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INVESTIGATION OF A VOLTAGE TUNABLE FILTER FOR P-BAND COMMUNICATION RECEIVERS

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ABSTRACT

A backward-wave oscillator was operated just below the threshold of oscillation as a high-gain amplifier over the frequency range 270 to 432 Mc. This gave a maximum "electronic" gain of 30 db; however, the overall gain of the device was unity, with the major portion of the loss occurring in the input and output couplers. The off-frequency signal attenuation capabilities were found to be 20 db over a bandwidth of 4 Mc at 330 Mc and 6 Mc at 400 Mc. These measurements were made with a power output of the device in the neighborhood of 50 db below 1 mw. Other characteristics of the tube such as oscillation starting current, large signal behavior, and cross modulation were studied briefly, with major emphasis being put on frequency rejection characteristics. Little size or weight reduction of the overall tube and solenoids was attempted in this study. While rapid electronic tuning would not be feasible with this tube, communication receivers in this frequency range operating in an environment of strong adjacent signals would be helped. Gain could probably be increased by constructing a tube to operate as a cascade amplifier.

PROBLEM STATUS

This report completes work on one phase of the problem; work on other phases continues.

AUTHORIZATION

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INTRODUCTION

This report describes an experimental study of a backward-wave tube for use with communication receivers over that part of P-band from 225 to 400 Mc. Such receivers, particularly those which must operate in an environment of strong adjacent signals, need an increased degree of discrimination against these spurious signals. Since the backward-wave amplifier is inherently a very narrow bandwidth filter, its use in this application is apparent.

Since this study was primarily intended to determine the feasibility of using backward-wave amplifiers (BWA) in many channel communication systems, little effort was made toward size or weight reduction of the device. Most of the bulk and weight of the device was consumed by the solenoids used to produce the magnetic field required to control the electron beam. Also it was assumed that the receiver, with which the BWA would be used, had sufficient sensitivity and reserve gain. For this reason no effort was made to provide net gain through the BWA. Attenuation of off-frequency signals was the major objective in this study.

In the following sections, the tube, its assembly, and experimental evaluation are described; the experimental results and recommendations are briefly summarized.

TUBE DESIGN AND FABRICATION

The parts of the experimental tube requiring investigation were (a) the electron gun, (b) the slow-wave structure, and (c) the impedance-matching transformers. Each of these will be described briefly before presenting data and evaluation.

Electron Gun

The electron gun was of the magnetic immersion type as described by P.G.R. King (1). This gun consists of a cathode, surrounded by a Pierce-type focusing electrode, followed by three aperture electrodes called A1, A2, and A3, as shown in Fig. 1. The region between the cathode and A1 is designed as a Pierce gun with the voltage on A1 controlling the magnitude of the beam current. The voltage on A3 controls the velocity of the electron beam. The voltage on A2 and the spacings between it and A1 and A3 are such as to produce cancellation of the net effect of the aperture lens distortions of the beam; in practice this voltage need not be changed when the other voltages are varied over quite wide ranges.

Figure 2 is a graph showing the desired characteristics of an almost constant beam current as the beam velocity is changed over wide limits. A standard oxide-coated cathode was used since its emission capabilities were more than ample for this study, and the electron gun was designed to produce an electron beam with a diameter of 0.150 inch.

Slow-Wave Structure

The slow-wave structure was a lumped-parameter low-pass filter circuit based on one described by Matthews (2). This structure consisted of 29 stainless-steel coaxial cylinders and 15 copper-wire coils connected to each other and to a ground plane. The

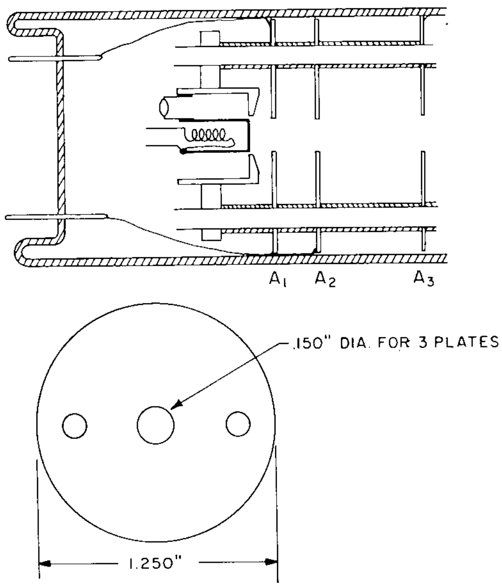


Fig. 1 - Electron gun used in the backward-wave tube

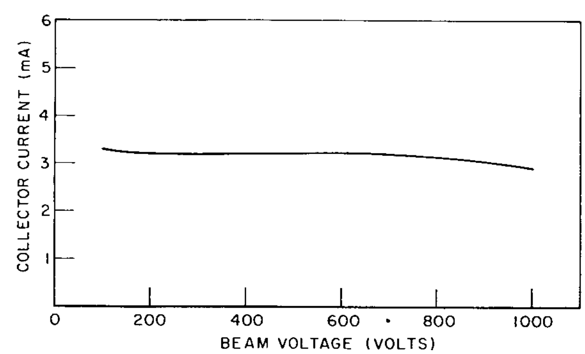
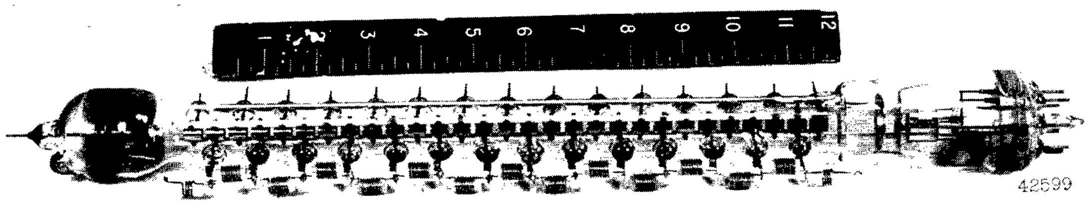


Fig. 2 - Beam current vs beam voltage for the electron gun

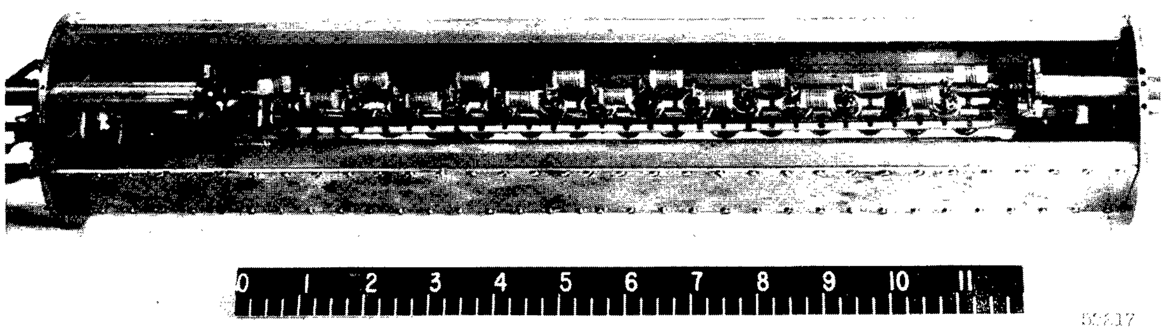
coils at each end were wound so as to have half the inductance of the other 13 coils. The principal difference between this and Matthews' structure was in the mounting arrangement for the cylinders. The cylinders were aligned and spaced by means of a mandrel and were then attached to two ceramic rods. In this way the cylinders do not depend upon the glass envelope for support. Each of the 13 central coils of the circuit had a measured inductance of 0.26 μh. The ground plane consisted of a rectangular trough made of 1/8-in.-thick brass plate to which alternate cylinders were grounded. Figure 3(a) shows the tube with the coils attached while Fig. 3(b) shows the tube mounted in the ground-plane trough. This assembly is then inserted in a brass cylinder (3.5-in. O.D. and 27 in. long) with a wall thickness of 1/8 inch.

Impedance-Matching Transformers

The input and output coaxial transmission lines had a characteristic impedance of 50 ohms. The characteristic impedance of the slow-wave structure varied over the band of operation and had an average value of about 300 ohms. The input and output impedance-matching transformers used were minimum-attenuation resistance pads designed for matching 50 ohms to 300 ohms. These transformers also served to attenuate the off-frequency signals. They performed quite satisfactorily and gave very close to the calculated attenuation of 27 decibels over the entire tuning range of the tube.



(a)



(b)

Fig. 3 - View of tube and coils (a) before attachment to ground plane and (b) enclosed in ground-plane trough

The magnetic field used for confining the electron beam was provided by aluminum-foil solenoids (4-in. I.D. and 6 in. long). Four of these were placed end to end and aligned so as to give a uniform magnetic field approximately 20 in. long and parallel to the axis of the tube. A photograph of these solenoids with the BWA in operating position is shown in in Fig. 4.

TUBE EVALUATION

Several experiments were conducted to determine the feasibility of using this tube in multichannel communication applications. A block diagram of the power supply and metering arrangement for measuring the dc and rf characteristics of the tube are shown in Fig. 5. The slow-wave structure was connected electrically to electrode A3 of the electron gun.

The first experiments to be performed were measurements of the dc characteristics of the electron gun in conjunction with the slow-wave structure. It was found that the maximum current through the cylinders was about 80 percent of the emission current and that this transmission could be attained with a magnetic field of 180 gausses. A graph of collector current I_{col} versus magnetic field for the conditions $V_{A1} = 250$ volts, $V_{A2} = 500$ volts, $V_{A3} = 1000$ volts, and $V_{col} = 1150$ volts is shown in Fig. 6. The collector current of 2 ma did not change measurably when V_{A3} was lowered to 500 volts.

The BWA is a negative-resistance amplifier; when the beam current is increased above a critical value called the start-oscillation current, the device becomes a backward-wave oscillator. To achieve maximum gain, when operated as a BWA, the beam current must be maintained at a level just below the start-oscillation value.

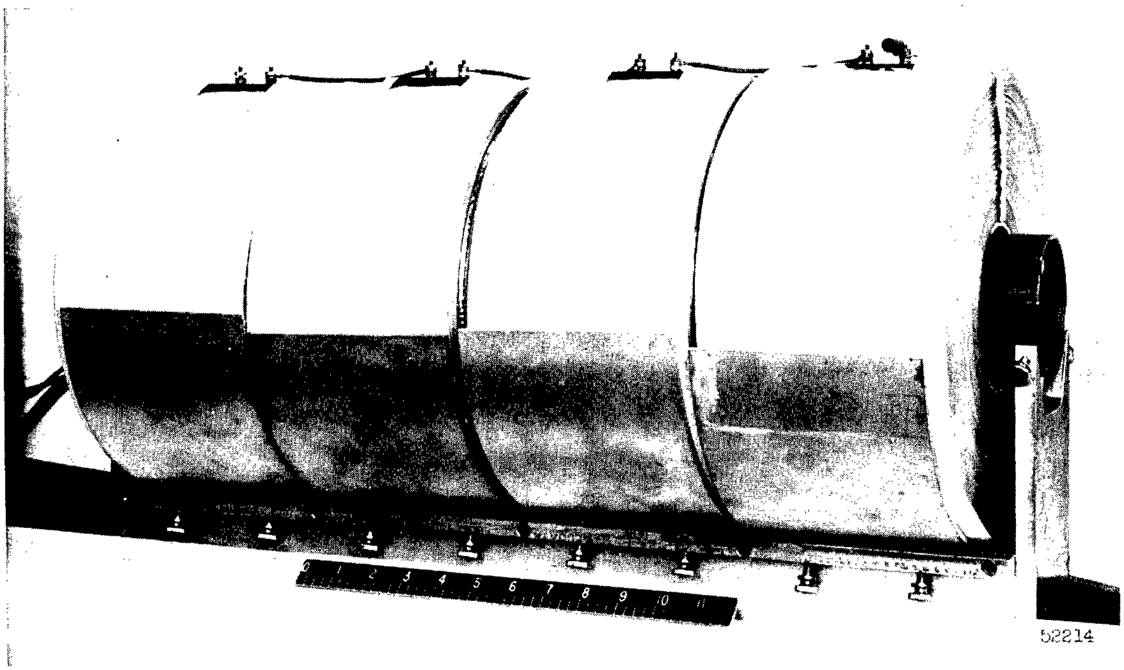


Fig. 4 - Tube positioned in aluminum-foil solenoids preparatory to evaluation

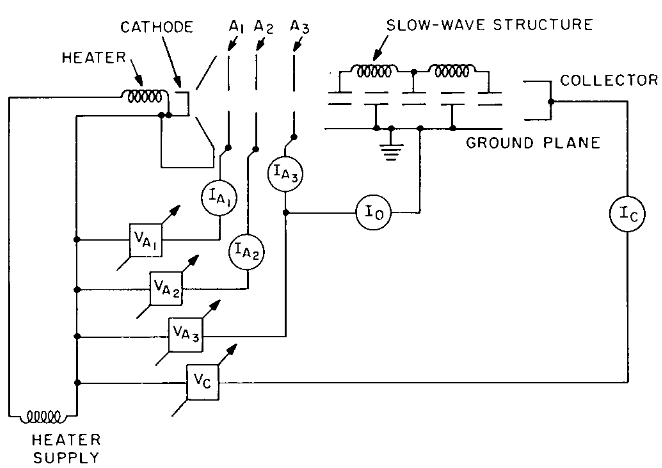


Fig. 5 - Diagram of circuit used in dc and rf measurements on the tube

The first rf experiments to be performed were a study of the characteristics of the tube as a backward-wave oscillator. The start-oscillation current was determined experimentally at several frequencies and found to vary from 0.33 ma at the lower end of the frequency range to 0.78 ma at the upper end. A plot of these data is shown in Fig. 7. With the backward-wave tube oscillating, data on the frequency of oscillation as a function of beam voltage were taken. This tuning curve is shown in Fig. 8. The useful frequency range was found to be from 270 Mc to 432 Mc, with a beam voltage variation from 150 volts to 1000 volts. The tube could not be made to oscillate with a beam voltage below 150 volts.

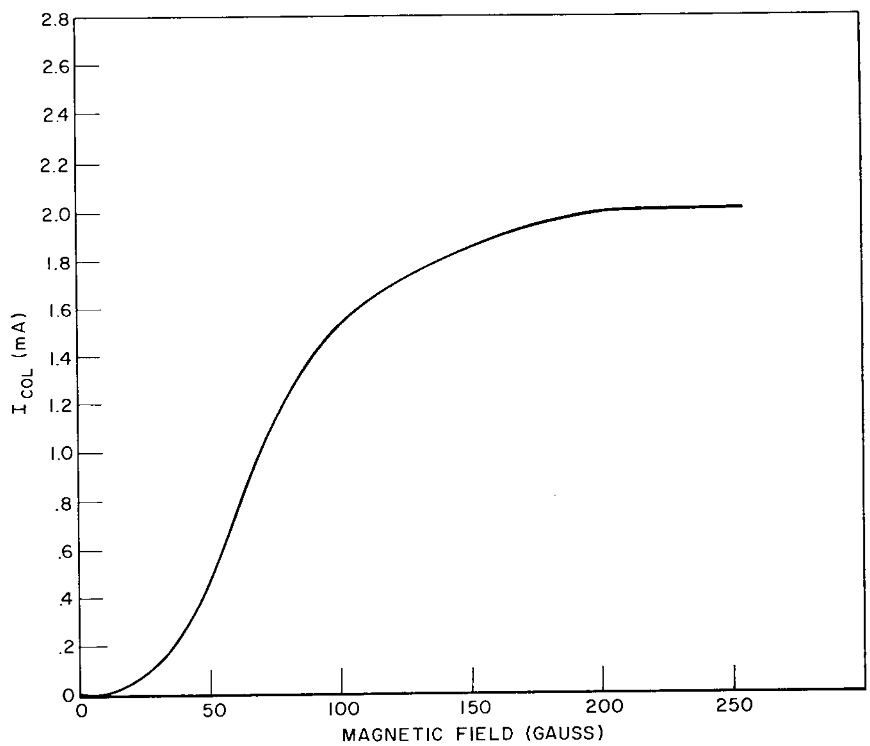


Fig. 6 - Collector current vs magnetic field

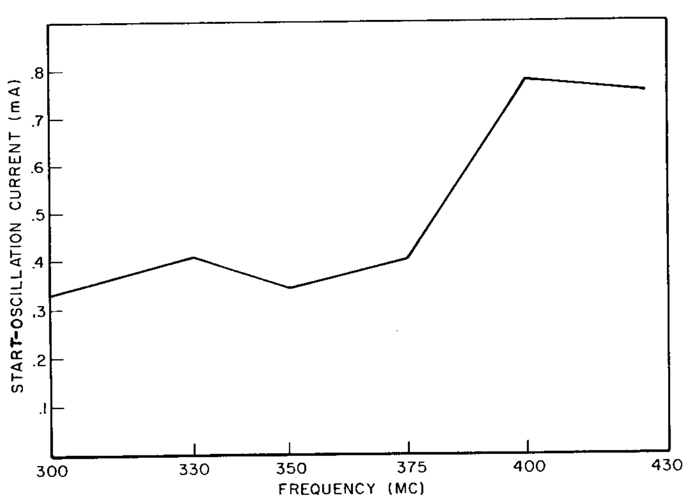


Fig. 7 - Start-oscillation current vs frequency

Using the oscillation data, an experimental ω-β diagram was constructed and is plotted in Fig. 9. The propagation constant β was computed with the assumption that the phase velocity of the circuit wave was in synchronism with the slow space-charge wave of the beam. The phase shift βD per section was computed to be π radians for the highest frequency of oscillation (D is the sum of length of two cylinders and two gap spaces). In plotting Fig. 9 the frequencies ω were normalized to this frequency ω_c. The solid curve

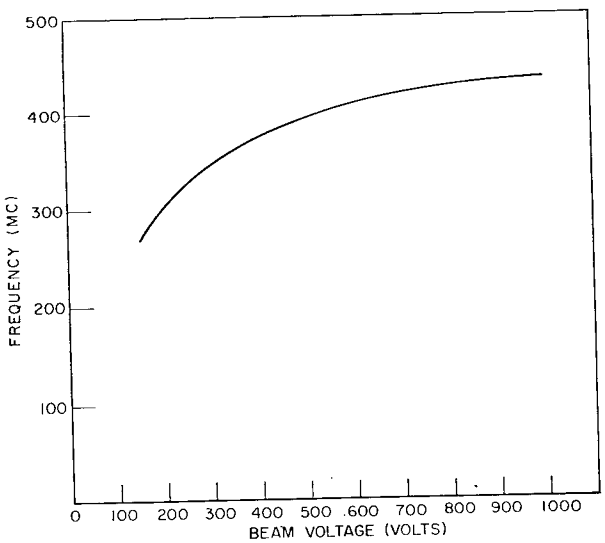


Fig. 8 - Frequency of oscillation vs beam voltage of the tube

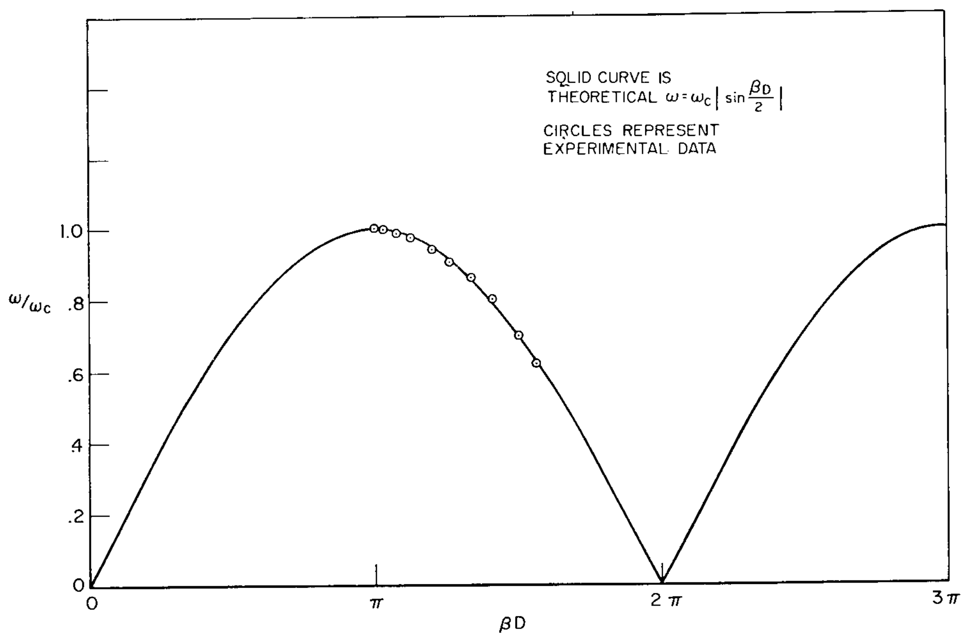
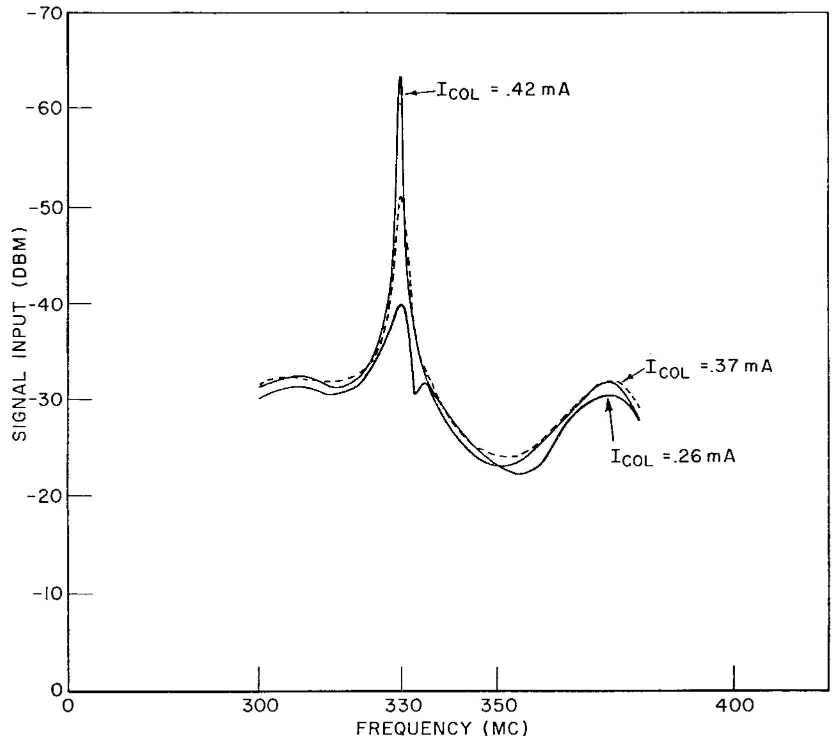


Fig. 9 - The ω-β diagram for the tube

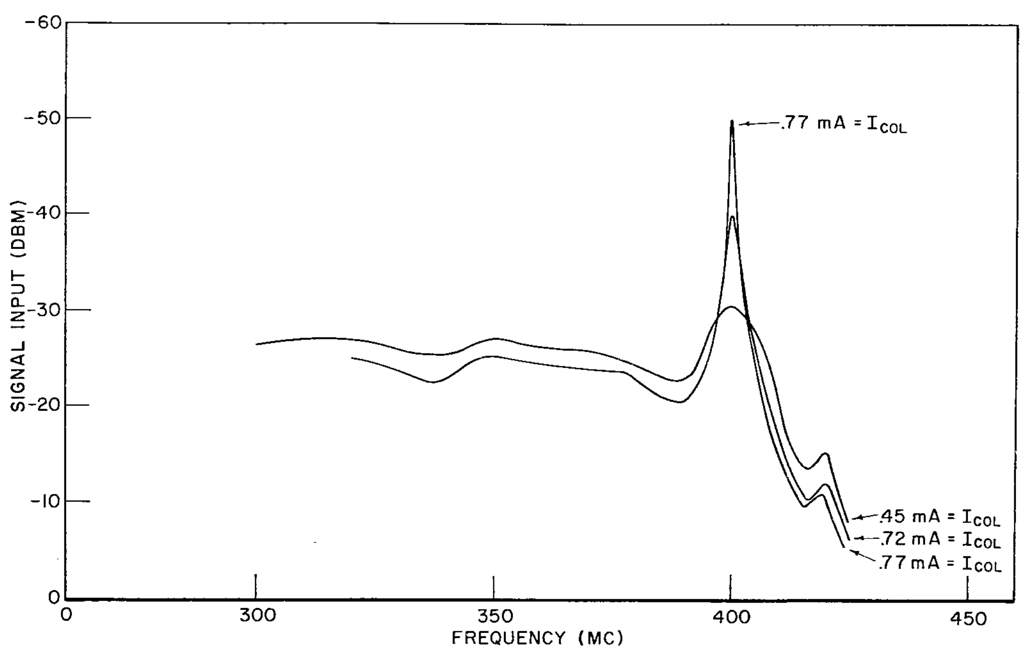
of Fig. 9 is the theoretical ω-β relationship for a filter circuit in which the series elements are pure inductances and the shunt elements are pure capacitances, this relationship being

$$\omega = \omega_c \left| \sin \frac{\beta D}{2} \right| .$$

The experimental points shown as circles are in good agreement with this assumption.



(a)



(b)

Fig. 10 - Electronic gain vs frequency with the resonant frequency of the tube at (a) 330 Mc and (b) 400 Mc

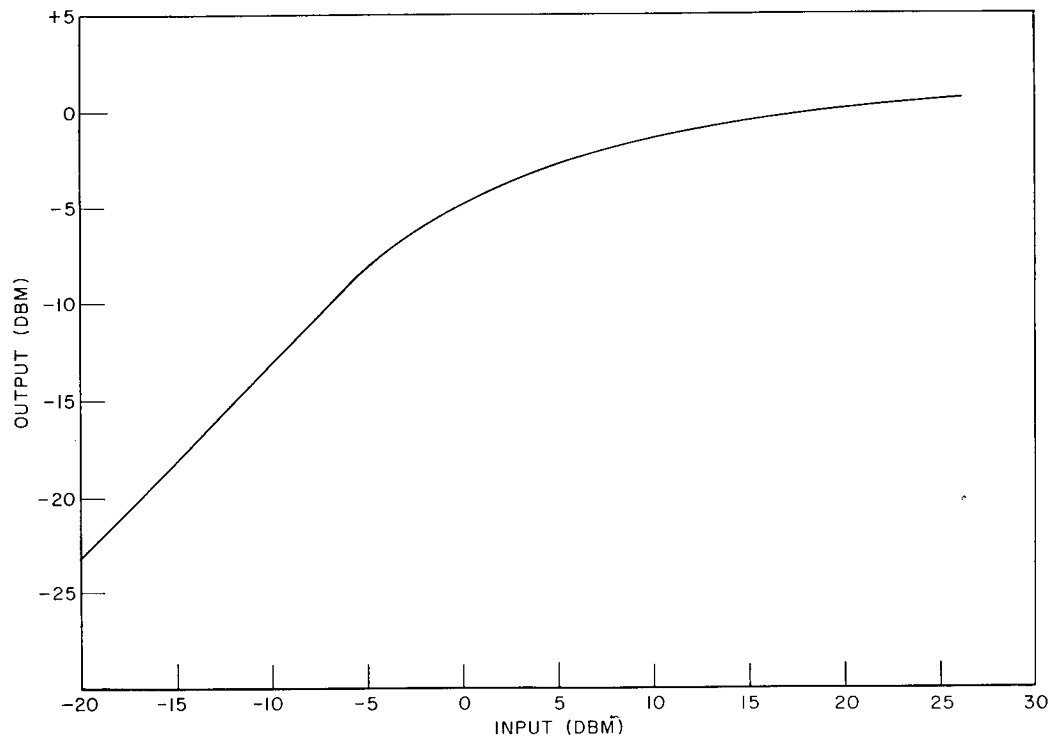


Fig. 11 - Power saturation characteristic of the tube operated at 400 Mc

Data were obtained at 330 Mc and 400 Mc for the tube operated as a backward-wave amplifier. A Hewlett-Packard model 608C signal generator was used as the signal source; an AN/APR-1 receiver with a TN-3B/APR-1 tuning unit was used to measure the output power from the BWA. The 400-Mc data were obtained by adjusting the tube so that it was oscillating at 400 Mc and then decreasing the beam current just below the threshold of oscillation. The frequency of the input signal was varied through resonance, and the input signal level required to maintain a constant power output, as indicated by the output level indicator of the receiver, was noted. The same procedure was followed at 330 Mc, except that the backward-wave tube was initially adjusted to oscillate at 330 Mc. The electronic-gain information thus obtained is plotted in Fig. 10 for several different values of beam current. It can be seen that as the beam current is increased toward the start-oscillation value, the electronic gain at resonance increases, and the bandwidth decreases. The maximum electronic gain that could be achieved in stable operation was 30 db, and the bandwidth 20 db down was approximately 4 Mc at 330 Mc and 6 Mc at 400 Mc.

A measurement of the large-signal behavior of the tube was made at 400 Mc. A Rollin model TS-608/U signal generator was used as the input source. The output power was measured with a Hewlett-Packard 476A bolometer mount in conjunction with a Hewlett-Packard 430B power meter. The output vs input power is presented in Fig. 11. It is seen from this curve that the output vs input becomes nonlinear for input powers greater than about 0.3 mw. A beam current of 0.76 ma was used when these data were obtained. A spot check of power saturation was also made at 330 Mc and found to be in substantial agreement with the above results.

In discussing the amplifier operation of the tube, the term electronic gain has been used. By this term is meant the change in output power between that when the beam is turned off and that when the beam is turned on. The overall attenuation of the tube with beam off was measured to be 30.5 db at 400 Mc and 28.2 db at 330 Mc. Most of this attenuation is accounted for in the input and output couplers, and from the values found it is seen that the BWA could perform essentially as a narrow-band, approximately unity-gain amplifier which is electronically tunable over the frequency range 270 Mc to 432 Mc.

Although accurate cross-modulation data could not be obtained with equipment that was readily available, some facts could be established. The following method of observation was used. A signal (30-percent amplitude modulated at 1000 cps) at the resonant frequency of the BWA was used to drive the tube. This was called the desired signal, and the magnitude of the 1000-cps modulation was measured at the output with a Ballantine voltmeter. With the modulation removed from the desired signal, a similarly modulated off-resonance carrier was introduced. The level of this undesired carrier was then raised until the same reading was obtained on the audio detector as before. It was noted that this carrier strength was required to be more than 20 db greater than the desired signal strength for all signals more than 1 Mc from the desired signal carrier when the tube was operating at maximum stable gain.

CONCLUSIONS

From the results reported in the preceding section, it can be concluded that this device offers a useful degree of discrimination against strong signals in adjacent communication channels. For carrier signals removed by more than 1 Mc from the desired signal, an attenuation of 20 db or greater was achieved. One method by which this attenuation might be increased would be to break the circuit near the center, resulting in a cascade backward-wave amplifier (3).

This backward-wave tube was capable of being operated either as an oscillator or amplifier over the 1.6:1 frequency range from 270 Mc to 432 Mc. An examination of the ω-β diagram (Fig. 9) shows that if operation below 270 Mc had been possible, interference with the -2 space harmonic would have set in very shortly. Hence, if a 2:1 frequency range is to be covered, either two tubes or a different type slow-wave circuit is required.

To achieve maximum gain and narrowest bandwidth, the tube must be operated with a beam current just below the start-oscillation threshold. Since the start-oscillation current is a function of frequency, it does not seem feasible to obtain rapid electronic tuning of the tube when used as an amplifier. This is not, however, considered to be a serious drawback in the intended application.

In its present form the complete device is quite bulky and heavy. Most of this results from the solenoids used with the tube. This situation could be alleviated to a great degree either through the use of periodic magnetic focusing or electrostatic focusing of the beam and by mounting the lumped-circuit inductors inside the vacuum envelope.

ACKNOWLEDGMENTS

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