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A LOW PHASE SHIFT BANDPASS LIMITER

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ABSTRACT

The need for a device to provide amplitude limiting of the MITRE experimental radar's intermediate frequency signal over a wide dynamic range led to the design of a bandpass limiter having very low phase shift over a wide range of limiting by using beam deflection tubes. The technique was established at 4 Mcs and it is believed that this value can be extended up to frequencies of about 150 Mcs.

1. Introduction

As part of the D-22 experimental radar program, the need arose for a device which would provide amplitude limiting of the radar intermediate frequency signal over a wide dynamic range. As the radar is fully coherent, it was essential that change in phase shift through the device over a wide range of input levels be minimized. Initial design objectives were established as follows:
Output amplitude: essentially constant over a 60 DB range of inputs.
Phase shift: less than 1° over the range 0 to 30 DB; less than 3° from 30 to 60 DB.

This paper gives the considerations leading to the particular design adopted, and details of the final design and results achieved.

2. The Limiter Problem

Phase shift arises in commonly used limiters (e.g. grid current limited tube, back-to-back diodes) from two principal causes:

1. As the input signal is increased beyond the point at which limiting occurs, the input impedance of the device changes (e.g. decrease of input impedance of a tube when grid current starts to flow.) Depending on the nature of the circuits coupling to the device a phase shift of varying amount will result.

2. There is inevitably some stray coupling between input and output of the device, normally in the form of capacitance. This coupling will produce a voltage across the output load in quadrature with the normal output of the limiting device. Since the latter stays constant (in the working range) whereas the quadrature component increases in proportion with the input, the net result is a voltage whose phase increasingly leads the phase at lower levels.

These problems can be reduced considerably by using the beam deflection tube.[1,2] The electrode structure of this tube is shown diagrammatically in Figure 1, and comprises a cathode, focus electrode, accelerator, deflection electrodes, screen, and anodes. The design is such that with more or less equal voltages on the deflectors, the electron beam is focussed into a sheet which impinges midway between the anodes. Application of a push-pull alternating voltage between the deflectors modulates the current drawn by the anodes and thus produces a push-pull alternating voltage across the load. As the input voltage is increased, an increasingly larger proportion of beam current is swept from one anode to the other. (This is the linear range of operation, the tube having an effective g_m of about 1mA/V).

Eventually the beam is swept entirely from one anode to the other. Further increase in the input then causes no corresponding increase in the output. This is the limiting region. A point is finally reached where the beam hits the deflectors, current is drawn, the input impedance falls and the device is no longer a useful limiter. Fig. 2 shows the limiter characteristic.

Within its working range, a ratio of input voltages of about 20DB, the deflectors do not couple with the beam so that current is not drawn. Further the structure of the tube is such that capacity between deflectors and plates is kept very small, less than .01 pF. (not including capacitance external to the tube) These characteristics make the tube very useful as a low phase shift limiter.

3. <u>Description of the Unit</u>

As in normal tube amplifiers the gain achieved per stage is determined by the "g_m" of the tube (in this case transconductance from deflectors to anodes), the total shunt capacity between stages, and the complexity of the interstage coupling circuits used.

Depending on the exact shape of the limiting characteristic of a stage, a certain minimum stage gain is required to achieve correct cascading of successive stages for a continuous overall characteristic.

This sets a limit to the maximum achievable bandwidth per stage. Provided this requirement is met, the number of stages is then determined mainly by the limiting range required. Starting with a single stage having an inherent limiting range of say 20 DB, each stage added extends the limiting range by an amount approximately equal to its low level gain. For a 60 DB range, it was found that 6 stages were required.

Some earlier work having shown that the variation of incremental permeability of powdered iron cores with signal level was sufficient to cause a significant phase shift across a tuned circuit, it was decided to use air-cored coils. Single synchronously tuned coupling circuits were originally used until it was found that this led to an undesirable phase shift. This was due to inadequate rejection by the inter-stage coupling of the third harmonic component of the limiter output. This component suffers a phase change of almost 90° lag through the coupling circuit, and unless adequately attenuated causes a small phase lag in the net input to the following stage. Considering a stage whose input voltage is below limiting, the percentage of third harmonic in its output will change from zero to 33 1/3 % as the input is raised to the fully limited level. The phase shifted third harmonic component present in the input to the next stage will similarly increase in amplitude and thus cause an increasing phase lag in the resultant voltage applied to the next stage. Double-tuned circuits using fixed capacity coupling were found to give adequate rejection at 12 Mcs when adjusted to the desired overall bandwidth.

Although the limiter stages operate in a balanced circuit, it was found quite acceptable to drive the input stage single-ended; the only effect is a 6 DB loss of gain. Since the output stage always delivers a constant voltage in the operating range, a powdered iron toroid was used to couple the output stage to the 50 ohm coaxial line.

A schematic of the final design appears in Figure 3. In addition to the points mentioned above, the use of 0.5 pF capacitors connected cross-wise from deflector to anode requires explanation. Without them, initial measurements showed an increasing phase-lead as the signal level was raised. This was due to stray capacity coupling, as discussed earlier. Making use of the push-pull circuits, it was found that capacitors of about 0.5 pF cross-connected would neutralize the effect.

It will also be noted from the schematic that the deflector bias voltages are taken from the anodes rather than from the B+ bus. This provides a D.C. feedback which serves to balance the current to each anode of a tube.

Power supplies required are:-

+300V, 20 mA, DC
+150V, 25 mA, DC
6.3V, 2 A (for heaters, AC or DC)

4. Results Obtained

Figure 4 shows the relation between input and output voltages of the unit. It is seen that the output is constant over a range of inputs of 60 DB. In the linear range the overall gain is 56 DB.

Over the limiting range of 60 DB, the maximum phase shift between input and output voltages is $2\frac{1}{4}^{\circ}$, as shown in Figure 4.

The 3 DB bandwidth of the amplifier was .75 Mcs, for signals in the linear range, centered at 4.0 Mcs. (For signals in the limiting range the bandwidth will be greater than this and approaches asymptotically the output circuit bandwidth for very large inputs).

5. Conclusion

A bandpass limiter having very low phase shift over a wide range of limiting can be realized using beam deflection tubes. The technique was established at 4 MCS; it is believed that it can be readily extended to other frequencies, up to about 150 MCS.

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References

1. "Phase stable limiting IF amplifiers using beam deflection tubes"
E. R. Wingrove, I.R.E. National Convention Mil. El. 1960

2. General Electric Engineering Information
(receiving tubes) EI-30, June 20, 1960

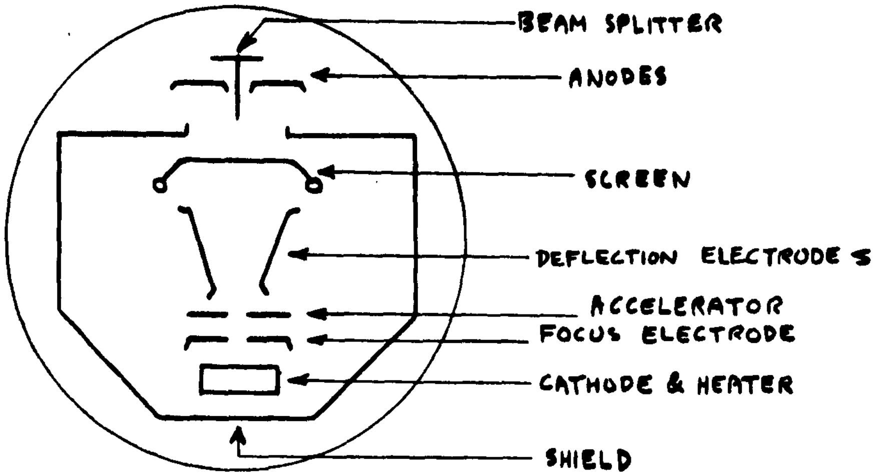

Fig.1 Beam Deflection Tube

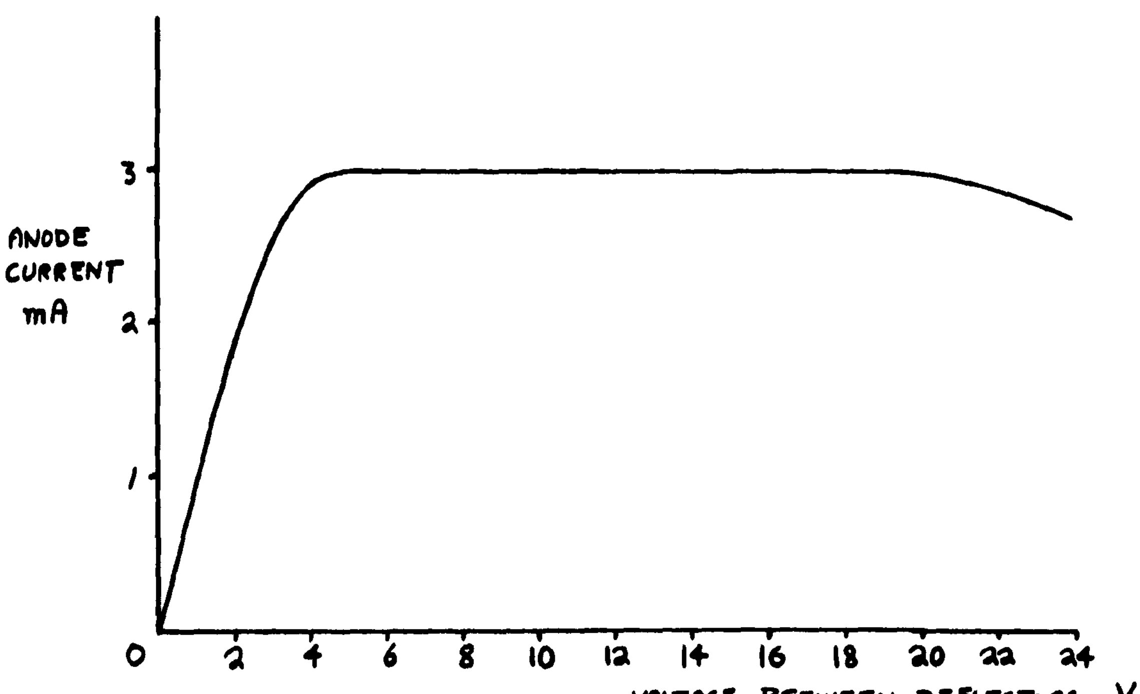

Fig.2 Limiting Characteristic of Single Tube

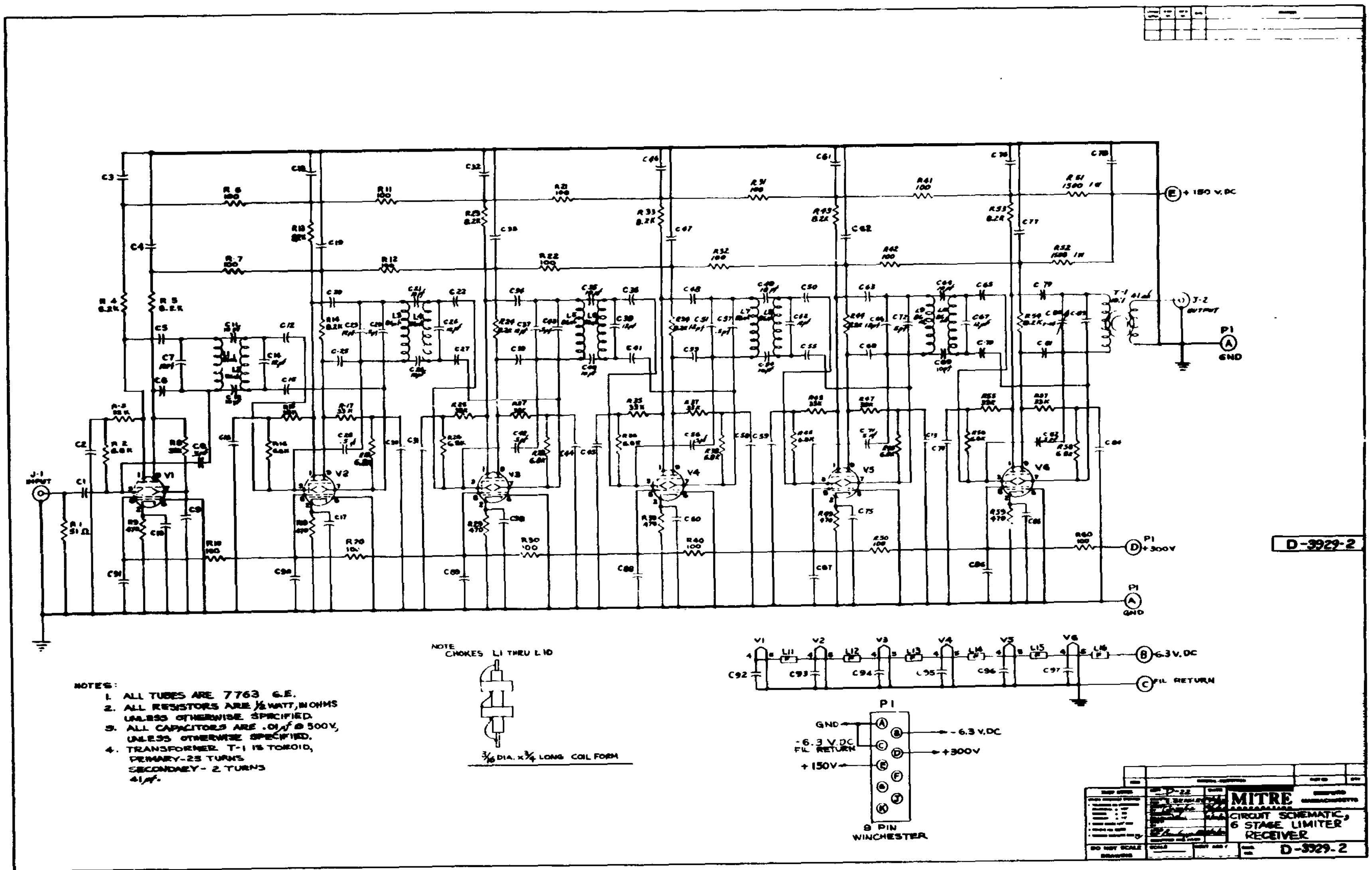

Fig.3 6 Stage Limiter Receiver - Final Design

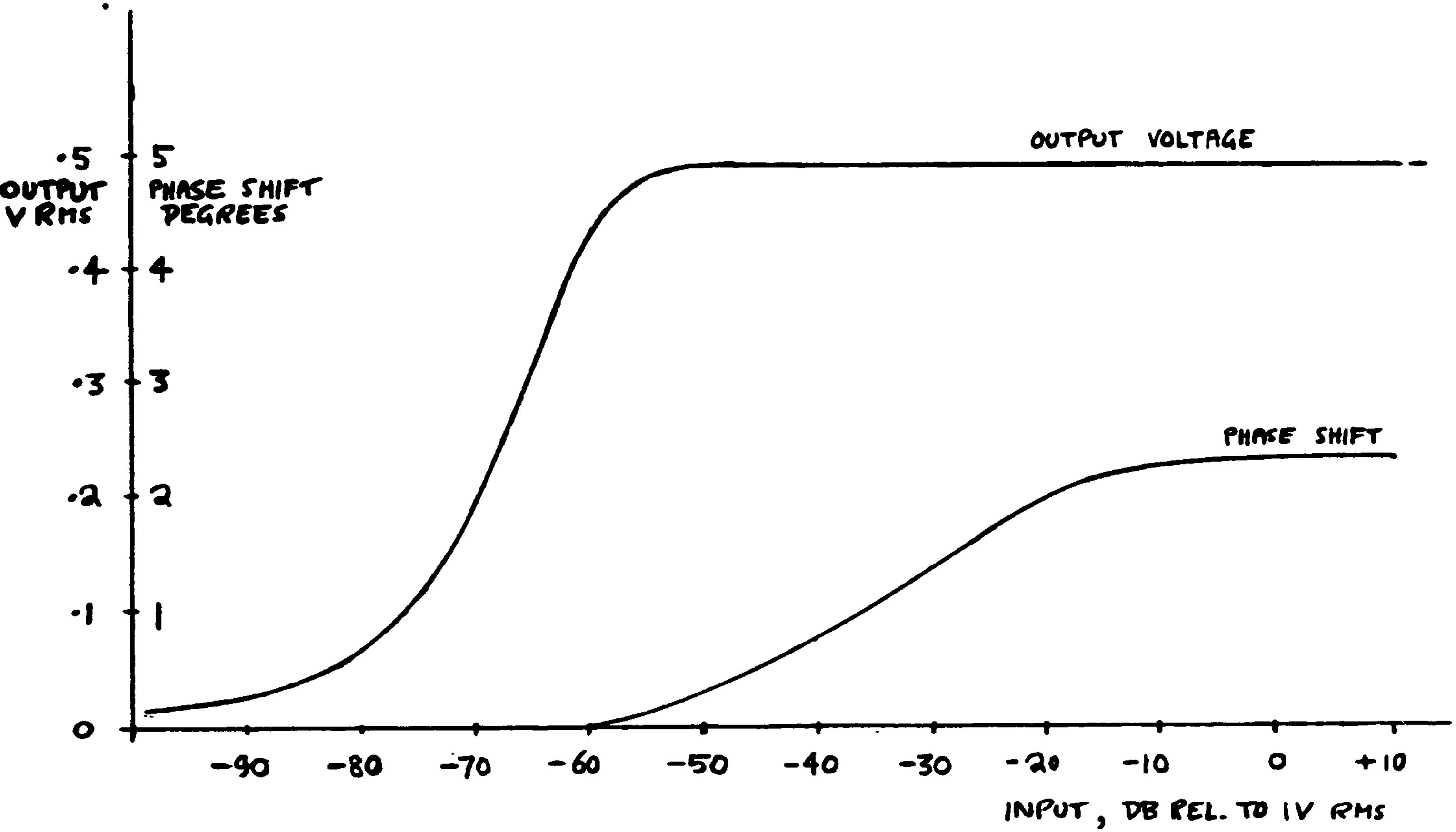

Fig. 4 Limiting Characteristics of Amplifier