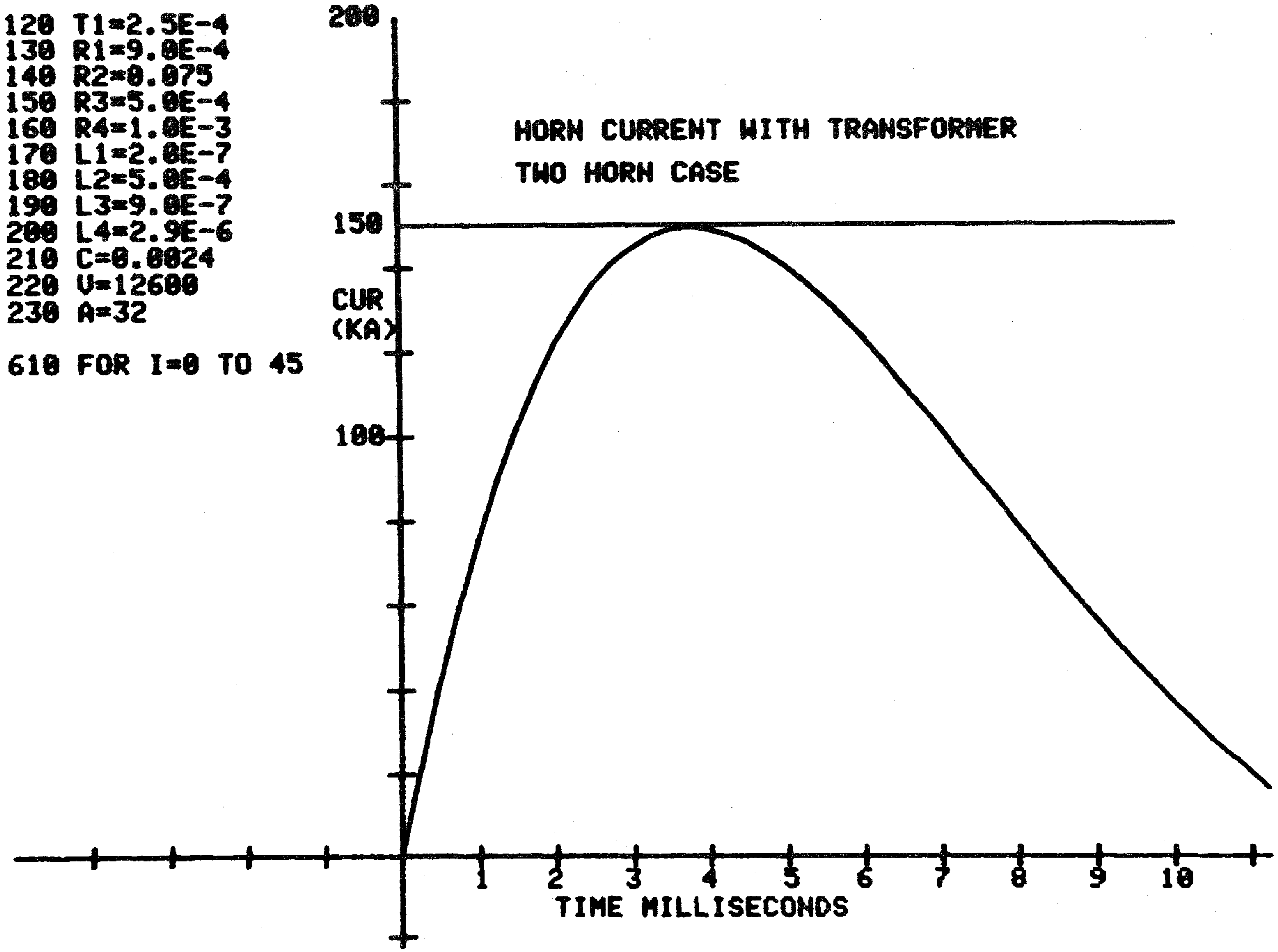

Figure 7

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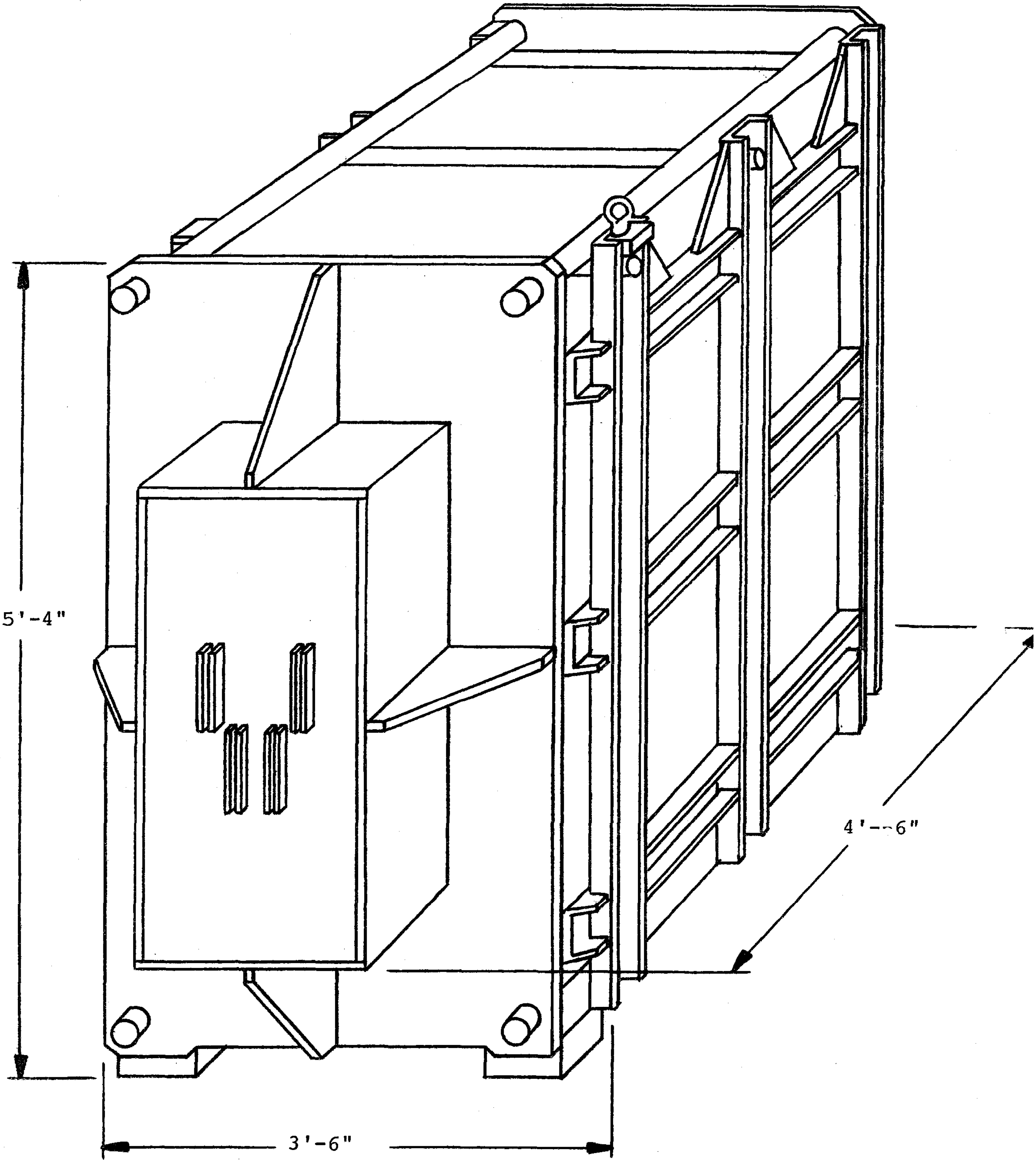

CERN PULSE TRANSFORMER

Figure 8