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# A SHORT-CUT TO ACCURATE DIMMER CHOKE DESIGN

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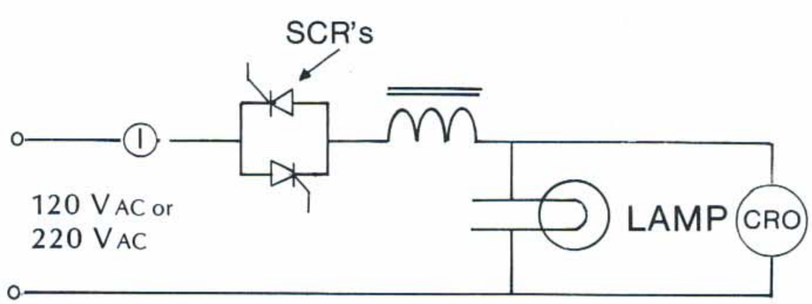
# INTRODUCTION

**To undertake the correct design of inductors for controlling slew rate and rise time in thyristor phase controlled circuits, would normally require extensive calculations and an in-depth knowledge of magnetics theory, for instance, understanding how to derive certain pertinent design data from very antiquated curves, and much more. To greatly simplify this, an easy graphical method has been created by Amecon's engineering staff, to execute many designs rapidly and accurately. This simple method has been developed to aid the expert as well as the novice designer, engineer, specifier and stage technician in determining the various necessary parameters of an inductor, totally eliminating the need for time consuming and rigorous mathematical analysis.**

*WHY A DIMMER INDUCTOR ...*

When an AC dimmer is controlling a lamp, the lamps filament produces a noise known as "singing" or "buzzing". This arises because a dimmer does not control the voltage applied to the lamp evenly at all times, instead it chops off parts of the sinusoidal applied voltage, known as phase controlling of the line voltage, leaving it with regions of very rapid current changes generating a wide band of frequencies. These frequencies also create EMI/RFI noise. Both of the described phenomena are unacceptable. An easy and widely used practice to remedy this situation is by simply inserting an inductor in the dimmer circuit. The primary function of the inductor is to limit the rate at which the current is increasing to, in effect, slow it down and smooth it out. This will greatly reduce the electrical shock imparted on the lamp's filament, which inturn creates the noise, due to mechanical resonances. We must keep in mind that when the inductor is correctly designed it will not only reduce the filament's singing to acceptable levels, it will also practically eliminate the EMI/RFI noise and will serve as a current limiter to keep the SCR's or SSR's from burning out under short circuit conditions. By all means this is not a small advantage in promoting higher reliability in a dimmer. One figure of merit for an inductor is known as the inductor's "Rise Time", this is defined as the time taken by the current to rise from 10% to 90% of its peak value when the dimmer's firing angle is set at exactly the one half power point, that is 90° firing, with the inductor in the circuit. The performance of an inductor may also be characterized by its ability to limit the current rise, di/dt. This property, known, as the slew rate, is more directly related to lamp filament noise, although the rise time "Tr" is more often specified because of its ease of measurement. Fig. #1 shows a typical lighting dimmer circuit. The on time of the SCR's or SSR's is controlled by an external circuit, known as driver, and can be adjusted from 0° (Full Power On, see fig. 2a) to 180 electrical degrees (Power Off Point). The largest current rise occurs at the 90° firing angle. Fig. 2c is an expanded profile of current as seen by an oscilloscope and fig. 2d is the current profile when the inductor is placed in the circuit. The tangent to the steepest portion of the curve is the maximum rate of current rise or slew rate, identified by di/dt, also shown is the rise time Tr for the current as it increases from 10% to 90% of its peak value.

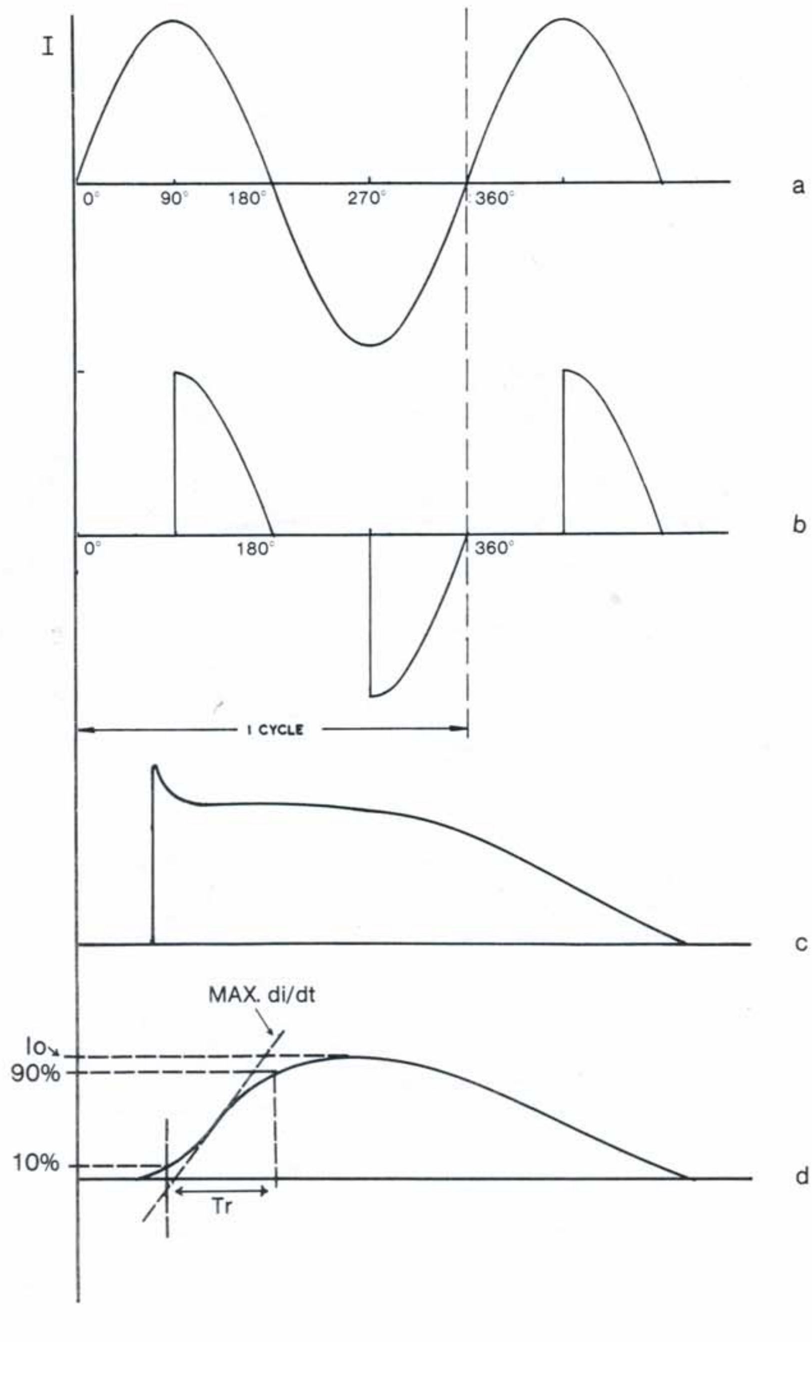
FIG. 1



Provided that the current rise is fairly linear (i.e. increasing at a smooth and gradual rate). A rise time of 300 to 500 $\mu s$ will often produce fairly acceptable results, although this will not get rid of all of the noise which is causing lamp filament vibrations.

In order to accomplish this feat, inductors in the area of 900 to 1400 $\mu s$ will be necessary. Should our long coming, and newly arrived, ultra-low noise material be used, then 750 to 950 $\mu s$ will be sufficient.

FIG. 2



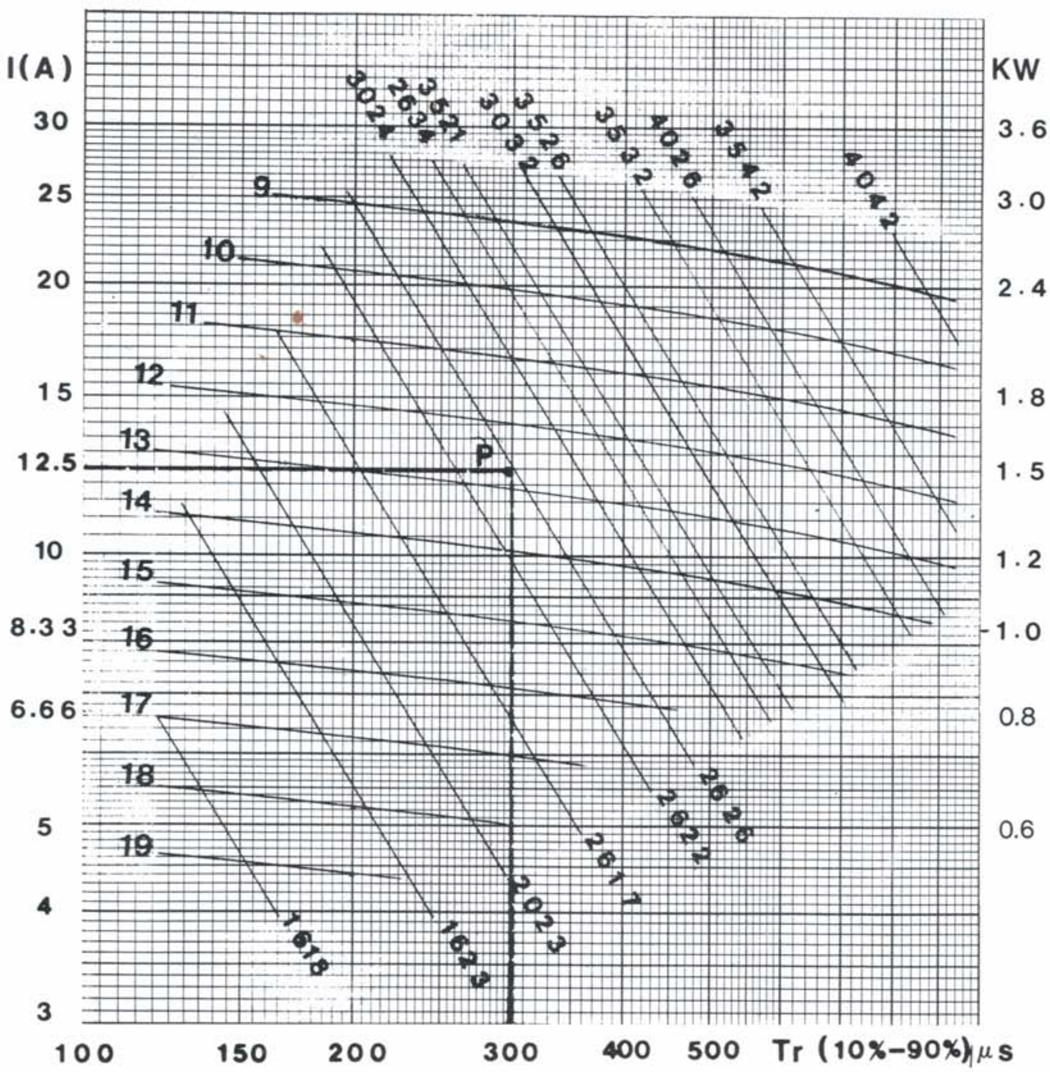
*DESIGN PROCEDURE FOR THE INDUCTORS:*

Simple as 1, 2, 3 . . . the selection of the inductor will depend on the required mechanical dimensions, the current handling capacity, the cooling medium used, maximum allowable temperature, and the rise time required as well as the extremely important "SLEW RATE." The latter a considerably more difficult quantity to define. Fig. #3 facilitates a fast method for determining the right inductor to meet the requirements for a given application. The vertical axis represent the RMS value of the load current and the horizontal axis represent the rise time with the SCR's switching at the 90° point, also known as the 1/2 power point. The horizontal lines represent wire gages and the inclined lines indicate cores (shown in Table I.). The required inductor may then be selected using the following three steps.

1. Locate the point "P" where the required rise time Tr ($\mu s$) and the full load current I (A) meet.
2. Locate the nearest core/wire intersection to the right of this point.
3. The inductor designed from 1 and 2 above will operate at a temperature of 70°C above ambient. Changing one wire gage in either direction will change the temperature by about 15°C.
   *DESIGN EXAMPLE:* Lets design an inductor for 12.5 A (1500 Watts) having a rise time of 300 $\mu s$.

   1: The I/Tr intersection point is denoted by "P" and is shown on Fig. 3.

FIG. 3



2: The nearest core/wire intersection to the right of IP is core number 2626 and wire gage 13. This choke would have a rise time of 310 $\mu s$ and operate at a $\Delta t$ of 75°C (convection cooled) with an 11.8 Amps load, at 12.5 AMPS, the temperature rise would rise to about 80°C.

3: For a hotter unit core 2622 (smaller and less expensive) can be chosen with 2 layers of #14 gage wire. This would result in a rise time of 300 $\mu s$. The vertical distance from the 2622/14 intersection to point "P" is about 1 ⅓ wire sizes, representing a temperature rise of $75° + (15° \times 4/3) = 95°C$ over ambient. Similarly, core 3024 (larger and more expensive) with #12 gage wire would exhibit a rise time equal to 335 $\mu s$, and be at a vertical distance of 2/3 wire sizes from the original design point. The temperature would then be $75° - (15° \times 2/3) = 65°C$ over ambient.

*DETERMINATION OF RISE TIME*
*"Tr AND THE MAXIMUM SLEW RATE "di/dt" OF INDUCTORS USED*
*IN PHASE-CONTROLLED SWITCHING CIRCUITS.*

When an inductor is not driven excessively, (i.e. is not reaching its saturating regions too quickly after firing of the thyristors) then the load current rise is uniform and the slew-rate (di/dt) will be inversly proportional to the rise time "Tr." Incidentally, if it were possible to maintain this condition constant over a wide range of loads, then we would have created an optimum compensating network for the lamp filament vibrations. This would result in extremely low lamp and fixture noise. Our series 59, 49 and 39 chokes have approached this capability. With present technology great savings can be realized by building a more efficient AC dimmer-pack which will rival it's DC counterpart on *QUIETNESS!!!*

The value of Tr (rise time) for a given core can be determined from the curve in Fig. 4 by using the following three setps:

FIG. 4

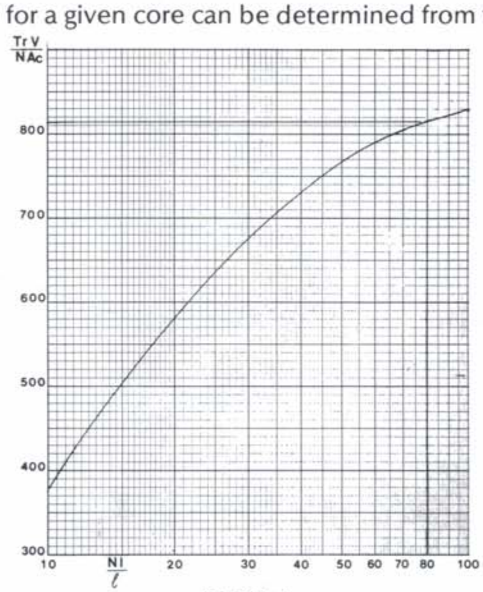



TABLE I

| CORE # | ℓ(cm) | Ac (in²) | CORE # | ℓ(cm) | Ac (in²) |
|---|---|---|---|---|---|
| 1618 | 10.10 | 0.177 | 3532 | 22.44 | 0.688 |
| 1623 | 10.10 | 0.221 | 4026 | 24.94 | 0.700 |
| 2023 | 12.97 | 0.267 | 4032 | 24.94 | 0.875 |
| 2617 | 16.61 | 0.275 | 3542 | 22.44 | 0.894 |
| 2622 | 16.61 | 0.356 | 3056 | 19.82 | 0.971 |
| 2626 | 16.61 | 0.414 | 3552 | 22.44 | 1.100 |
| 3024 | 19.82 | 0.416 | 4042 | 24.94 | 1.138 |
| 2634 | 16.61 | 0.550 | 4052 | 24.94 | 1.422 |
| 3521 | 22.44 | 0.447 | 4058 | 24.94 | 1.575 |
| 3032 | 19.82 | 0.555 | 4063 | 24.94 | 1.706 |
| 3526 | 22.44 | 0.550 | 4067 | 24.94 | 1.846 |

1. Determine the value of NI/$\ell$ for the inductor, where
   N=Number of turns of the magnet wire
   I=RMS current in amperes
   $\ell$=Means magnetic path length in cm (see table I)
2. Read off the value of TrV/NAc corresponding to NI/$\ell$ from fig. 4 where:
   V=Line voltage
   Ac=Core cross sectional area in $inch^2$
3. The rise time is given by:
   $Tr=\frac{NAc}{V} \times$ (The value of $\frac{TrV}{NAc}$ as read off the curve.)

EXAMPLE: Determine the rise time of an inductor having the following parameters:

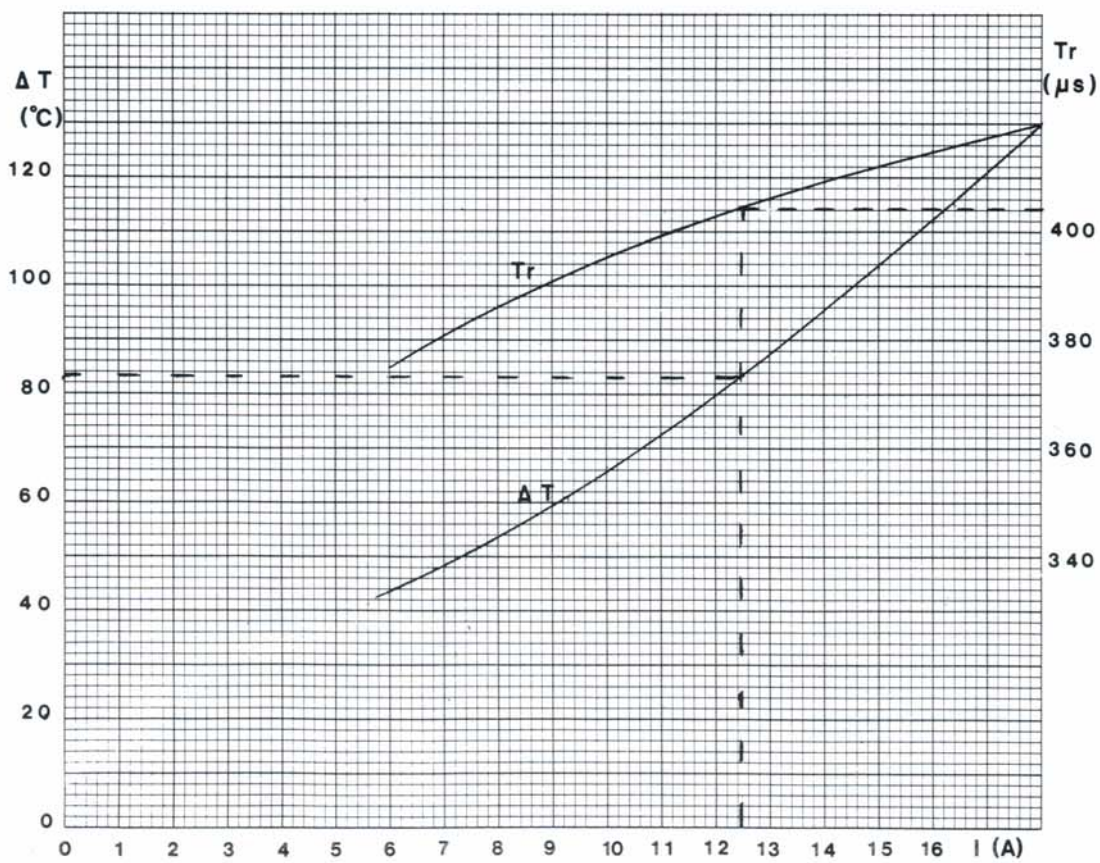
Ac=0.7 $in^2$
$\ell$=25 cm core #40XX
N=100 Turns
V=120 Volts RMS
I=20 AMPS RMS

1. $\frac{NI}{\ell} = \frac{100 \times 20}{25} = 80$
2. From the curve, $(TrV) = \frac{815}{NAc}$
3. $Tr = 815\ (NAc) = \frac{475}{V}\ \mu s$

*THE INTERDEPENDENCE OF THE DECIDING PARAMETERS*

Temperature-rise Δt *vs* rise time Tr *vs* load current $I_L$. Fig. 5 shows two curves relating the inductor temperature-rise Δt over ambient, and Tr to the load current $I_L$ for an inductor designed for 12.5 Amps.

FIG. 5



The Rise time is given by the curve denoted Tr showing a value of 404 $\mu s$ and the temperature is given by the curve identified by the left vertical scale corresponding to 82°C rise above ambient for the given current.

*240 VOLTS 50 Hz INDUCTORS*

Inductors behave differently at different voltages and must therefore be designed specifically for the line voltage used. Fig. 6 shows the Rise-Time Temperature curve for various core/wire combinations intended for 240 Volts operation. The instructions are the same as for the 120 V version. Fig. 7 shows the variations in $\Delta t$ and Tr with I for the 3526 core with #15 wire ga. at 240 V. line voltage.

FIG. 6

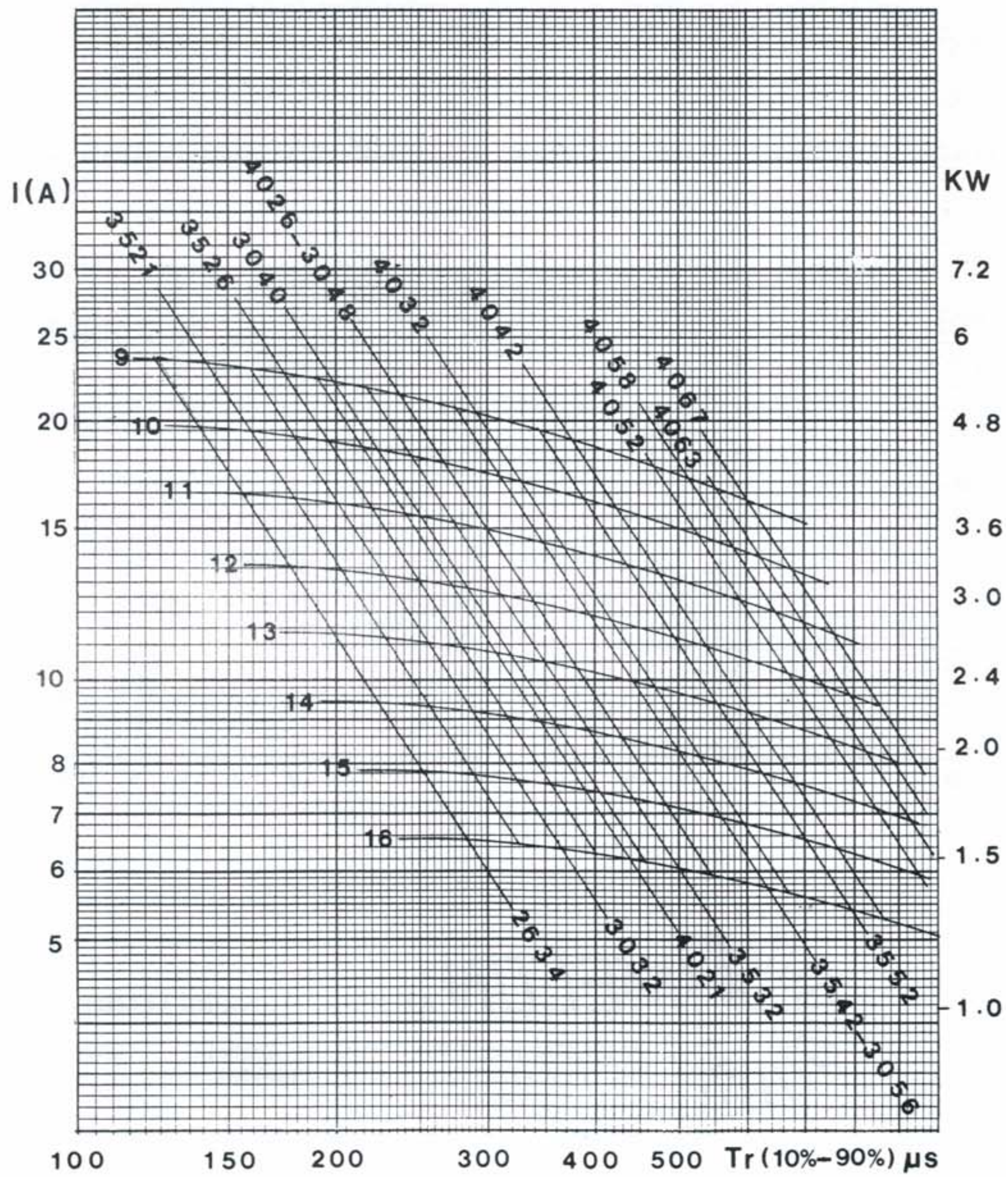
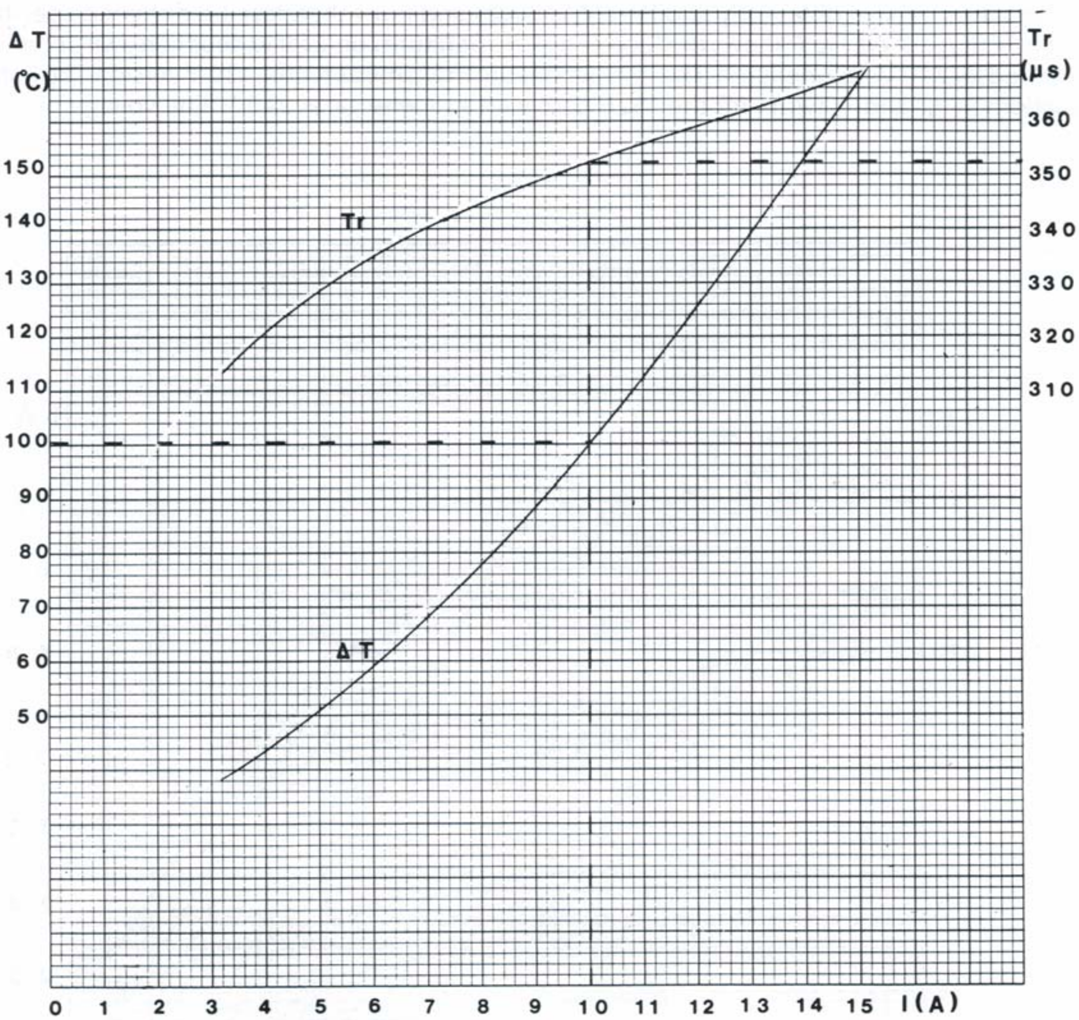


FIG. 7



Δ T
(°C)
150
140
130
120
110
100
90
80
70
60
50
Tr
(μs)
360
350
340
330
320
310
Tr
Δ T
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
I (A)