A REFLECTIVE DIODE LINEARIZER FOR SPACECRAFT APPLICATIONS

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Abstract

There is an increasing interest in the use of predistortion linearizers to improve Carrier-to-Intermodulation ratios (C/I) of spacecraft power amplifiers. This paper describes a Ku band reflective diode linearizer designed to provide high reliability and to function over the changing environmental conditions required for space applications. This linearizer is electrically tunable to allow its characteristics to be easily trimmed to compensate for the different non-linearities of a variety of amplifiers. When used in conjunction with a TWTA, it is is capable of providing a two-tone C/I of 30 dB or an improvement of greater than 10 dB over the critical power back-off range from -3 to -8 dB. Both two and multi-tone C/I performance are reported and the performance degradations of aging, temperature and bandwith are discussed.

INTRODUCTION

When spacecraft transponders are used to transmit multi-carrier signals (FDM), the power amplifier's output power operating point must be reduced or "backed off" to reduce intermodulation products to an acceptable level. This backoff reduces signal levels and transponder efficiency. For some time predistortion linearizers have been used to increase the efficiency of terrestrial microwave links by generating a transfer characteristic which is the opposite of the saturation characteristic of link power amplifiers in both magnitude and phase.(1,2) Benefits accrue for both TWTA and solid state power amplifiers.

More recently the value of linearizers for spacecraft applications has been recognized.(3,4,5) However, there has been little discussion of the need for a linearizer to operate over a wide range of temperatures and to maintain its performance as components age.

In spacecraft production, the TWTA is usually one of the last system components available before integration. A viable linearizer must be easily tuned to match the characteristics of different power amplifiers and provide this match over the required channel bandwidth.

REFLECTIVE DIODE APPROACH

A number of different linearizer configurations were investigated and the reflective diode linearizer (RDL) approach chosen. This arrangement has many advantages. It is simple, small in size and uses only passive components. In its basic form, shown in figure 1, only two schottky diodes are required. These diodes have a long history in space, in detector applications and have a known reliability. All other components can be implemented in microstrip.

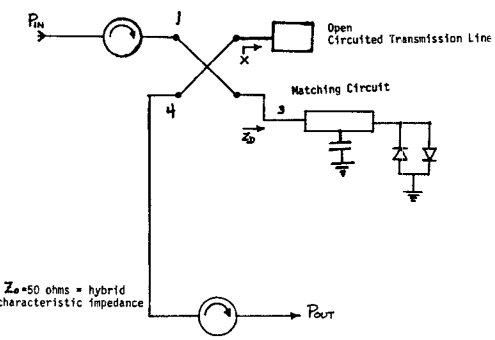

Figure 1. Basic Reflective Diode Linearizer

The RDL uses a quadrature hybrid to split an incoming signal into two equal levels. One half of the input is applied to a variable reactance load (X) at port 2. All power arriving at X is reflected back to the hybrid. The phase angle of this reflected voltage is related to the incident voltage by the angle of the reflection coefficient of the reactance.

$$\theta x = \mathrm{ARCTAN}(Zo \cdot X/(X^2 - Zo^2)) \qquad (1)$$

The other half of the input signal emerges from port 3 and is applied to antiparallel diodes through a matching network. The majority of the power reaching these diodes is also reflected back to the hy-

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brid. As these diodes are driven with greater power, the magnitude and phase angle of the voltage reflected from them will change, e.g., from $V_d\angle\theta_d$ to $V_d'\angle\theta_d'$ as illustrated in figure 2. The relationship between the incident and reflected voltages from the diode port is:

$$V_d\angle\theta_d = Vi((Zd-Zo)/(Zd+Zo)) \qquad (2)$$

where Zd is the impedance terminating port 3. Zd varies as a function of the input power.

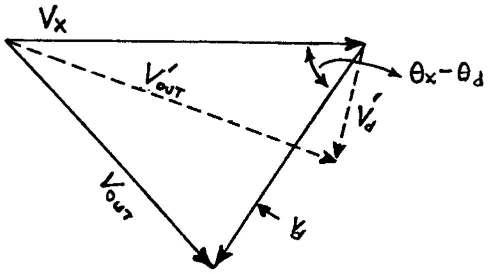

Figure 2. Vectorial Relation Between an RDL's Input and Output Signal Voltages

The reflected voltage from ports 2 and 3 are vectorially combined by the hybrid and appear at port 4. The relation between the input power and the output power is

$$Pout = Pin\ (\ 1\angle\theta_x - pd\angle\theta_d\ )\ /4 \qquad (3)$$

where $1\angle\theta_x$ is the reflection coefficient of reactance X and $pd\angle\theta_d$ is the reflection coefficient of the diode branch.

By proper choice of θ_x and Zd characteristics, an expanding nonlinear transfer characteristic can be achieved whose variation from linear (as a function of Pin) is the opposite of that generated by a TWTA or solid state amplifier in both magnitude and phase - see figure 5.

LINEARIZER PERFORMANCE

Six prototype RDL linearizers have been constructed and tested with 3 different TWTA's and a solid state amplifier. One of these linearizers was integrated into a standard driver amplifier and tested at a satellite system level. Figure 3 shows the magnitude and phase transfer characteristics of a typical RDL tuned for optimum carrier-to-total intermodulation (C/I) performance with a 20 watt TWTA in the 3 to 8 dB output power back-off (OPBO) range and over a 200 MHz frequency band. (Total C/I is used in this paper rather than carrier-to-third order intermodulation (C/I3), since it is possible to tune a linearizer for excellent C/I3 and still have a poor C/I ratio). Figure 4 shows a comparison of the C/I performance achieved by the TWTA alone to that of the above RDL/TWTA combination. Figure 5 shows the variation in RDL performance with temperature.

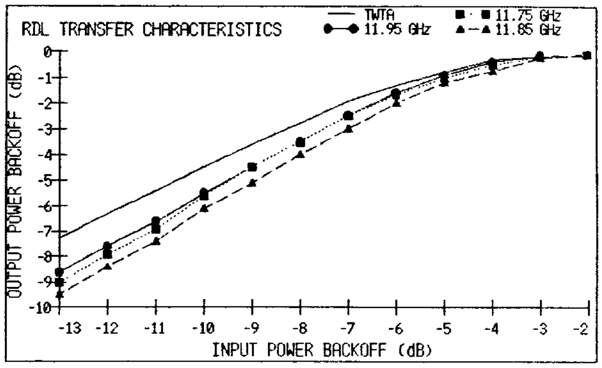

Figure 3a. Pin - Pout Transfer Characteristics of a Typical RDL/TWTA

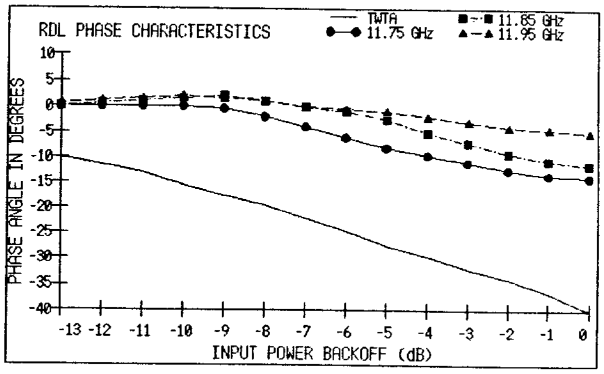

Figure 3b. Phase Transfer Characteristics of a Typical RDL/TWTA

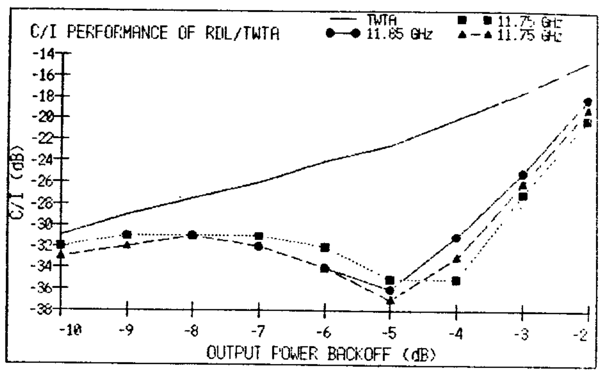

Figure 4. Comparison of C/I Performance of Typical RDL/TWTA to TWTA Alone

Performance stability over the 10 year plus life times of modern satellites is a major concern in spacecraft design. To determine the effect of end-of-life (EOL) gain variations on RDL performance, amplifier gain changes of +/- 0.5 and 1.0 dB were simulated by increasing the attenuation between the linearizer and the TWTA used during these tests. The resulting C/I variation is shown in figure 6. The projected TWTA gain drift with life, of +/- 0.5 dB does not produce a significant degradation in performance and provides a C/I well above 30 dB for OPBO's greater than 4 dB. Even in the +/- 1.0 dB case, the C/I ratio drops by only one dB below a ratio of 30 dB.

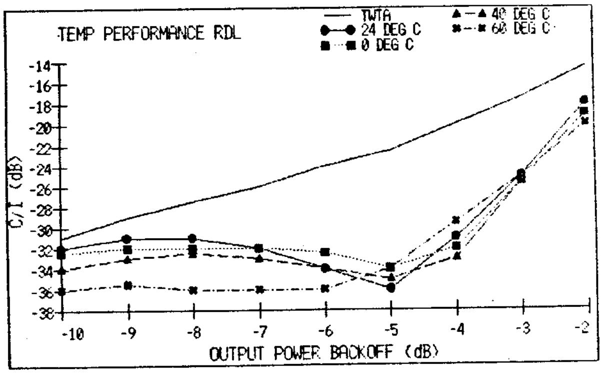

Figure 5. Variation RDL C/I Performance with Temperature

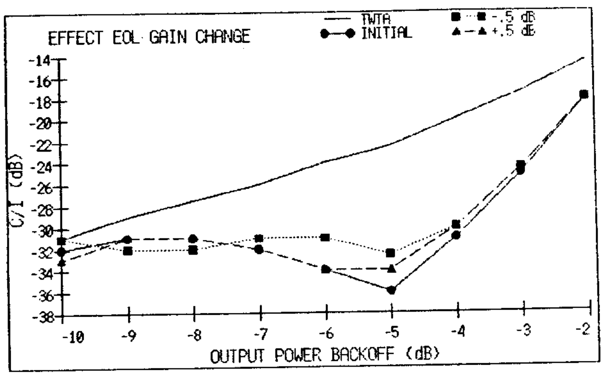

Figure 6. Effect of EOL Gain Change on RDL C/I Performance

To determine the effect of EOL TWTA phase variation, a computer program was written to calculate C/I from linearizer/TWTA magnitude and phase transfer characteristics. (The projections of this program correlated closely with experimental results and if anything, produced a pessimistic indication of RDL performance.) TWTA EOL phase shift is estimated to be a maximum of +/- 7 degrees at saturation and linearly decreases to zero at large back-off (>15 dB). This projected EOL phase change was added to the measured RDL/TWTA phase characteristic so as to result in a maximum phase differential, and this modified transfer characteristic was used to calculate the degradation in C/I due to EOL TWTA phase variation. A comparison of calculated beginning of life (BOL) and EOL RDL/TWTA performance due to phase change is shown in figure 7. This figure shows that a reduction in C/I of 1 to 2 dB is possible as a result of EOL TWTA phase variation.

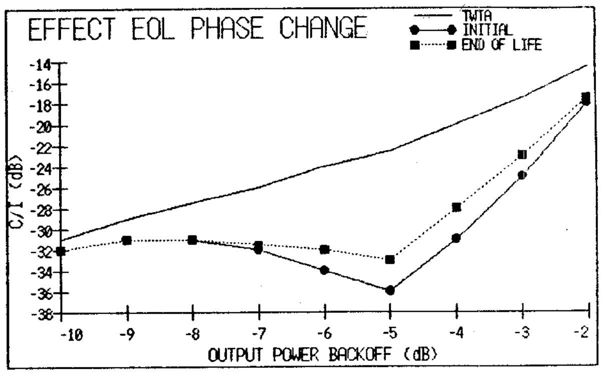

Figure 7. Effect of EOL Phase Change on RDL C/I Performance

The performance of the RDL was also investigated when excited by multi-tone signals. Figures 8 and 9 show photographs of the intermodulation spectrum generated by 2 and 4 tone signals at an OPBO of -4 dB when applied to a TWTA and to an RDL/TWTA combination. Figure 10 shows the measured improvement in C/I for two and four tone excitation as a function of OPBO obtained by adding an RDL to a TWTA. The expected performance for the infinite carrier case was determined using computer modeling.[6] The results of this calculation is also shown in figure 10. From these curves it can be seen that although the improvement provided by a linearizer is reduced as the number of tones is increased, and the point of optimum C/I improvement moves to a greater level of OPBO, a significant improvement in C/I (on the order of 9 dB) can still be achieved in the infinite carrier case. Interestingly, the significance of EOL gain and phase changes decrease with an increasing number of tones.

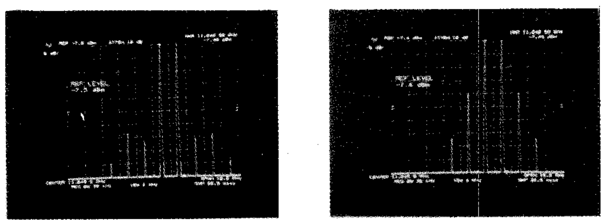

Figure 8. Photographs of Two-Tone Intermodulation Spectrum Generated By a Typical RDL/TWTA and a TWTA Alone

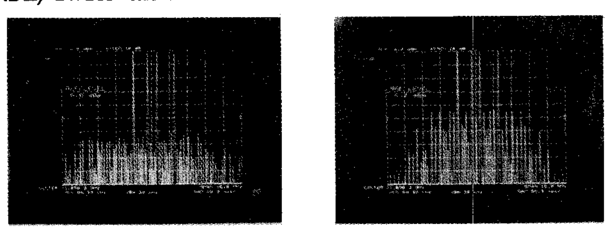

Figure 9. Photographs of Four-Tone Intermodulation Spectrum Generated By a Typical RDL/TWTA and a TWTA Alone

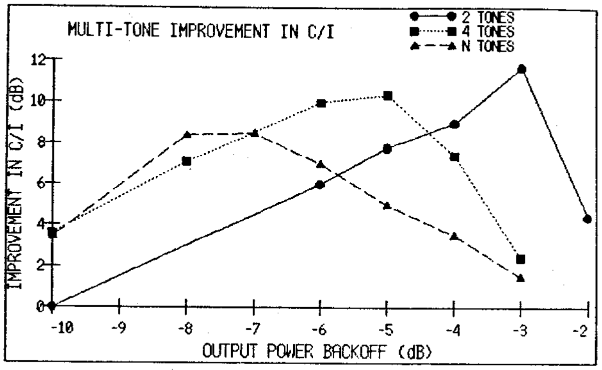

Figure 10. Improvement in C/I Provided by a Typical RDL for the Two, Four and Infinite Carrier Cases

The actual system improvement provided by a linearizer is a function of many parameters such as the ground station antenna gain and receiver signal-to-noise ratio and is thus highly systems dependent. One indicator of potential system performance enhancement is the reduction in OPBO required to provide a specific level of C/I. Figure 11 shows typical reductions in OPBO provided by the RDL for the two, four and infinite carrier cases. (The first two curves were determined by measurement while the infinite carrier data is based on computation.)

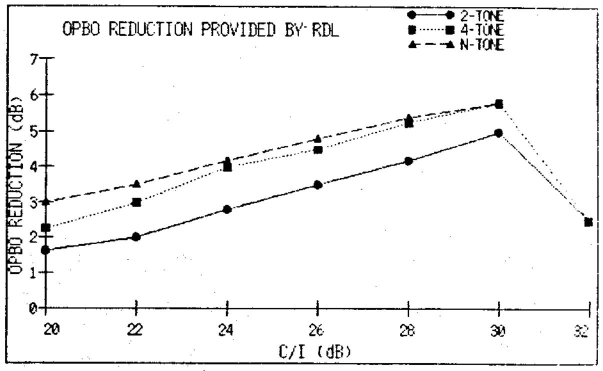

Figure 11. Reduction in OPBO Provided By a Typical RDL as a Function of C/I for Two, Four and Infinite Carrier Excitation

CONCLUSION

This investigation indicates that the RDL has great potential for spacecraft applications. A Ku band reflective diode linearizer has been produced which provides the high reliability and functions over the changing environmental conditions required by space. This linearizer has been electrically tuned to match the characteristics of a variety of amplifiers. When used in conjunction with a TWTA, it is capable of providing a two-tone C/I of 30 dB or an improvement of greater than 10 dB over the critical power back-off range from -3 to -8 dB. Even when the EOL component degradation, bandwidth and environmental requirements of typical space applications are considered, a two-tone C/I improvement of greater than 6 dB is achievable. This corresponds to a reduction in OPBO on the order of 5 dB for an infinite-tone C/I of 30 dB and can be translated into a more than doubling of system channel capacity or a reduction of spacecraft weight and power requirements.

ACKNOLEDGEMENT

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