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SERIES-CONNECTED ELECTRON BOMBARDED SEMICONDUCTOR DEVICES.(U)

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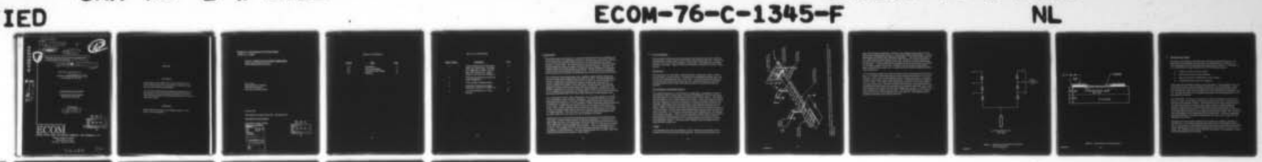

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FINAL REP[redacted]T. Apr 76 - Dec 77

April 1976 - December 1977

CONTRACT No. DAAB07-76-C-1345
W-J Project No. 22-4151

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Research and Development Technical Report
ECOM-76-C-1345-F

SERIES-CONNECTED ELECTRON BOMBARDED SEMICONDUCTOR DEVICES

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1.0 Introduction

During this program the design for a series-connected EBS device was completed and six of these devices were fabricated, burned-in, and delivered. Each device consisted of three basic sub-assemblies; the electron gun, the beam deflection and rotation structure, and the target. The electron gun and beam deflection and rotation structure utilized designs previously developed at Watkins-Johnson Company. The target was modified from previous EBS designs to incorporate a target consisting of two groups of three series-connected diodes operated Class B. The six devices were supplied to USAECOM for use in evaluation and lifetesting of the series-connected diode techniques.

In most previous EBS developmental work, amplifiers capable of high output power have used targets with multiple diodes connected in parallel. With this configuration, however, as the number of diodes in the array increases, the source impedance decreases, significantly complicating the problem of matching to a 50 ohm load. A series connection of the diodes, on the other hand, greatly simplifies the matching problem by virtue of the increased source impedance presented. Furthermore, the effective capacitance of an array of N series-connected diodes is reduced by a factor of 1/N compared to the capacitance of a single diode. This, in turn, serves to increase the power bandwidth product of the device when matching to a high impedance load.

These advantages of series diode configurations for broad-band amplifiers are offset by one potentially serious drawback: instability. The individual diodes are close to being ideal current sources, the value of which depends upon the beam illumination. When placed in a target array, it is impossible to achieve absolutely identical illumination of each diode. Series-connected diodes can thus act as unequal current sources in series. Since current continuity must be maintained, the diode currents will attempt to balance through parasitic paths in the array or through driving some of the diodes to voltage saturation. This can result in a non-uniform voltage distribution across the diode string and in some cases can lead to damage to the diodes.

Stabilization can be improved by providing separate biasing for each individual diode with either a resistive divider network or separate bias supplies. Previous work on high-voltage switches at Watkins-Johnson has successfully incorporated resistive network stabilization of series configurations of diodes. However, this was in the context of low duty cycle, pulsed saturation mode operation. Thus, the stabilization was DC in nature. No investigation has as yet been undertaken regarding the effects of RF instabilities at high duty factors. The goal of this program was to develop L-band EBS devices that would permit evaluation of this problem.

2.0 Device Description

The six devices constructed under this program were deflected beam EBS amplifiers, incorporating a Class B target of three series-connected diodes per side. Each device consisted of three basic sub-assemblies: electron gun, beam deflection and rotation structure, and target. Figure 1 shows the basic device construction and power supply hook-up.

Electron Gun:

The electron gun is a sheet beam, laminar flow gun, comprising a heater, cathode, focus electrode, and four anodes. The cathode is an impregnated tungsten type, with an active area approximately .023 x .700 inches. The focus electrode and anode one control the beam current level; anodes one, two, and three provide the adjustments for optimizing the electron beam at the diode; anode four is maintained at ground potential.

Beam Deflection and Rotation Structure:

The deflection structure is a traveling-wave configuration, consisting of a meander line suspended above a ground plane, such that the propagation of the RF input signal along the meander line is synchronized with the electron beam velocity. The meander line is designed to have an input impedance of 50 ohms. When an RF signal is applied, the beam undergoes a transverse acceleration as it passes through the meander line structure, deflecting it from its rest position. Further lateral separation from the beam boresight occurs in the drift region between the deflection structure and the target. Between anode four of the electron gun and the start of the deflection structure is a beam rotator. This consists of two deflection plates slanted toward each other to form a truncated "V" in the cross-sectional plane of the electron beam, and bisected by the plane of the beam. When a non-zero potential is applied between the two plates, the non-uniform spacing across the beam width results in a non-uniform electric field causing the beam deflection to be a monotonic function of transverse position, thus imparting a rotation. The beam rotator facilitates accurate alignment of the beam with the meander line.

Target:

The semiconductor target was designed to allow evaluation of the stability and performance of the series-connected diode approach. Six semiconductor diodes were

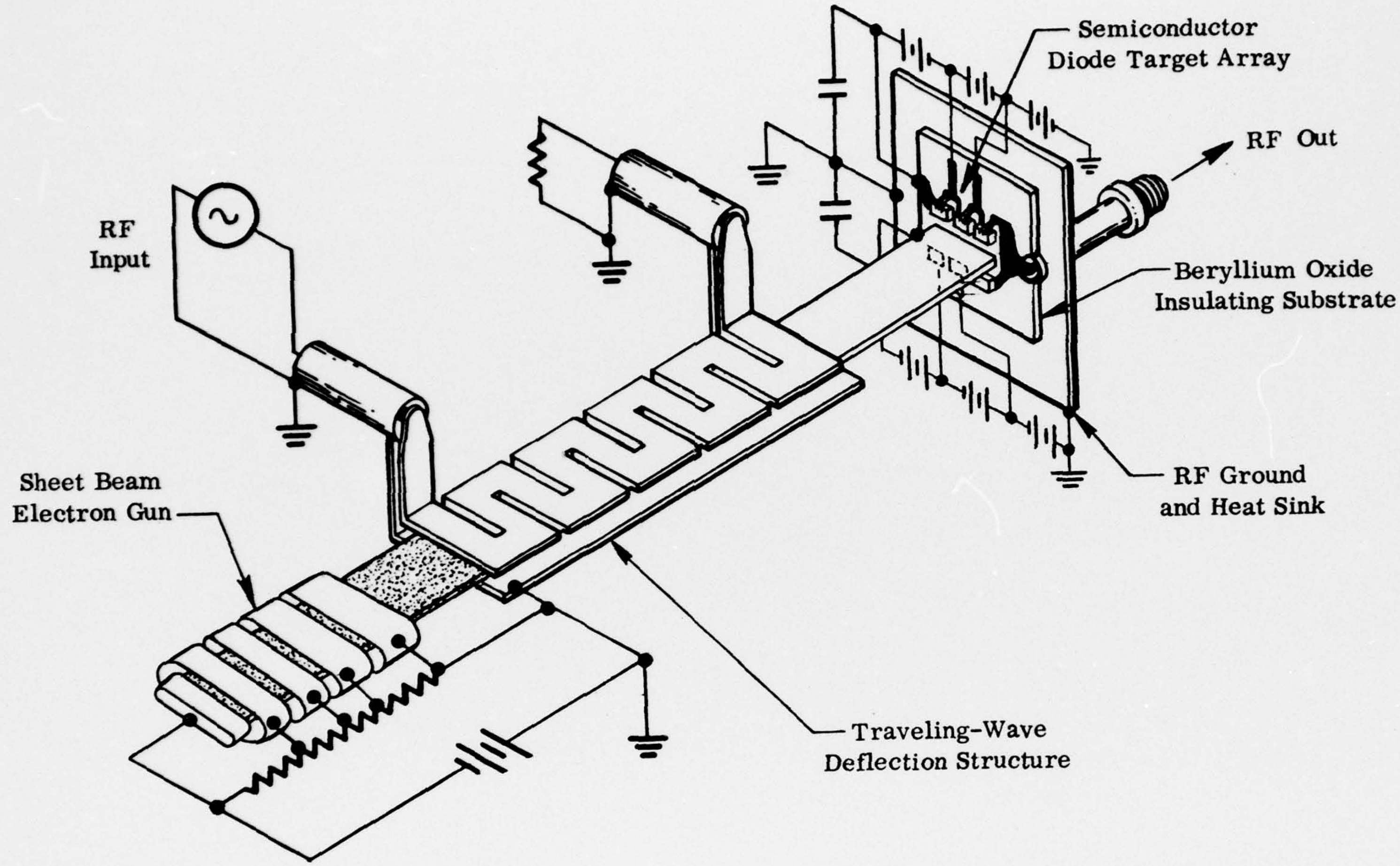

Figure 1 - Class B deflected beam EBS using a sheet beam electron gun, traveling-wave deflection structure, and multiple diode target array, showing individual biasing of the series array. (Beam rotator is not shown for simplicity).

used, with the diodes electrically connected in two strings of three diodes in series. This is shown schematically in Fig. 2. At each diode interconnection point, a vacuum feedthrough is provided to allow electrical connection. The vacuum feedthrough is at the interconnection point between the two diode strings is a coaxial transmission line with a characteristic impedance of 50 ohms; the other six vacuum feedthroughs are bias pins. These bias pins allow monitoring of the current flowing in each diode and individual biasing of each diode. In addition, the diode target mount includes water cooling of the six diode array to allow operation at power dissipation densities of up to $20W/mm^2$.

The semiconductor diodes were fabricated with a P on N planar geometry as shown in Fig. 3. The diode is fabricated with an N-type epitaxial layer grown on an N+ silicon substrate. The P+ layer is then diffused into the N layer to form the P - N junction. To form a good ohmic contact on top of the diode, a 200 Å layer of nickel is deposited on the P - layer. This nickel is then alloyed into the silicon to form nickel silicide. The junction perimeter of the diode is passivated with layers of thermally grown S_iO_2 and phosphorus-doped glass; this passivation layer prevents degradation of the diode when exposed to the vacuum and to the high-energy electron beam. As shown in Fig. 3, the N+ substrate is typically 6-8 mils thick. The N-type epitaxial layer was approximately 18 μm thick, with a doping level of 10-20 ohm-cm. This thickness allows operation of the diode target at up to 1200 MHz.

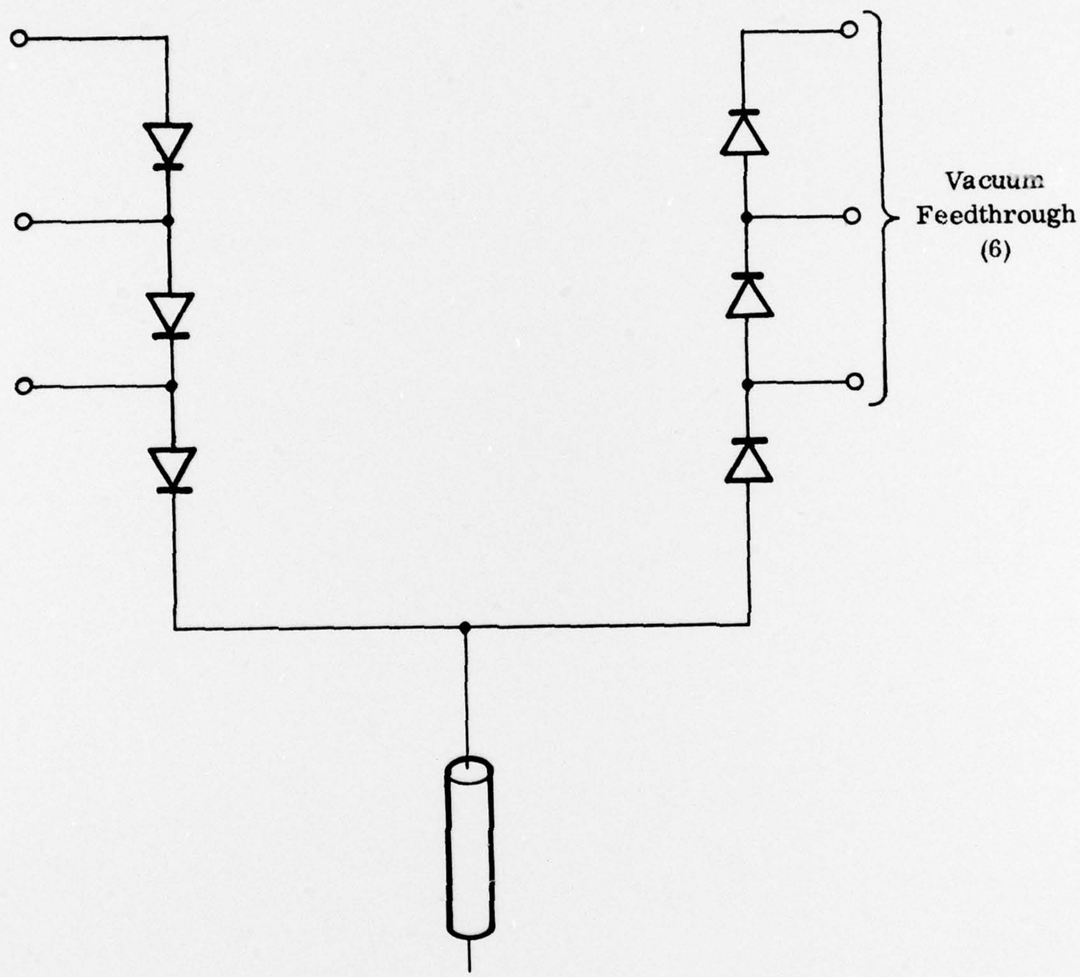

Figure 2 - Schematic showing series-connected diode configuration.

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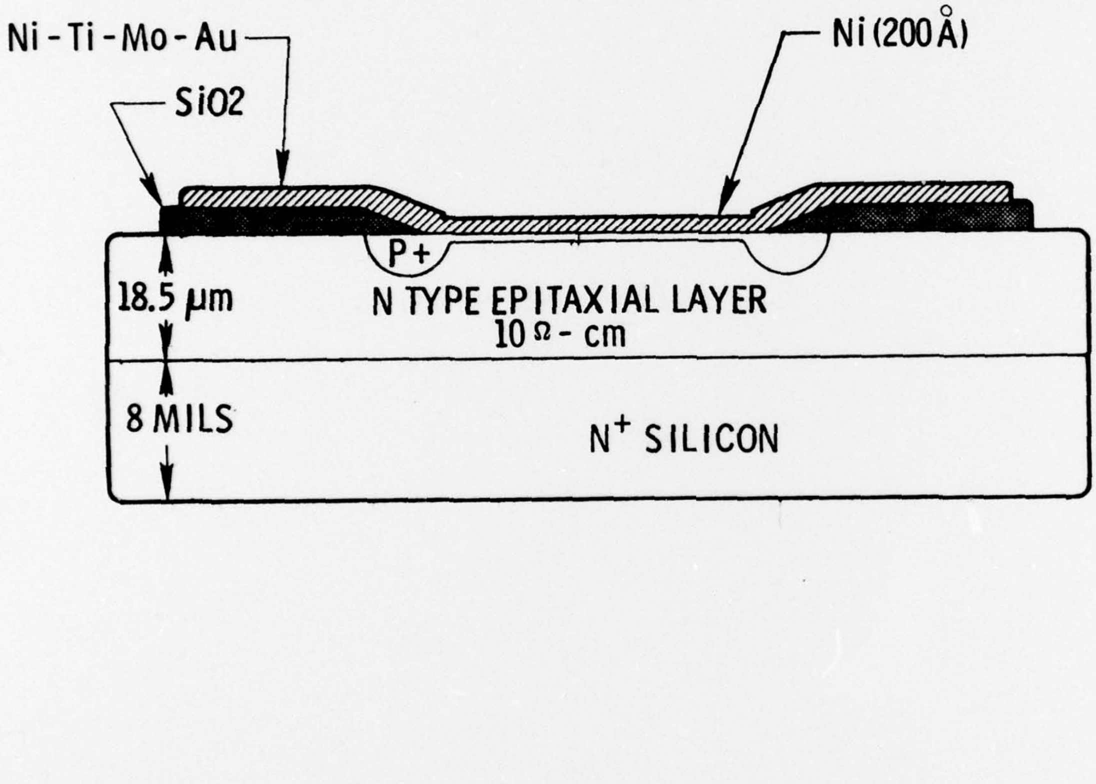

Figure 3 - Cross-section of diode geometry.

3.0 Fabrication and Testing

Six devices were fabricated and delivered to USAECOM during this program. The fabrication of the individual sub-assemblies was completed first, and the devices were assembled as the semiconductor diode targets were completed. The fabrication of the semiconductor target was performed by the following procedure:

a) Scribe 2 x 3 diode array from wafer.

b) Braze the diode array to BeO substrate.

c) Separate the diodes mechanically by laser scribing.

d) Wirebond the diodes to the BeO substrate.

Each array was electrically checked to verify the diode I-V characteristics, and each array was X-rayed to verify the integrity of the braze to the BeO substrate. Diodes from two diode runs were used; the first four devices were assembled with diodes from the first run, which had an Epi thickness of 18 μm thickness and doping of 10 ohm-cm. The last two devices were assembled with diodes with an Epi thickness of 18 μm and doping of 20 ohm-cm.

After fabrication, each device was baked out at 250°C while drawing a vacuum in the device. A large vac-ion pump was used with a rating of 110 l/sec. The bakeout for each device was typically 72 hours. After bakeout, the devices were pinched off from the large vacuum pump; a smaller 2 l/sec pump was used to continue pulling the vacuum. Each device was then hi-potted to insure that the electron gun to body stand-off voltage was at least 25 kV. The devices were then operated for a minimum of 24 hours with the electron beam striking the semiconductor target, while the electron beam was deflected with an input signal to the meander line. This burn-in stabilized the cathode emission, continued the outgassing of the devices, and verified the basic operation of the devices.

Operation of the beam rotator and diode bias circuitry was verified in operation of WJ-3623 S/N 3. The basic circuit which was used to bias the six diodes is shown in Fig. 4. Each diode was individually biased and the current in each loop was monitored. It was found that there was a current imbalance between the diodes at the end of each string. By rotating the electron beam with the beam rotator, it was possible to balance the currents flowing in the six diodes.

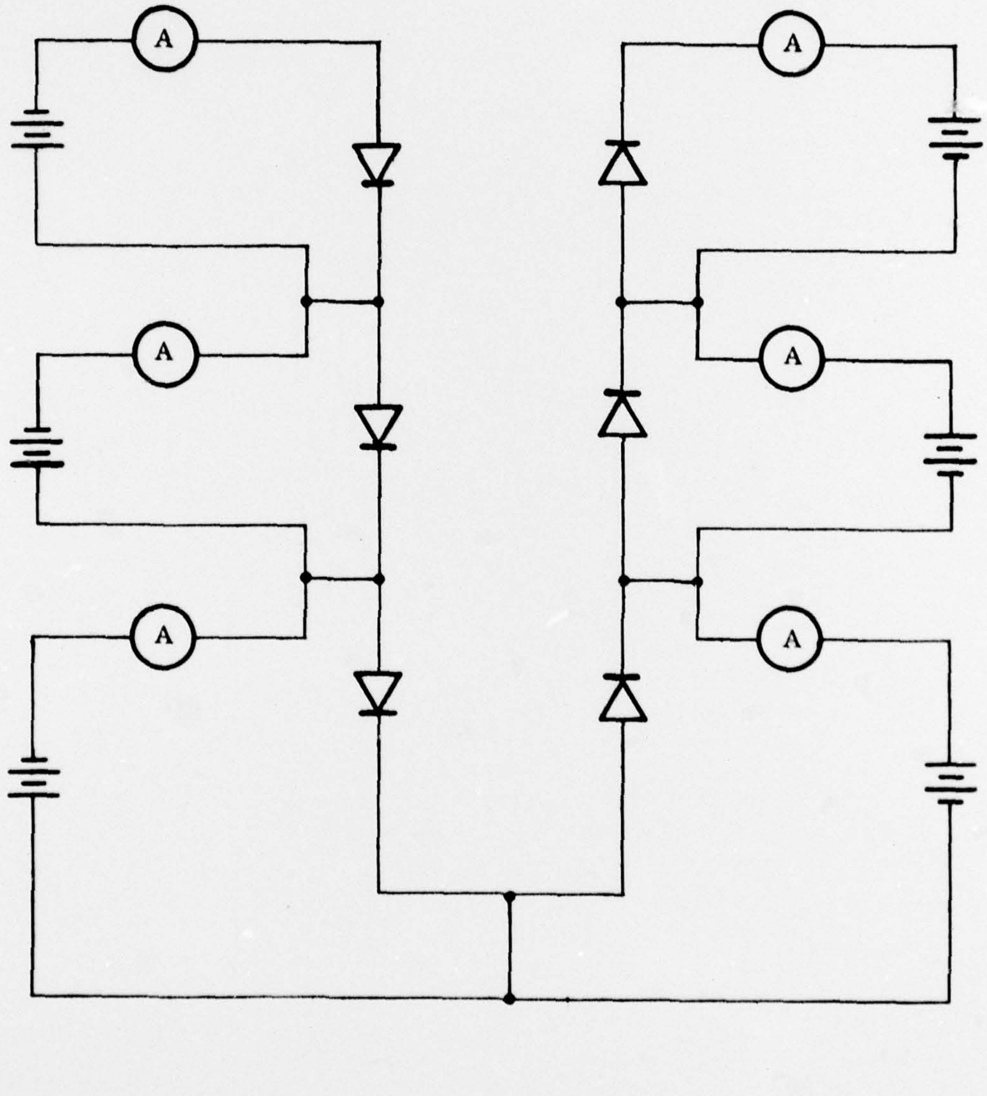

Figure 4 - Schematic showing power supply hook-up for testing of WJ-3623 S/N 3.

After burn-in of each device, the electrical characteristic of the diodes was checked. The diodes all showed breakdown voltages of greater than 200 V. The I-V characteristic for S/N 5 is shown in Fig. 5. The diode breakdown voltage for each diode is greater than 200 V, and leakage current at 200 V is less than 10 μA.

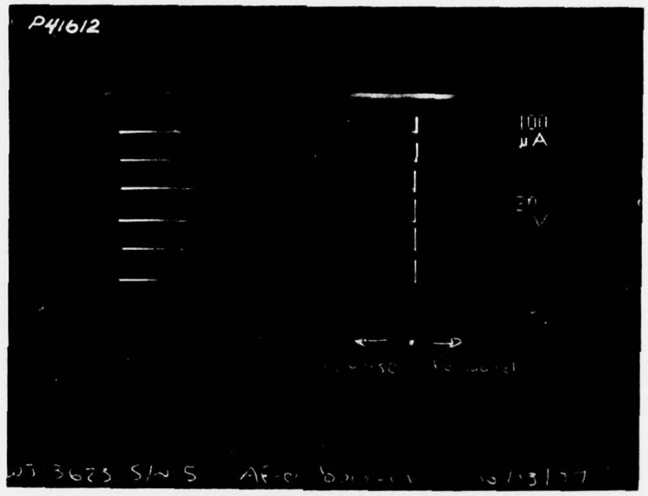

Figure 5 - I-V characteristic of S/N 5 after burn-in.

4.0 Summary

During this program, the design for a series-connected EBS device was completed and six of these devices were fabricated, burned-in, and delivered to USAECOM. The series-connected diode approach has two significant advantages over the parallel connection of diodes; one, it provides a significantly higher impedance into which the diode array must operate; and two, the diode array capacitance is reduced, providing a much broader operating bandwidth. Currently there is a lack of information regarding the stability and long-term reliability of the series-connected diode EBS device. The program was successful in supplying these test vehicles which can now be evaluated at USAECOM to determine if the series-connected diode approach should be considered for high power EBS amplifiers.

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