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# A TRANSIENT ANALYZER FOR MAGNETIC AMPLIFIERS

BY
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MRI

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# A Transient Analyzer for Magnetic Amplifiers

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## ABSTRACT

The transient analyzer described is a simple and reliable electronic device which operates by generating a number of pulses exactly equal to the number of cycles required for the output current or voltage of a magnetic amplifier to change from its initial value to a predetermined value. The response time in cycles is obtained directly by recording the output of the analyzer with an electronic counter or conventional recording devices.

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## INTRODUCTION

The response time of a magnetic amplifier is defined as the time required for the rms or rectified average value of output current or voltage to change a prescribed percentage of the difference between the corresponding initial and final steady state values. When the magnetic characteristics of the core materials approach the rectangular B-H loop shape, the wave form of the output current exhibits the typical rapid rise as one core saturates at some angle $\gamma_{MA}$ and sinusoidal form after saturation, until the end of the half cycle. Under these conditions, the peak value of load current is independent of the average or rms value when

$$\gamma_{MA} \leq \frac{\pi}{2}.$$

Unfortunately, conventional recording instruments are better suited to the measurement of cyclic peak values and can be adapted to the measurement of the rms or average value response time only at the expense of considerable inconvenience and difficulty. An electronic cyclic integrator which permits direct measurement of the rectified average value of the output taken over each cycle has been previously described[1,2]. With this method the response of the amplifier in terms of cyclic average values is portrayed on the screen of a cathode ray oscilloscope, is photographed and the response time determined in the usual manner.

The device to be described in this paper (called the Transient Analyzer) is also electronic but is very simple and reliable as compared with the above device, and possesses accuracy of a high order. The output of the transient analyzer is a series of pulses equal in number to the number of cycles required for the load current to change from its initial value to any arbitrarily specified value (called the reference value). The reference may be specified in terms of rectified average or rms values by the use of a suitable meter by performing a manual adjustment prior to the initiation of the transient.

## DESCRIPTION OF TRANSIENT ANALYZER

### Principle of Operation

The operation of the transient analyzer is best described by making reference to Figure 1. The values of control circuit voltage ($E_{c1}$,$E_{c2}$) or current corresponding to the desired initial and final steady state values of load current or voltage are first established. The output of the magnetic amplifier is then set at the reference value (i.e. 63,90 percent, etc.of the total change) by applying a suitable signal to the control circuit. Corresponding to the reference value of output, the magnetic amplifier saturates at some angle

$$\alpha_{MA} = \alpha_R,$$

$\alpha_R$ is called the reference angle. When the core materials are not "ideal" the current wave does not jump abruptly at saturation; however, if $\alpha_{MA}$ is taken as the angle of maximum slope of the wave, the operation is the same as though the materials were rectangular.

The transient analyzer generates a voltage pulse of very short duration once every cycle. The phase of this (reference) pulse is next made to coincide with the reference angle by a manual adjustment. When the output current is less than the reference value

$$\alpha_{MA} > \alpha_R,$$

and when the output current is greater than the reference value *

$$\alpha_{MA} < \alpha_R.$$

The function of the transient analyzer is to compare the angles $\alpha_{MA}$ and $\alpha_R$ every cycle and to indicate the result by generating an output pulse every cycle if $\alpha_{MA} > \alpha_R$ but no pulse if $\alpha_{MA} < \alpha_R$ - for a build-up transient; and by generating a pulse every cycle if $\alpha_{MA} < \alpha_R$ but no pulse if $\alpha_{MA} > \alpha_R$ - for a decay transient. The transient analyzer becomes operative only after the switch initiating the transient is thrown. Therefore, the number of pulses generated by the analyzer after the swtich is thrown is equal to the number of cycles required for the magnetic amplifier output to change from the initial value to the reference value. The response time of the magnetic amplifier is obtained directly by counting the number of pulses generated by the analyzer during the transient. An electronic counter of the conventional type# was found to be a very convenient means for counting the pulses; however, a

---

* Although these remarks apply only to a single-ended magnetic amplifier, the method itself can be applied to a push-pull amplifier by comparing the saturation angle of one reactor with the reference angle.
# Multiple decade counters employing Eccles-Jordan flip-flop circuits as used in electronic digital computers.

standard type recording oscillograph could be used equally well, but with perhaps less convenience.

The comparison of the angles $\alpha_{MA}$ and $\alpha_R$ is made during one half of the cycle (the negative half in Figure 1). If the output of the magnetic amplifier is a-c, as shown in Figure 1, the signal into the transient analyzer can be obtained from the load(i.e. load voltage). If the signal is full-wave d-c (rectified d-c) then the signal to the transient analyzer must be taken as the voltage across one reactor winding(see waves in upper left corner of Figure 2). In any case; i.e. full-wave d-c, full-wave a-c, half-wave, or push-pull a-c or d-c; the signal can always be taken from a winding of one reactor. The reason for the above is that the analyzer operates by comparing the reference pulse with some negative pulse derived from the magnetic amplifier which occurs only once during a cycle. This requirement is always met by taking the signal from a winding on any core in the amplifier*.

The reference pulse phase angle $\alpha_R$ is readily adjusted without the aid of an oscilloscope as follows: The output of the magnetic amplifier is set at the reference value by applying an appropriate steady state control signal and observing the output with a suitable a-c or d-c meter. The transient analyzer is unclamped and the phase adjustment varied until pulses are obtained from the output terminals. (The electronic counter counts continously as indicated by neon bulbs.) The phase adjustment is then varied (coarse and fine adjustments) until the output from the analyzer just ceases. The reference angle $\alpha_R$ is now adjusted properly. The analyzer is again clamped, the counter reset to zero, and the transient initiated by throwing the switch. At the completion of the transient, the reading of the counter is exactly equal to the response time in cycles.

## Description of Circuits

The internal operation of the transient analyzer can best be explained by reference to the block diagram of Figure 2. The input signal (a) is clipped‡, differentiated, and amplified resulting in a sharp negative pulse of short duration (b) which occurs at phase angle $\alpha_{MA}$. An a-c voltage (c) having the same frequency as the magnetic supply is passed through a phase shifter which is equipped with coarse and fine adjustments for varying the phase. The phase shifted a-c wave (d) is clipped(e), differentiated and amplified resulting in a sharp negative pulse of short duration (f); this is the reference

*The input impedance of the transient analyzer is high enough (one megohm) to prevent detrimental loading of the circuits.

‡The negative half cycle is removed if the negativedrop in the signal occurs on the positive half cycle(input from a reactor winding) and the positive half cycle is removed if the negative drop occurs during the negative half cycle. See(a) in Figure 2; for circuit details see Figure 3.

pulse. The phase of the reference angle $\alpha_R$ is determined by the phase adjustments previously described. The two pulses (b) and (f) are fed into opposite plates of a conventional Eccles-Jordan Flip-Flop Circuit. The operation of the Eccles-Jordan[3] circuit is such that a negative pulse received at one plate "triggers" the stage causing that plate voltage to drop to its "low" value and the voltage of the opposite plate to rise to its "high" value. The circuit then remains in this condition until a negative pulse is received at the plate of the second (opposite) tube, at which time the plate voltage values of the two tubes reverse .

The voltage from one plate of the flip-flop circuit (g) is used to control the gate stage. When this plate is "high" the gate is open and allows to pass through it a signal appearing at its input terminals (i). When this plate is "low" the gate is closed and the incoming signal (i) is blocked.

The two input connections to the flip-flop circuit are interchanged for build-up and decay transients. For a build-up transient, the pulse derived from the magnetic amplifier (b) is connected to trigger the flip-flop in such a direction as to open the gate, and the reference pulse (f) is connected in such a direction as to close the gate. The signal input (called the "sensing" pulse) to the gate (i) occurs at angle $\alpha_s$, where

$$\alpha_s = \alpha_R + \pi.$$

It follows immediately that if (b) occurs after (f), that is

$$\alpha_{MA} > \alpha_R,$$

the gate will open when the sensing pulse (i) arrives at the input to the gate; therefore, a pulse appears at the output (j and k) of the device. On the other hand, during a build-up transient, if (f) occurs after (b), that is

$$\alpha_{MA} < \alpha_R,$$

the gate will be closed when the sensing pulse (i) arrives at the input to the gate; under these conditions, no pulse appears at the output of the transient analyzer. For a decay transient, the roles of the (b) and (f) pulses are interchanged by throwing the reversing switch shown in Figure 2. The operation of the transient analyzer then proceeds as previously described.

The complete circuit diagram of the transient analyzer is shown in Figure 3. Conventional pulse-circuit techniques are used; therefore, no detailed description is necessary.

The particular circuit design shown is intended primarily for 60 and 400 cps operation but could be modified for higher frequency use with minor changes. Wave forms of voltages at various points in the circuit are shown in Figure 4.* In Figure 4 the letters "a" to "k" refer to the circuit points shown in Figures 2 and 3. a1 and a2 are the output voltages across the load of a Hipernik V. full-wave a-c amplifier for two values of control signal; a3 is the voltage across the load winding of one reactor corresponding to a2. g1 and g2 correspond to signals a2 (or a3) and a1 respectively for a decay transient in which the reference angle (f) lies in between these two limits. The magnetic amplifier source is 20 volts rms and is shown in all oscillograms to the same scale.

## OPERATING EXPERIENCE AND REMARKS

The primary aim in developing the transient analyzer was to keep the circuitry as simple as possible and yet provide a device which would be suitable for testing a wide range of magnetic amplifiers. Certain limitations exist; these will be brought out in the course of the following discussion.

The sensitivity of the circuit was found to be sufficient to allow satisfactory operation on signals obtained from typical 10 volt, 60 cps, (supply voltage and frequency) half-wave and full-wave magnetic amplifiers using Mumetal and Hipernik V core materials. For much smaller signals, an additional stage of preamplification would be necessary. While there is virtually no upper limit to the amplitude of the signal that can be accepted, it may be necessary to restrict the amplitude in certain cases where distortions or spurious pulses exist in the output of the magnetic amplifier wave; this can always be done with a high resistance voltage divider network.

The logic of the circuit operation requires that the input from the magnetic amplifier be sufficient to trigger the flip-flop stage for all values of $\gamma_{MA}$ realized during the transient. This condition becomes difficult to fulfill when either the initial or final value of $\gamma_{MA}$ approaches $\pi$, even though the signal strength may be adequate over the major portion of the transient. While the logic of the design could be changed to take care of this situation, the additional circuit complexity makes the change undesireable, and contrary to the original aim at simplicity. Furthermore, the case for which $\gamma_{MA}$

*Oscillograms (b) and (f) are obtained with the tube $T_2$ removed from its socket.

approaches π is a very unusual one and its exclusion does not impose a serious limitation on the usefullness of the device. At this point it may be asked whether the aforementioned limitation on $\alpha_{MA}$ does not exclude the application of the transient analyzer to push-pull magnetic amplifiers of the null-balance type in which the initial or final steady state output is usually zero. The answer is negative because with such circuits the signal is obtained not from the output but from a winding on one core. Hence, even at null balance, the signal $\alpha_{MA}$ is not likely to approach π.

The accuracy of the transient analyzer depends upon how accurately the reference angle ($\alpha_R$) can be set according to the procedure previously given. In every case tested, the reference adjustment (point at which the "counting" just ceases) could be set as accurately as the meter (indicating output current or voltage) could be read.

## REFERENCES

1. S. Roman, "A Cyclic Integrator", Polytechnic Institute of Brooklyn, M.E.E. Thesis, 1951.

2. E.J. Smith, "A Study of Magnetic Amplifiers, Part IV: Transient Response", Microwave Research Institute, Polytechnic Institute of Brooklyn, Report R-238-50,PIB-183

3. H.J. Reich, "Theory and Applications of Electron Tubes", McGraw-Hill, 1944.

# APPENDIX

## List of Components - Transient Analyzer

| | | |
|---|---|---|
| Tubes: | T1 to T5 - 6SN7 | |
| Transformer: | X1 - 120.v PRI,80v. center tapped SEC,60&400 cps. | |
| Potentiometers: | P1 - 850.K, 4.W | |
| | P2 - 20.K, 4.W | |
| Crystal Diode: | CR- IN34 | |
| Switches: | S1,S2,S4,S5,S6 - DPDT, No Neutral Position | |
| | S3 - SPDT, Neutral Position | |
| Power Supply: | B+, 150.v, 40. ma | |
| | B-, 100.v, 10.ma | |
| Resistors: | (1 watt, carbon, ± 5%) | |
| | R13,R14,R28 | -10.K |
| | R3,R17,R25 | -18.K |
| | R6,R7 | -24.K (Matched within 2%) |
| | R5,R19,R27 | -100.K |
| | R23 | -150.K |
| | R8,R9, and R10,R11 | -240.K (Matched within 2%) |
| | R2,R15,R21,R22 | -470.K |
| | R1,R18,R20,R24,R26 | -1. Meg |
| | R4 | -1.3 Megs |
| | R12,R16 | -2.2 Megs |

| Condensers: | (± 10. %) | |
|---|---|---|
| | C11 | -56 μμf |
| | C4,C5 | -100 μμf |
| | C9 | -230 μμf |
| | C12 | -360 μμf |
| | C3,C10 | -0.001 μf |
| | C2 | -0.002 μf |
| | C8 | -0.003 μf |
| | C6 | -0.007 μf |
| | C7 | -0.05 μf |
| | C1,C13 | -0.1 μf |

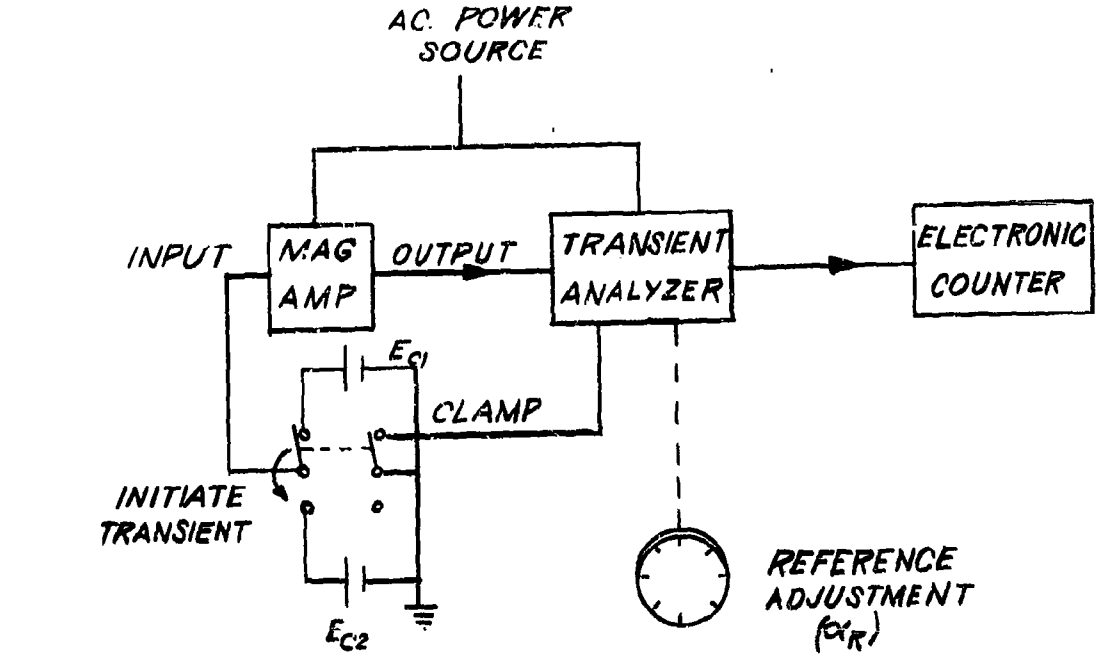
## LIST OF FIGURES

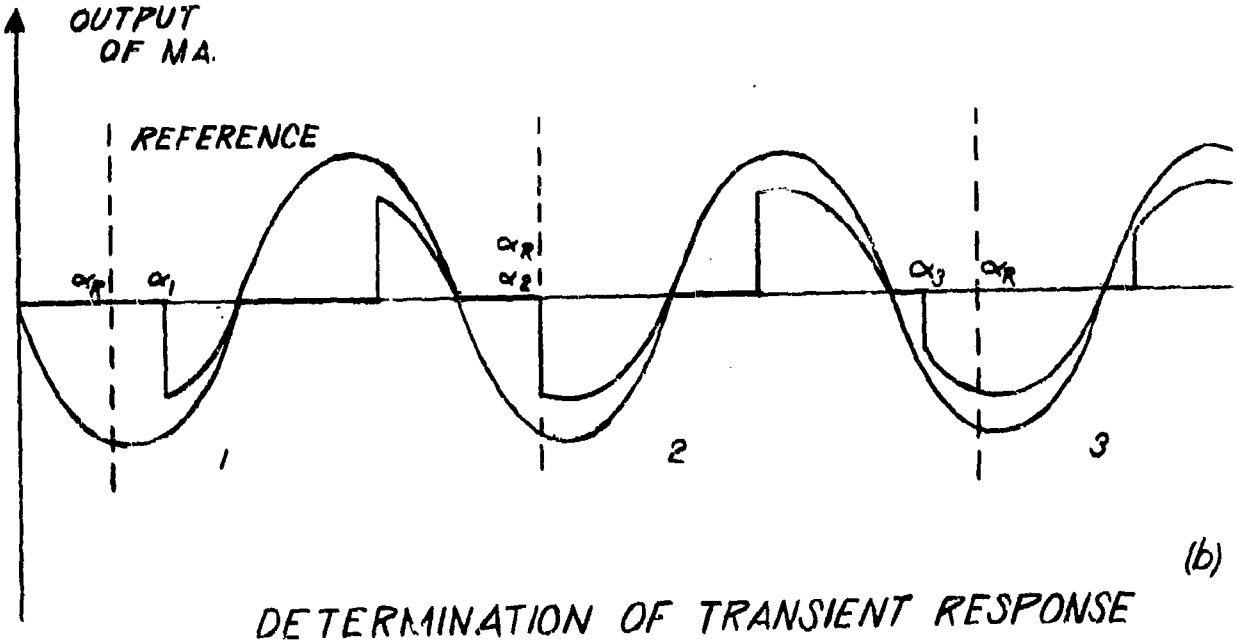
Fig. 1 - MRI-13052

Fig. 2 - MRI-13053

Fig. 3 - MRI-13054

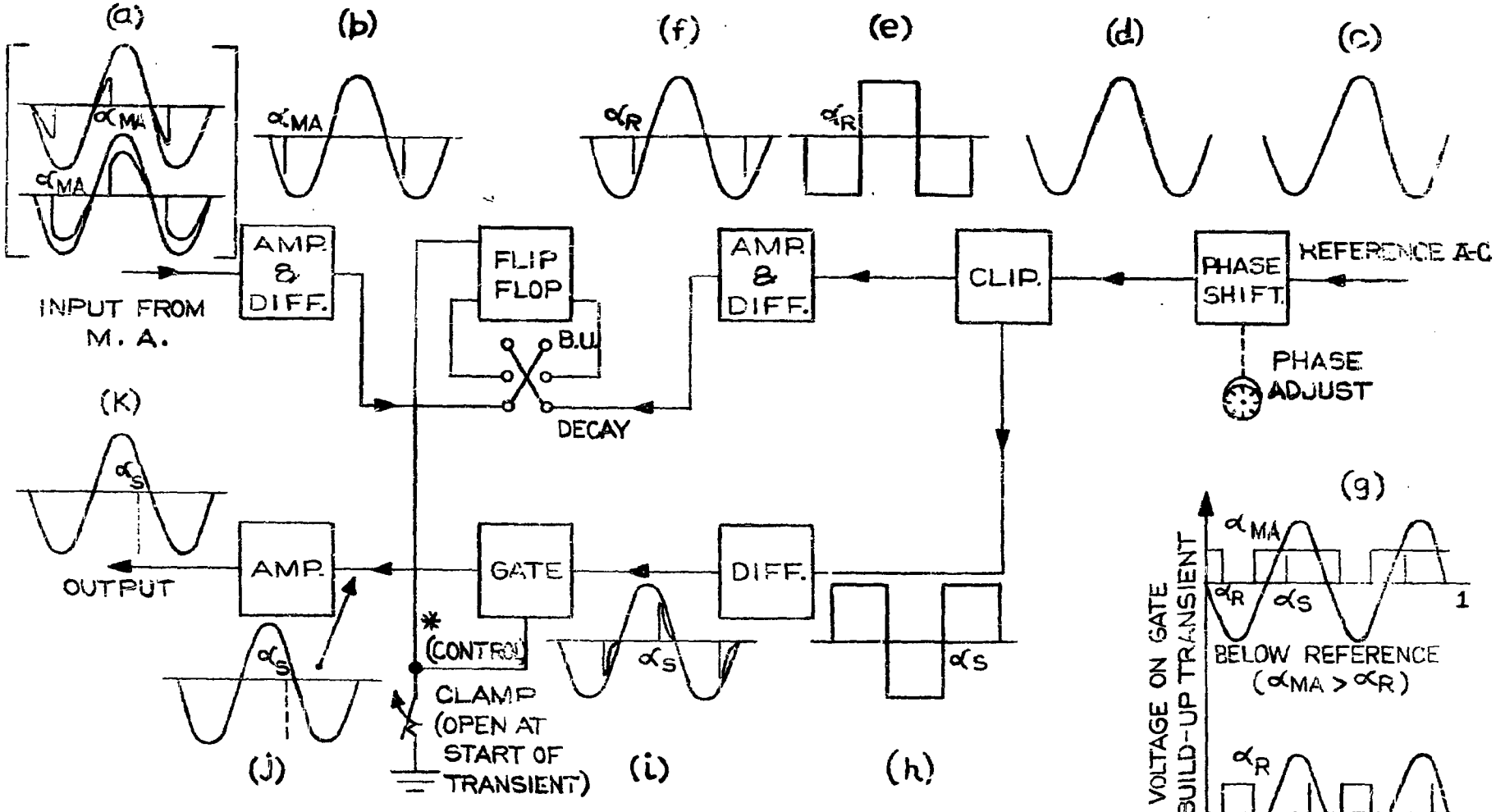
Fig. 4 - MRI-13055



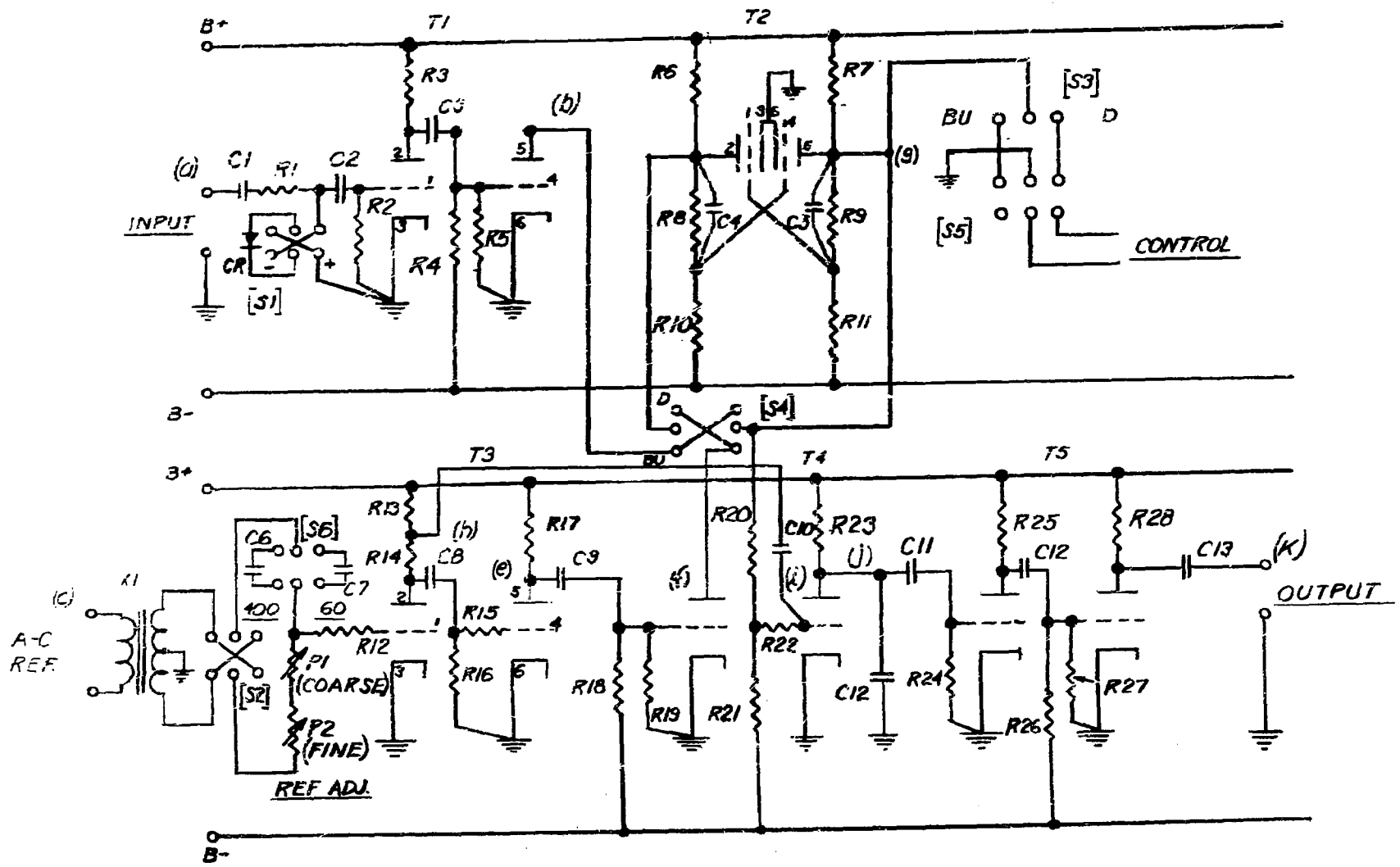

DETERMINATION OF TRANSIENT RESPONSE OF A MAGNETIC AMPLIFIER

FIGURE 1



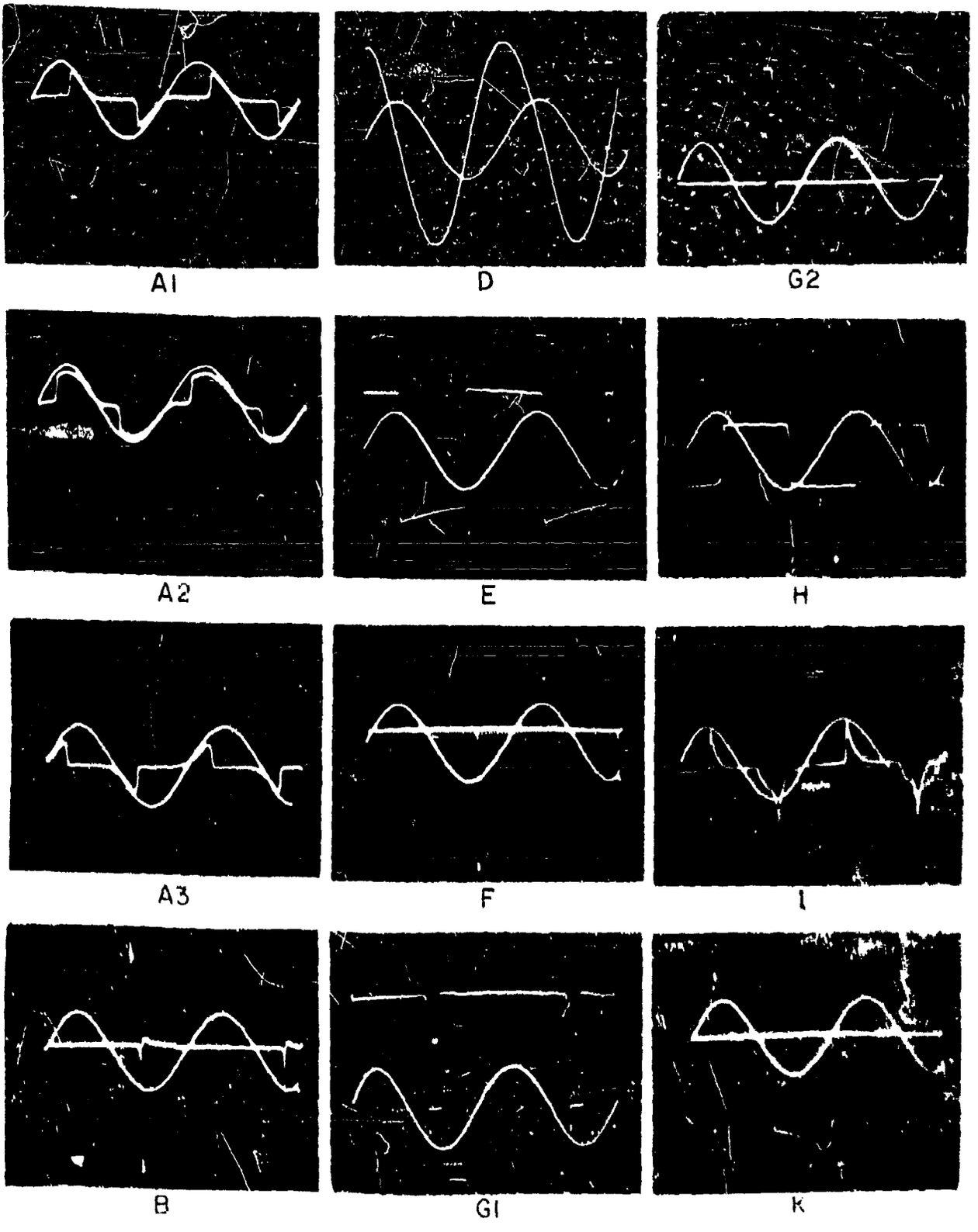

# TRANSIENT ANALYZER
# (BLOCK DIAGRAM)

FIGURE 2




# TRANSIENT ANALYZER
## CIRCUIT DIAGRAM
FIGURE 3

MRI 13054




VOLTAGE WAVE FORMS

Figure 4