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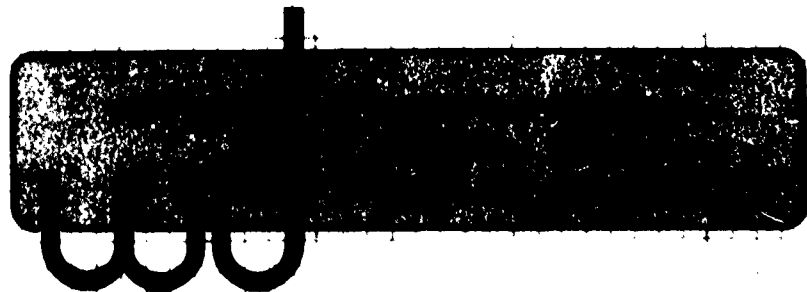
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**DEVELOPMENT OF S-BAND
VERY LOW-NOISE TRAVELING-WAVE AMPLIFIER**

Report No. 4

Fourth Quarterly Progress Report

1 October through 31 December 1961

Contract No DA 36-039 SC-87396

**Signal Corps Technical Requirements SCL-700/54,
dated 28 July 1960**

DA Project No. 3G19-03-001-04

File No. W-J 62-334K12

Object of the Development

**A reduction of noise figure presently obtainable
in S-band, with a traveling-wave tube
using a permanent magnet**

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Prepared by

B. P. Israelsen

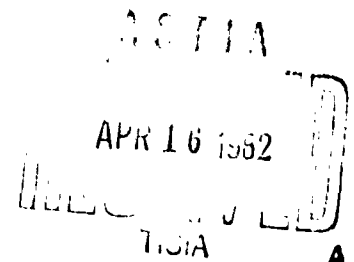


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PURPOSE

The purpose of this contract is to conduct research and development leading to a very low-noise traveling-wave amplifier capable of operation over the frequency band 1980 to 4040 Mc. This tube is to have a noise figure of 2.5 db maximum somewhere within the band, and no greater than 4.5 db over the entire band. It is also to be ruggedized and to use permanent magnet focusing. To accomplish these objectives, the work has been divided into the following tasks:

TASK A - Ruggedization of the helix and gun structures.

TASK B - Noise figure reduction in accordance with the above specifications.

TASK C - Development of a permanent magnet to replace the solenoid.

ABSTRACT

A tube in which the beam-forming anode was made in three equal segments was tested and gave minimum noise figure with all three segments at the same potential.

A magnet assembly providing a single field reversal is described. A WJ-229 one-milliwatt low-noise tube, when tested in this assembly, had 100 percent beam transmission and a noise figure of 6.5 db. Adjustment for best focusing and minimum noise figure was found to be quite critical with regard to positioning and alignment of the magnets.

A noise figure of 3.5 db was obtained with a WJ-211 in a straight-field permanent magnet 16 inches long. The maximum noise figure measured in S-band in this experiment was 4.7 db, at 4 Gc. These figures include correction for the noise figure of the mixer, due to low gain in the tube (12 db). In an 8-inch permanent magnet, the same tube yielded 4.1 db noise figure. This tube had an active helix length of only 2.75 inches.

PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES

Publications

No papers were published during the report period. The paper listed below under Lectures was submitted to and accepted by the IRE Transactions on Electron Devices for publication in the March, 1962 issue.

Lectures

A paper titled "The effect of helix loss on noise figure in traveling-wave tubes", by B. P. Israelsen, was presented at the Electron Devices Meeting, Washington, D. C., October 27, 1961.

Reports

No reports were published during the report period.

Conferences

A conference between Watkins-Johnson personnel and Lt. Alan W. Shaw of the U. S. Army Signal Research and Development Laboratory was held at the Watkins-Johnson Company on December 13-15, 1961. Current status of the work and future project plans were discussed.

FACTUAL DATA

The following discussion of work accomplished during the past quarter will be considered under three headings, identified with the three major tasks, i.e., ruggedization, reduction of noise figure, and development of a permanent magnet.

TASK A - RUGGEDIZATION

No work aimed at ruggedization was performed during the past quarter. Development work described in previous reports has resulted in a tube structure capable of meeting the specified vibration environment (approximately 13 g's maximum). There remains yet the task of packaging the tube, capsule and permanent magnet as a complete unit meeting the same environment.

TASK B - REDUCTION OF NOISE FIGURE

1. Evaluation of segmented beam-forming anode.

As described in the last Quarterly Report, a tube having a beam-forming anode split radially into three equal segments was constructed. The anode configuration is shown in the sketch of Fig. 1. The purpose was to determine whether unintentional cathode asymmetries of magnitude sufficient to influence noise figure might exist, and if so, whether they could be counteracted by applying different voltages to the various segments.

No noise reduction was obtained by asymmetrical voltage excitation of the segments. Noise figure was consistently a minimum with all of the segments at the same potential. The following conclusions are drawn from this result:

1. In a well-constructed and carefully processed cathode, azimuthal asymmetries are a minor cause of beam noise.
2. Differences in anode voltage on the three segments evidently raises beam noise and masks any compensation effects for cathode irregularities, except possibly where the irregularity happens to coincide with the anode segmentation.

TASK C - PERMANENT MAGNET FOCUSING

1. Reversed Field

A. Description of set-up

Fig. 2 is a sketch showing the experimental arrangement used in tests with a reversed magnetic field. Each magnet is eight inches long and weighs 10 pounds. The two magnets are placed end-to-end, separated by a pole piece consisting of several layers of .014 inch thick Hipernik sheet. This pole piece has an I. D. of .244 inch, providing a close fit to the stainless steel jacket that surrounds the glass helix barrel of the tube. This small I. D. is necessary in order that the field reversal be accomplished in a short axial distance. Short rings of cold rolled steel are mounted on the stainless steel support tube. Their function is to produce ripples in the beam symmetrically on either side of the transition plane, separated by an even number of half cyclotron wavelengths. In effect, the upstream focusing ring puts a disturbance on the beam and the downstream ring, in mirror image fashion, takes it off. This is the system described by Bodmer¹ at the 1961 Electron Devices Meeting.

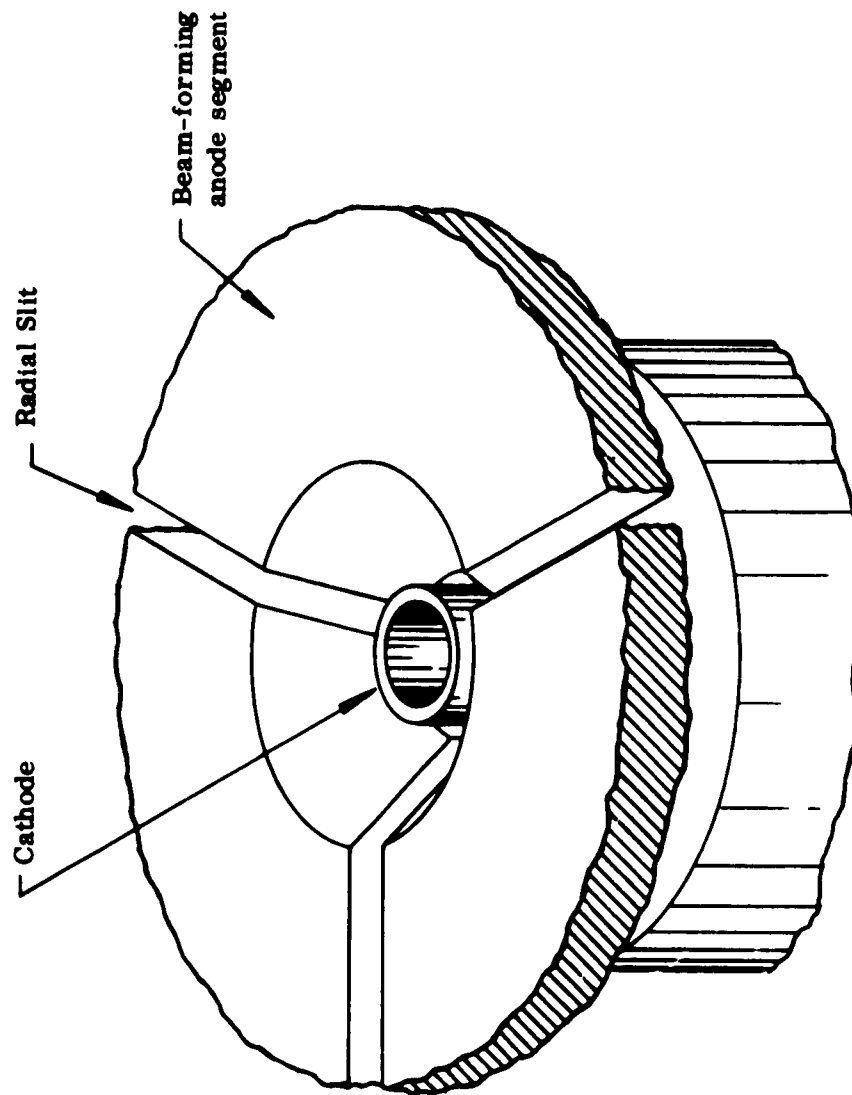


Fig. 1 - This sketch illustrates construction of the segmented beam-forming anode used to investigate the effect of cathode asymmetries.

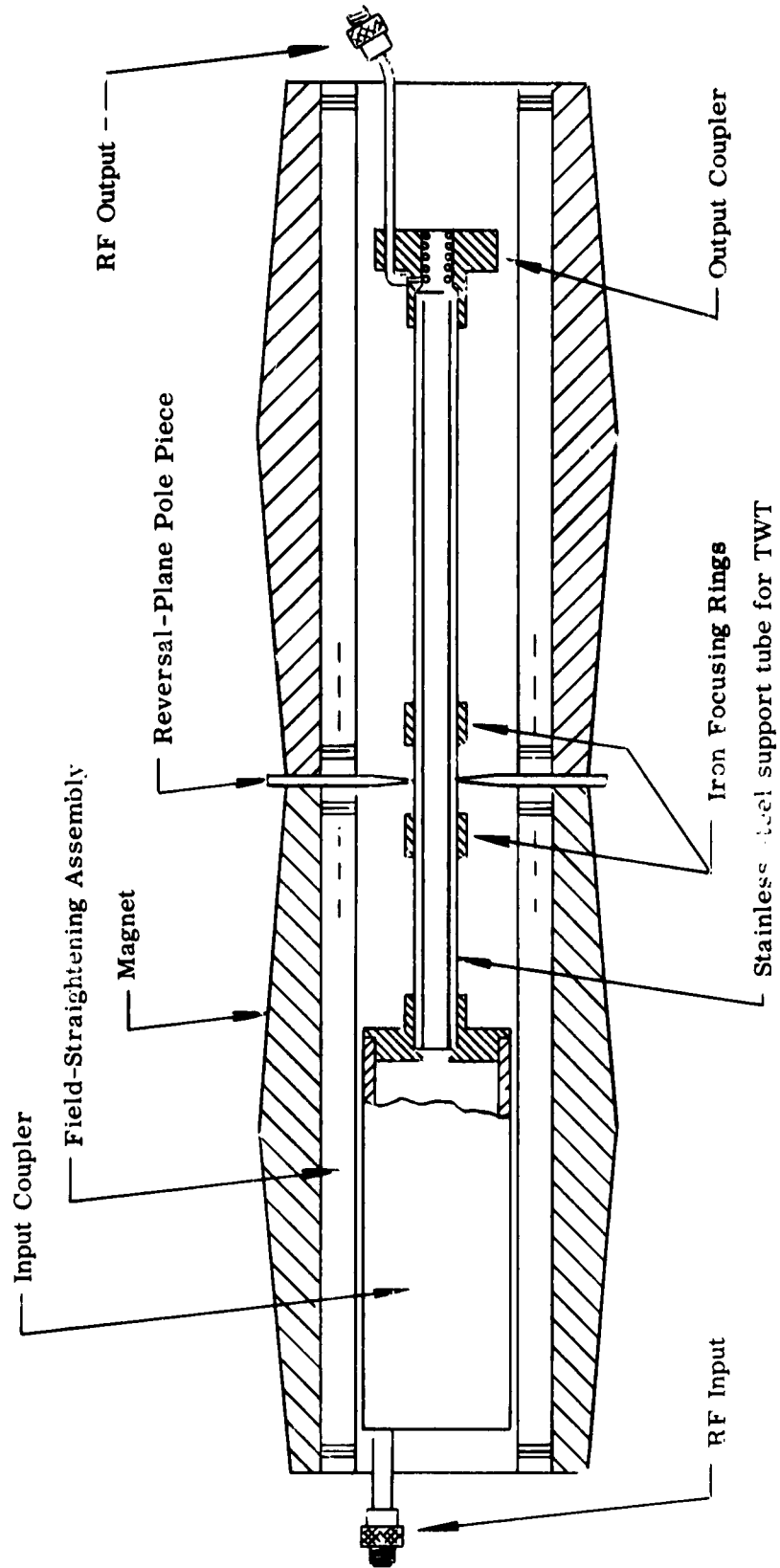


Fig. 2 - Sketch of the reversed-field magnet configuration. The reversal-plane pole piece between like poles of the two magnets produces a steep change of field direction on the electron beam axis.

Each magnet has a uniform field about five inches long, with peak intensity of around 600 gauss. An essential feature of such a focusing system is that the fields of the two magnets be not only parallel but colinear. Otherwise, large transverse field components will exist which can render focusing difficult if not impossible. Each magnet was subjected to several tests including a continuous plot of both longitudinal and transverse fields, and a determination of alignment error between magnetic and geometric axes. The latter was done by accurately determining the position at each end of the magnet corresponding to zero transverse field, relative to the geometric center. This determination was made with the magnet in a vertical position, using a steel needle to determine magnetic vertical. The largest observed separation between geometric and magnetic axes was 0.14 inch. Six poles of the 12 measured fell within a circle of 0.02 inch diameter centered on the geometric axis. Magnets were selected in pairs to provide closest alignment between magnetic axes. Two of the magnets with the largest alignment discrepancy were returned to the vendor for remagnetization.

The coupler which holds the tube differs from the standard coupler in that it must pass through the small center hole of the pole piece. For this reason, it was built with the input coupler on one end of stainless steel tube and a removable output coupler on the other end. This construction is illustrated in the sketch of Fig. 2.

B. Measurements

Noise figure was measured in this reversed field assembly using a WJ-229 one-milliwatt low-noise tube. The first test resulted in a noise figure of 9.5 db at 2.7 Gc. In a subsequent test this was reduced to 6.5 db. With the WJ-229, it was possible to obtain 100 percent transmission of the beam through the reversal. With the WJ-211, having a somewhat smaller beam-to-helix clearance (.013 inch), maximum transmission was less than 100 percent. No measurements of noise figure were made with the WJ-211.

C. Evaluation

The critical nature of the focusing adjustments and the relatively high value of noise figure obtained gave rise to the belief that, for the present, straight-field focusing would be a more fruitful approach.

One of the more difficult problems to be solved in any attempt to make a reversed-field system reliable would be that of support and alignment of the magnets, and of the tube within them. With proper shaping of the magnets for alignment in a rigid tubular support, this problem could undoubtedly be met. The substantial time delay involved in magnet procurement and modification, and the lack of readily available magnetizing facilities made this approach presently impractical. For these reasons it was decided to concentrate further effort on reducing the length of the tube to a value that would enable it to be focused in a straight-field magnet of about 20 pounds weight.

2. Straight Field

A. Description of magnets

Two different magnet types have been used in the straight field tests to date. The first of these is 16 inches long, designed to have a uniform field about 12 inches in length, of 600 gauss magnitude. This magnet weighs 45 pounds and has an inside diameter of 2 inches. The second magnet type is eight inches long and weighs about ten pounds, and is the same type as used in the reversed-field assembly described above. Transverse field tests on both types of magnet have yielded values on the order of 50 or 60 gauss maximum. Clearly, to achieve good focusing and low noise figure, these values must be reduced to the order of one gauss or under. Two basic types of field straightening assemblies have been used to accomplish this. The first consists of thin rings of Hipernik alloy, separated by aluminum spacers. The second uses wire of a permeable material wound in the form of a tight helix on a nonmagnetic tube. Both the rings and the wire act as transverse shunts for the flux, while having essentially no effect on the longitudinal field because of the separation between adjacent turns or rings. Fig. 3 is a plot showing transverse field obtained with one, two, and three layers of wire. The uncorrected field was approximately 50 gauss.

Subsequent work by one of the vendors, General Magnetic Corporation, has resulted in an improved method of magnet processing which substantially reduces the transverse field. Measurements recently conducted on a magnet so processed indicate 15 gauss maximum transverse field over the center 12 inches of a 16-inch magnet. This development will render the focusing problem somewhat simpler in these magnets.

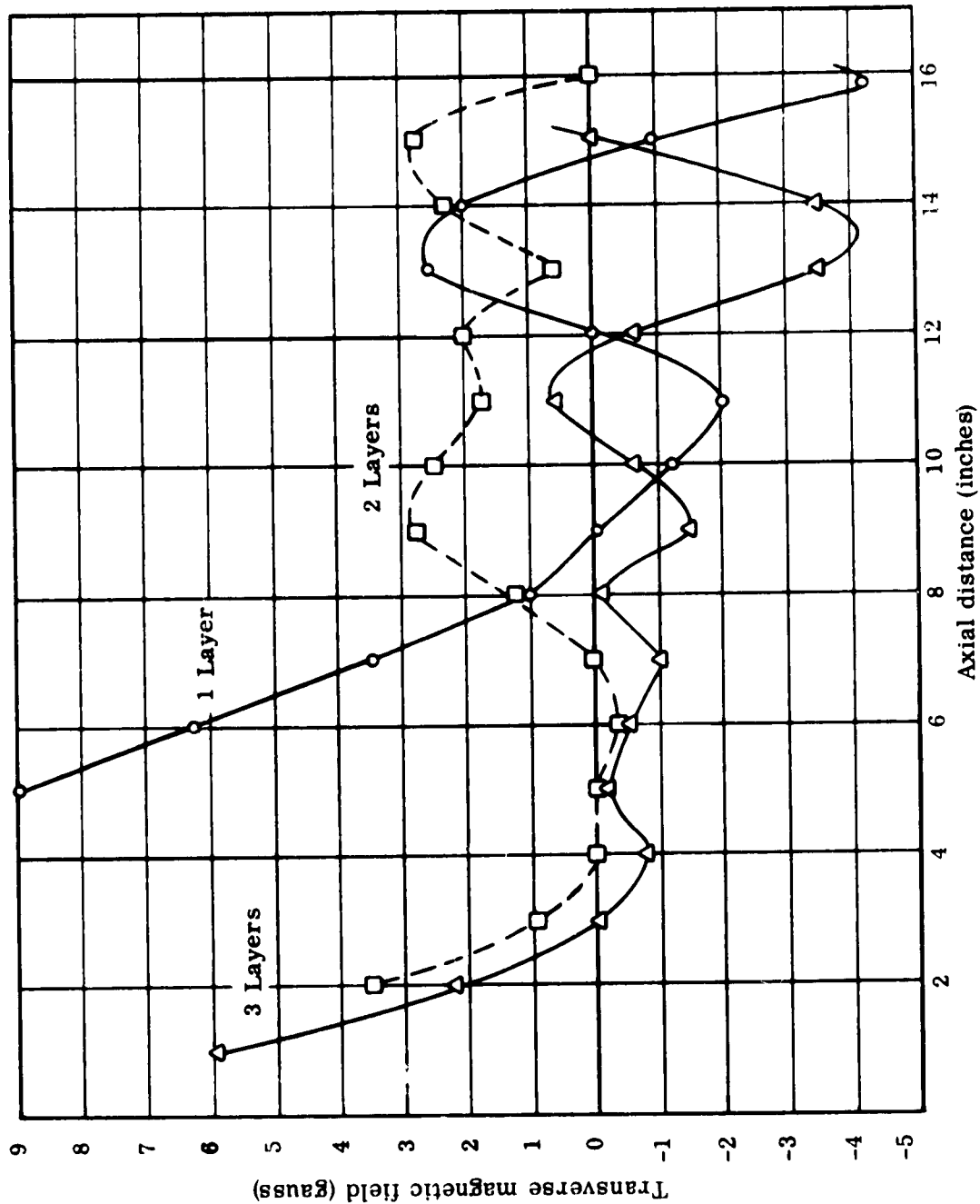


Fig. 3 - The effect of iron wire field straighteners on transverse magnetic field. The curves show the effect of one, two, and three layers of .028 diameter iron wire wound in the form of a tight helix. Initially, the field was approximately 50 gauss peak.

B. Measurements

Fig. 4 shows broadband noise figure obtained with WJ-211, Serial No. 176, in a 16-inch magnet. With all voltages fixed for broadband operation, the lowest value reached was 3.9 db and the maximum was 4.7 db, the latter occurring at 4 Gc. With all voltages optimized at 2.4 Gc, the noise figure was 3.5 db. Gain with this tube was low, only 12 to 14 db, due to its short helix length. In an 8-inch magnet, the tube yielded a noise figure of 3.8 db minimum. Beam transmission of 100 percent is not difficult to obtain in these straight-field magnets. With the reduced transverse field and the use of wire and disk straighteners, focusing is as readily accomplished as in a solenoid.

In order to use a straight magnetic field and yet not have an excessively long structure, it is necessary that the tube length be held to a minimum. In a standard WJ-211 the beam length is just over 11 inches, divided in the following manner:

Active helix	6.0 in
Attenuator	2.5
Drift length	1.85
Collector	<u>0.75</u>
	11.10 inches

This can be reduced to approximately 7 inches by the following modifications:

1. Reduce active helix length to 4 inches
2. Reduce attenuator length to 0.5 inch
3. Reduce collector internal length to 0.5 inch

Two tubes (Serial Nos. 174 and 175) have been tested with an active helix length of 3 inches and have yielded 22 db gain at 100 μ a beam current.

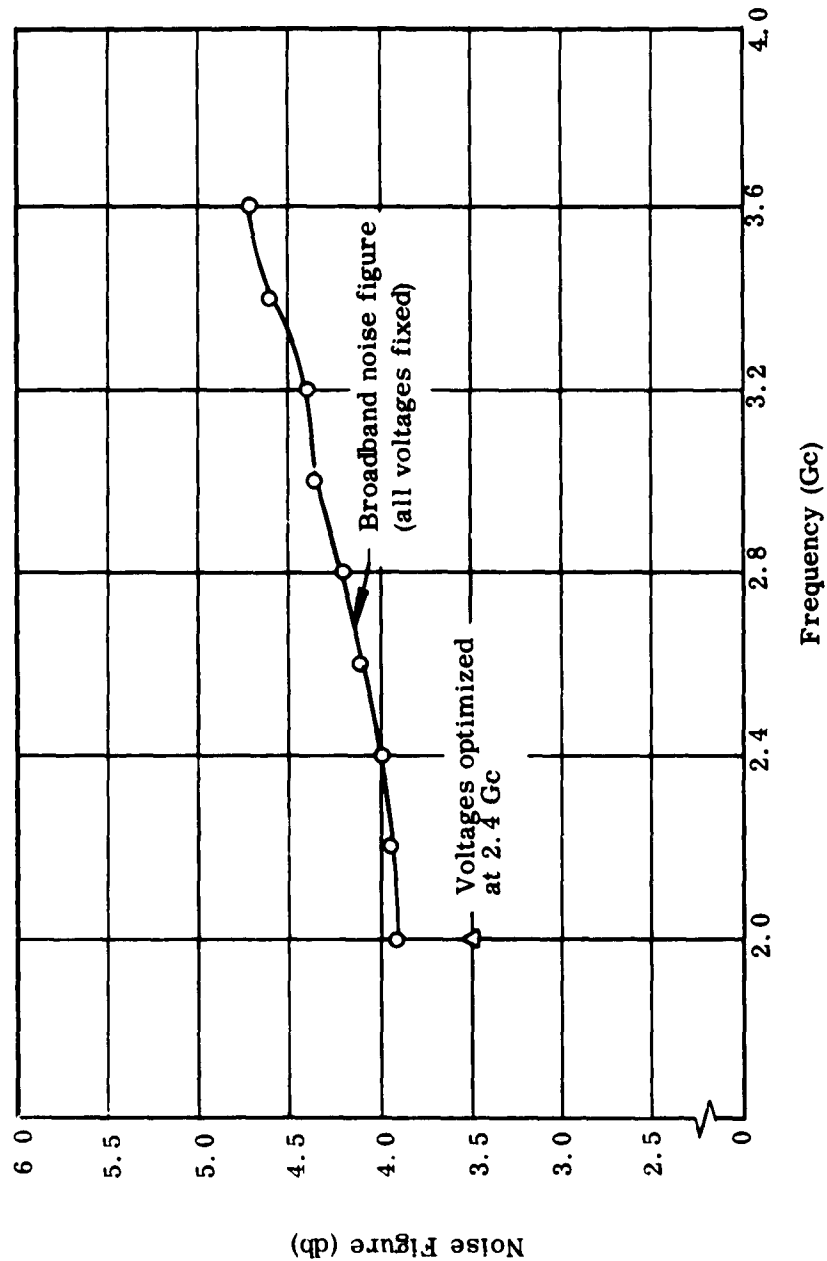


Fig. 4 - Noise performance of WJ-211, Serial No. 176 in a 620-gauss permanent magnet, with the field at the cathode peaked to 850 gauss by means of a flux concentrating ring. This curve is corrected for the effect of the mixer noise figure following the tube.

The first of these had a noise figure of 3.5 db. Serial No. 176 had gain of between 12 and 14 db over the band at 100 μ a, with 2.75 inches of active helix. This was lower than had been expected on the basis of the previous tests. Other tubes are being constructed with these reduced dimensions and will be used to determine the optimum choice of parameters. The attenuator is shortened by using a thin resistive film (either aquadag or chrome) on the inside of the helix barrel, rather than an external lossy coupling helix. With such an internal attenuator, 75 db loss has been measured over a length of 3/8 inch. As an alternative, using a bifilar lossy coupling helix one inch in length, attenuation of 78 db has been obtained at 3 Gc.

The advantage to be realized from such a length reduction is illustrated in the sketch of Fig. 5. This shows the theoretical weight of a 600-gauss magnet of 1.75 inch I. D. as a function of its length. Alnico 5 with a permeance coefficient (B/H) of 17 is assumed. The magnet must be about 1.4 times as long as the length over which the field is to be uniform (e.g., where it has dropped to 90 percent of its maximum value. Therefore a beam seven inches long can be focused in a magnet 10 to 11 inches long, weighing about 20 pounds. A little extra length should be left to allow for peaking of the field in the region of the cathode by means of a high permeability ring around the capsule. In the tests on Serial No. 176, the uniform field was 620 gauss, peaked at the cathode to 850 gauss by a flux concentrator of this type.

3. Combined Straight and Periodic Fields

No work has been done during this period on focusing systems using combined straight and periodic fields. Ceramic magnets for a stack with a period of 0.210 inch were ordered but have not been received.

CONCLUSIONS

Evaluation of the segmented beam-forming anode indicates that no reduction of noise can be expected by this means when the cathode is properly constructed and processed.

Beam transmission and noise figure tests have been conducted using both reversed-field and straight-field focusing configurations.

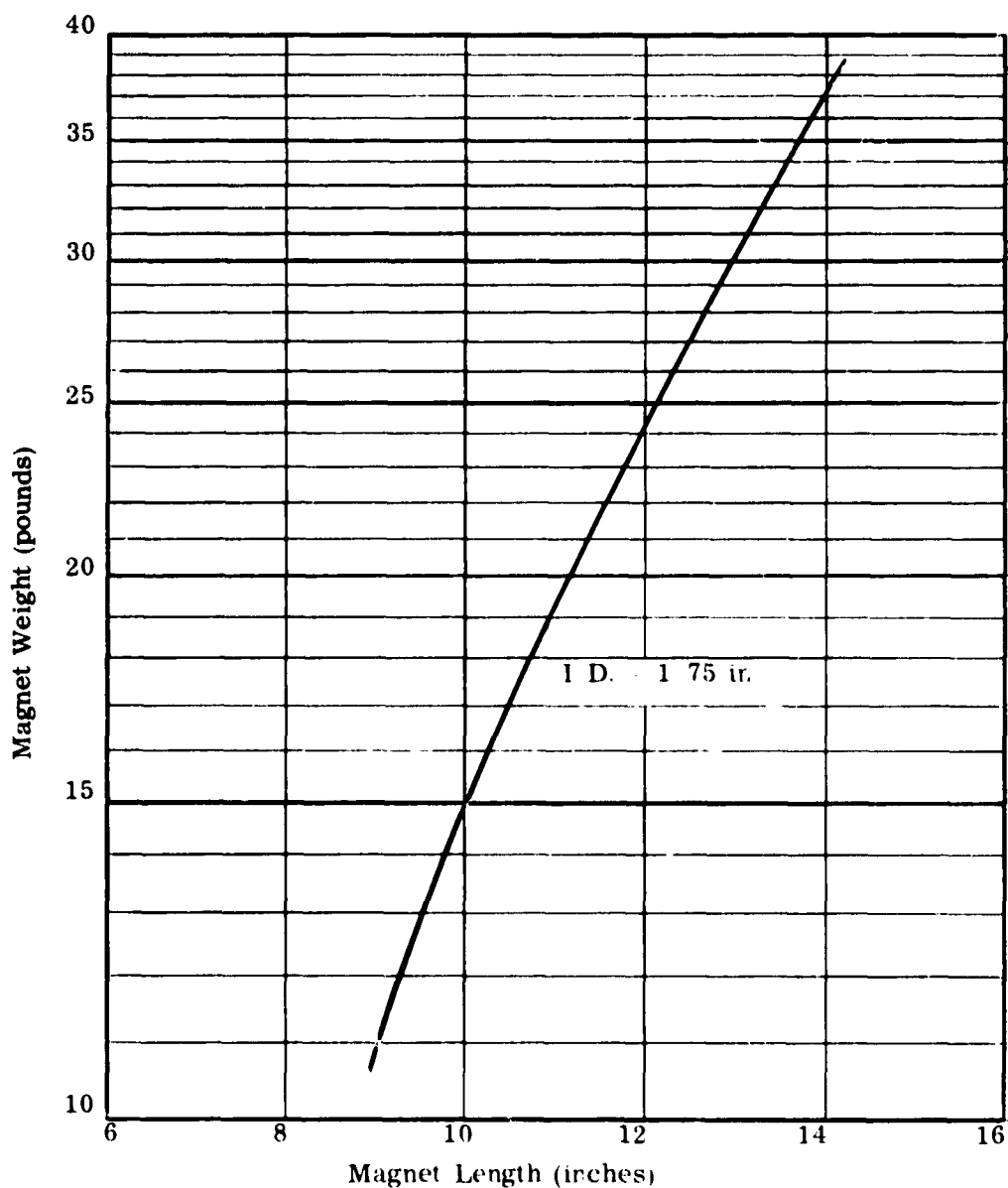


Fig. 5 - Curve of theoretical magnet weight vs length for an Alnico 5 magnet with 600-gauss field. 1 D. is assumed constant at 1.75 inches.

In the reversed field, a WJ-229 gave 100 percent transmission and 6.5 db noise figure. Due to difficulties in properly focusing a WJ-211 in the reversed field, no noise figure measurements were taken. Because of these considerations, and the much more favorable results obtained with straight-field magnets, it was decided to concentrate the remainder of the program effort on straight-field focusing. In a 16-inch permanent magnet, a WJ-211 with less than three inches of active helix gave a minimum noise figure of 3.8 db. Correcting for the noise figure of the mixer following the tube, this value would be 3.5 db. Gain was low, varying between 12 and 14 db, because of the short helix length. In an 8-inch magnet, the same tube gave a measured noise figure of 4.1 db, which is equal to 3.8 db after correcting for mixer noise figure.

PROGRAM FOR NEXT INTERVAL

Additional tubes will be constructed with short helices and with electron guns modified to provide low-noise operation at higher beam currents than used in the standard long-helix WJ-211. Magnets with lengths of 10 to 12 inches will be procured and packaged into an integrated assembly with the tube, the package being designed to withstand vibration up to a level of 13 g's. Three such units will be prepared for delivery.

IDENTIFICATION OF PERSONNEL

The following engineering personnel have been assigned directly to this project during the past quarter.

Boyd P. Israelsen	168 hours
Alexander Sproch	59
Rowland W. Haegele	39
Bruce G. Bleecker	31
John H. Foster	30

REFERENCES

1. M. G. Bodmer, "A 4 kMc satellite TWT for the AT and T communication satellite", paper presented at the 1961 Electron Devices Meeting, Washington, D. C., 28 October 1961.

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