Final progress report on ECDC project T-34

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NATIONAL RESEARCH COUNCIL OF CANADA
RADIO AND ELECTRICAL ENGINEERING DIVISION

FINAL PROGRESS REPORT ON ECDC PROJECT T-34

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OTTAWA
JULY 1959 NRC# 35611

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ABSTRACT

Development of the VAD-161 double-ended backward-wave oscillator by Varian Associates of Canada Ltd. is described. Data obtained from measurements made on the final models delivered to this laboratory are included, along with discussion of the performance as a superregenerative and autodyne receiving tube.

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FINAL PROGRESS REPORT ON ECDC PROJECT T-34

- J.K. Pulfer -

INTRODUCTION

Experimental work carried out at this laboratory [1] showed that an O-type carcinotron or backward-wave oscillator can be operated as a superregenerative receiver at microwave frequencies. When a traveling-wave tube is operated at beam velocities which produce backward-wave oscillations, there is negligible interaction between a signal traveling along the oscillator delay line, from gun to collector, and the electron beam. Experimental results show, however, that a signal as small as -65 to -70 dbm inserted at the gun end of a backward-wave oscillator is sufficient to cause a detectable increase in phase coherence of the output pulses. It was assumed, therefore, that a small portion of the injected signal was being reflected from the termination at the collector end of the tube, and this reflected signal traveling in the opposite direction to the electron beam initiated the oscillations. Reflectometer measurements indicated a reflected wave 15 to 20 db below the input signal, so that it was hoped that an increase in sensitivity of this order might be obtained if the signal could be applied directly to the collector end of the helix.

Project T-34 is an ECDC contract with Varian Associates of Canada Ltd., to develop a double-ended backward-wave oscillator for use in superregenerative receiver experiments. Four experimental models have been built, and the results of measurements made on these tubes have produced sufficient information that no further development work is required at the present time. The developmental tube has been assigned the designation "VAD-161".

The first and second models of the tube (VAD-161-1 and VAD-161-2) were similar in construction to the Varian VA-161 backward-wave oscillator. These tubes are described in earlier progress reports [1, 2, 3]. The first model was retained by Varian Associates, the second — VAD-161-2 — is shown in Plate I.

DESCRIPTION OF VAD-161-2

To provide a basis for description of the work done in this project, the discussion and recommendations of the first progress report describing the VAD-161-2 are repeated here:

1) The life of the tube was only 18 hours, after which it ceased to function because of filament burnout.

2) Because of the filament failure, maximum usable quench frequency was not determined.
3) The match at the helix-to-waveguide transitions was fair (see Fig. 1), but a reduction of standing-wave ratio at input and output was desirable.
4) Inter-electrode capacities were small and did not seem to limit the usable quench frequency.
5) Frequency pushing due to the quench voltage on the tube grid was not objectionable.
6) VAD-161-2 was awkward and fragile. A more rigid, compact structure was recommended.
7) It was recommended that the cause of filament burnout be studied.
8) Results indicated that the expected increase in sensitivity as a superregenerative receiver using the collector end input would be realized.

FURTHER MEASUREMENTS MADE ON THE VAD-161-2

The tube was returned to Varian Associates because of the filament burnout, and was equipped by them with a new heater assembly. The tube has since been used at the National Research Council for several hundred hours and is still performing satisfactorily.

Further studies of the VAD-161-2 operating as a superregenerative receiver produced the following information.

1) Maximum usable quench frequency was approximately 30 mc/s. Attempts to quench at 50 mc/s failed, as the tube would operate only in a coherent fashion. The upper quench frequency limit was ascribed to phase-locking of the oscillator with the extremely sharp leading edge of the 50 mc/s quench pulse. Stated in another way, the output of the oscillator was phase-locked to a harmonic of the quench frequency propagating on the electron beam.
2) A sensitivity of 90±2 dbm to c-w signals was obtained uniformly over the 8.2 to 12.4 kmc/s frequency range of the oscillator. This sensitivity was obtained by carefully optimizing all parameters, such as beam current and quench voltage, at each frequency.
3) Sensitivity to c-w signals (as measured by detecting the presence of lines in the output spectrum on a spectrum analyzer with 25 kc/s resolution) was not dependent on quench frequency, although bandwidth (and thus minimum detectable pulsed signal) varied with quench rate and waveform.
4) It was considered that a more rigid and compact structure would be highly desirable. A permanent magnet to be supplied with the tube was also considered desirable, as oscillator starting current fluctuated over wide ranges for small changes of orientation of the tube in the magnetic field.

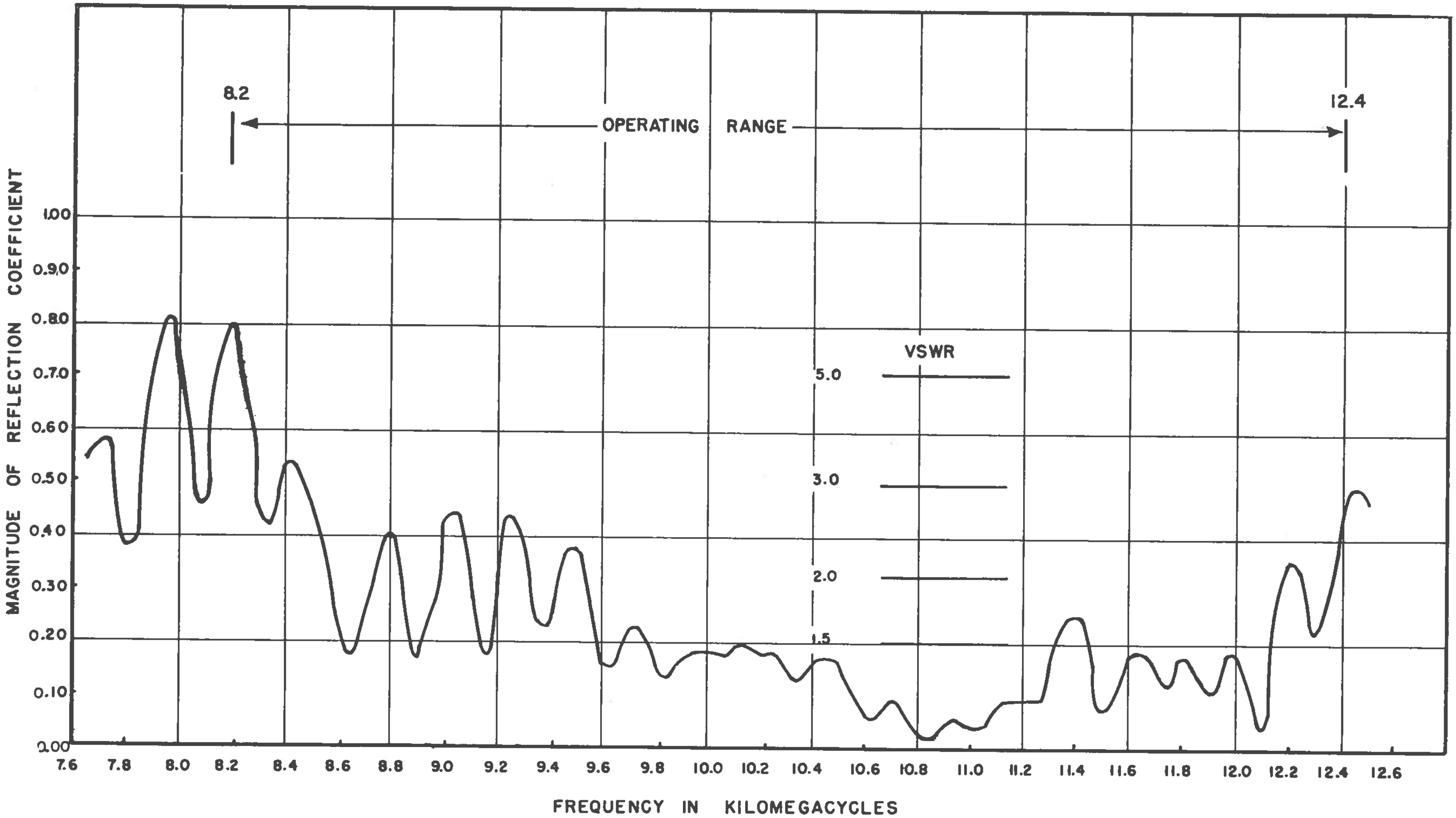

FIG. 1 (a) INPUT REFLECTION COEFFICIENTS FOR HELIX-TO-WAVEGUIDE TRANSITIONS OF TYPE VAD-161-2 TUBE

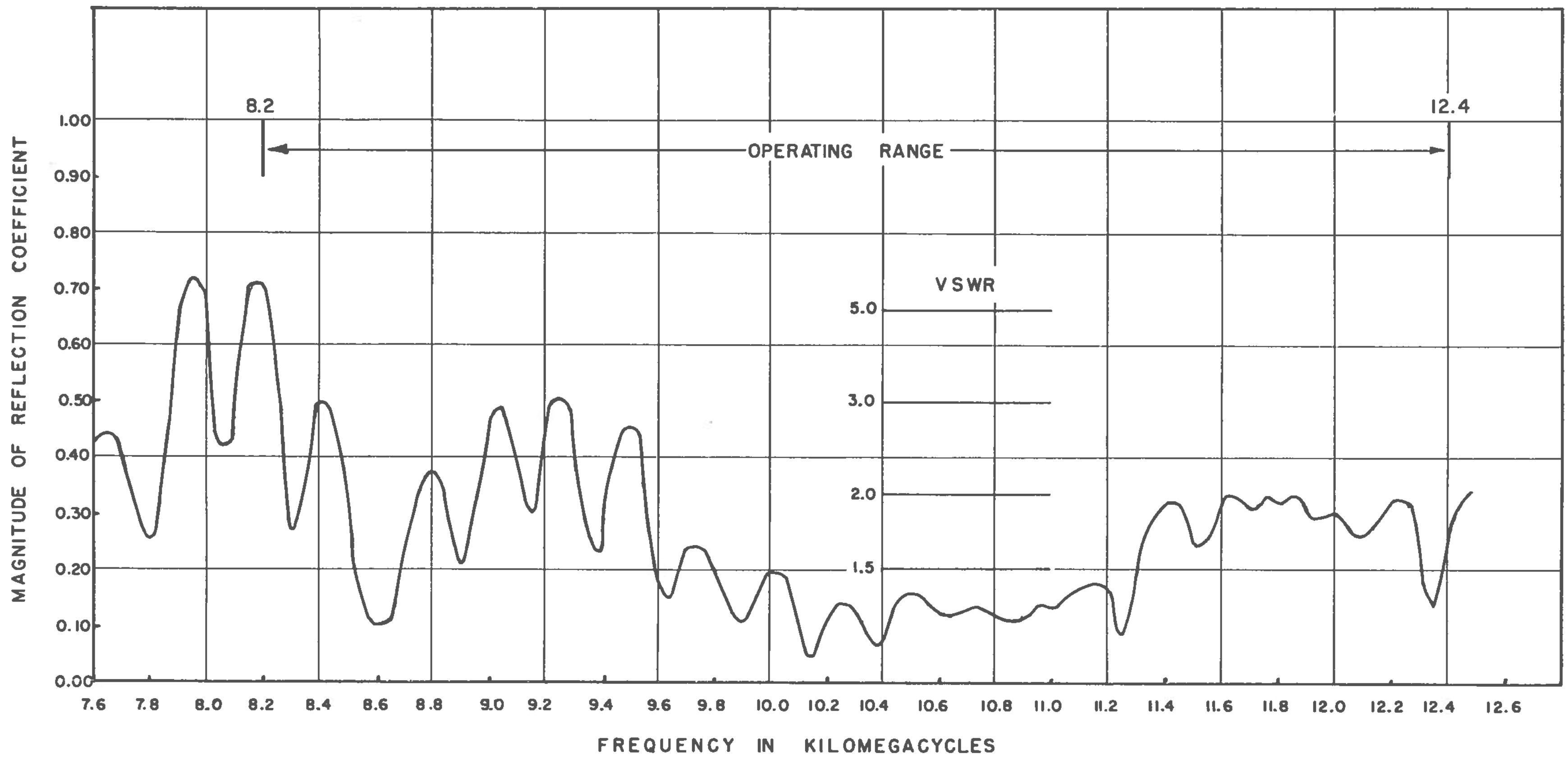

FIG. 1 (b) OUTPUT REFLECTION COEFFICIENTS FOR HELIX-TO-WAVEGUIDE TRANSITIONS OF TYPE VAD-161-2 TUBE

5) An improvement of the waveguide-to-helix transition was considered essential for electronically tuned operation. Internal reflections from the transitions caused variations of starting current with frequency. Since the superregenerative method of receiving required the beam current to be varied just above and below starting current, changes in frequency resulted in changes in the optimum value of operating parameters for maximum sensitivity, and thus sensitivity varied with frequency.

OPERATION AS AN AUTODYNE RECEIVER

In the course of measurements on the VAD-161-2, it was discovered that much higher sensitivity with a corresponding decrease in bandwidth could be obtained by operating the tube with no quench voltage, and a beam current slightly above starting current. Further investigation showed that the tube was operating in a fashion similar to an autodyne detector [4]. It was decided that this type of operation was useful in countermeasures applications, and a study of the properties of a backward-wave autodyne receiver was made in order that further improvements of the tube characteristics could be recommended. The results of this study were reported [5, 6], and some of them will be given here:

1) The autodyne receiver was found to be more sensitive to variations in starting current than the superregenerative type, so that improvement in the waveguide-to-helix transition was considered essential for wideband operation.
2) The increased sensitivity to starting current variations was accompanied by increased sensitivity to variations of magnetic focusing field, so that a permanent magnet attached to the tube was desirable.
3) It was found that video signal could be removed directly from the electron beam of the tube by biassing the collector negatively to produce velocity-sorting detection. With the VAD-161-2, the collector was not designed for depressed operation with the result that space charge density was high at certain beam velocities and currents, and a negative resistance looking into the collector was created [7, 8]. Because of the negative resistance, oscillations occurred at the particular collector voltage which produced maximum video output. It was, therefore, recommended that in newer models of the tube, the collector be redesigned for operation at a negative potential relative to the helix.

THIRD MODEL: VAD-161-3

The third model of the tube was supplied by Varian Associates of Canada Ltd., complete with permanent magnet. The entire body of the tube, and the helix-to-waveguide transition were redesigned and the result was a more compact and rigid mechanical structure [9]. The tube is shown in Plate II.

Experimental measurements on the VAD-161-3 indicated that the impedance match at the helix-to-waveguide transitions was very poor. By using tuning screws in the waveguide as near as possible to the transitions, it was possible to match the transitions (VSWR < 2:1) over a 500 megacycle bandwidth, at any point in its tuning range. Within the matched bandpass, the tube behaved like the VAD-161-2. Fig. 2 shows the input and output reflection coefficient for optimum matching from 9000 to 9500 mc/s.

Because of an internal short circuit between collector and body of the VAD-161-3, no studies could be made of collector velocity-sorting detection.

FOURTH MODEL: VAD-161-4

The fourth model of the tube was also completely redesigned mechanically [10]. It is shown in Plate III. The tube used a new helix-to-waveguide transition similar to the one presently in use in the backward-wave oscillator constructed by Varian.

The fourth tube was equipped with a shell-type permanent magnet which made it much less sensitive to external magnetic fields, and more compact in construction. In Plate IV tubes 161-2, 161-3 and 161-4 are shown for comparison.

The collector of the tube was designed for depressed operation, and measurements indicated that there was no sign of instability at any collector voltage within the useful range.

The performance of the helix-to-waveguide transition of Type VAD-161-4 was slightly better than that of the VAD-161-2, but fell well below expectations. Varian Associates felt that the transitions could be improved on a fifth model of the tube, but it was decided that the expense was not justifiable.

EXPERIMENTAL RESULTS

Experimental measurements on the VAD-161-4 were made using the same type of equipment, and the same setup as with earlier tubes. The voltage reflection coefficient of the oscillator was measured at both the gun and collector ends of the helix by means of a reflectometer.

Plots of reflection coefficient versus frequency are given in Figs. 3(a) and 3(b).

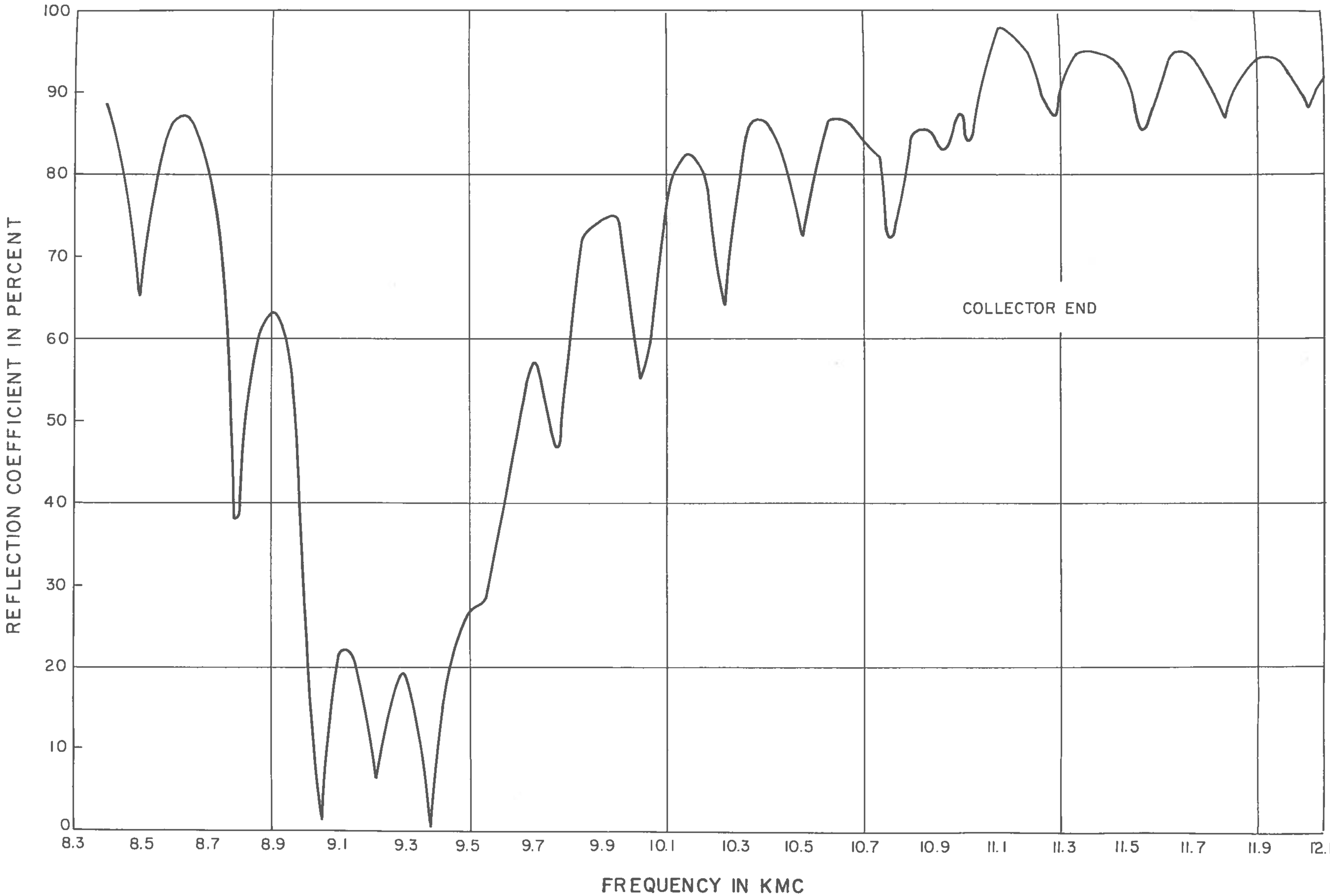

FIG. 2 (a) INPUT REFLECTION COEFFICIENTS FOR HELIX-TO-WAVEGUIDE TRANSITIONS OF TYPE VAD-161-3 TUBE

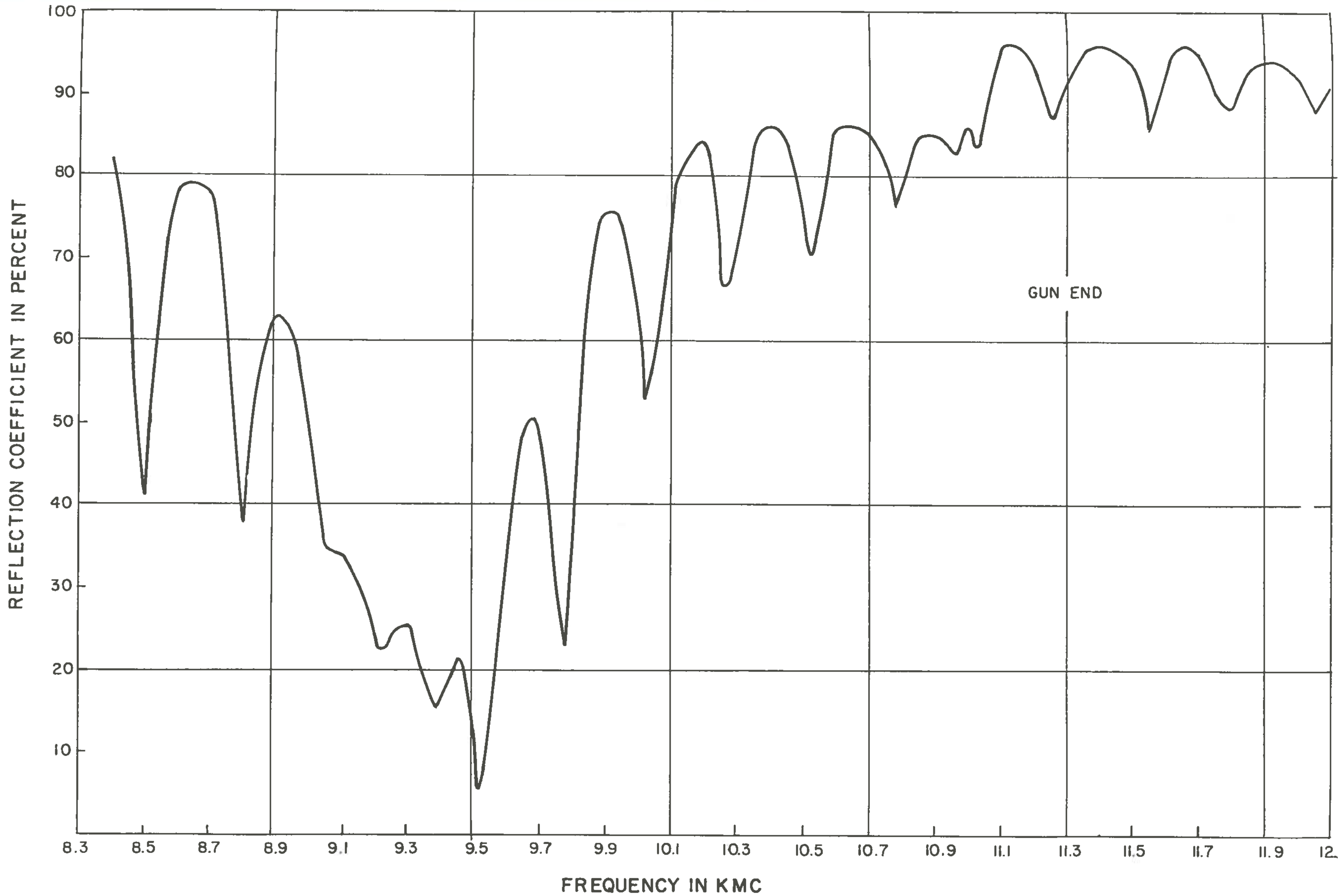

FIG. 2 (b) OUTPUT REFLECTION COEFFICIENTS FOR HELIX-TO-WAVEGUIDE TRANSITIONS OF TYPE VAD-161-3 TUBE

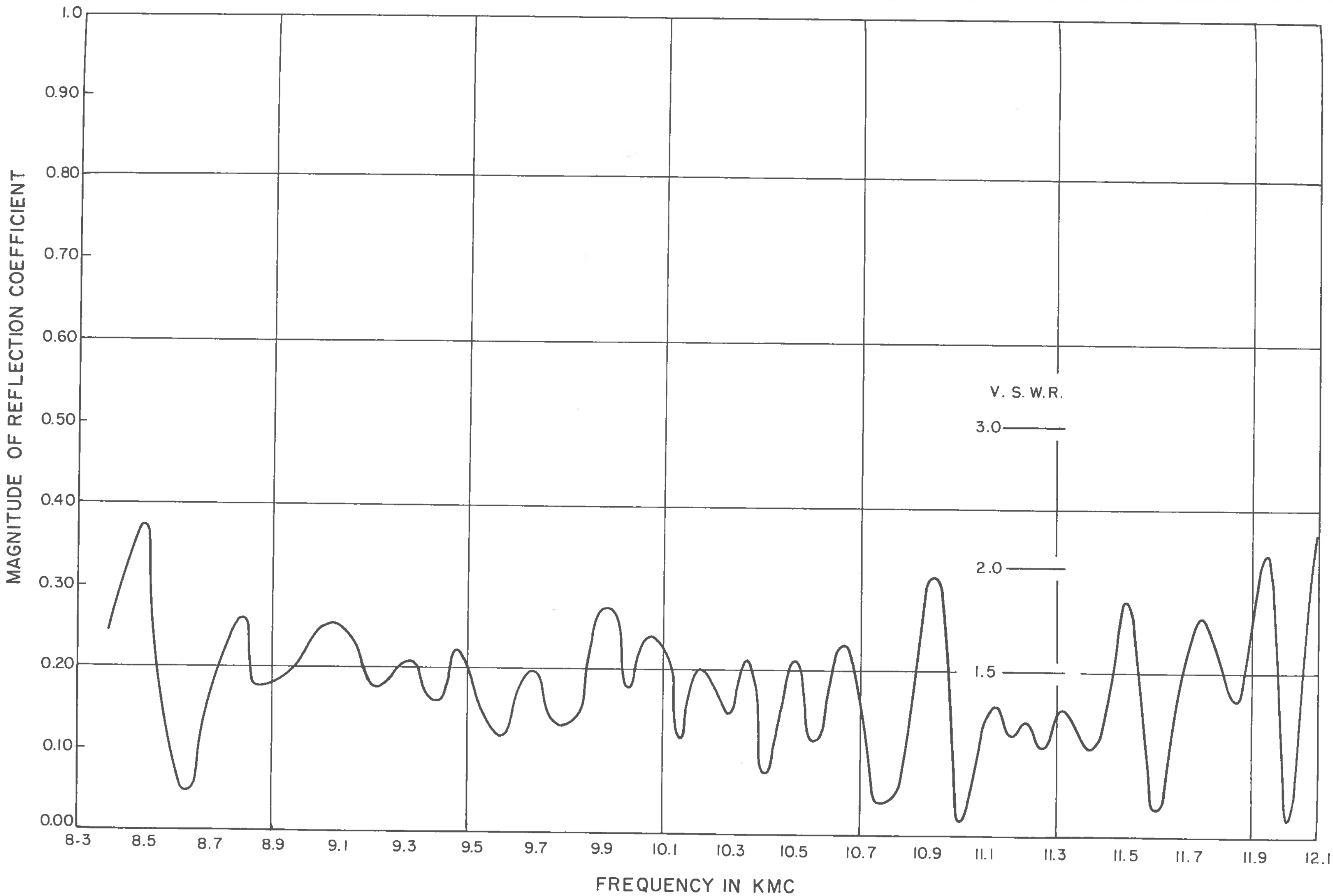

FIG. 3 (a) INPUT REFLECTION COEFFICIENTS FOR HELIX-TO-WAVEGUIDE TRANSITIONS OF TYPE VAD-161-4 TUBE

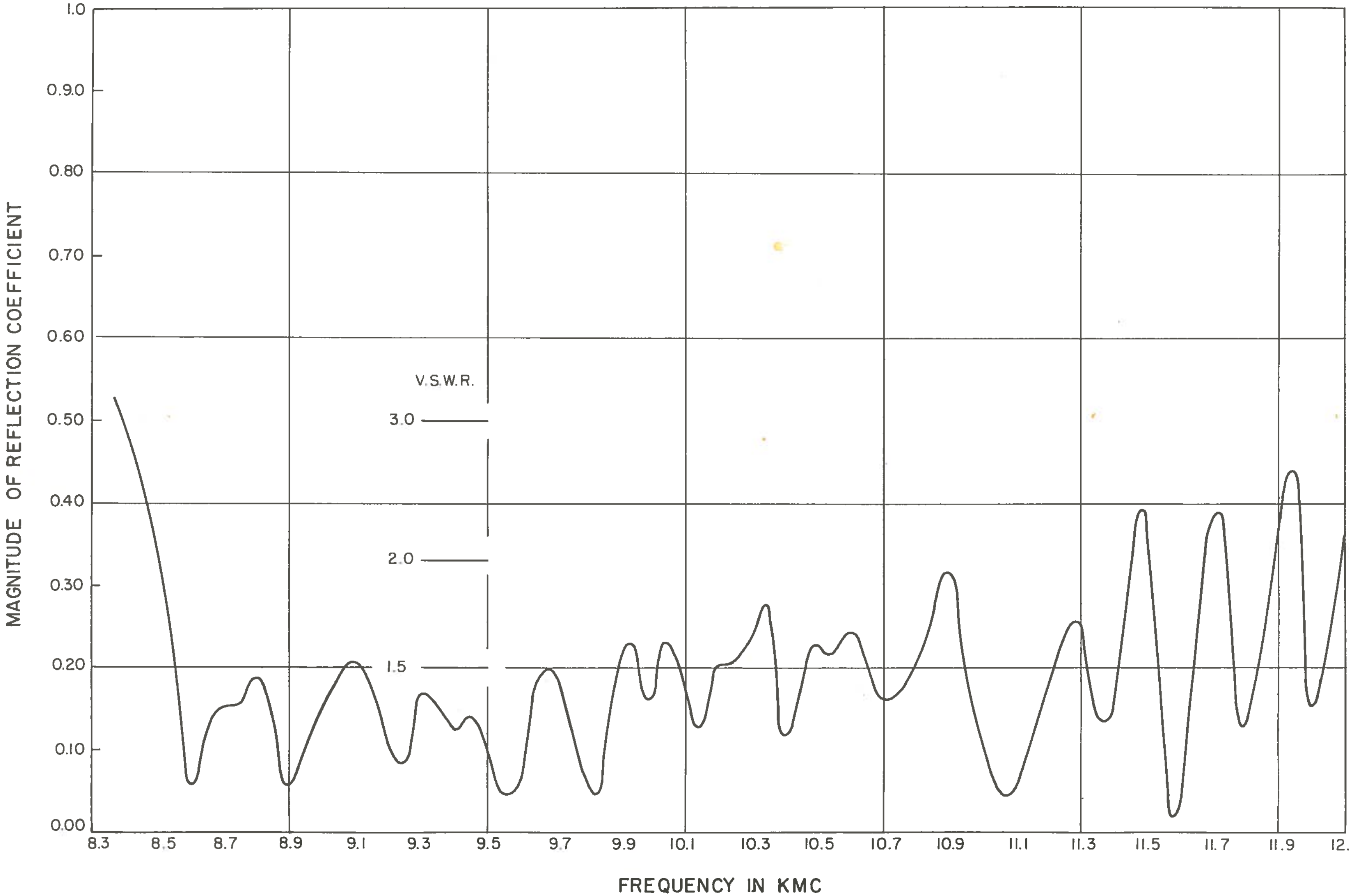

FIG. 3 (b) OUTPUT REFLECTION COEFFICIENTS FOR HELIX-TO-WAVEGUIDE TRANSITIONS OF TYPE VAD-161-4 TUBE

Note: Curves were taken without bent waveguide output on collector end

A — gun end
B — collector end

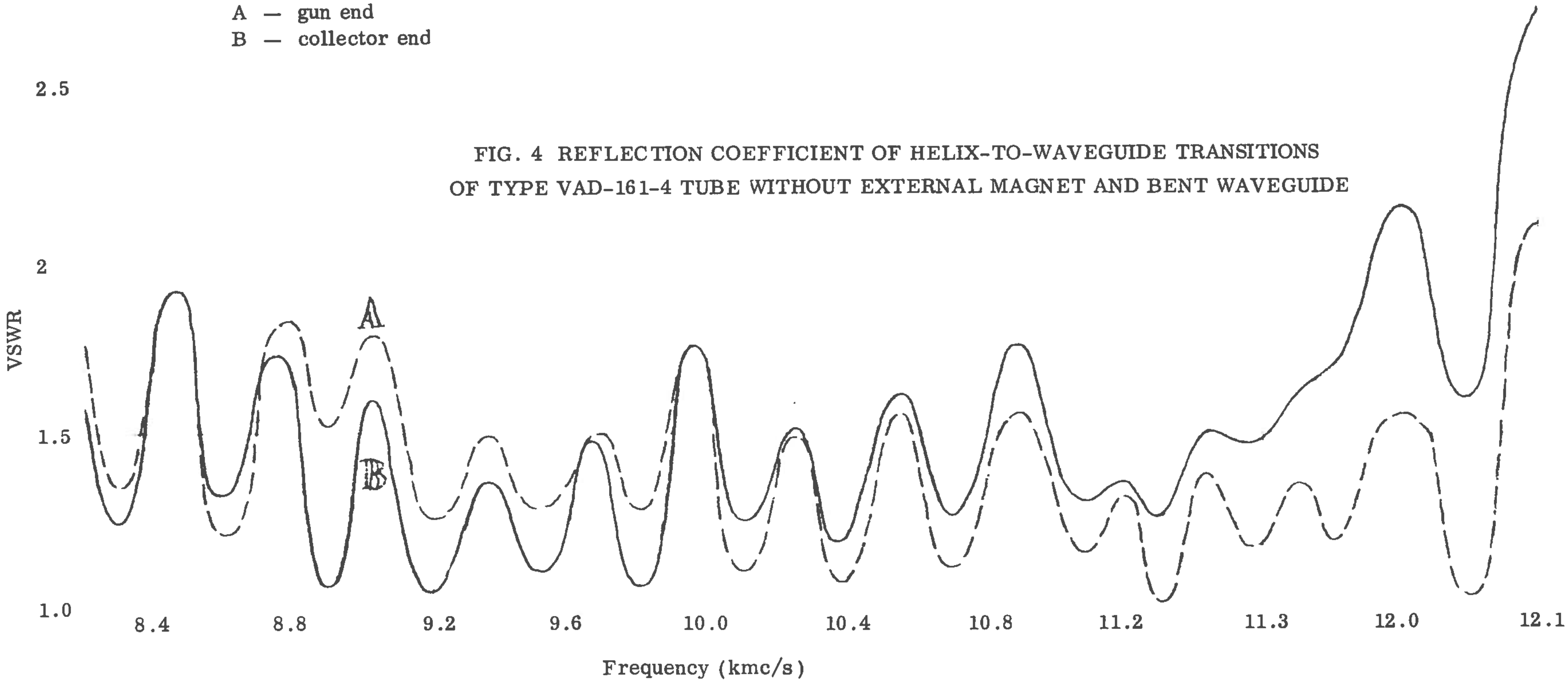

FIG. 4 REFLECTION COEFFICIENT OF HELIX-TO-WAVEGUIDE TRANSITIONS OF TYPE VAD-161-4 TUBE WITHOUT EXTERNAL MAGNET AND BENT WAVEGUIDE

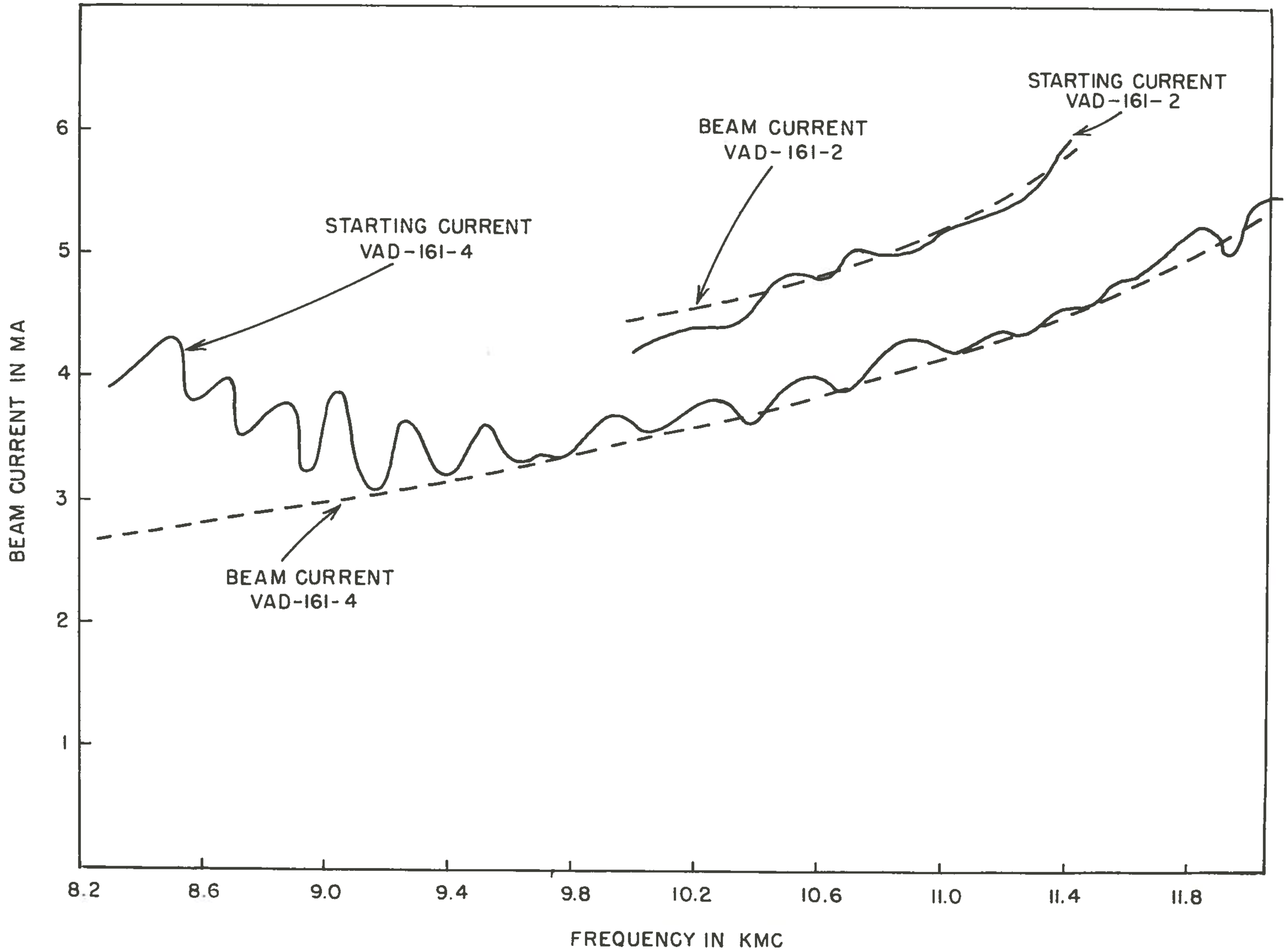

FIG. 5 BEAM CURRENT VERSUS FREQUENCY FOR TUBE TYPES VAD-161-2 AND VAD-161-4

Fig. 4 is a curve of reflection coefficient which was measured by Varian Associates on the VAD-161-4 before the tube was encased in its magnet, and the bends inserted in the input waveguide.

Measurements of beam current versus frequency at the start of oscillations were made, since the object of production of a low reflection coefficient at the helix-to-waveguide transition was to reduce the effects of mismatch on starting current. These are represented in Fig. 5. The data available from previous measurement on the VAD-161-2 was also plotted on the same figure for comparison.

To obtain an idea of the performance of the tube as a swept receiver, it is desirable to know how closely beam current tracks with starting current as frequency is varied. The dotted lines on the graph of Fig. 5 were obtained by varying the line voltage with the grid of the tube fed as shown in the circuit of Fig. 6. In this way, beam current was made to track closely with starting current over a large fraction of the tuning range of the tube.

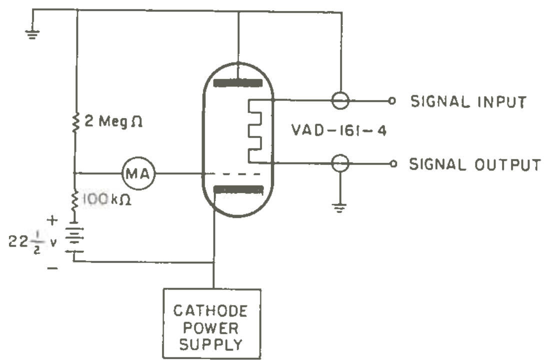

FIG. 6 CIRCUIT USED FOR BEST TRACKING OF OSCILLATOR BEAM CURRENT WITH STARTING CURRENT

When the tube is operated as a superregenerative receiver, the sensitivity to c-w signals as a function of frequency is an important property. The technique for measuring sensitivity used on previous tubes was used on this one also. Sensitivity was defined as the minimum signal which produced visually detectable coherence in the output spectrum of the oscillator, as observed on a spectrum analyzer with 25 kc/s resolution.

Fig. 7 is a plot of sensitivity versus frequency for the VAD-161-4, with a quench frequency of approximately 4.5 mc/s. Further measurements were made on the tube with a quench frequency of 30 mc/s. It was found that sensitivity was very nearly the same as at the lower quench frequency, and that the tube was easily quenched at 30 mc/s. It was observed, however, that the high quench rate reduced the output power over a given bandwidth, as had occurred with the previous tubes. This was due to the spreading of the power over a much wider output band of frequencies and to the reduced time available for build-up of a single pulse (< 20 milli-microseconds).

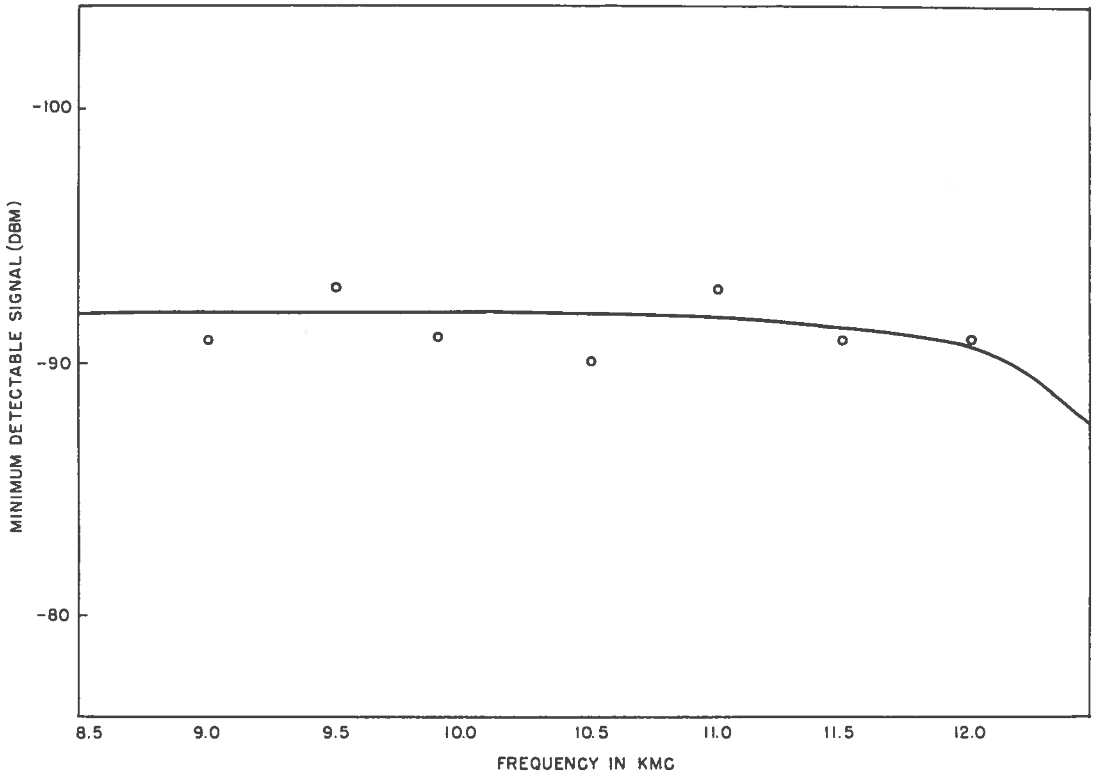

FIG. 7 SENSITIVITY VERSUS FREQUENCY FOR THE TYPE VAD-161-4 TUBE OPERATED AS A SUPERREGENERATIVE AMPLIFIER

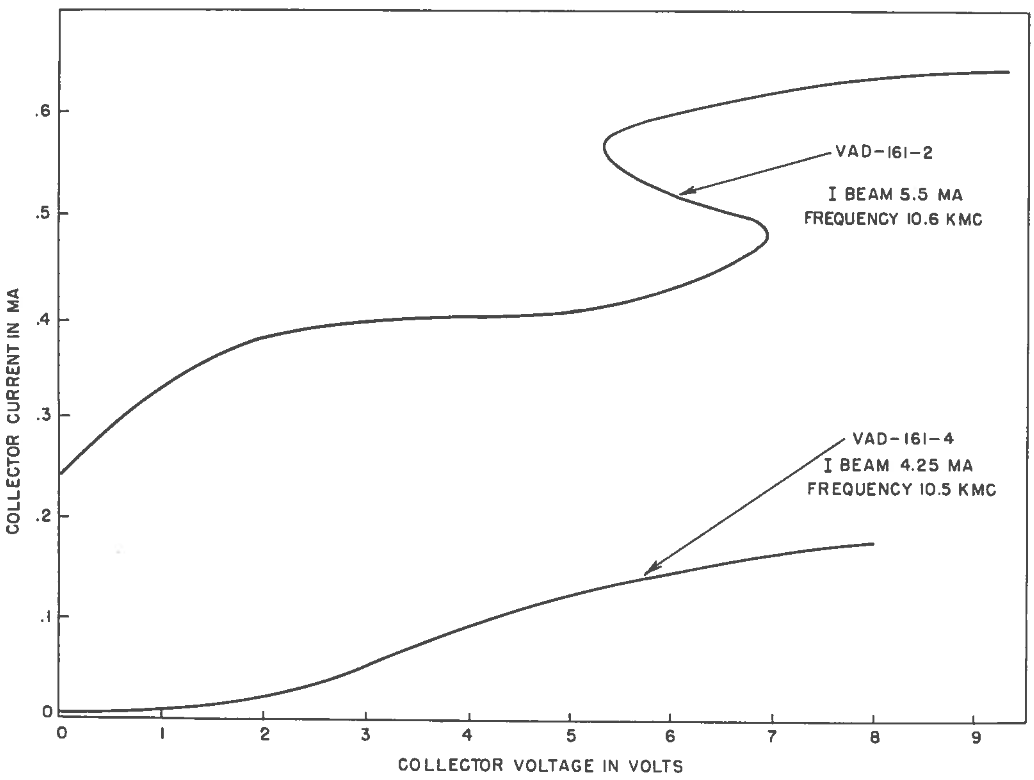

FIG. 8 COLLECTOR CURRENT VERSUS COLLECTOR-TO-CATHODE VOLTAGE FOR THE TYPES VAD-161-2 AND VAD-161-4 TUBES

The tube was operated as a fixed, and as a sweeping autodyne receiver. Detection was accomplished both by using a crystal mount at the radio frequency output, and by using a depressed collector for velocity-sorting detection. When the crystal mount was used, operational parameters, such as sensitivity and bandwidth, were found to be the same as for the VAD-161-2, as would be expected. Operation as a sweeping receiver was slightly better than with the earlier models because of the improved helix-to-waveguide transitions.

Operation as an autodyne receiver with velocity-sorting detection using a collector at cathode potential was much superior to that observed on previous models. The collector on the VAD-161-4 had been redesigned for depressed operation [10], and all signs of instability at low collector potentials were gone.

Fig. 8 is a graph of collector current versus collector voltage for both the VAD-161-2 and the VAD-161-4. As can be seen, the negative resistance loop in the curve has completely disappeared (in the case of VAD-161-4).

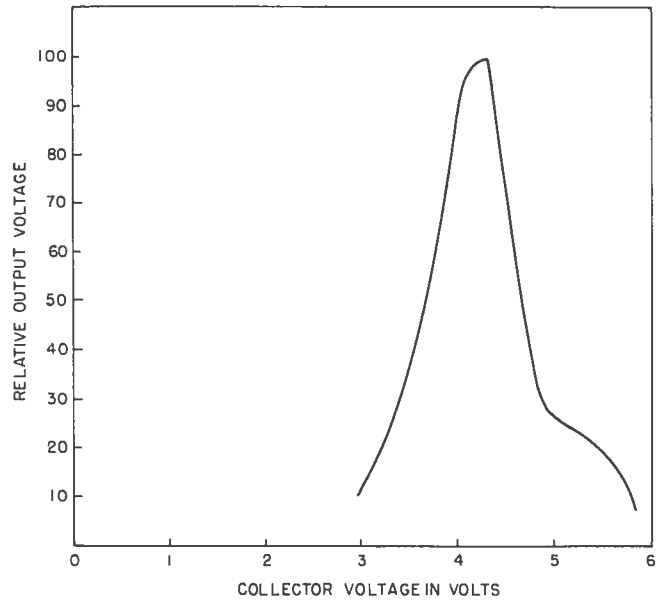

FIG. 9 VIDEO VOLTAGE OUT OF THE COLLECTOR OF THE TYPE VAD-161-4 TUBE AS A FUNCTION OF COLLECTOR-TO-CATHODE VOLTAGE

Fig. 9 is a graph of relative video voltage out of the collector as a function of collector-to-cathode voltage. This type of curve could not be taken for the VAD-161-2 because of low frequency relaxation oscillations which always occurred at collector voltages near maximum sensitivity.

A more detailed study of the process of detection at the collector together with other data obtained on this subject will be presented in a separate report [11].

CONCLUSIONS

From the experimental measurements made on the VAD-161-4 backward-wave amplifier tube, the following conclusions have been reached:

1) Modifications of the helix-to-waveguide transitions have resulted in a lower input and output reflection coefficient, although there is still room for considerable improvement in this aspect of tube performance.
2) Variation of starting current with frequency has been reduced slightly as a result of the improved transitions, but again, there is considerable room for improvement.
3) The mechanical structure of the tube is more rugged, and the tube is of a more convenient size and shape than previous models.
4) Addition of a shell-type of permanent magnet to the final model of the tube has resulted in increased freedom from the effects of external magnetic fields, as well as a more compact package. The additional bends in the collector-end waveguide do not seem to have contributed to the impedance mismatch at the input.
5) The redesigned collector structure has resulted in satisfactory operation of the tube with velocity-sorting detection.
6) The project is considered to be successfully terminated in that the initial aim, i.e., development of a backward-wave oscillator tube for use in the study of superregenerative receivers, has been fulfilled.
7) As a by-product of the tube development, a considerable amount of knowledge has been gained about the behaviour of autodyne microwave receivers, and about velocity-sorting detection at the collector of a backward-wave oscillator.

ACKNOWLEDGEMENT

The author is indebted to his colleagues for helpful suggestions given during the preparation of this report and to Mr. H.W. Poapst who took the experimental data.

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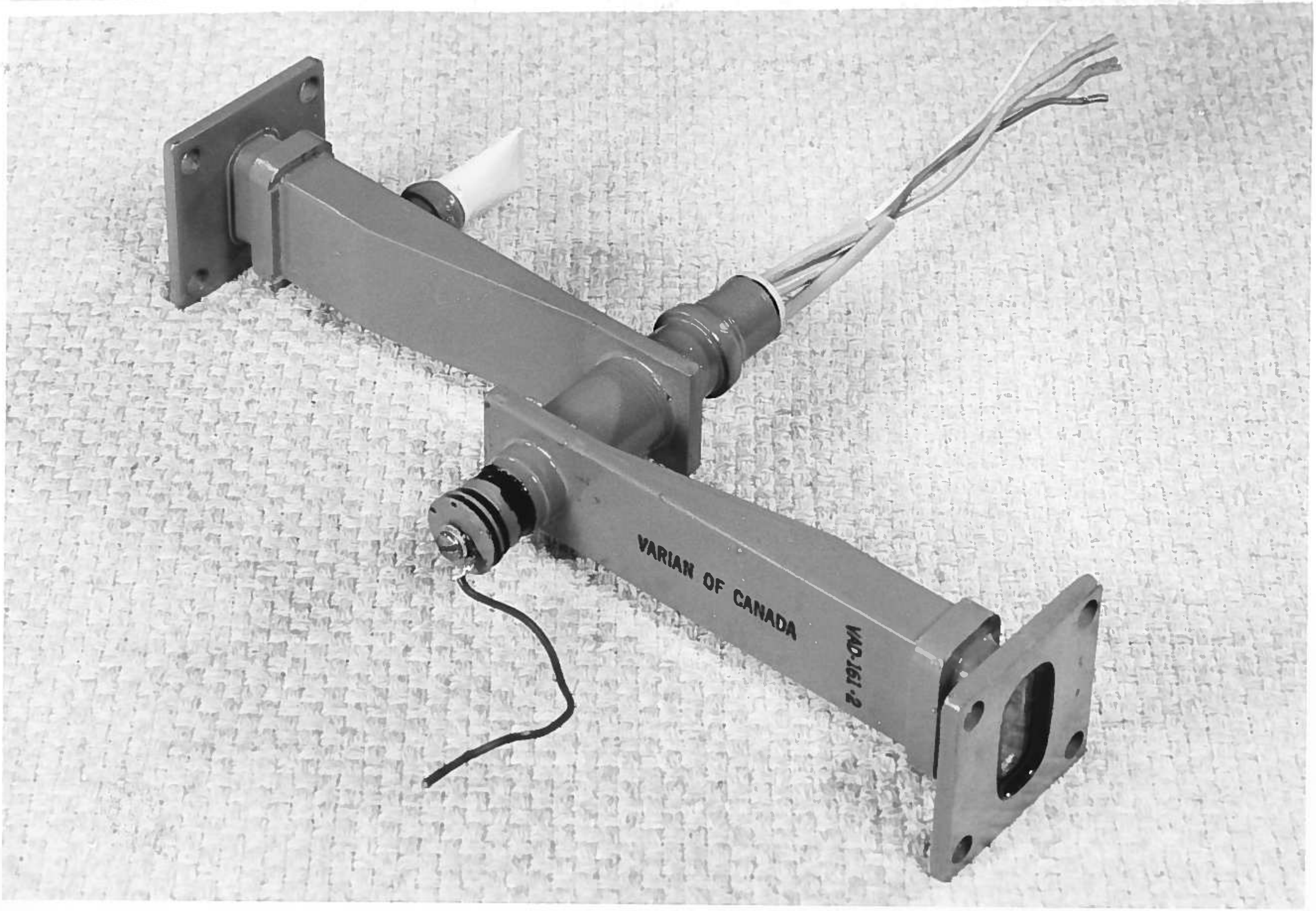

PLATE I TYPE VAD-161-2 OSCILLATOR TUBE

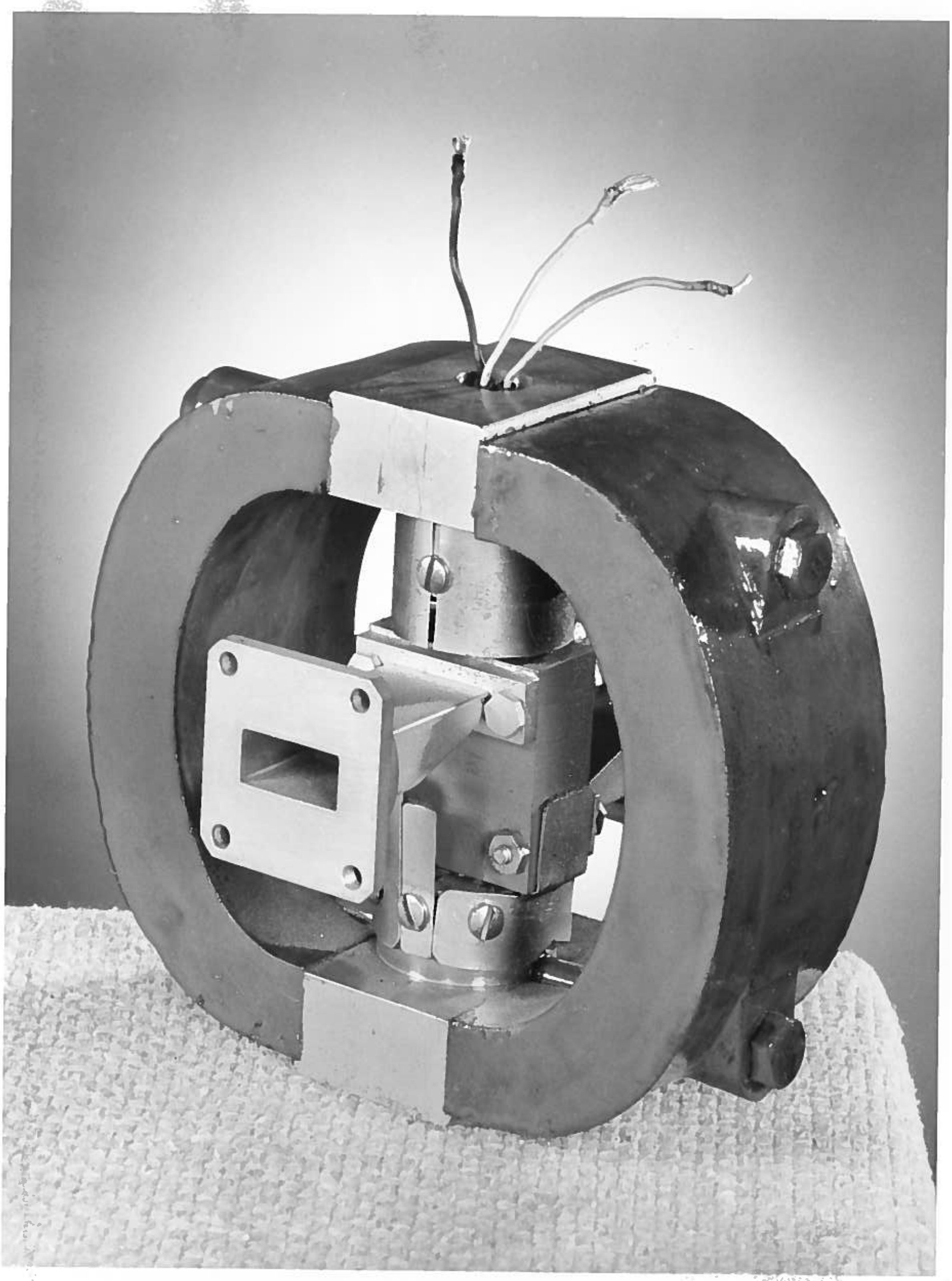

PLATE II TYPE VAD-161-3 OSCILLATOR TUBE

PLATE III TYPE VAD-161-4 OSCILLATOR TUBE

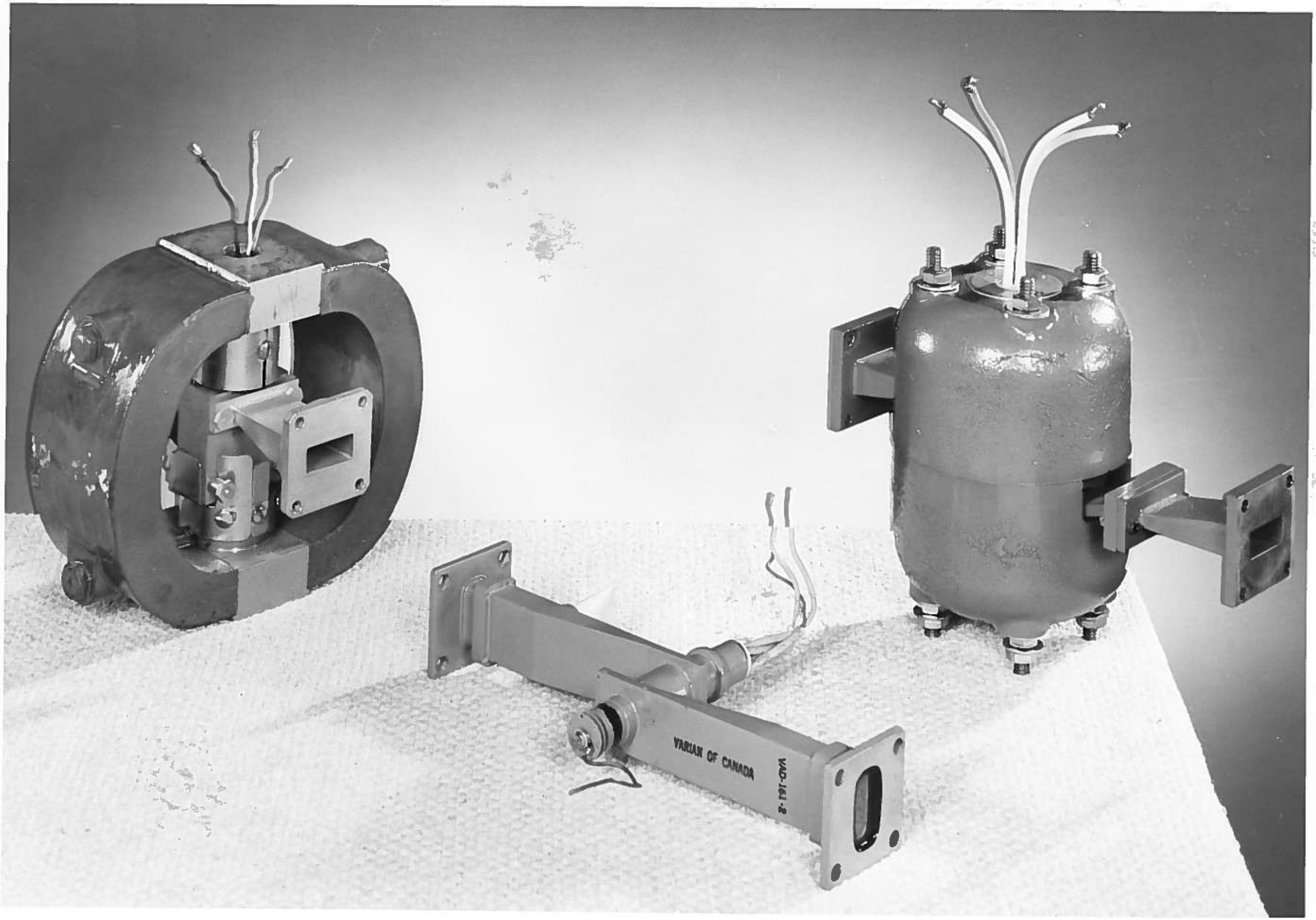

PLATE IV   RELATIVE SIZES OF VAD-161 OSCILLATOR TUBES