WHERE A MULTIPLICITY of information sources must be observed, some system of scanning or sequential sampling may be employed so that certain pieces of measuring equipment need not be duplicated for each information source to be studied. Where the information sources are of low level, special design problems arise. Several high-speed scanning systems are described below that are applicable to low-level operation.

There are two general types of scanners. First, scanners in which the commutating element also carries the information; and second, the type in which the information-carrying element is controlled by a separate commutating system. The capacitance scanner is one of the first type.

Capacitance Scanner

Basically, the capacitance scanner consists of a large number of input plates to which the individual signal sources are attached. The information applied to the input plate is capacitively coupled to a pickup plate which is moved successively from one plate to another in a predetermined order.

Within the frequency limits of the scanner, the capacitance system is an ideal scanning device. The noise components resulting from the scanning operation are practically eliminated since the variation in average d-c potential from input element to input element is negligible and no direct current flows through the scanner. The noise performance is limited by the output impedance, Johnson noise, and the losses through the scanner.

As is true with most mechanical devices, the life of the capacitance scanner is limited. Another basic limitation of this type of scanner is the top operating speed.

MERB Tube Scanner

For very high scanning rates it is necessary to go to the use of electron beams or electronic circuits. Figure 1 shows a cutaway view of a typical multiple element radial beam tube scanner. For the sake of simplicity the abbreviation MERB
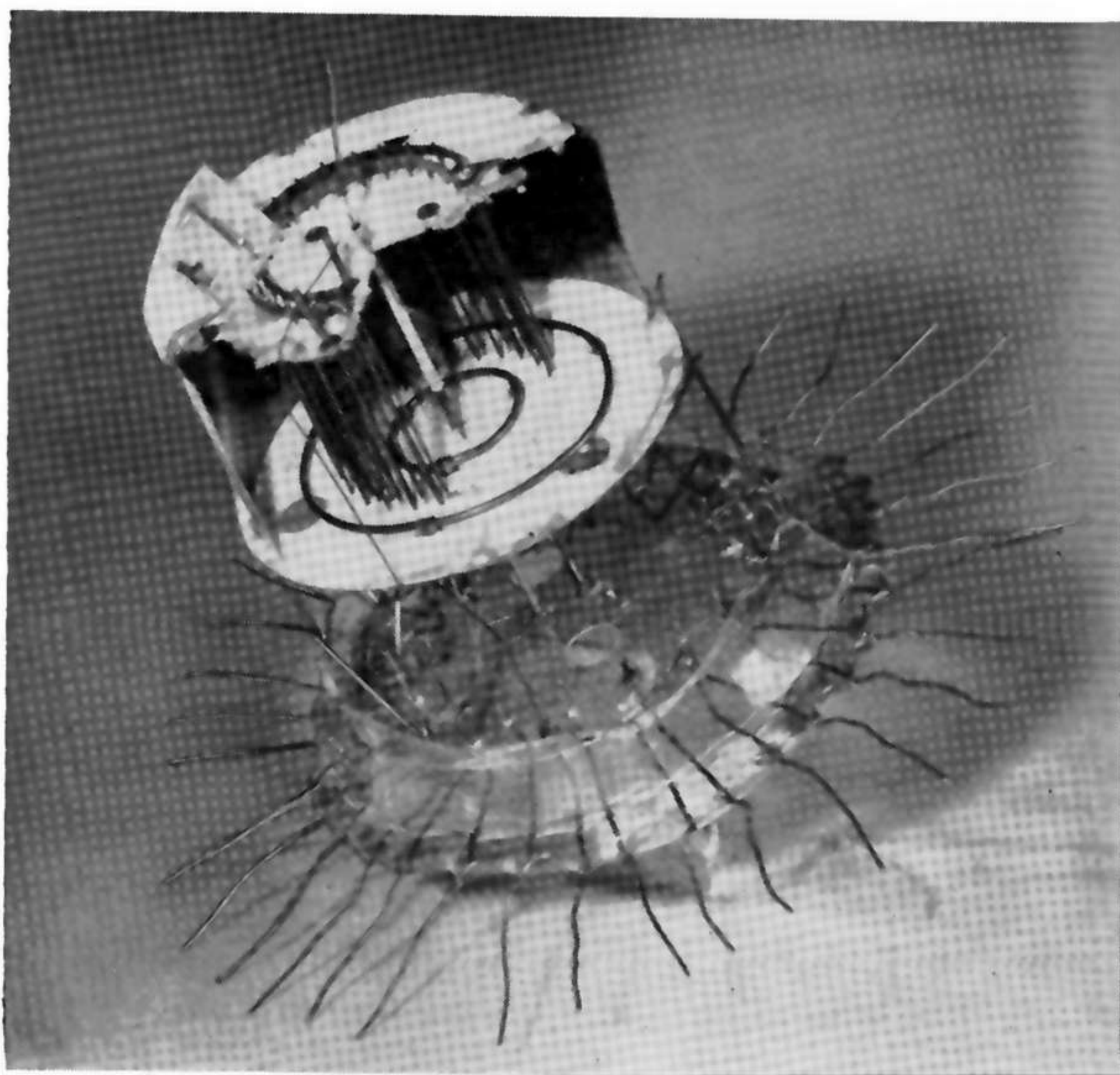
FIG. 1—Cutaway view of multiple element radial beam tube scanner

High-Speed

tube[1] will be used in connection with this tube. Figure 2 is a photograph of such a tube in a complete 50-element scanner. The arrangement of the elements is shown in Fig. 3.

The physical construction and relative location of the elements is similar to a standard pentode. A common heater and cathode are located at the center as an electron source. The next element out is the inner grid or accelerating grid common to all elements; next, the screen posts, then the signal grids, in the suppressor grid position, and finally the plate. Each signal grid is separated from the adjacent signal grid by a post. The MERB tube shown in Fig. 1 has twenty-five separate signal grids.

In operation, the tube is placed in a strong uniform magnetic field perpendicular to the cathode so that the electron stream from the cathode is focused into a radial beam which flows through one of the signal grid elements to the plate. The

focusing of the electron beam is controlled both by the strength of the field and by the voltages on the tube elements. By varying the voltage on this signal grid the current to the plate can be varied. By rotating the field about the axis of the cathode the electron stream can be focused successively on each signal grid. The focusing action of the field produces a double-ended electron beam; with the result that all elements are scanned twice with each revolution. The scanning rate is twice the number of elements times the excitation frequency.

In the scanning system shown in Fig. 2 the MERB tube is used to scan 50 input elements. Each input element has a preamplifier and each element of the MERB tube is connected to two preamplifier outputs. By switching the input preamplifiers *on* alternately in groups as each end of the scanner beam comes around, all 50 elements are scanned by one revolution of the field about the MERB tube. This
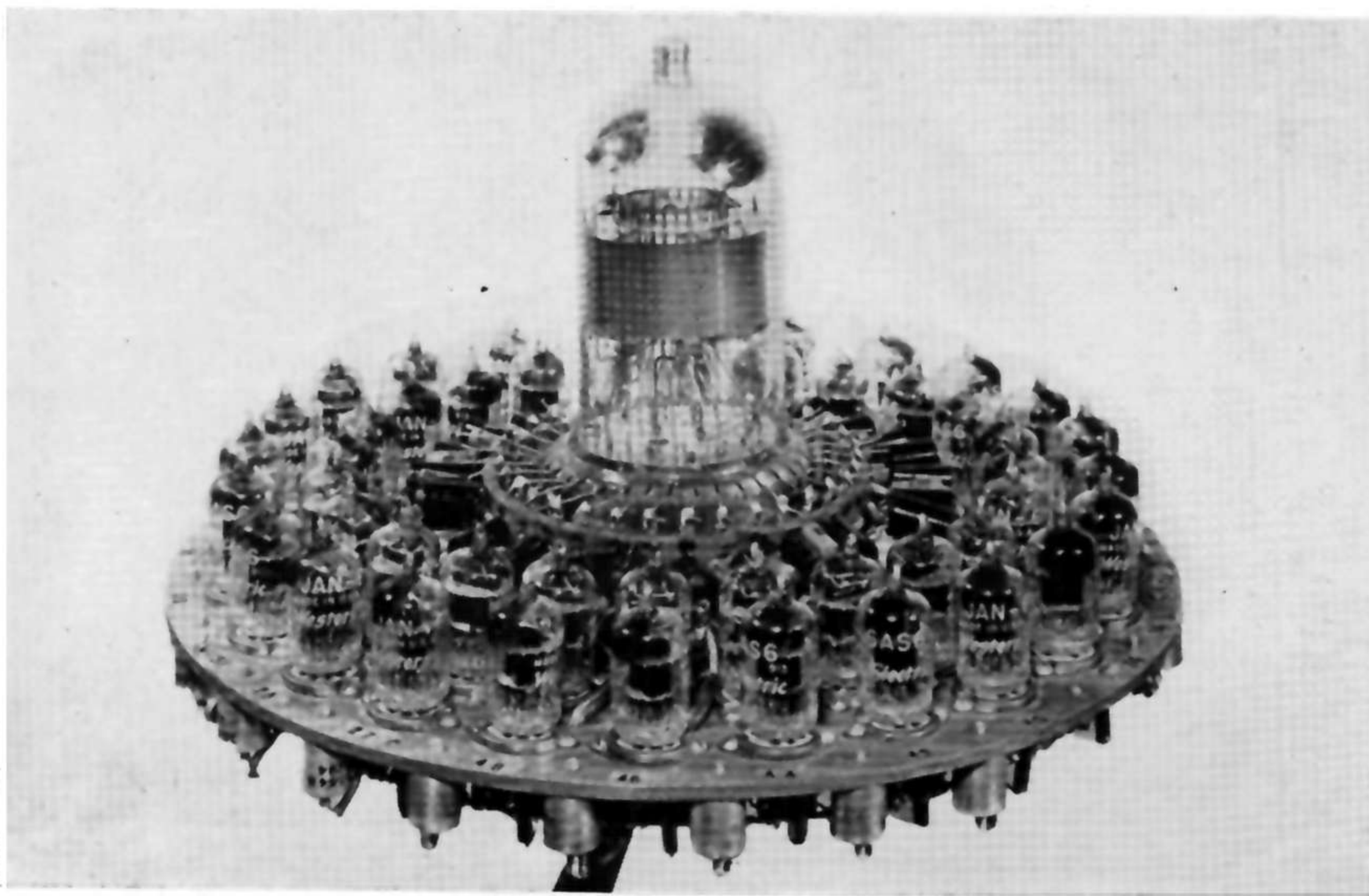
FIG. 2—Complete scanner using multiple-element radial beam tube to sample 50 different signal sources

Sampling Techniques

Space, materials and money can be saved by scanning low-level information sources and using common amplifying, indicating and recording equipment. Survey of sampling systems helps designers choose best system for application to future developments

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same system could be extended to enable a 25-element MERB tube to scan any multiple of 25 inputs.

The major precaution necessary to keep the scanning noise of the MERB tube at a low level is to operate with very low plate current. Low plate current and reasonable transmission is obtained by the use of low voltages on the tube elements. This method of operation necessitates accepting relatively high loss through the tubes, about 6 to 1. The actual gain or loss through the scanner is not in itself too important except for its affect on overall signal-to-noise ratio of the system. The scanner noise should always be greater than the thermal noise level in the scanner output circuit. For most applications it has been necessary to use a one-tube preamplifier ahead of each element to get optimum signal-to-noise ratio.

F-M Scanner

Figure 4 shows a circuit diagram of an f-m scanner. This scanner is the type in which a vacuum-tube amplifier is provided for each input element. The vacuum-tube amplifier is normally biased *off* so that no information can be transmitted from the input to the common output. When it is desired to read information from that particular input element the vacuum-tube amplifier is biased *on* and allowed to transmit the information to the
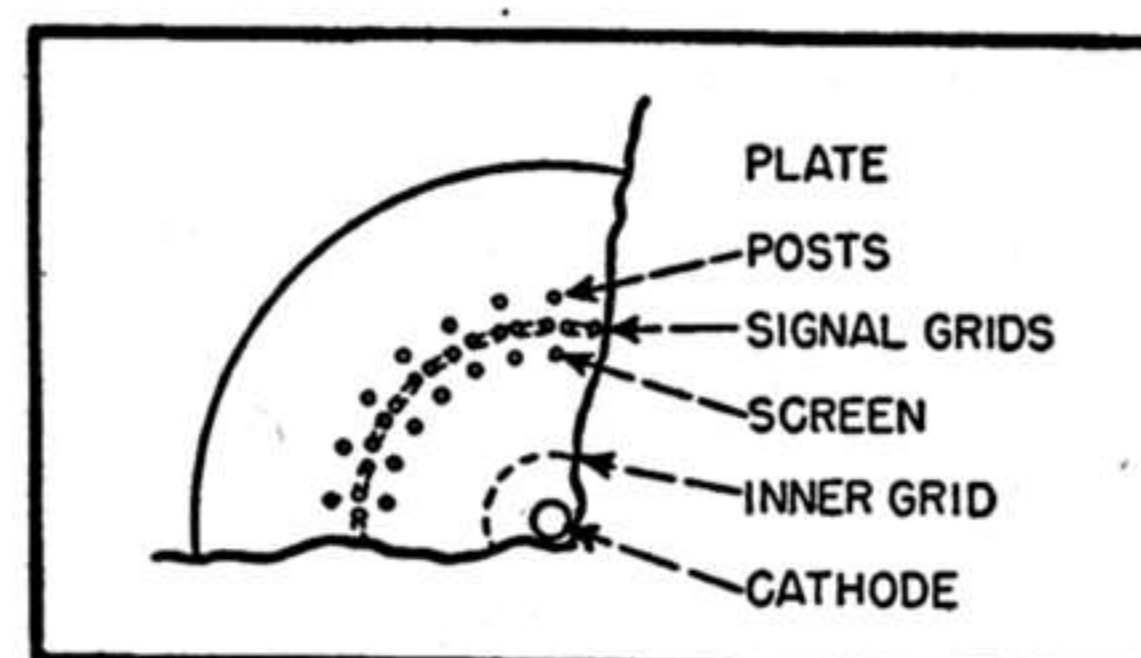

FIG. 3—Physical construction and element arrangement of MERB tube is similar to standard pentode

output circuit. Several methods are available for performing this switching operation. The particular commutation control element described here is called an f-m scanner control unit. It has the advantage that the equipment required at the scanner itself is small and light and does not necessarily contain vacuum tubes. Only one line is needed between the scanner and the control element, and the control element can be remotely located if necessary. The number of elements is not restricted and can be easily changed.

Each scanner element is provided with a tuned circuit T_1 and diode rectifier D. Power is coupled into each tuned circuit from a common bus coming from the control unit. When the common bus is excited at the frequency of the tuned circuit, an a-c voltage is transmitted to the diode rectifier element and a d-c output proportional to the excitation on the common bus is applied to the grid of the scanner tube. If the tube is normally biased *off* and the polarity of the rectified signal is such as to bias the tube *on*, then that particular tube can be turned on by exciting the common bus at the frequency of the resonant circuit. If each resonant circuit of the different scanner elements is tuned to a slightly different frequency from the one next to it, the circuits can be switched *on* in sequence by sweeping the common bus excitation frequency through the range of the tuned resonant circuits.

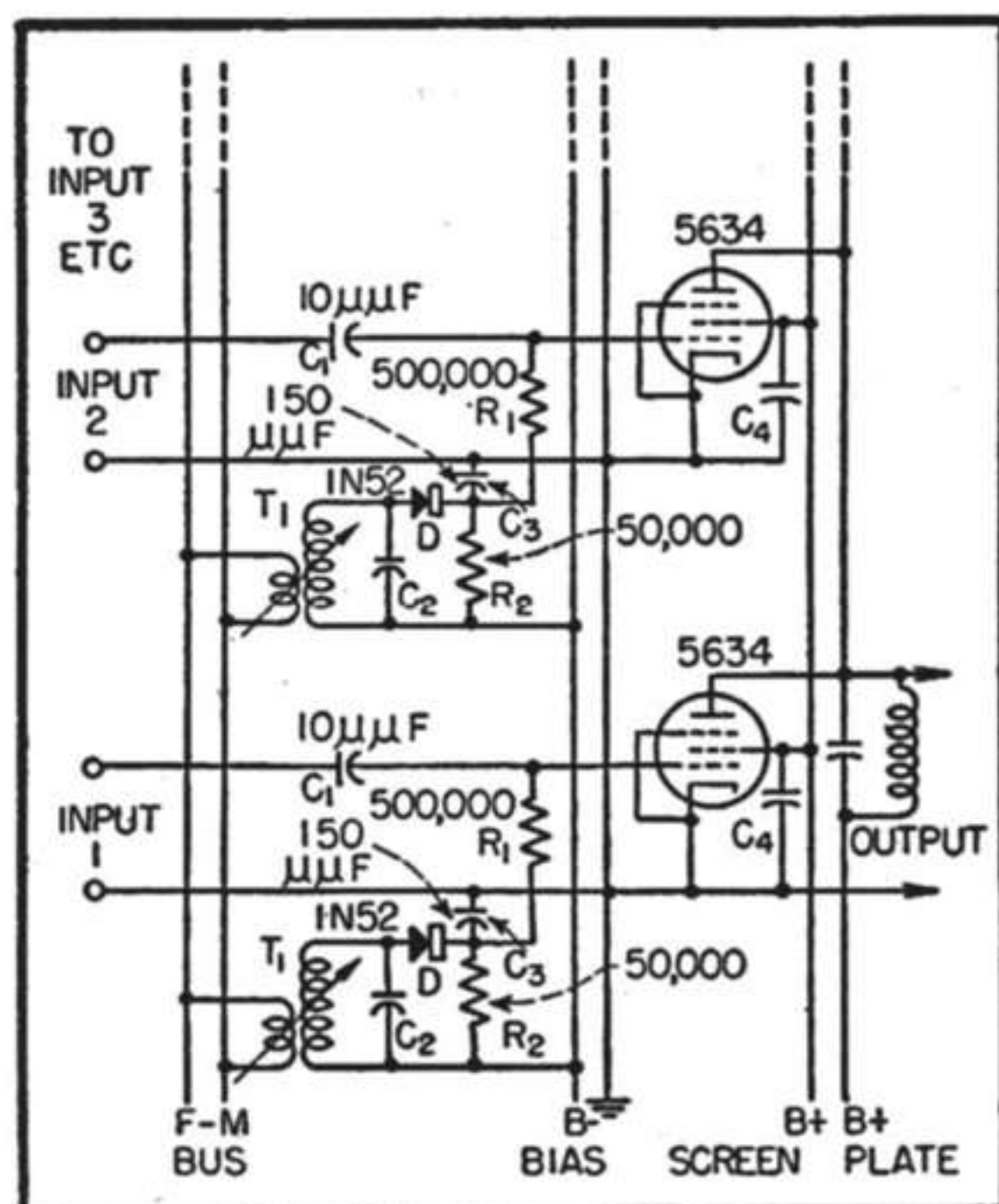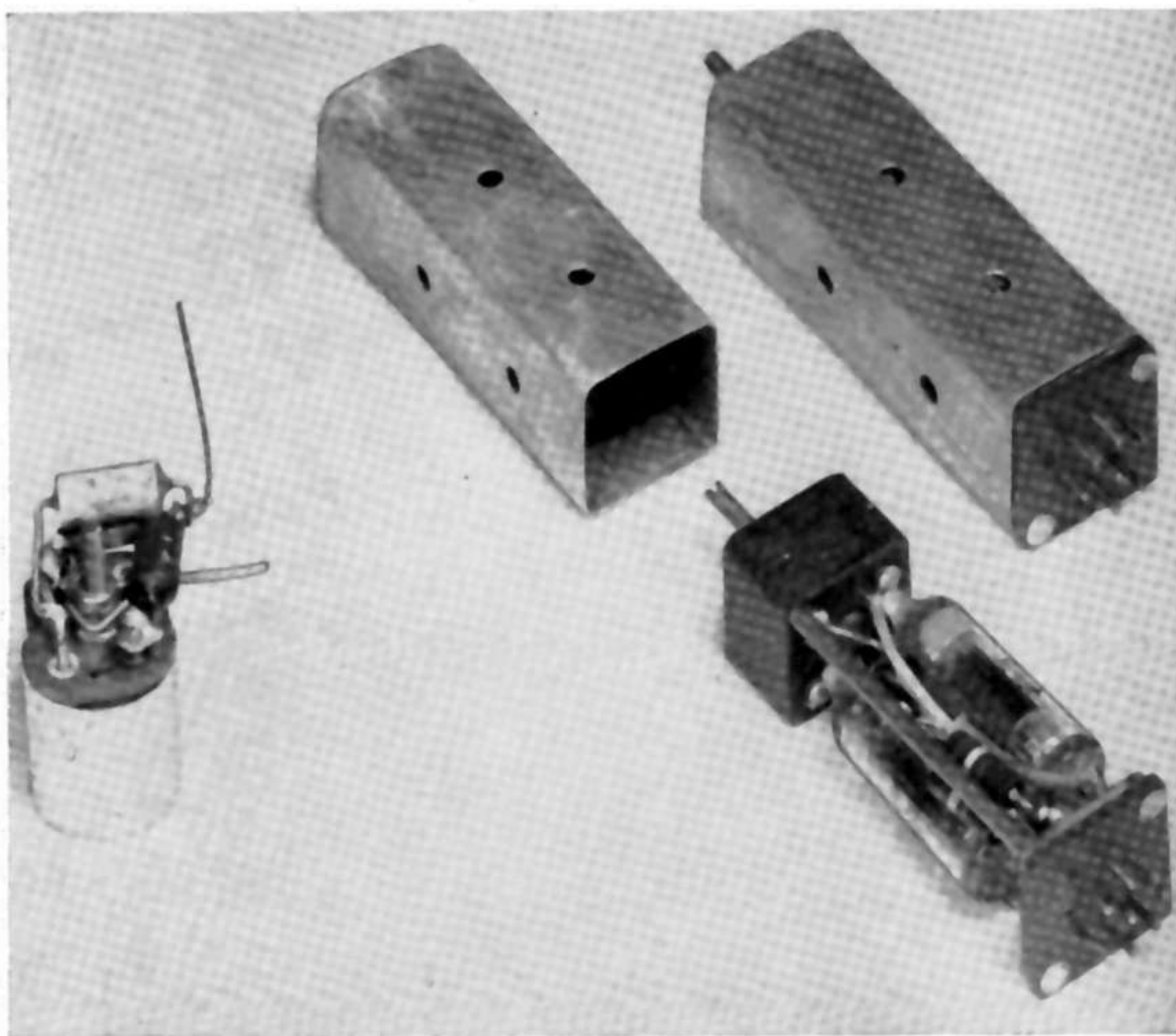Smooth commutation from element to element is obtained by us-

FIG. 5—Subminiature f-m scanner elements

ing the tuned circuit resonance curve as the switching pulse. A smooth or linear sweep frequency rate is used in this case. If desired, an effective square-wave pulse can be applied to each grid by stepping the frequency from that of one tuned circuit to that of the next and so on. It is also possible to stop and turn on only one element at a time and look at that element for as long as necessary by merely exciting the common bus at that particular frequency.

Figure 5 shows two different types of resonant frequency circuits and diode rectifier elements. The unit on the right and center uses subminiature tubes and contains both controlled preamplifier and the switching circuit. The unit on the left uses a germanium diode mounted directly on the tuned circuit. The preamplifier is not included.

Scanning Noise

A scanner as it operates, scanning the input circuits, will generate in its output circuit a complex voltage or current fluctuation which is caused by the scanning action. This noise voltage or current fluctuation is a complex wave which repeats each scanning cycle. In general, this scanning noise is larger than the Johnson noise of the system and is the noise level which

limits the application of the scanner to low-noise circuits.

The scanning noise of a scanner is actually made up of a broad spectrum of finite frequency components each of which is a multiple of the scanning rate. The amplitude of each of these components decreases as the frequency of the component increases. In practice, the scanner output is fed into a band-pass filter which allows only the frequencies around the signal frequency to pass.

If the proper restrictions are placed upon the band pass of the filter following the scanner it is possible to plot a universal noise characteristic curve for the scanner. This noise characteristic will be the same regardless of the actual scanning rate of the scanner. The restriction which must be placed upon the band pass of the system following the scanner is that the band pass be just wide enough to pass the important modulation components introduced by the scanning action. Under these conditions the band pass becomes a fixed multiple of the scanning frequency, the multiplying factor depending upon the shape of the scanner output wave.

The actual noise characteristic for a scanner can be obtained at any practical operating scanning speed. It is possible to evaluate a

FIG. 4—Typical f-m scanner circuit

scanning apparatus with normally available laboratory equipment and using low or readily available scanning speeds. If the information obtained is plotted as shown in Fig. 6 with a horizontal scale which is a multiple of the scanning rate, the resultant curve is the noise characteristic of the scanner and can be applied to all operating scanning rates for the scanner to determine the circuits required ahead of the scanner.

The two curves on Fig. 6 show the noise characteristic of the MERB tube scanner and the f-m scanner. Both characteristics have essentially the same shape. The level of the noise curve depends upon how well balanced are the different tubes or elements of the scanner. If all of the elements are exactly the same and are switched simultaneously there will be very little scanning noise generated. Practically speaking, this is never true; hence, the amount of noise generated in a scanner depends upon the patience and ability of the designer to select tubes or design a circuit to eliminate tube variations.

The actual rate of cutoff of the noise characteristic curve can be improved by the use of properly shaped pulses for switching. Smooth commutation such as that available in the f-m unit will tend to reduce the high-frequency components of the noise. This is shown by the faster decay in the characteristic curve for the f-m scanner. In this particular case the element amplifiers were operated at normal plate current levels. In general, the level of the noise charactertistic can be reduced by operating the tubes at very low current levels.

Reducing Noise

Once the noise characteristic of a scanner is obtained it is fairly easy to outline methods which can be used to make a scanner operate at lower signal levels. Two general approaches can be applied. One is to modify the external circuit to make the best use of the scanner noise characteristic; the other is to work directly with the scanner to try to reduce the level of the noise characteristic.

A study of the noise characteristic curve will show that there are two ways of reducing noise by external circuit modifications. One is to increase the frequency of the signal carrier and the other is to reduce the band pass to the absolute minimum required to pass the information. If the application permits, raising the carrier frequency is an easy way to reduce scanner noise. If the signal frequency cannot be changed, the operating frequency of the scanner can often be raised by mixing in the scanner. The normal loss in gain due to mixing must be taken into account so that a larger increase in frequency is required than would be needed if mixing were not used.

In working with the scanner directly there are four methods or approaches for improving the noise
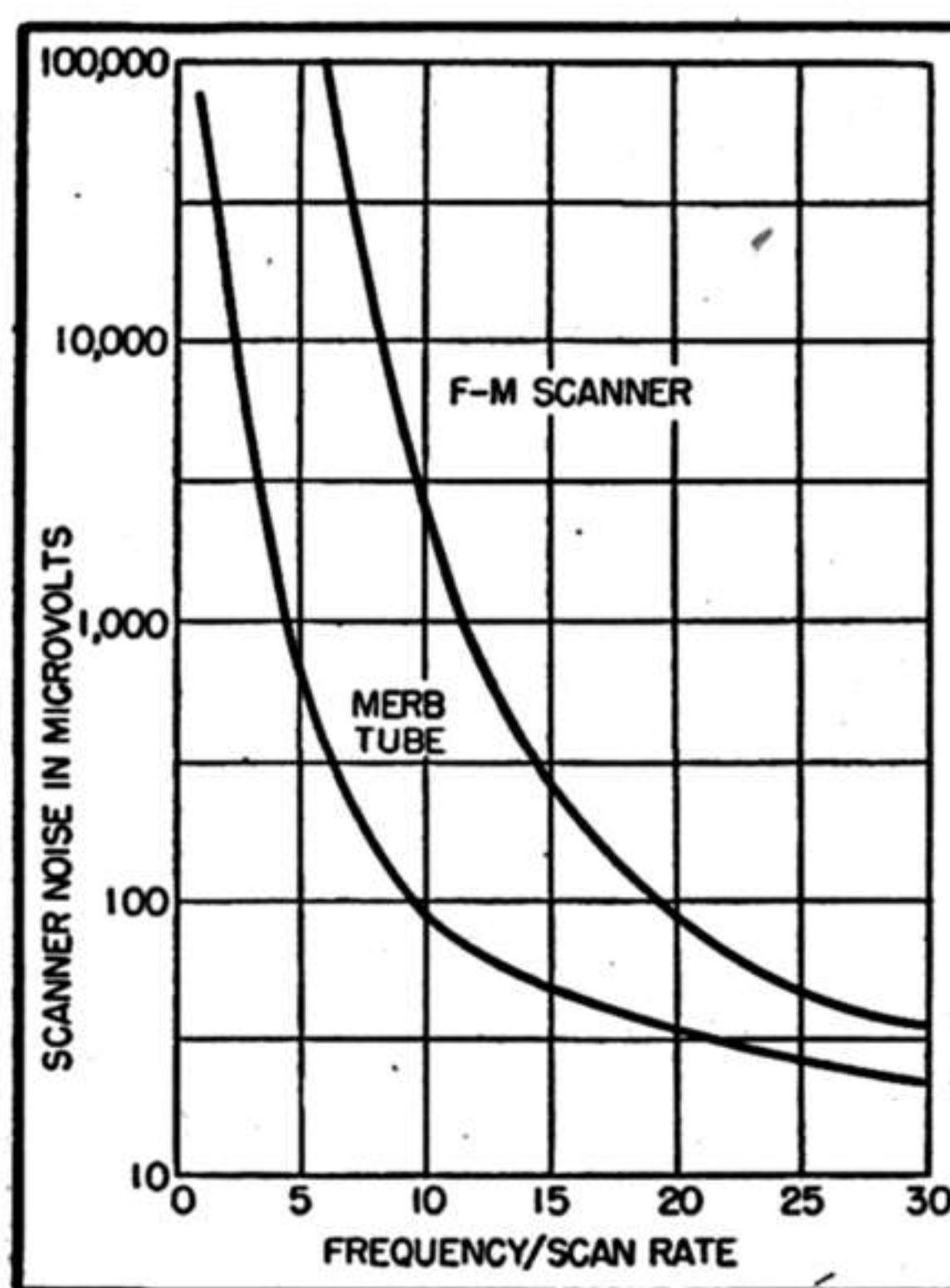

FIG. 6—Noise characteristics of two scanner types

characteristic or reducing the amount of noise generated by the scanning action. All four methods are based on reducing the amplitude of the variation between elements or reducing the switching rate between elements:

(1) Reduction of the quiescent or average d-c level of the scanner to the absolute minimum necessary to give useable results. The scanning noise components are proportional to the average current. If the average current can be reduced without a proportional reduction in signal gain, a net improvement in signal-to-noise ratio results.

(2) Balancing of all the scanner

elements so that differences between d-c element values are reduced to a minimum.

(3) Increasing the cross-over time between elements. This can be done by proper shaping of the transfer conditions so that a minimum amount of high-frequency components is generated. In general, the noise is generated during the switching period between elements and is caused by dissimilarity between elements of the scanner or gaps in transmission between elements. Any procedure which tends to reduce the dissimilarity and eliminate the gap or reduce the rapidity with which the dissimilarity or gap occurs will aid in reducing the amplitude of the high frequency component generated by the scanning action. An improvement of this kind makes the noise characteristic decay faster with increase in signal frequency.

(4) Reduction of scanning rate. If a slower scanning rate can be tolerated, this will have the same effect as increasing the signal carrier frequency. In addition, a narrower band pass can also be used.

The foregoing methods for improving signal to noise performance of a scanner can be applied to any such commutating device. In general, to utilize a scanner at very low signal levels it is necessary that the information in the signal be available to the scanner at a frequency higher than the scanning rate. Just how much higher will depend upon how low a signal level must be observed and upon the noise characteristic of the particular scanner.

The scanners described here have utilized a switching characteristic or wave form approaching a cosine function in order to obtain smooth commutation. Other switching characteristics will produce a different scanner noise characteristic curve, but the basic problems are the same. Optimum scanner design for any application requires a suitable compromise between circuit complexity, switching characteristics, scanning rate, and scanning noise performance.

REFERENCE

(1) A. M. Skellett, Magnetically Focused Radial Beam Vacuum Tube, Jour. App. Phy., p 704, Oct. 1944.