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APPENDICES

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Appendix A

MAGNETIC AMPLIFIER NOTATION

A	Core cross-sectional area
B	Magnetic flux density
E	A-c supply voltage
f	Frequency of the a-c supply voltage
H	Magnetizing force or magnetic intensity
I	Current
I_B	Current in the bias winding
I_C	Current in the control winding
I_F	Current in the feedback winding
I_{LO}	Quiescent or standing current
K_I	Current gain
K_P	Power gain
l	Mean length of the core
L	Inductance
μ	Permeability of a medium
N	Number of turns in a conductor
N_B	Number of turns in the bias winding
N_C	Number of turns in the control (input) winding
N_F	Number of turns in the feedback winding
N_L	Number of turns in the load (output) winding

ϕ	Magnetic flux
R	Resistance
R_C	Resistance of the control circuit
R_L	Load resistance
SX	Saturable reactor
X_l	Inductive reactance
Z	Impedance

Appendix B

CORE AND COIL ASSEMBLIES

Core Construction of Saturable Reactors.

For optimum performance, the structure of magnetic-amplifier cores should have the following characteristics:

1. Effective air gap as small as possible, in order not to shear over the hysteresis loop

2. Spirally wound tape-core construction with loose-fitting insulated container to support the multilayer toroidal windings, when grain oreinted rectangular-hysteresis-loop material are used

3 Very thin laminations or tape (e.g., 0.001 to 0.003 in. only, or even less), to reduce eddy-current effects to a minimum

In general, the cores of reactors designed for single-phase applications may be subdivided according to their construction as follows:

a. Toroids or ring cores
    1. Stacked cores
    2. Spiral cores
b. Rectangular cores
    1. Stacked cores
    2. Spiral cores

Ring Cores (Toroids)

1. Stacked Cores

This core is a stack of washer-shaped laminations, that is, flat circular-shaped laminations with a concentric circular opening in the center (Fig B1). The coil is toroidally wound over this core. The core material for this type of

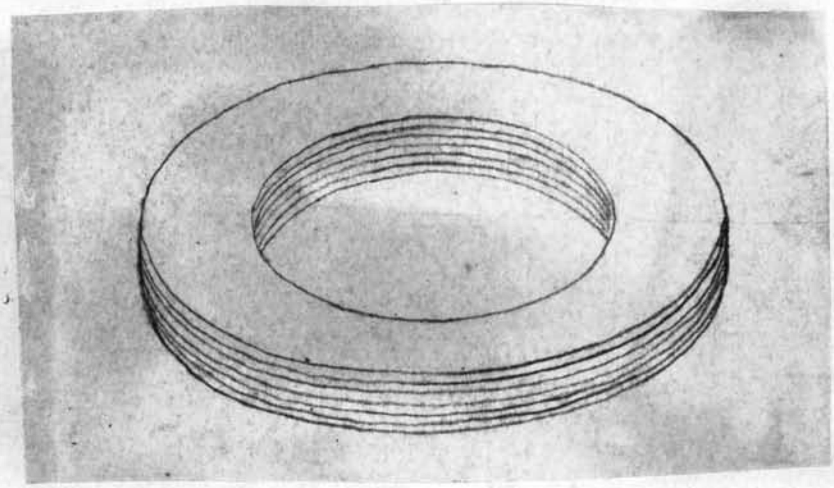


Fig.B1 Laminations of a stacked ring core.

construction is preferably nondirectional in magnetic characteristic.

2. Spiral Cores

For grain-oriented core materials, wound cores are used. The round spiral core of Fig. B2.is similar in external shape to the stacked ring core of Fig. B1. The core is made by winding a tight spiral from a strip of core material. If grain orientation is present in the core material and the direction of orientation is parallel to the long side of the strip, the best qualities of the core materials can be utilized.

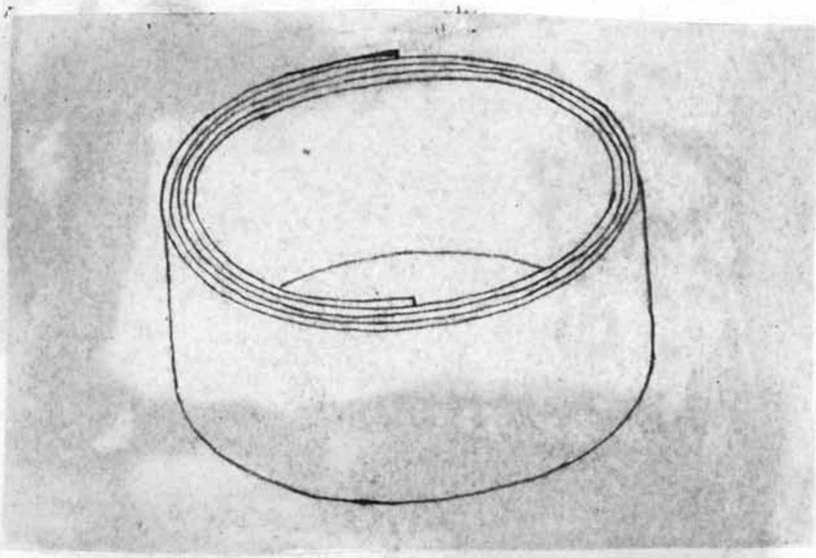


Fig. B2. Circular spiral core.

Rectangular Cores

1. Stacked Cores

The stacked rectangular core consists of rectangular laminations, which may be arranged in UI fashion. To understand the derivation of the "UI" terminology, consider the uncut piece of core material illustrated in Fig. B3(a). If a bar of the metal is stamped out along the dotted lines in Fig.B3(b), the two UI-shape pieces of material shown in Fig. B3(c) result. If,now, these two pieces are arranged as in Fig. B3(d), and are joined along their junction, a rectangular lamination is produced. Rectangular laminations are preferred because they permit the coils to be wound on the straight arbor of a standard high-speed winding machine. In order to maintain

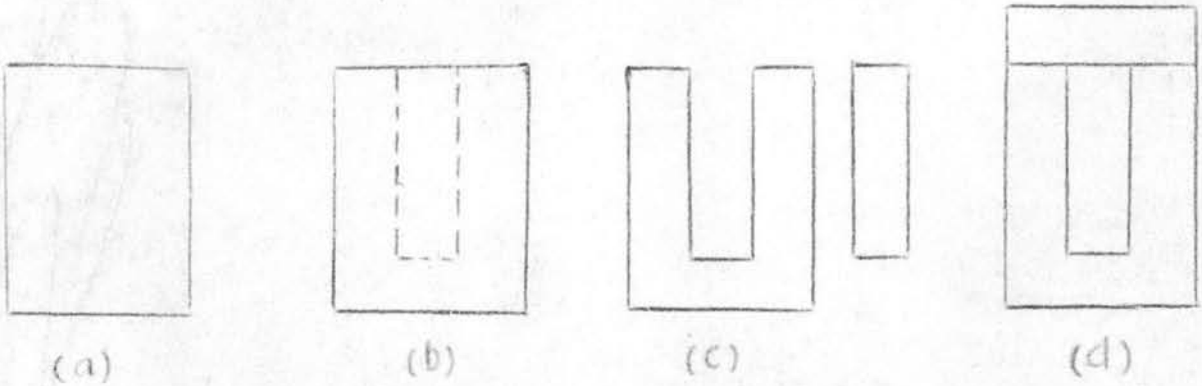


Fig. B3. Procedural steps in the construction of a UI rectangular lamination.

a uniform flux density throughout all regions of the core, the rectangular UI laminations are alternated throughout the core. Thus, for the first lamination, the I is placed in a given position (at the top of the U,as in Fig. B3(d)).The next lamination is placed with the I portion in the opposite direction (Fig. B3(d) reverse, with the I section on the bottom). In this manner, the laminations are alternated throughout the height of the core.

The stacked rectangular core may also be constructed in EI fashion, as illustrated in steps (a) through (d), Fig. B4. The core material is stamped to produce E and I pieces, which are then joined together to form a three-legged rectangular lamination. these laminations, too, are alternated to produce a constant flux density throughout the core.

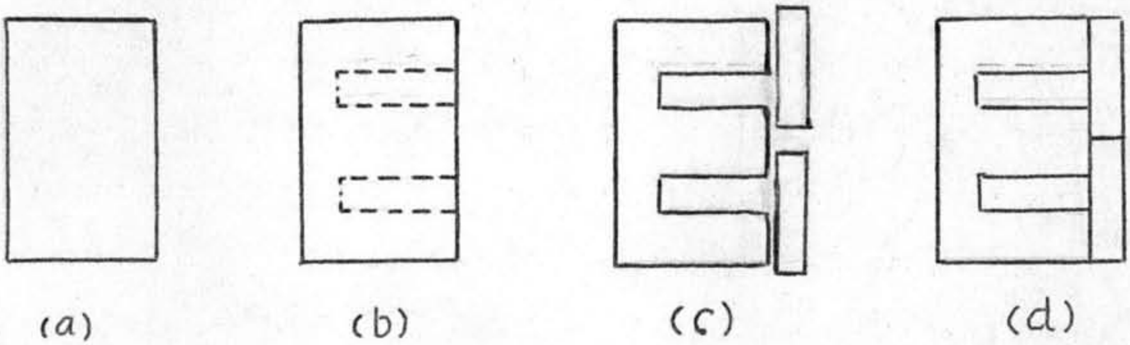


Fig. B4. Procedural steps in the construction of an EI rectangular lamination.

The spiral rectangular core is constructed in much the same manner as the spiral toroidal core, except that the strip of material is wound in rectangular, rather than spiral, form. The spiral configuration is preferred where high, consistent performance of the magnetic amplifier is essential. The is, in part, due to the fact that the tape wound core can be readily fabricated in very thin gauges of fixed thickness. The stacked core, on the other hand, must be made from carefully punched laminations which cannot be assembled after anneal, for fear of straining the core material.

Three-phase reactors can be produced in any of several ways. The most common method is by placing on top of each other three spiral toroidal cores, each having one load winding.

The control winding is wound around the three cores. The result is a three-phase assembly. In another type of constrution, three rectangular cores, each with its own load winding, are placed in a Y relationship. The control winding is placed over each of the load windings. Again, the final assembly is a three-phase reactor.

Other reactors with variations of the basic arrangements described in this appendix may be encountered in the magnetic-amplifier field. In all cases, however, the arrangements are an attempt to obtain a device with a small, inexpensive core, an optimum efficiency consistent with an allowable temperature rise, and low magnetic leakage.

Arrangement of Windings.

The performance of magnetically controlled saturable-reactor devices depends to a considerable extent on the arrangement of the various windings operating as load windings, control windings,bias windings, feedback windings, or as additional windings for special purposes. It is generally desirable that all the windings be placed on the core construction in such a way that leakage effects are reduced to a minimum. Another most important requirement consists in preventing the circulation of disturbing the alternating currents of fundamental frequency in d-c control, bias, and feedback circuits. Such currents may be induced in these circuits by transformer action from a-c components of currents flowing through the load windings.

Circulation of fundamental-frequency currents in the control circuit can be prevented in two ways:

1. Connecting a sufficiently high impedance in series with the control windings so that the fundamental-frequency voltage induced from the load winding into the control winding is unable to produce excessively large currents in the control-circuit loop

2. Using a special arrangement of windings so that no net voltage voltage of fundamental frequency appears across the control-circuit terminals

The first method is extensively used in those types of very sensitive magnetic-amplifier circuits which utilize external or internal feedback, so that the ratio N_C/N_L between the number of turns N_C of the controlwindings and the number of turns N_L of the load windings can be made very small (N_C/N_L about 0.01 to 0.1). This method is particularly useful when the control windings of the magnetic amplifier are supplied with pure alternating current or unidirectional current (e.g., half-cycle pulses), and when special push-pull circuits having only two saturable reactors are used.

Referring to the second method, it is to be noted that there are two possibilities for designing the arrangement of windings so that no net voltage of fundamental frequency will appear at the terminals of the control circuit:

1. Providing two separate saturable-reactor elements, for example, with series-aiding-connected d-c control windings N_C', N_C'' and series-opposing-connected a-c load windings N_L', N_L'', as shown in Fig. B5(a) and (b). The two fundamental-frequency voltages which are induced in the control windings N_C', N_C'' cancel each other out, and there is no resultant voltage of fundamental frequency in the d-c control circuit. However, it is important to note that actual voltage across each individual winding will be very large when the turn ratio $N_C'/N_L' = N_C''/N_L''$ is large, necessitating a high degree of insulation and, therefore, requiring comparatively large space occupied by the insulating material. This arrangement will successfully be used in connection with magnetic-amplifier feedback circuits having a small turn ratio N_C/N_L.

2. Providing one of the single core or twin-core arrangements, as shown in Fig. B5 (c) to (f). Each of these a arrangements has only one d-c control winding, which embraces both magnetic circuits, so that there is no resultant a-c flux through this winding and no net voltage of fundamental frequency can appear across the control-circuit terminals.

Referring to the three-legged core with one control winding on the center leg and two parts of the a-c load windings on the other legs [Fig. B5 (c) and (d)], it is necessary that the center leg be split lengthwise [Fig. B5 (d)], to eliminate disturbing hysteresis effects. If the center leg of the core is not split (Fig.B5 c), then the a-c flux components produced by the load windings N_L' and N_L'' tend to flow around the circumference of the core and not to flow through the center leg at all. Thus, only unidirectional flux will flow through the center leg, and this may cause disturbing hysteresis effects, particularly in such an arrangement is used for amplification of very feeble input signals. By splitting the center leg lengthwise (Fig. B5 d), a narrow air gap is provided between the two cores, which prevents the flux from flowing the circumference path. Therefore, alternating flux components as well as unidirectional flux components must flow through the center leg of the core, and disturbing hysteresis effects will be eliminated in this way.

The arrangement with two separate three-legged cores (Fig. B5 e) has one common d-c control winding linking both center legs and their a-c load windings. When toroidal arrangements are used, it is sometimes possible to put the a-c load windings on the two separate cores and wind the d-c windings over the two toroids together (Fig. B5 f).

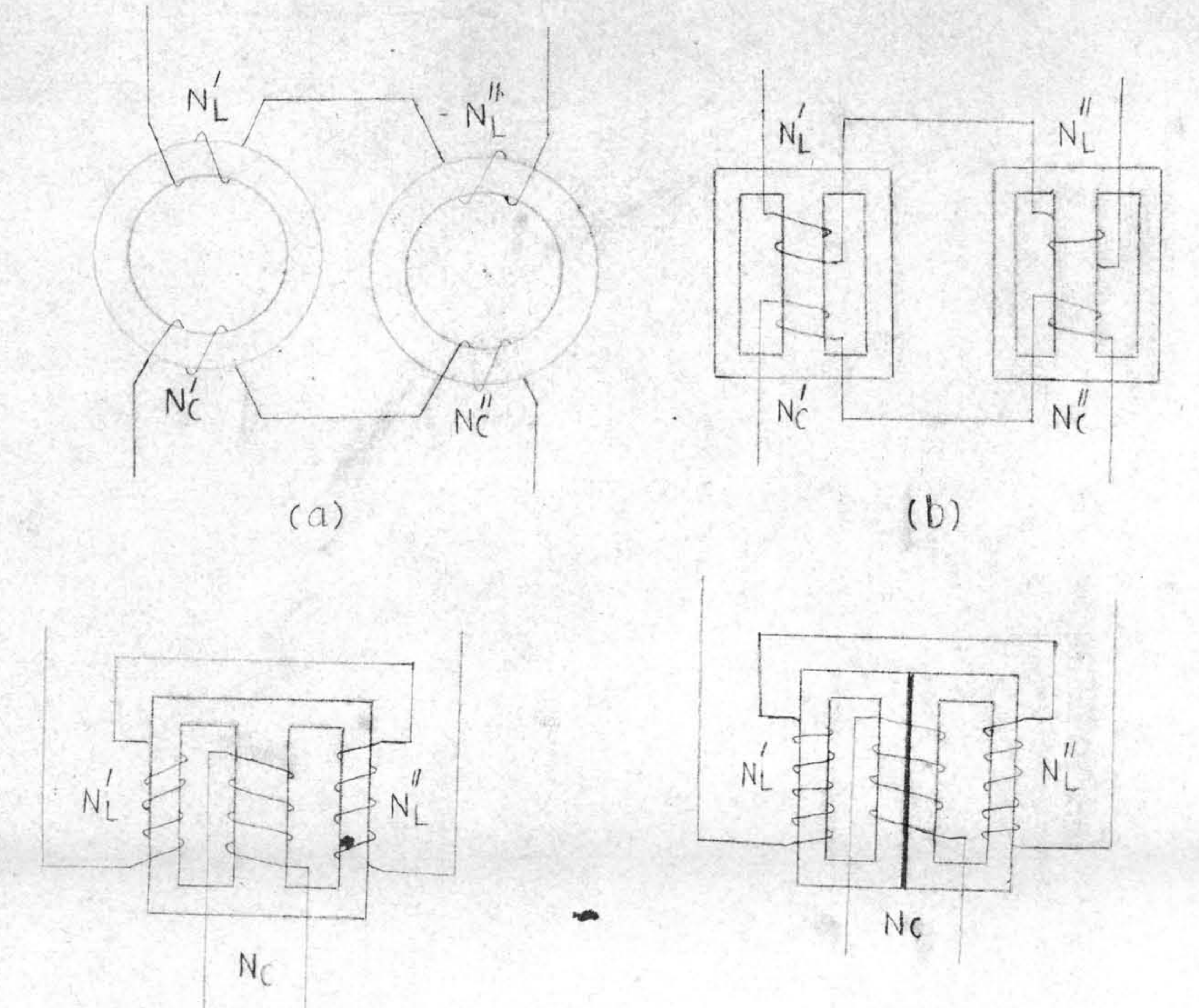
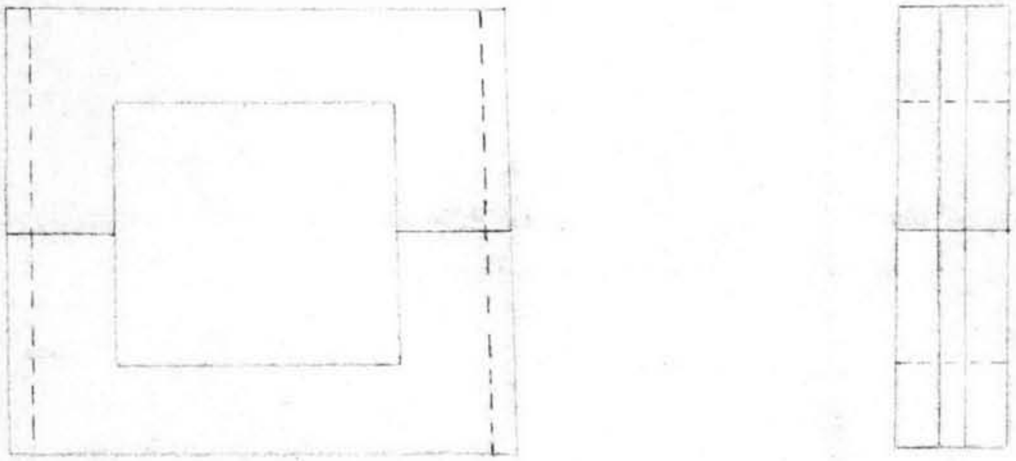


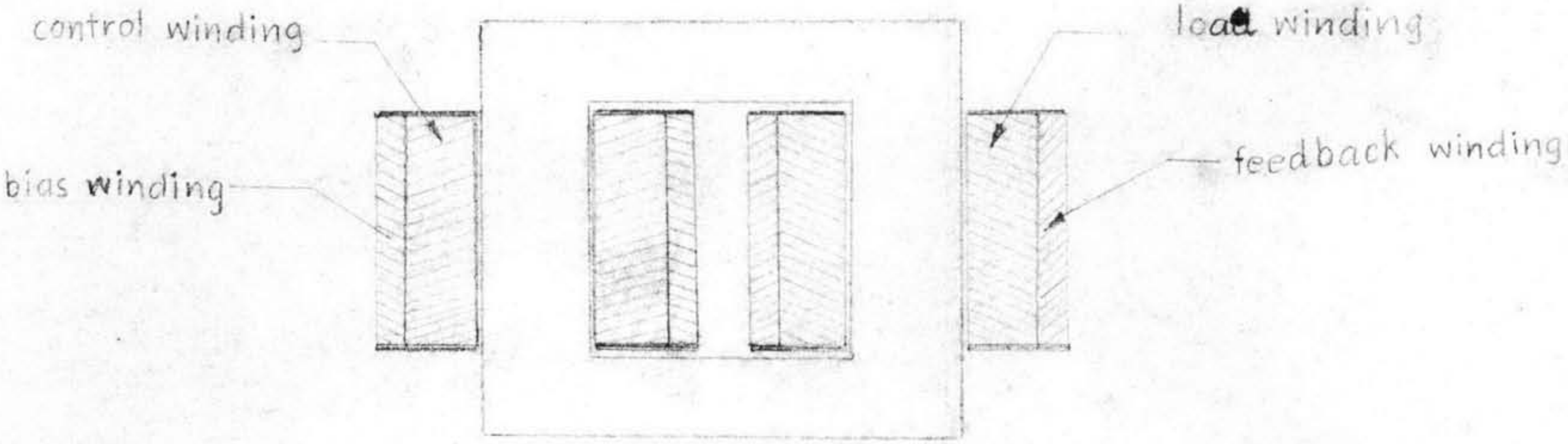
Fig. B5. Various arrangements of windings on saturable reactors: (a) two separate ring-core saturable-reactor elements; (b) two separate three-legged-core saturable-reactor elements; (c) a three-legged-core saturable-reactor element, the center leg of which is not split. This arrangement may cause disturbing hysteresis effects because there is substantially no a-c flux flowing through the center leg of the core; (d) a three-legged-core saturable-reactor element, the center leg of which is split lengthwise to eliminate disturbing hysteresis effects; (e) Two separate three-legged cores having one common d-c control winding (N_C) linking both center legs and their a-c load windings (N_L' and N_L''); (f) toroidal arrangement with one common d-c control winding (N_C) linking both tape cores and their a-c load windings ($N_L$and N_L'').

top view



front view

side view



Core and Coil Assembly of the Ferrite Core Reactor

Scale 1:1

Appendix C

MAGNETIC AMPLIFIER LABORATORY INSTRUCTION

Purpose: To study the characteristics of the magnetic amplifier.

Apparatus:

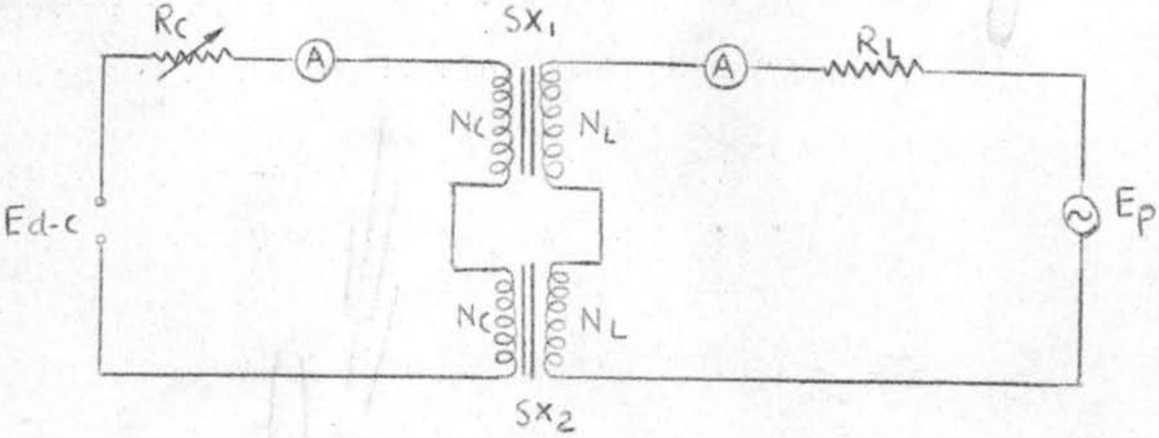
2 Saturable core reactors
1 A-c voltmeter 0-150 V
1 D-c voltmeter 0-150 V
1 2-A 50 mV shunt
1 1-A 50 mV shunt
2 Millivoltmeters 0-50 mV
1 A-c milliammeter 0-500 mA
2 1100 ohms variable resistors
2 4200 ohms variable resistors
4 Silicon rectifiers 2A-110 V
1 Battery eliminator
1 Variable transformer

References: Sidney Platt " Magnetic Amplifiers Theory and Application"

H. F. Storm " Magnetic Amplifiers"

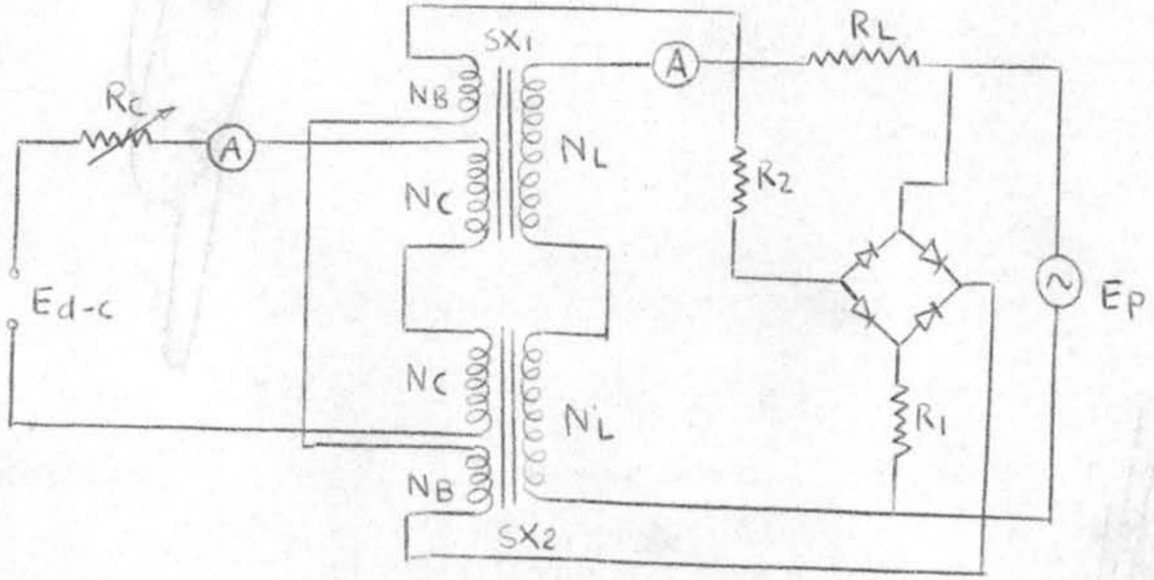
William A Geyger " Magnetic-amplifier Circuits "

Procedure: (1) Connect the circuit as shown. Set $E_P = 10$ volts and $R_L = 17$ ohms. Vary the control current from 0 to 500 mA by means of the resistor R_C.



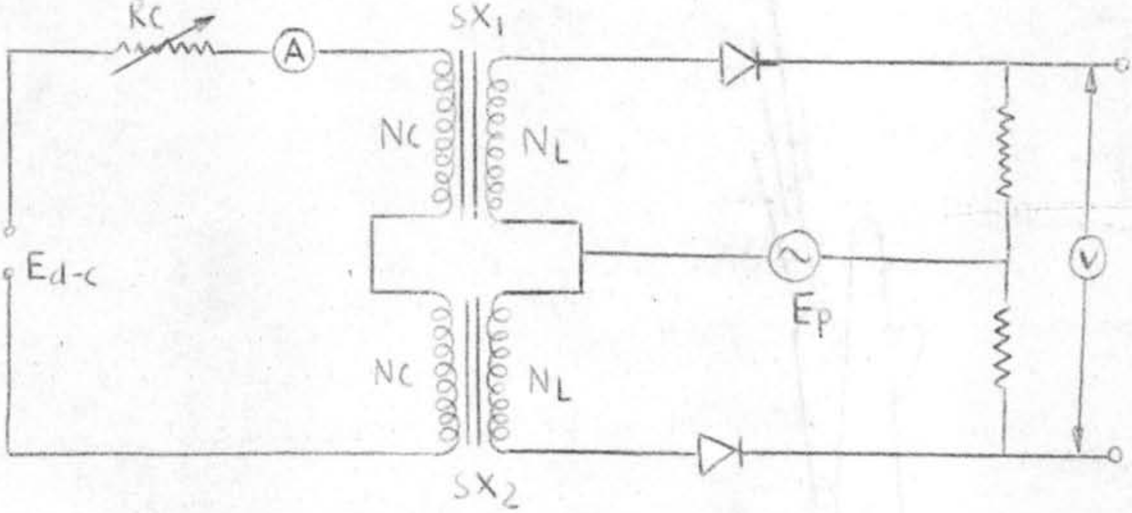
Take the readings of load current. Reverse the polarity of the control current and repeat the procedure.

(2) Arrange the circuit as shown. Set E_P = 10 volts, R_L = 17 ohms and the bias current = 300 mA. Vary the control



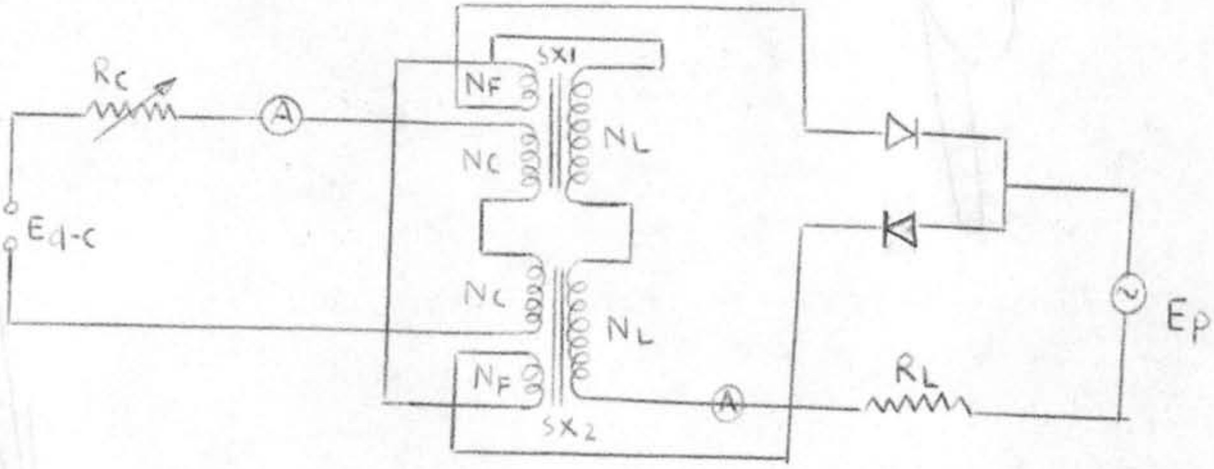
current from 0 to 600 mA by means of the resistor R_C. Take the readings of load current for every step of current changing in the control circuit. Reverse the polarity of the d-c supply and then repeat the procedure.

(3) Connect the circuit as shown. Set E_p = 19 volts. With no current in the control circuit, adjust the resistor



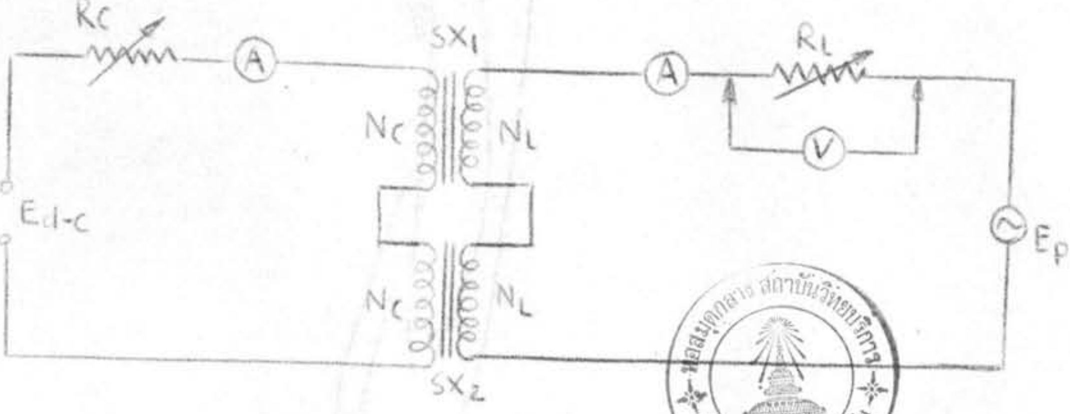
R_1 and R_2 until the zero output voltage is obtained. Vary the control current from 0 to 100 mA. Take the readings of output voltage. Reverse the polarity of the d-c supply and then repeat the procedure.

(4) Connect the circuit as shown. Set E_p = 20 volts,



R_L = 40 ohms. Vary the control current from 0 to 600 mA by means of the resistor R_C about 8 steps. Take the readings of the load currents. Reverse the polarity of the d-c supply and then repeat the procedure.

(5) Arrange the circuit as shown. Set E_P = 18 volts, I_C = 200 mA. Vary the load resistance R_L about 8 steps from its minimum to its maximum value (80 ohms). Take the readings of load currents, and also load voltages, and also measure the d-c supply voltage.



<u>Result</u>: (1) Plot graphs of control currents against load currents for test (1) and (2)

(2) Plot graph of output voltages against control currents for test (3)

(3) Plot graph of control currents against load currents for test (4)

(4) Calculate the power gain for test (5)

(5) Plot graph of the power gain against the load resistance.