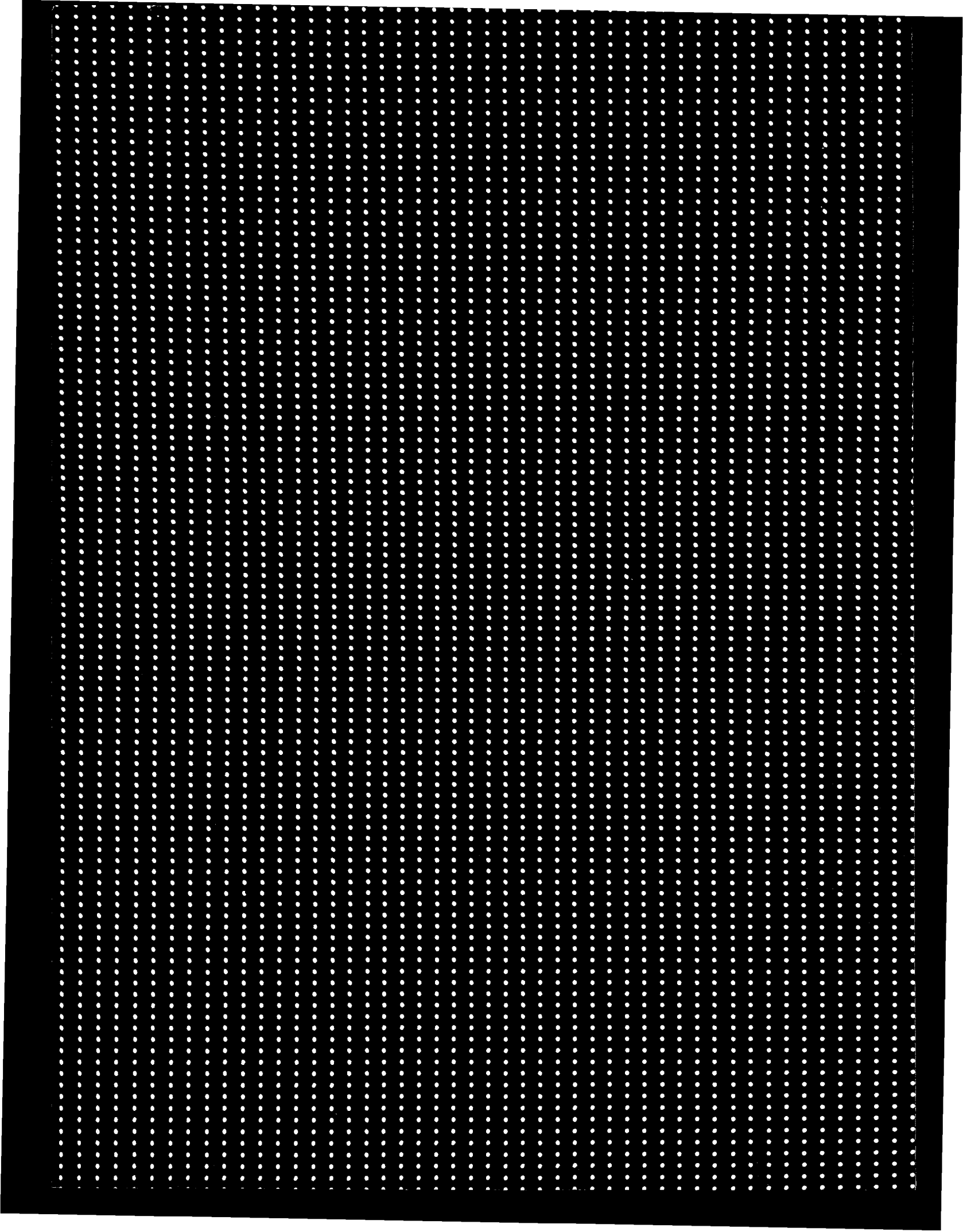




A Binary-Weighted Current Decoder

Abstract: A novel method for driving cathode-ray-tube deflection yokes from digital equipment has been found. The system is compared with other methods and outstanding features are described. The important design parameters are outlined and their effect on circuit operation noted. A printed-circuit-package assembly of a typical converter using this system is shown.

Introduction

Cathode-ray tubes are being used extensively as high-speed output devices for digital computers. Thus digital-to-analog conversion devices with high stability and accuracy are needed. From previous work at IBM,* an improved decoder has been developed with several unique advantages.

Conversion from digital to analog positional information in magnetic-deflection systems can be performed in a number of ways. A cascaded cathode-follower constant-current source with an appropriate ladder network driving a suitable amplifier and driver arrangement is an advantageous system. Such a decoder is shown in Fig. 1, and is similar to that proposed by R. L. Walquist.† Digital outputs are applied as push-pull switching levels to points $S_1, S_2, S_3, \dots S_n$.

The accuracy of the cascaded cathode-follower constant-current decoder is determined primarily by the tolerance and temperature coefficient of the cathode and ladder-network resistors.

The current stages are balanced against each other by means of the cathode sensing resistors, a 50-0-50 microammeter and the cathode potentiometers. For an accurate output, R_1 must be of very close tolerance to obtain a constant-current balance; likewise all resistors designated R and $2R$ must be of close tolerance to insure proper division of the voltage drops. The requirement for close

tolerance on these elements is costly for precision displays.

The dc amplifier associated with the magnetic deflection system (Fig. 1) must have very good linearity to reproduce the decoder signals faithfully. To achieve this, plus stability, feedback must be used. The high open-loop gain necessary makes the feedback loop critical from the standpoint of oscillations. The very nature of the inductive load in the output driver stage and the $L(di/dt)$ voltage present during switching can overload the amplifier with the result that it can be quite difficult to maintain stability. Self oscillations can occur during flyback or the amplifier can saturate in one direction with the result that yoke settling time may be increased because of the reduction in output impedance.

Direct-yoke-coupled cathode-follower constant-current source

The system developed by the author employs binary-weighted constant-current sources. Outputs from the switch tubes are tied in parallel and fed directly to the deflection yoke as shown in Fig. 2.

Although the high-order decoder stages (V_3, V_4) require vacuum tubes with high-plate-current capability, it can be seen that the push-pull dc amplifier and driver (Fig. 1) have been eliminated with the resultant considerable saving in equipment, while retaining comparable accuracy.

Left, system of dots generated by binary-weighted current decoder.

The dot pattern, which is analogous to a television test pattern, demonstrates the linearity of the magnetic deflection system comprising the current decoder and the deflection yoke.

*Performed by R. G. Mork.

†R. L. Walquist, "Analysis and Design of a Digital-To-Analog Computer," Report 220, Digital Computer Laboratory, MIT, Cambridge, Mass., p. 65.

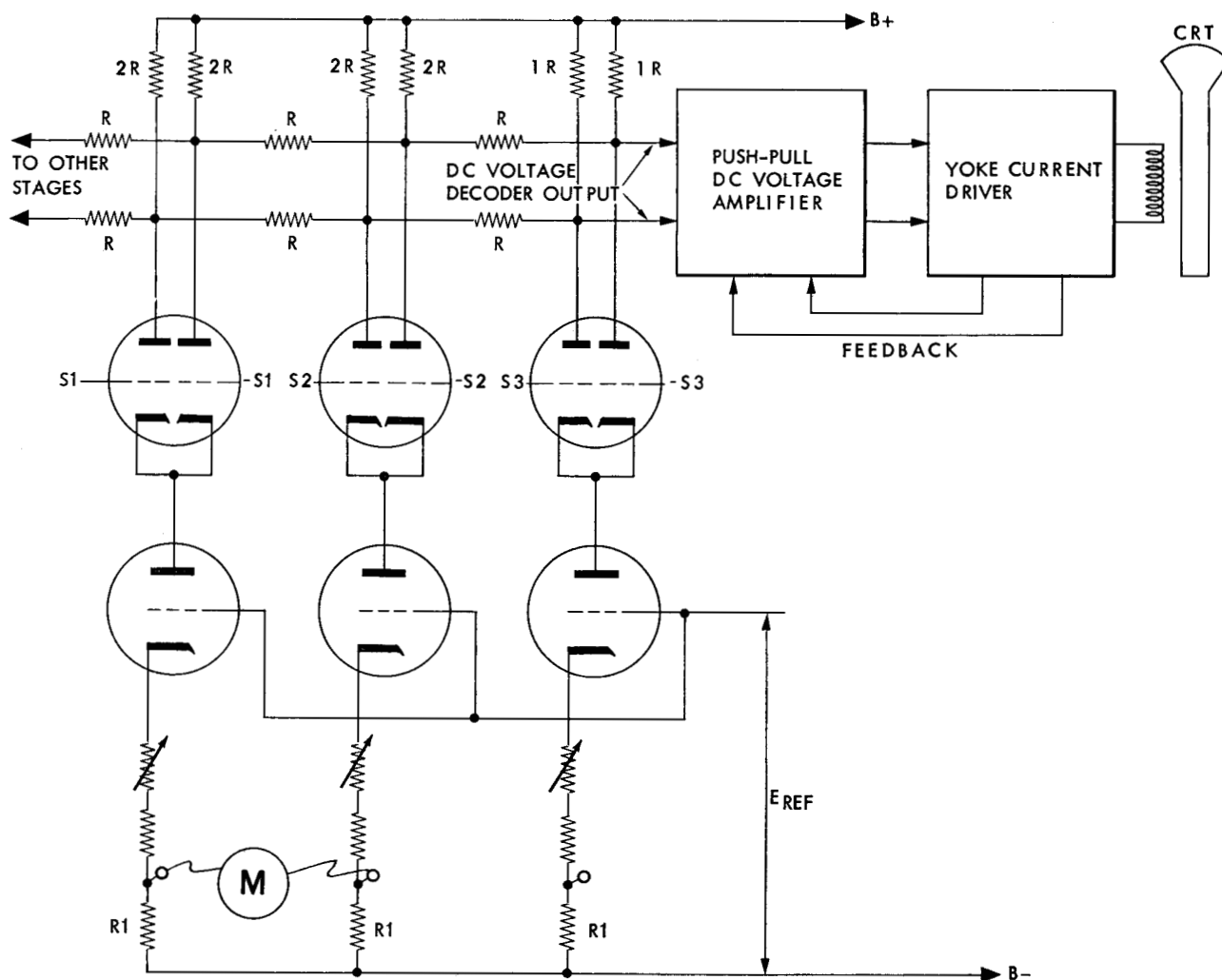


Figure 1 Cascaded cathode-follower constant-current decoder.

Advantages

The binary-weighted current decoder possesses the following advantages over the cascaded cathode-follower constant-current decoder:

1. The ladder network has been eliminated and the only precision resistors remaining are R , $2R$, $4R$, etc. The function of these resistors is to enable the balancing of the current stages against each other. Due to the very nature of the single adjustment element in each stage, a more exact current balance can be obtained. It is unnecessary to rely on ladder resistors for appropriate division of voltage.
2. The yoke is a more ideal load, under steady-state conditions, for a decoder than the ladder network since its dc resistance is much less than that of the network. Therefore, the current stages are not as seriously affected by the changing plate voltage resulting from the turning on of various stages. The ratio of current in this system to the one previously described (Fig. 1) may be 10 to 1, but the load resistance is in a ratio of about 1 to 100.

3. Since all current stages are binary-weighted through the cascaded system and the yoke resistance is small the system possesses excellent linearity. The current of any one stage is affected by the varying yoke dc voltage drop (caused by other stages) in the following manner:

$$\Delta I \cong \Delta E / \mu_1 \mu_2 R_k$$

where ΔE is the yoke voltage drop due to some binary input signal, μ_1 is the amplification factor of the switch tube, μ_2 is the amplification factor of the current tube and R_k is the total cathode resistance.

As an example, the effect of the highest current stage on a smaller current stage will be computed. The highest current stage in a binary system represents half the yoke voltage drop. Therefore if $\mu_1 = \mu_2 = 10$, the current to the highest stage is 50 milliamperes, the yoke resistance is 100 ohms, then the effect on the next stage (25 ma) with an $R_k = 5,000$ ohms is

$$\Delta I_2 = \frac{(100)(50)}{(10)(10)5000} = 0.01 \text{ ma}$$

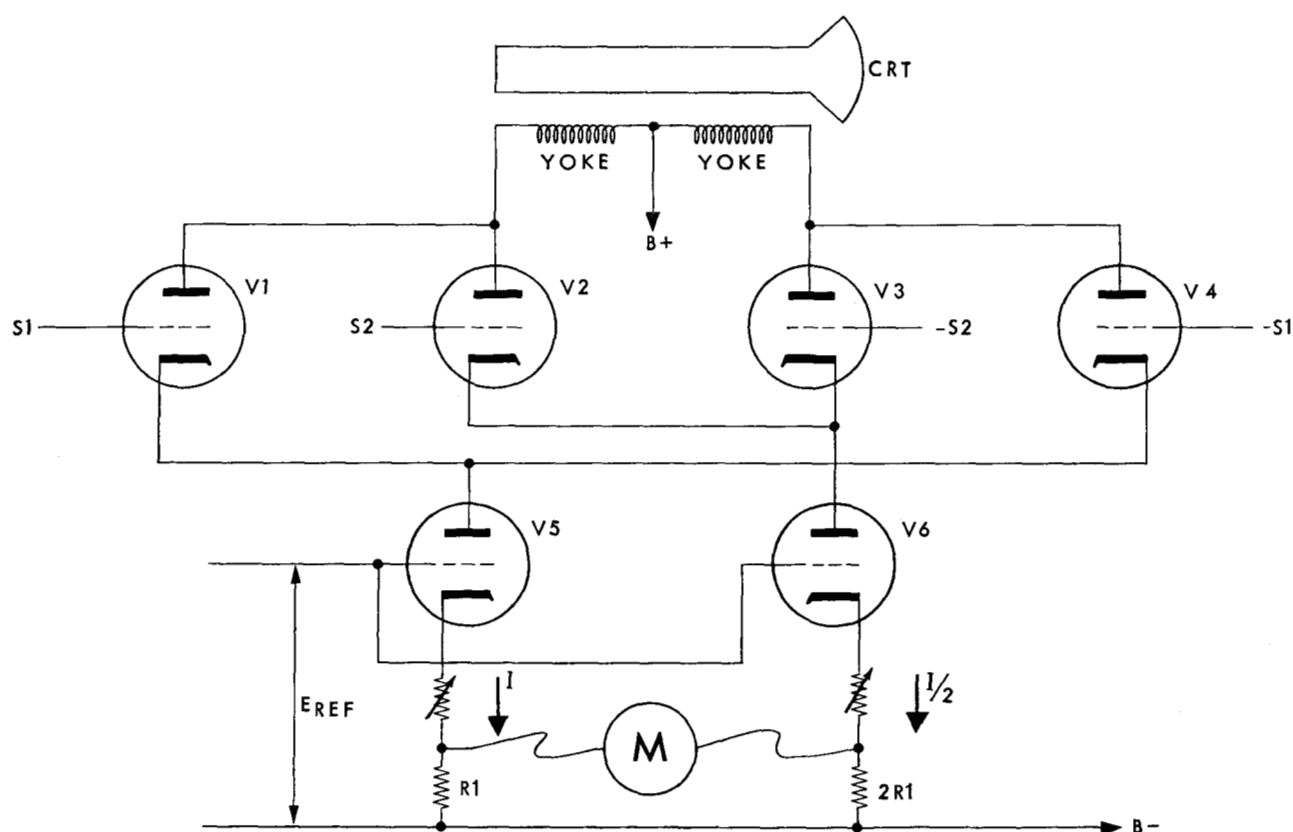


Figure 2 Direct-yoke-coupled cathode-follower constant-current source with parallel current generators.

$$\% \text{ Error} = \frac{0.01}{25} \times 100 = 0.04\%$$

For correspondingly lower current in other stages, μ may fall, but R_k increases and the error is about the same. If other errors are kept to approximately 0.05%, the total error will not exceed 0.2%. In practice, the total error can be reduced considerably through use of the means described below under *Design considerations*, especially as regards the amplification factor per milliampere of current and the cathode-resistor value. Since the plate resistance of the cascaded cathode follower was not used in the above calculations, the actual percentage of error will be less than that computed.

4. Since the currents are switched in a push-pull manner, the current tubes V5 and V6 experience very little variation due to switching signal levels and the result is improved stability. This is true of any push-pull system.
5. The system is simple and easy to maintain. Each current stage is an independent stage in itself and is not affected by other stages to any great degree. It is not prone to self oscillations since feedback is direct in each stage.

• Design Considerations

Some of the important design parameters are as follows:

The output impedance to the system is governed primarily by the largest current stage since it has the smallest cathode resistor. Amplification factor per milliampere

of current is a quantity that reaches a peak and falls fairly rapidly for higher currents in present-day power tubes.

In a binary system R_k , the cathode resistor, would double from stage to stage as current is decreased and the output impedance per stage would be approximately $\mu^2 R_k$ if current-tube amplification equaled switch-tube amplification or $\mu_5 = \mu_1 = \mu_4$. The output impedance is then approximately

$$R = \frac{1}{\frac{1}{\mu_a^2 R_k} + \frac{1}{\mu_b^2 2R_k} + \dots}$$

where $\mu_a, \mu_b, \dots$ are the amplification factors of the various current stages in a binary system with μ_a being the higher-current-stage amplification factor.

The tubes chosen for this system must have a very low cathode-to-filament leakage current since this current loss causes a system error. The current tube regulates current very closely; leakage is not detected in balancing, and subtracts from the total regulated current reaching the yoke. This causes unequal weighting of currents with resulting errors. It has been found that computer- and premium-type tubes have very low leakage currents, making possible systems of 0.1% accuracy.

Power supplies for the decoder must be regulated very closely as the error due to varying voltage is the same as for yoke dc voltage drop. The total error can become

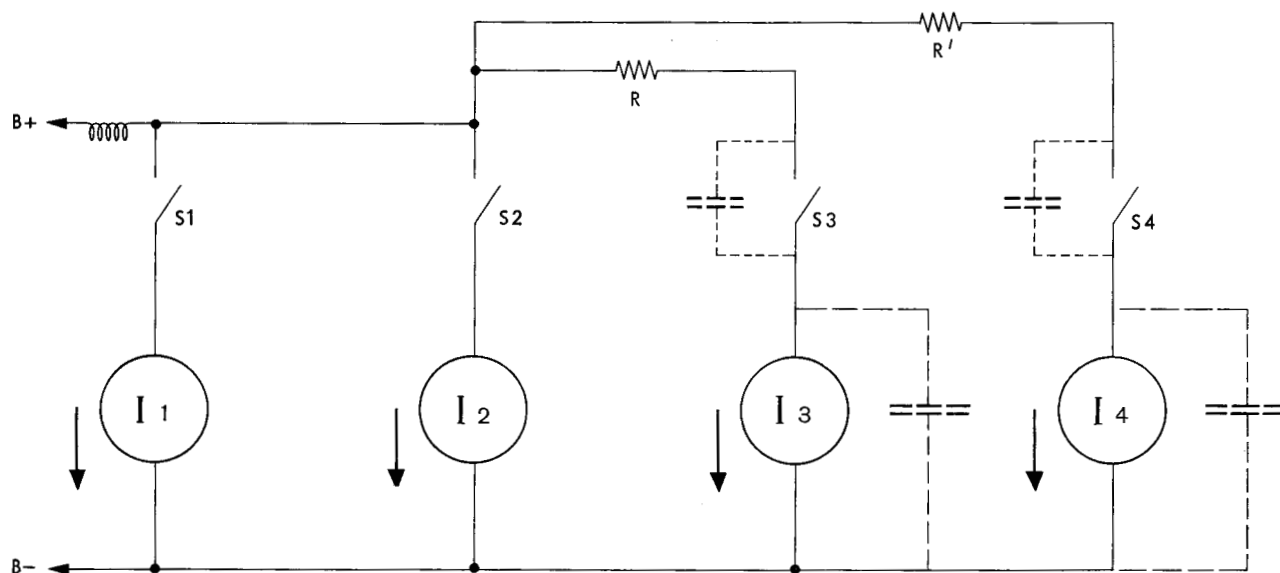


Figure 3 Suppression of tube capacitance in low-current stages.

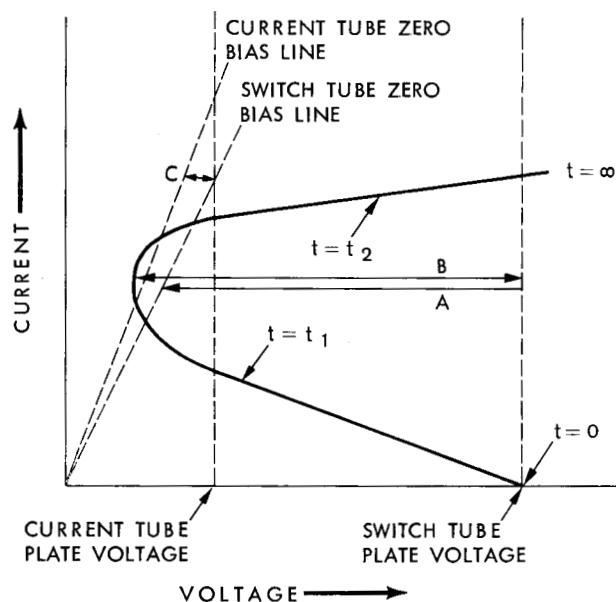


Figure 4 CRT yoke voltage-current plot versus time, superimposed on tube characteristics.

large if all factors are not kept under control.

The output capacity of the system increases as the number of stages is increased thus reducing system speed. This reduction can be kept small by proper choice of tube types, minimizing stray capacity, etc. For very low current stages a resistor can be added as shown in Fig. 3 to suppress the effect of tube capacitance.

It must be pointed out that this reduces the voltage to the switch tubes and therefore the value of R and R' is dependent on tube type, power-supply voltage, current, design requirements, etc. A Thévenin's equivalent of the

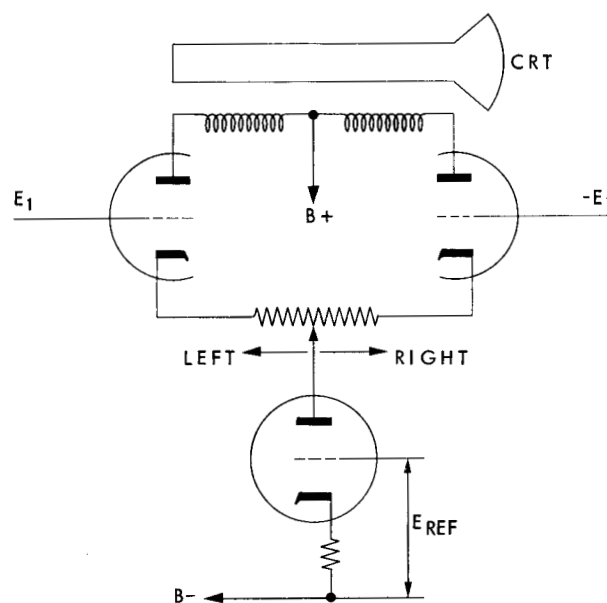


Figure 5 Method of centering deflection-yoke output.

circuit can be obtained and the effect of R and R' determined.

For a given reference voltage, the use of a higher current in the first stage means a reduction of R_k and a lower output impedance. Power tubes have a low μ as a general rule and the effect on the yoke of the lower output impedance must be investigated. The effect of other stages on the higher current stages must also be investigated.

If all factors are controlled the reference voltage can be used over a limited range as a gain control without

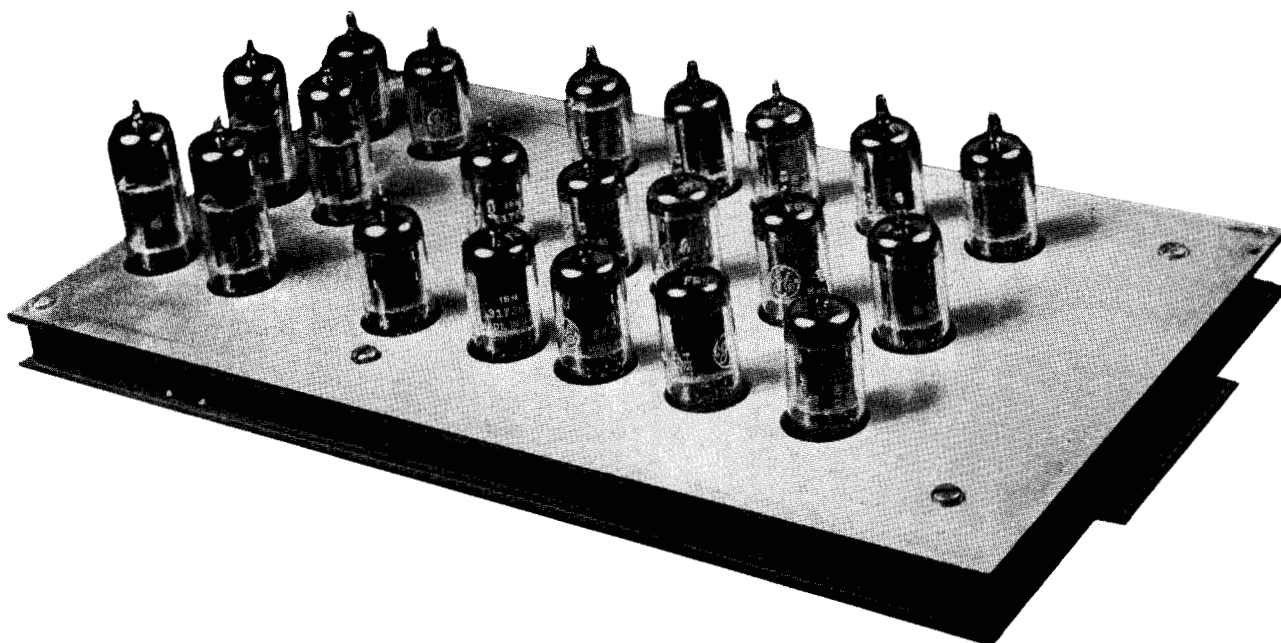


Figure 6a Printed-circuit assembly of several decoder stages showing covering metal supporting plate.

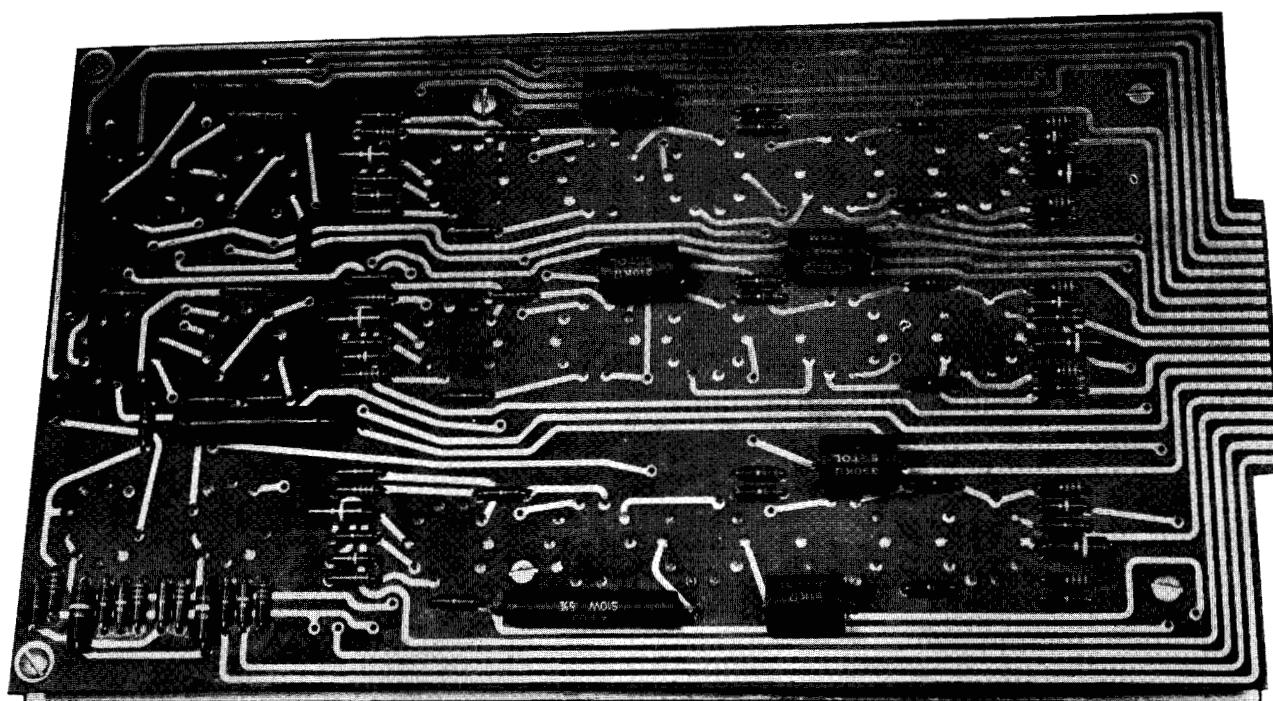


Figure 6b Wiring details of several decoder stages on printed-circuit board.

upsetting the balance between stages. A three-stage decoder driver has been designed and tested with an accuracy of 0.1% and a total current output of 70 milliamperes. The system maintained balance to within 0.1% as the reference voltage was varied 5% to change display size. Over a period of about 30 hours the system remained

balanced to within 0.1% with no visible evidence of drift.

Grid current cannot be tolerated anywhere within the system as a reduction of output impedance occurs and the binary-weighting of currents is upset. For this reason the steady-state grid-to-cathode voltages must be chosen

so as to minimize this effect. The cut-off potentials of the switch tube also contribute to the error in the binary-weighting of currents. The switch tube must be cut off completely as any current remaining in the tube subtracts from the total regulated current reaching the yoke.

An important consideration in the design of the system is the behavior under transient conditions, i.e., the action of the decoder in settling to a steady-state condition after a switching operation. To aid in this investigation, a yoke voltage-current plot was made with time as a parameter and superimposed on the static tube characteristics. The current wave form is determined by the yoke impedance and the output characteristic of the decoder. The voltage swing due to the switching of individual stages, and of all stages together was observed on an oscilloscope, thus enabling a stage-by-stage analysis. The resultant graph is shown in Fig. 4.

The switch-tube plate-to-cathode voltage is plotted for an *on* condition because of the possibility of reaching zero bias due to the falling plate voltage. The cathode of the switch tube is assumed to remain fixed. As can be seen, the tube can reach a zero-bias condition under the conditions plotted (Fig. 4). To reduce the effect of the falling output impedance in this case, which results in prolonged settling time, a high-impedance drive must be used in the switch-tube grid circuit. Under this condition the switch-tube cathode voltage will change. The voltage of the cathode will fall since the other switch tube is assumed to be cut off. The high-impedance drive allows the cathode level to adjust itself to an appropriate value at a small amount of grid current. The cathode of the switch tube is also the plate of the current tube, therefore the current tube will see the yoke transient. If the current tube regulates the current then the yoke $L(di/dt)$ will control the division of current between the

two switch tubes properly under the following conditions. If the switch-tube grid drive impedance is high and the voltage transient *B* does not exceed the voltage $C + A$ at any time then the current tube will not reach zero bias. Under this condition the decoder will maintain a high impedance during settling. Although this impedance is not $\mu^2 R_k$, as under steady-state conditions, it is sufficiently high so as not to affect settling. The yoke damping resistor is lower than the output impedance in practical systems and yoke settling is not impaired. In a well designed system the switch tube will not reach zero bias, but the limitations above are shown in the extreme case.

The system has applications outside of binary-coded systems; decimal-coded binary systems and others are possible simply by changing the cathode resistors.

One method of centering the deflection-yoke output is shown in Fig. 5.

Figure 6 shows top and bottom views of a printed-circuit assembly of several decoder stages. A unique method of construction is shown in Fig. 6a whereby the large metal plate through which the vacuum tubes protrude acts as a stiffening and heat-dissipating means (especially for the high-current stages) for the large printed-circuit board shown in Fig. 6b. The metal plate is further utilized as a means for mounting the relatively fragile printed-circuit board.

Acknowledgment

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