MAGNETIC AMPLIFIERS

PART 2

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SELF-SATURATING MAGNETIC AMPLIFIERS *(continued)*

If the control current is zero, the core is taken through a small magnetisation cycle and has an inductance determined by the average flux contributed by the secondary current. If the control current is in the *opposite* direction, the flux due to control current opposes it and the core can be made to change from negative to positive saturation when signal current flows. In this state, flux change is maximum and inductance is large so that the voltage drop across the secondary winding is large.

In a core operated in this way, the amplification obtained depends mainly on the shape of the magnetisation B—H curve, and a steep sloped curve with a very low value of saturation magnetic field strength is desirable. To obtain this shape of curve, cores are usually made by winding tapes of suitable material (permalloy etc.) round a former to form a toroid and winding the coils round these cores.

When such materials are used in such a core, the B—H curve is of the type shown in Fig. 6, where the scales of the graph are such that the values of B are large and those of H small. Saturation occurs at such a low value of flux (measured in milliamps of current X turns of coil) that the cores will saturate with the output current even with no control current applied, and so the control current must be applied so that its flux *always opposes* the output flux.

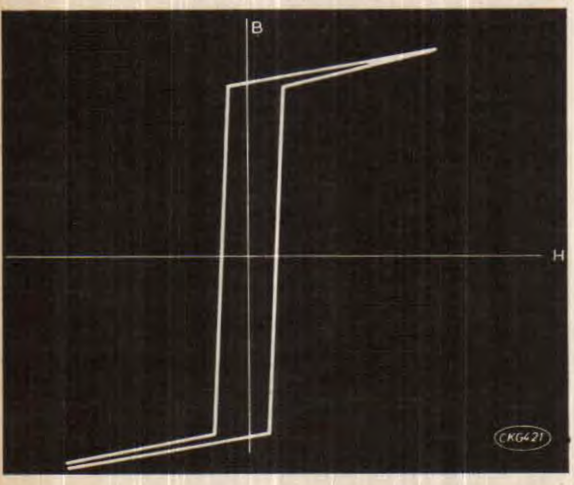

Fig. 6: B-H curve for material used for cores of magnetic amplifiers.

The circuit of a full-wave self-saturating magnetic amplifier is shown in Fig. 7. Since the secondary current in each core must be in one direction, a rectifier is used in series with each secondary winding and two windings are used so that control can be exerted over the whole of one cycle. Note that the voltage across the load is alternating, despite the rectifiers. The output waveform of such an amplifier is also shown in Fig. 7; except for the value of voltage at minimum signal, the waveform is similar to that obtained from a thyristor circuit.

The transfer characteristic (voltage out plotted against *current* in control winding) is shown in Fig. 7. The precise form of this curve can be calculated if the B—H curve for the core in use is known, and it is one of the considerable achievements of core manufacturers that cores and core materials can now be made with reproducible values of B—H curve. The greatest sensitivity can be obtained if the control current is biased to the point 0 on this control curve, and for this purpose, if the bias signal cannot be obtained from the source, a separate bias winding may be used.

The self-saturating magnetic amplifier will give an a.c. voltage output across a load almost independent

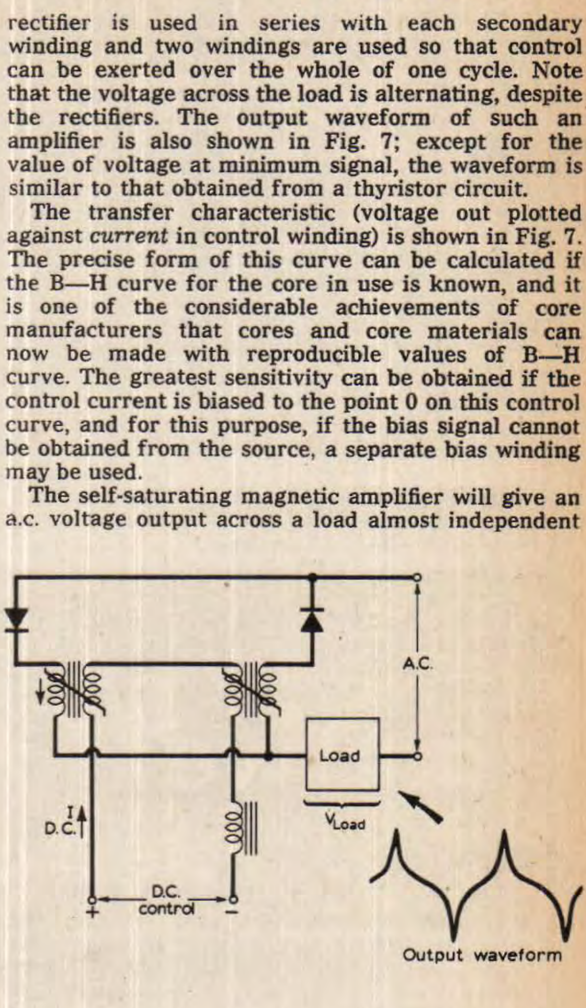

Fig. 7: Circuit of fullwave self-saturating magnetic amplifier with output waveform and amplifier characteristic curve.

of load impedance and determined only by the d.c. control current, so that a d.c. signal at the control winding produces an amplified a.c. output. The output power obtained depends on the size and type of core used.

DC OUTPUT FEEDBACK

The magnetic amplifiers described so far give an a.c. output for a d.c. input. Where the load of the amplifier must be supplied with d.c., or where one magnetic amplifier feeds a second (as when very large power amplification is required) the output of the magnetic amplifier must be rectified. This may be done by taking the output terminals to a bridge rectifier and connecting the load across the other two terminals of the rectifiers (Fig. 8a). A more economical method is to make use of the rectifiers which feed the cores, and add two more to form a bridge rectifier circuit (Fig. 8b) or to use a centre tapped transformer as power source and use the core rectifiers to provide the d.c. output (Fig. 8c).

When linearity of control is particularly important, this may be improved by feedback. To apply feedback to a magnetic amplifier a direct current must be obtained from the output and applied to a feedback winding in the direction opposite to the current in the control winding. The feedback ratio which by the usual feedback theory is approximately the new gain of the amplifier, is the ratio of control winding ampere-turns to the feedback ampere-turns.

DESIGN AND CONSTRUCTION OF PRACTICAL AMPLIFIERS

Because magnetic materials vary so much, it is not easy to give a "circuit" for a magnetic amplifier for home construction; it is rather like giving a circuit for a radio in which all the transistors had to be made at home as well! We can, however, outline the steps in design, so that the experimenter can construct reactors, determine their characteristics and make use of them in the circuits shown earlier. Since commercially obtainable reactors are £10 and upwards, there is a strong incentive for home construction!

CORES

The type of core material which can be used depends on the power available to drive the control winding. When large powers (about 1kW) are being controlled, and several watts can be used to drive the amplifier, an old transformer core can be rebuilt, provided that the transformer was rated to take such power loads. This requires some trial and error unless the core *material* is known and information on it is available. If this is not the case, the best cut-and-try method is to keep the original windings on the bobbin and reassemble the core with no gap, by replacing the **E** and **I** sections facing alternatively in opposite directions. The inductance of the main winding should then be checked for saturation point; this is easily done if an oscilloscope is available by feeding the winding from an a.c. supply through a large variable resistor and checking the voltage across the winding with an oscilloscope. As the current is increased, the voltage waveform becomes flat-topped when saturation point is reached, and the current flowing at this point is saturation current (the saturation current here is peak current=1·4×rms meter reading). Alternatively an a.c. voltmeter and ammeter can be used and voltage plotted against current on a graph, saturation being when the graph becomes flat-topped. Note that the a.c. current must be varied by a resistor, if a constant voltage source such as an auto-transformer is used, the *current* waveform will be the one which appears distorted.

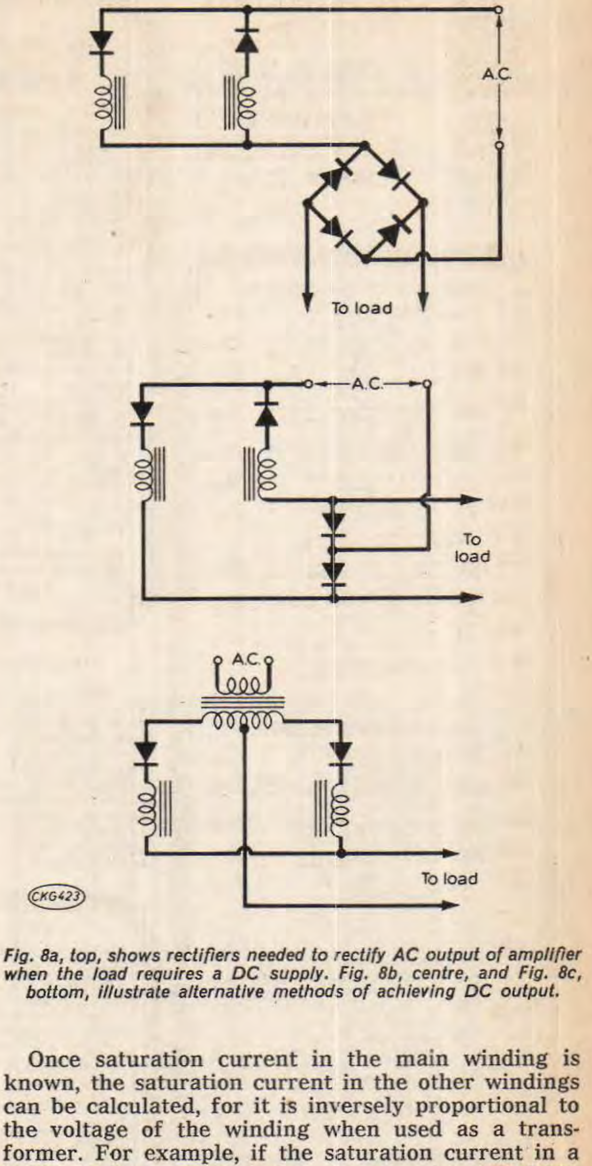

Fig. 8a, top, shows rectifiers needed to rectify AC output of amplifier when the load requires a DC supply. Fig. 8b, centre, and Fig. 8c, bottom, illustrate alternative methods of achieving DC output.

Once saturation current in the main winding is known, the saturation current in the other windings can be calculated, for it is inversely proportional to the voltage of the winding when used as a transformer. For example, if the saturation current in a 250V winding is 100mA the saturation in a 350-0-350 winding, total 700V is

$$100 \times \frac{250}{700}\,\text{mA} = 36\text{mA}$$

and this 700V winding can be used as the control winding. If the control winding has resistance of 100Ω, the voltage across it at saturation is 36V and this will be able to control currents of ±100mA at 250V in the other winding. The voltage gain in this case is not impressive, but the power gain is fairly high and is achieved at less cost than many comparable devices.

FROM SCRATCH

Much more efficient magnetic amplifiers can be obtained by designing from scratch. If the control power is more than about 200mW, transformer steel cores (such as Hypersil) can be used either in tape or C-core (with no gap) form, for lower powers a μ-metal or permalloy core is available. For any core, the power which can be controlled is approximately equal to $\frac{D^2ABf}{200}$ where D is the diameter of the whole core (in cm), A the area of cross section of core

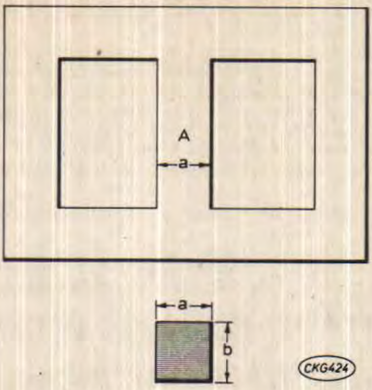

Fig. 9: The cross sectional area of the core can be obtained by multiplying 'a' and 'b' measured in cms.

(in sq.cm) in the bobbin, B is the saturation flux density of the core in Teslas (Weber per sq.m) and f is the frequency in Hertz (cycles per second).

The wire size may then be selected if the output current is known. Using a table of wire size which shows area in "circular mils" choose a wire size of about 1 circular mil for each milliamp of output current. The number of turns for the voltage required at the output is then $\frac{25V}{A}$ where the area of cross-section of the core (Fig. 9) in sq.cm and V is the voltage of the winding in volts.

After this, the design depends on the core material used, whose characteristic must be known. The ampere-turns for control should be obtained from the maker's information, and the control winding designed to suit amplification required and to fill the available bobbin shape.

In the case of a commercial design, considerably more would be done to calculate leakage flux, winding thickness, etc. but a cut-and-try approach is better for the amateur who is more interested in making a working device than in establishing a production line.

FINAL NOTES

Voltage gains are of the order of 8-40 with straight saturating circuits and up to 1200 with self-saturation. Feedback lines should include a choke to prevent a.c. feedback.

The frequency of the input signal should not be more than one-tenth of the frequency of the operating a.c.; for 50Hz operation, the input signal bandwidth is d.c. to 5Hz. ■