MICROWAVE INTEGRATED TUNNEL DIODE AMPLIFIERS FOR BROADBAND, HIGH PERFORMANCE RECEIVERS*

by

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A family of X-band thin-film microstrip tunnel diode amplifiers (TDA's) have been developed for use in broadband, high-performance receivers. These TDA's exhibit half-octave bandwidth capability, with about 9-dB gain per stage over 8.0 to 11.5 GHz, 5.0 to 6.0 dB noise figure (using Ge tunnel diodes), and -14 to -17 dB output level at 1-dB gain compression (using GaAs tunnel diodes). This represents a considerable advance in performance with respect to previously reported MIC-TDA's.[1,2,3] Figure 1 shows a two-stage TDA, including an output isolator per stage.

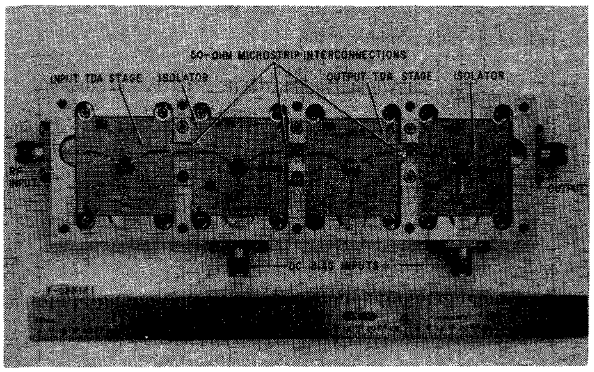

Figure 1. Two-State X-Band Thin-Film Microstrip TDA

The individual circulator-coupled TDA stages and terminated-circulator output isolators comprising the two-stage MIC TDA were each fabricated in microstrip transmission line on 1-inch square, 25-mil thick alumina substrates, with the vacuum-deposited metallization on each consisting of a composite chromium-copper film. The conductor pattern is photoetched on the upper surface of each substrate and the entire metallization is then gold flashed. A single, thin-film microstrip TDA stage, shown in Figure 2, contains the following components:

- Encapsulated tunnel diode in a micropill package, shunt mounted through a hole in the substrate between the conductor pattern and the ground plane. By virtue of the high degree of compatibility of this encapsulation (50-mil diameter, 20-mil active height, alumina support ring within a package) with the 25-mil height alumina microstrip environment, the parasitics associated with this shunt mounting configuration are not much in excess of those associated with series mounted beam-lead tunnel diodes.[2,3] This is particularly true in the normal shunt-tuned mode of TDA operation, in which a dc or RF ground return (which adds to the diode series inductance by at least 50 pH) is required. Suitable commercially available tunnel diodes in this encapsulation exist in both the conventional ball-alloy construction[4] and in the more advanced planar solid structure construction.[5] The former provides superior electrical characteristics at this time; hence, both Ge and GaAs tunnel diodes of this construction were used in the TDA's to be described herein. However, the solid structure diodes are ultimately preferred due to their superior structural properties and potential reliability.

- Embedded 200-mil YIG disc, metallized as previously described, to form the three-port circulator junction, the dc bias field being provided by an appropriately mounted platinum cobalt magnet.

- Pair of parallel composite open stubs, providing a parallel inductive tuning element for the tunnel diode without shorting the externally applied dc bias. The latter is provided via an RF-isolated bias feed network at one port of an output isolator.

- Parallel-connected, lumped BRF stabilizing network to prevent out-of-band oscillations, yet appear completely reactive in the amplifier passband.

- Dual quarter-wave transformers at each port of the circulator junction to provide a wideband match to the 50-ohm microstrip-to-3 mm coaxial input and output transducers, and to provide a specified three-pole reflection gain response at the amplifier port at a particular midband gain level.

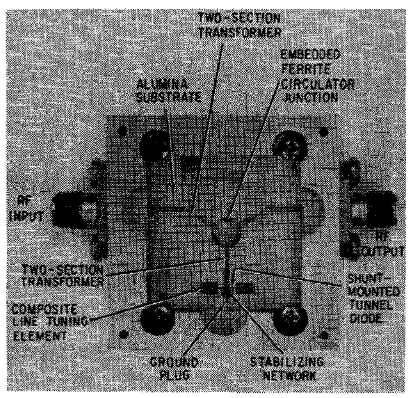

Figure 2. Single-Stage Thin-Film Microstrip TDA

Prior to realization of the single-stage TDA, some of the individual thin-film microstrip circuit elements comprising it required individual development. In particular, the symmetrical three-port circulator counterpart of that used in the TDA exhibited an average of 18 to 27 dB isolation and 0.6 to 1.2 dB insertion loss per pass between each pair of adjacent ports, and its input impedance locus at the ferrite junction essentially conformed to that postulated in the TDA equivalent

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circuit of Figure 3. The latter was also true with respect to the thin-film stabilizing network (over 0 to 18 GHz), and the tuned and stabilized tunnel diode, each characterized individually on a separate substrate.

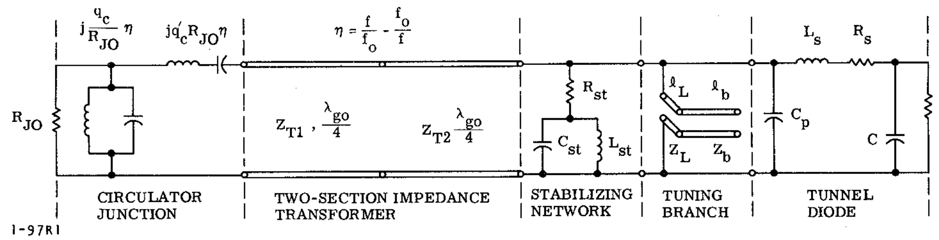

Figure 3. Equivalent Circuit Representation of Single-Stage TDA

These results permitted implementation of a three-pole broadbanding design[6] for the TDA in accordance with Figure 3. A computer-aided analysis involving perturbations of nominal design values for optimum response provided further refinement of this design. Theoretically predicted performance over 8 to 12 GHz includes 6.2 ±1.0 dB gain per stage and 5.3 and 6.8 dB passband noise figure for stages using Ge and GaAs tunnel diodes, respectively.

Four single-stage TDA's were fabricated, two using Ge and two GaAs tunnel diodes. Figure 4 shows the measured performance of these amplifiers, each evaluated in its own test housing. This is summarized as follows:

Tunnel diode	AIG-2250	AIA-2250	AIG-2250	AIA-2250
Semiconductor	Ge	GaAs	Ge	GaAs
Passband (GHz)	7.8 to 11.5	8.0 to 11.5	8.0 to 11.6	8.0 to 11.4
Passband gain (dB)	8.4 ±1.0	10.0 ±2.0	9.0 ±1.0	10.0 ±1.0
Passband noise figure (dB)	5.75 ±0.4	7.2 ±0.6	5.5 ±0.5	8.0 ±0.6
Output level at 1-dB gain compression (dBm)	-23 to -20	-17 to -14	-23.5 to -20	-19 to -13

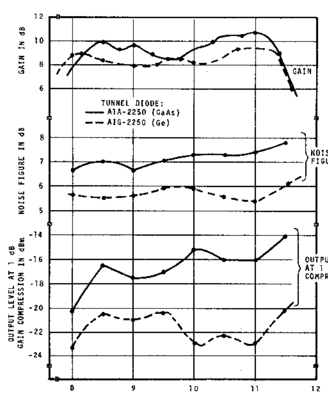

Figure 4. Measured Performance of Representative Single-Stage TDA's

A two-stage TDA (Figure 1), using a previously described Ge and GaAs TDA as the input and output stage to simultaneously optimize noise figure and dynamic range, was fabricated in a compartmentalized aluminum housing and included an output isolator per stage. This level of integration permitted pretesting of individual components and inhibited spurious intercomponent coupling and higher order mode box resonances.

The output isolators employed in the TDA (Figure 1) are merely adaptations of the three-port circulator used in the TDA stages, with one port resistively match terminated and an RF-isolated bias feed network and a dc blocking capacitor connected to the output arm to provide dc bias voltage to the preceding TDA stage. The average measured performance of four of these isolators include 15 to 25 dB isolation (overcoupled response), and 0.5 to 1.5 dB insertion loss over the 8 to 12 GHz range.

A preliminary model of the two-stage TDA using 50-ohm microstrip interconnections between the partitioned components exhibited 11.5 to 13.5 dB average gain, 3 dB peak-to-peak gain ripple, 6.8 to 7.2 dB noise figure, and -20 to -23 dBm output level at 1-dB gain compression (Figure 5). The degradation in noise figure and large signal linearity as compared to that obtained with the individual input (Ge) and output (GaAs) TDA stages can be attributed, respectively, to output and input stage contributions.

Further improvement in the gain flatness of the two-stage TDA should be achievable by: 1) more precise matching of the monotonically rising average gain-frequency and loss-frequency responses of the TDA stages and output isolators, respectively, and 2) more closely integrating each TDA stage with its corresponding output isolator, on a single substrate with an optimized interjunction connecting line.

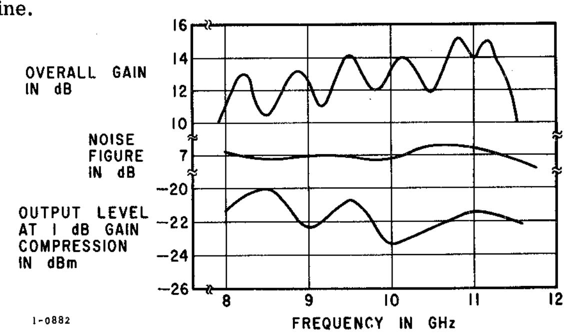

Figure 5. Measured Performance of Two-Stage TDA

References

1. W.G. Matthei and W. Crowe, "New Microwave Integrated Circuit Modules," Wescon 68 Technical Papers, 12, p 2/1-1 to 2/1-6, Aug 1968.
2. H.C. Okean, "Microwave Amplifiers Employing Integrated Tunnel Diode Devices," IEEE Trans MTT-15, p 613 to 622, Nov 1967.
3. J.D. Welch, "Beam Lead Tunnel Diode Amplifiers on Microstrip," Dig 1970 G-MTT Int Symp, p 212 to 216, 1970.
4. S. Virk, "The State of Tunnel Diode Technology," Electronic Products, p 30 to 32, Nov 1969.
5. A. Lueck, W. Schultz, and A. Marmiani, "The Solid Structure Tunnel Diode," Microwave J, Vol 9, p 49 to 52, July 1966.
6. H.C. Okean, "Synthesis of Negative Resistance Reflection Amplifiers Employing Band Limited Circulators," IEEE Trans MTT-14, p 323 to 337, July 1966.