INCREASING MULTI-TONE POWER NEAR SATURATION

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ABSTRACT

Microwave high power amplifiers, particularly TWTAs and klystrons are increasingly being used for the transmission of multi-tone signals. Such signals are frequently in the form of complex digital modulated waveforms as OFDM or CDMA. Some systems require multi-tone operation at or near saturation. The relationship between single-tone and multi-tone saturated power is investigated in this paper. It is shown that the 2-tone saturated power of TWTAs and similar amplifiers can be increased by more than 1 dB, and multi-tone ($\geq$4) saturated power by more than 2 dB, through the use of a limiter-linearizer combination.

I. INTRODUCTION

The need to transmit greater amounts of information has greatly increased the use of microwave high power amplifiers (HPAs) with multi-tone signals. Many of these systems require only moderate linearity. In some cases the HPA can be operated at or very near saturation and still provide the specified BER, and/or intermodulation distortion (IMD) performance. In such systems multi-tone saturated power becomes a key parameter.

The choice between solid state and vacuum technology (TWTAs and klystrons) is often decided by the required saturated power. At low power levels almost all factors favor a solid-state approach. However as the required power increases, the tradeoffs move to favor a TWTA and eventually a klystron solution. For example at C-band, a 400 watt TWTA is about a quarter of the size, draws about half the dc power, and cost about 50 percent less than a comparable SSPA. SSPAs are considered to provide superior linearity than TWTAs, but modern linearized TWTAs (and klystrons) have comparable or better linearity than SSPAs.

One problem not solved by a linearizer is the issue of multi-tone saturated power. It is generally known that power amplifiers saturate at a lower level with multiple carriers than with a single carrier. TWTAs generally provide a lower multi-tone saturation level than SSPAs. However, little has been written to quantify these differences. Frequently during HPA testing, multi-tone power levels are measured with a conventional power meter. This approach yields satisfactory results at higher output power backoff (OPBO), but can be in error by a dB or more near saturation. This discrepancy occurs because power meters respond to both carrier and IMD power. (A low pass filter is commonly used to eliminate harmonic, but not IMD power).

II. MULTI-TONE SATURATED POWER

The multi-tone (or carrier) saturated power (P_{MTSAT}) can be related to three factors,

$$P_{MTSAT} = P_{STSAT} - \Delta P_{ENV} - P_{IMD} - \Delta P_{DP} \qquad (1)$$

where P_{STSAT} is the single tone saturated power, ΔP_{ENV} is the power loss due to the changing envelope of the multi-tone signal, P_{IMD} is the power converted to IMD, and ΔP_{DP} is the power loss due to any decrease in power as an amplifier is driven beyond saturation. TWTA output power decreases with input power beyond saturation as shown by the TWTA transfer curve in Figure 1. The ΔP_{DP} term is the principal cause for the lower P_{MTSAT} displayed by TWTAs in comparison to SSPAs. Generally, SSPAs maintain a constant output level beyond saturation. (Some SSPAs also drop in power beyond saturation. In the SSPA case, the drop is usually due to thermal effects and not a result of inherent device physics.)

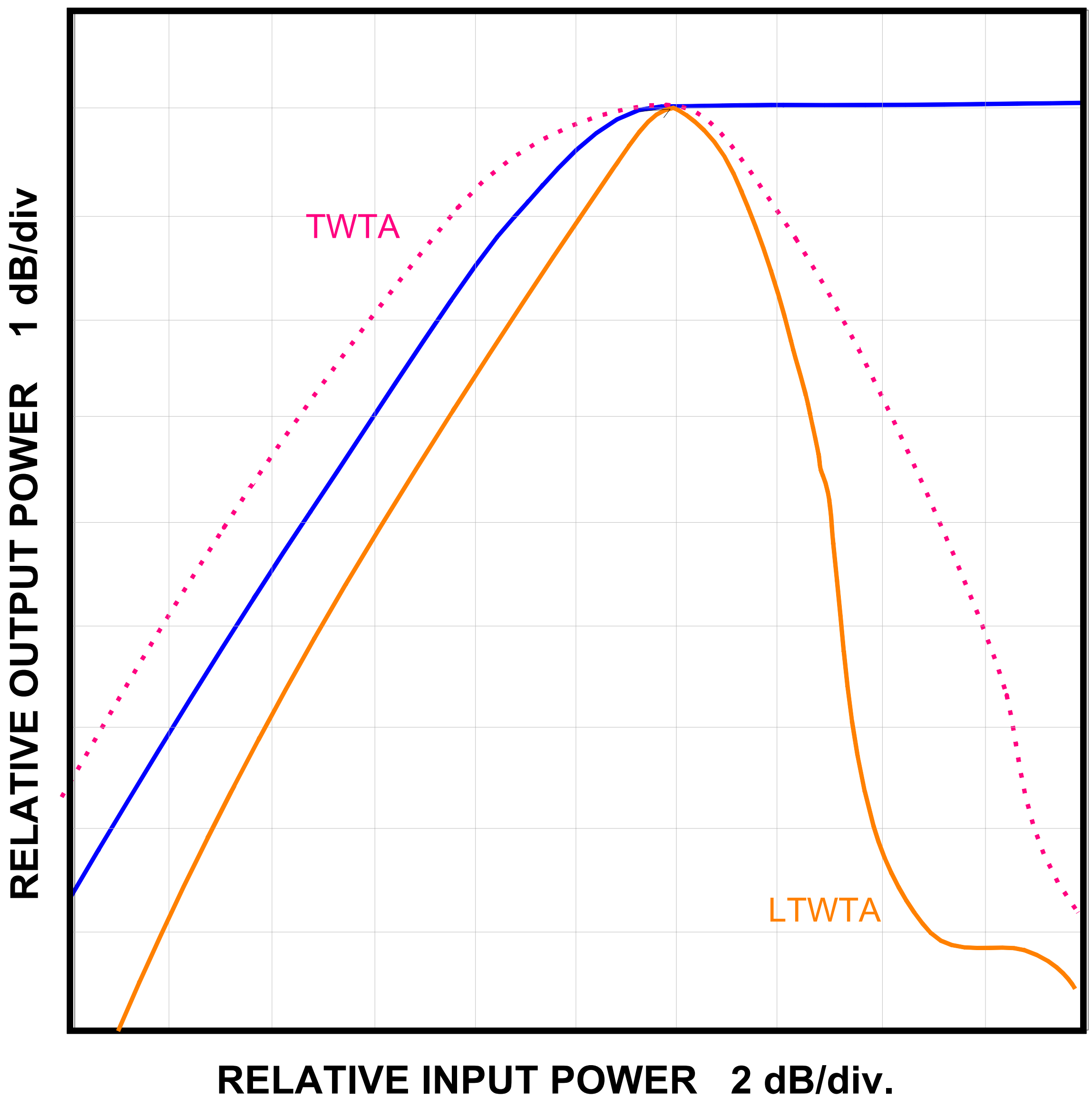

Figure 1. Input/output power transfer characteristics of TWTA and L/TWTA showing that the post saturation power decrease can be eliminated with a limiter.

The value of P_{MTSAT} was investigated both experimentally and by simulation. Special care was taken to measure only signal (carrier) power during testing. An HP 8720C vector network analyzer was used both as a signal source to generate one of the test carriers, and as a tuned power meter to precisely measure carrier power – see Figure 2.

CARE MUST BE TAKEN TO MEASURE **ONLY** CARRIER POWER

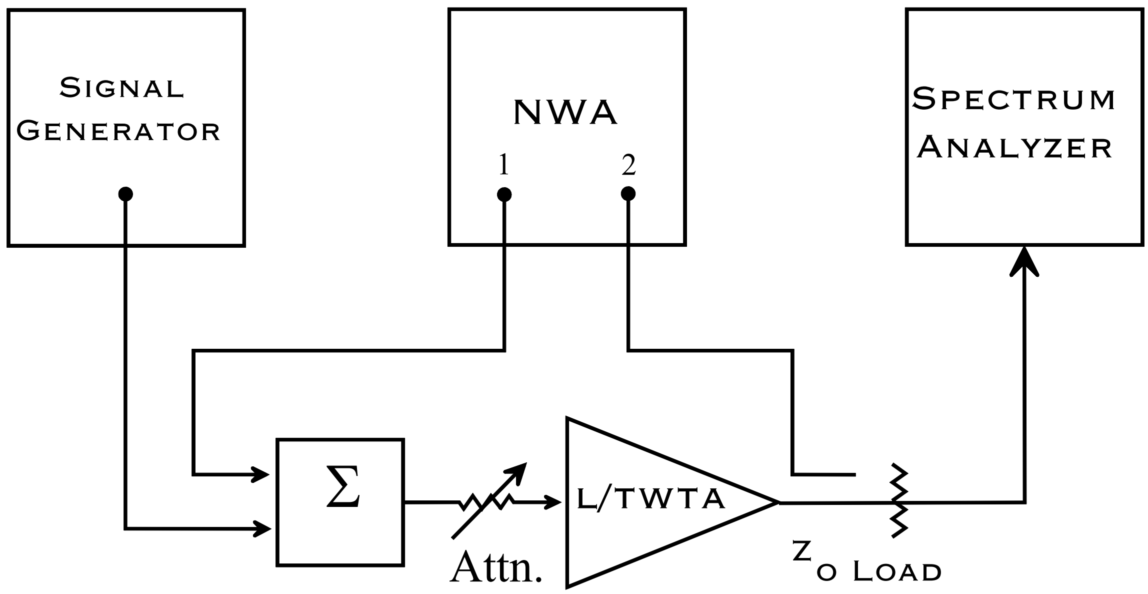

Figure 2. An HP 8720C vector network analyzer was used as a tuned power meter to measure carrier power independent of IMD.

The amount of power loss will depend not only on the transfer characteristics of the amplifier, but also on the characteristics of the signal. Generally the greater the peak-to-average-ratio of the signal, the greater is the loss in power. Figure 3 attempts to illustrate this point: Figure 3a shows the envelope of a 2-tone signal (3 dB peak-to-average power ratio); Figure 3b shows the same signal after passing through an "SSPA like" amplifier (no power drop beyond saturation), driven to near saturation; and Figure 3c shows the same signal after passing through a "TWTA like" amplifier, driven to near saturation. Note the dimple in Figure 3c. Even though the average power has not quite reached saturation, the instantaneous input power is at times well beyond the level for saturation, and must cause a power drop at these times. As the peak power increases, the power drop becomes greater, and the corresponding dimple will become deeper.

The difference between P_{MTSAT} and P_{STSAT} in dB can be expressed as:

$$\Delta OPBO_{SAT} = 10 \text{ LOG } (P_{MTSAT}/P_{STSAT}) \quad (2)$$

For a typical TWTA with 2-tone excitation, $\Delta OPBO_{SAT}$ is about 1.6 dB.

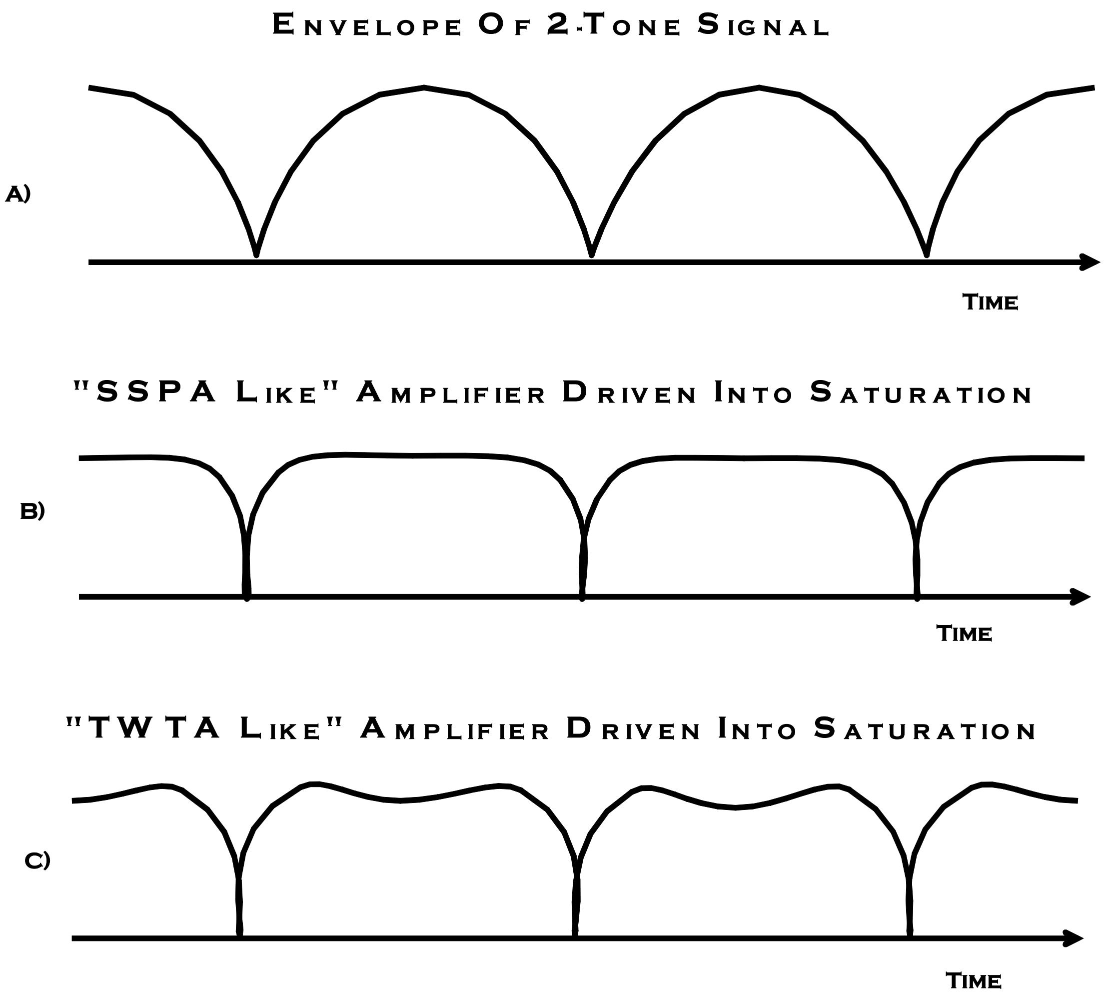

Figure 3. Affect of Amplification near saturation on signal envelope.
3a. Envelope of a 2-tone signal.
3b. 2-tone signal after passing through an "SSPA like" amp. driven into sat.
3c. 2-tone signal after passing through a "TWTA like" amp.r driven into sat.

III. THE AFFECT OF LINEARIZATION ON P_{MTSAT}

Linearizers are used to increase amplifier linearity. They allow HPAs to operate closer to saturation for a given level of IMD. Predistortion (PD) type linearizers have been used almost exclusively with TWTAs.[1,2] PD has been employed because of its excellent performance, relative simplicity, and ability to be added to an existing amplifier as a separate stand-alone module. PD linearizers generate a nonlinear transfer characteristic, which equalizes the amplifier's transfer characteristics in both magnitude and phase. The gain of the linearizer must increase with input level to cancel the corresponding decrease in gain of the TWTA. An increasingly greater change in gain is required for distortion compensation as saturation is approached. This *gain increase* should cease at the point where the TWTA is driven to saturation. Such a response is very hard to achieve in practice. Most linearizers cannot turn off their *increasing gain* immediately. Consequently, the TWTA is driven further into saturation by the linearizer, as illustrated in Figure 1 by the linearized TWTA (L/TWTA) curve. This growth in overdrive causes a further decrease in P_{MTSAT}. The resulting $\Delta OPBO_{SAT}$ for a L/TWTA can be greater than 2 dB.

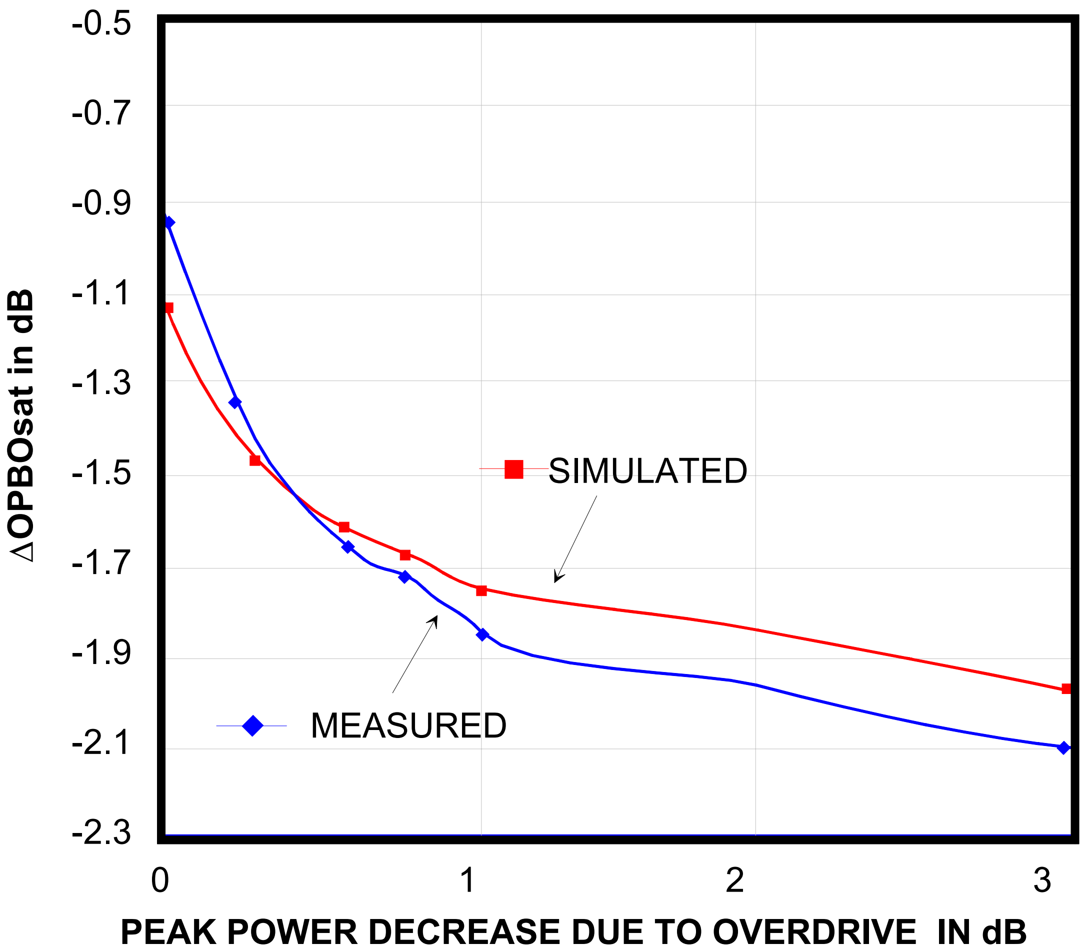

Figure 4. The loss in saturated power ($\Delta OPBO_{SAT}$) due to multi-carrier excitation can be related to the peak decrease in power due to overdrive, *beyond saturation.*

Figure 4 shows how $\Delta OPBO_{SAT}$ varies with the instantaneous peak decrease in power, *beyond saturation,* due to overdrive for a typical TWTA. (This decrease can be obtained from Figure 1 by entering the peak envelope power (PEP) of the multi-tone signal). The curves shown in Figure 4 were calculated/measured for a 2-tone signal, but appear to also apply for cases involving a larger number of tones.

IV. THE ADVANTAGE OF LIMITING

Preceding the TWTA with a limiter can reduce the PEP overdrive. If the limiting point is made to coincide with the point of TWTA saturation as shown in Figure 5, overdrive and the consequent ΔP_{PD} can be prevented.

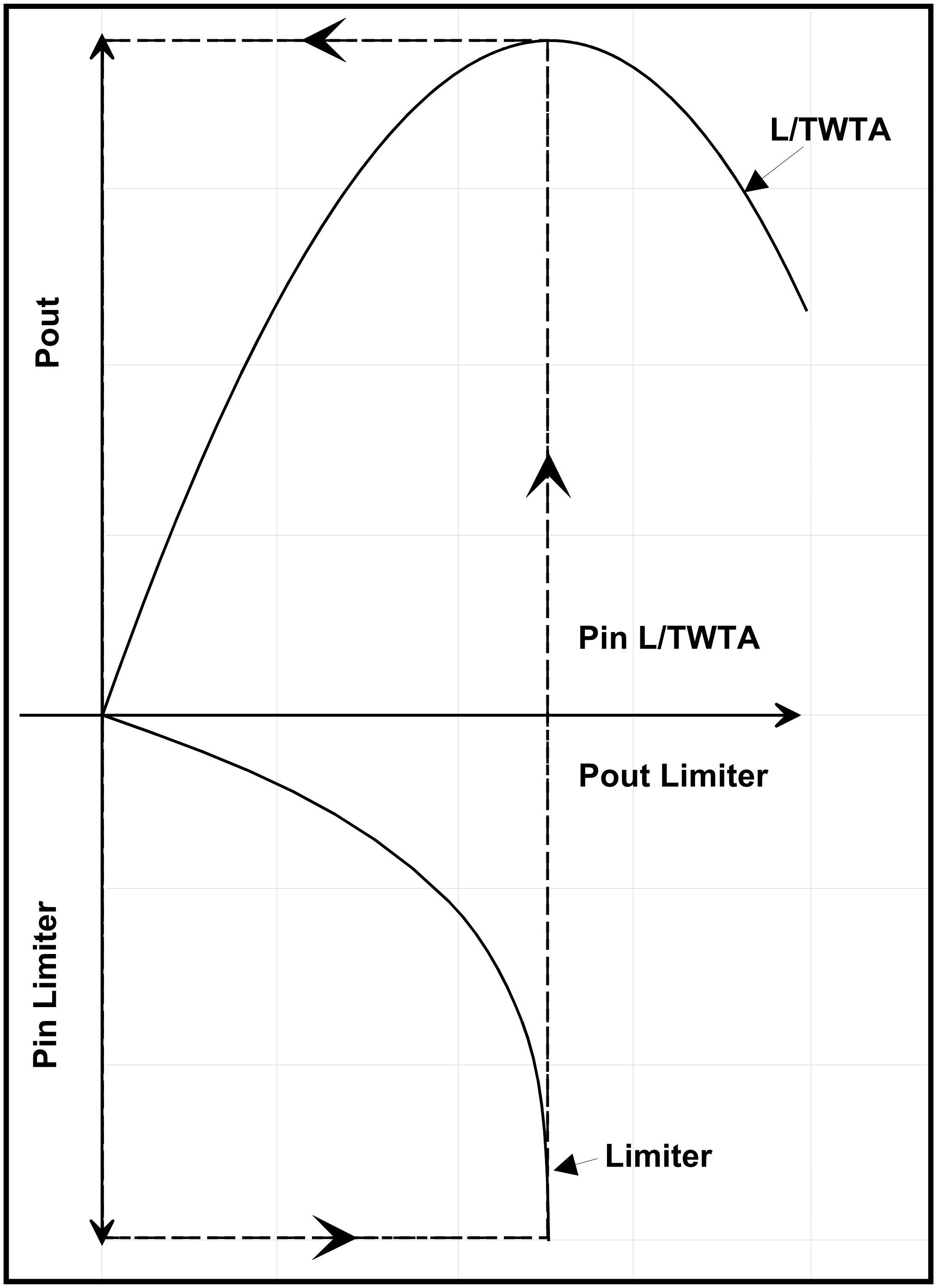

Figure 5. Proceeding the TWTA with a limiter can reduce PEP (overdrive) and hence $\Delta OPBO_{SAT}$

Unfortunately, real limiters tend to have a soft transition into limiting. This gradual change in gain degrades TWTA linearity and increases IMD. Combining a limiter with a linearizer can produce a near ideal transfer characteristic. The linearizer compensates for the limiter's gain change, while the limiter prevents the linearizer from overdriving the TWTA. Figure 1 shows the input power/output power transfer characteristics of a limiter-L/TWTA combination with the limiter adjusted for different levels of PEP overdrive. The $\Delta OPBP_{SAT}$ of a 2-tone signal can be reduced to less than 0.9 dB without any sacrifice in IMD performance at higher backoff levels, when the limiter is set for a zero dB PEP overdrive. Carrier-to-IMD (C/I) performance can actually improve close to saturation. The advantage of combining a L/TWTA with a *soft limiter* was first recognized by G. Satoh and T. Mizuno.[3] Actually, the more rapidly a limiter can switch from a constant gain to a constant power state, the more effective it will be in this application.

The effect of a limiter with a L/TWTA was also examined for single-tone (with and without QPSK modulation), 4-tone, and infinite-tone (noise power ratio - NPR) excitation. As expected the use of a limiter was found to not affect single carrier saturated power. Although, it should be noted that limiters can produce harmonics, which may in some cases be phased to increase TWTA power and efficiency.[4] A low pass filter was used to prevent harmonics from affecting carrier power measurements in these tests.

Interestingly, it was found that for a single-carrier QPSK modulated signal, the addition of the limiter had a negligible impact on the saturated power and L/TWTA induced spectral regrowth (SR). Even very close to saturation, there appears a negligible advantage in adding a limiter to improve SR. This result is likely an outcome of the relatively small amplitude ripple displayed by single carrier QPSK in comparison to multi-carrier and other higher PEP digitally modulated signals.

EXCITATION	ΔOPBOsat REDUCTION	
	TWTA	L/TWTA
1 - TONE	0 dB	0 dB
1 - TONE QPSK	<0.1 dB	<0.1 dB
2 - TONE	~0.6 dB	~1.0 dB
4 - TONE	~1.0 dB	~2.0 dB
N - TONE (NPR)	~1.2 dB	~2.3 dB

TABLE I $\Delta OPBO_{SAT}$ improvement achieved by adding a limiter to a TWTA and L/TWTA.

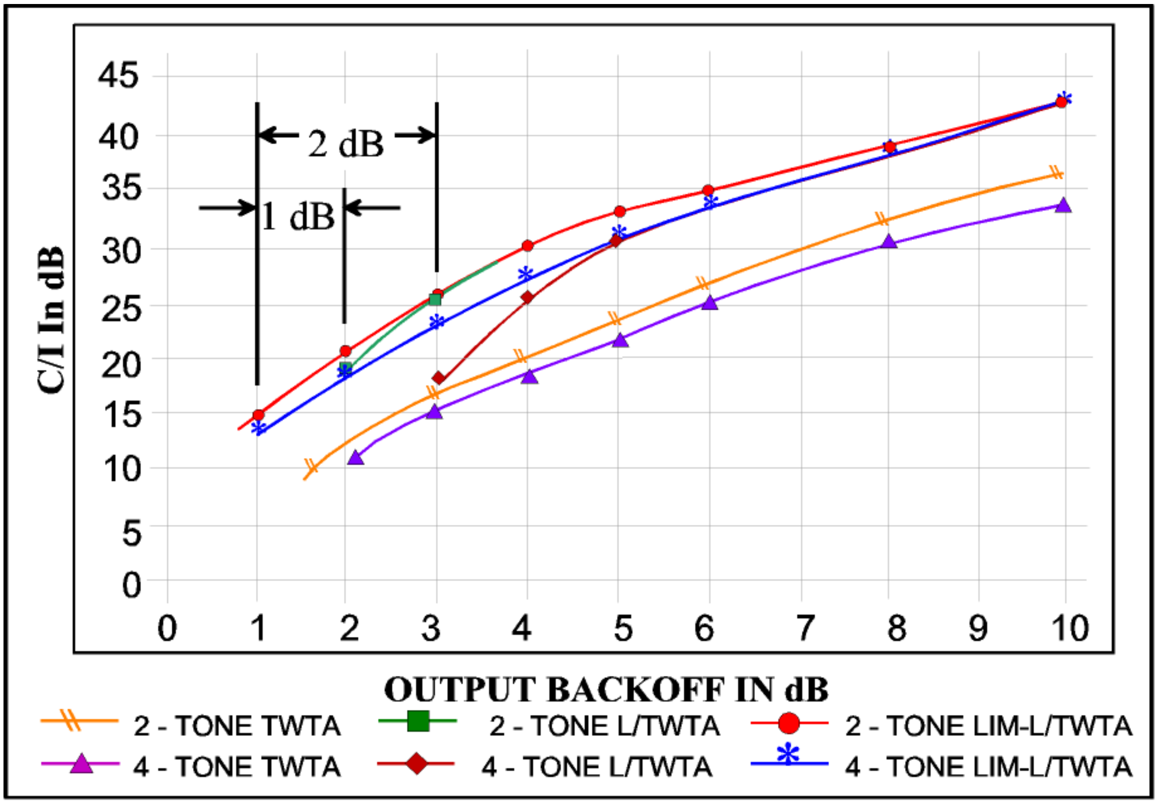

Figure 6. The addition of a limiter to a L/TWTA increases near saturation carrier power and C/I.

In general the greater the number of carriers, the greater is the advantage of adding a limiter. Table I gives the improvement in $\Delta OPBO_{SAT}$ achieved by adding a limiter to a TWTA and a L/TWTA for different forms of excitation. Figure 6 illustrates the enhancement in C/I near saturation provided by the addition of a limiter to a L/TWTA for 2 and 4-tones signals. Figure 7 illustrates the enhancement for an infinite-tone signal ((NPR). The two and four-tone C/I values shown are based on the highest individual IMD term.[1] In the case of the NPR data, the equivalent carrier power cannot be measured directly because of the inability to separate the IMD from signal (noise) power. Consequently the signal power was estimated from the NPR level and total noise power.

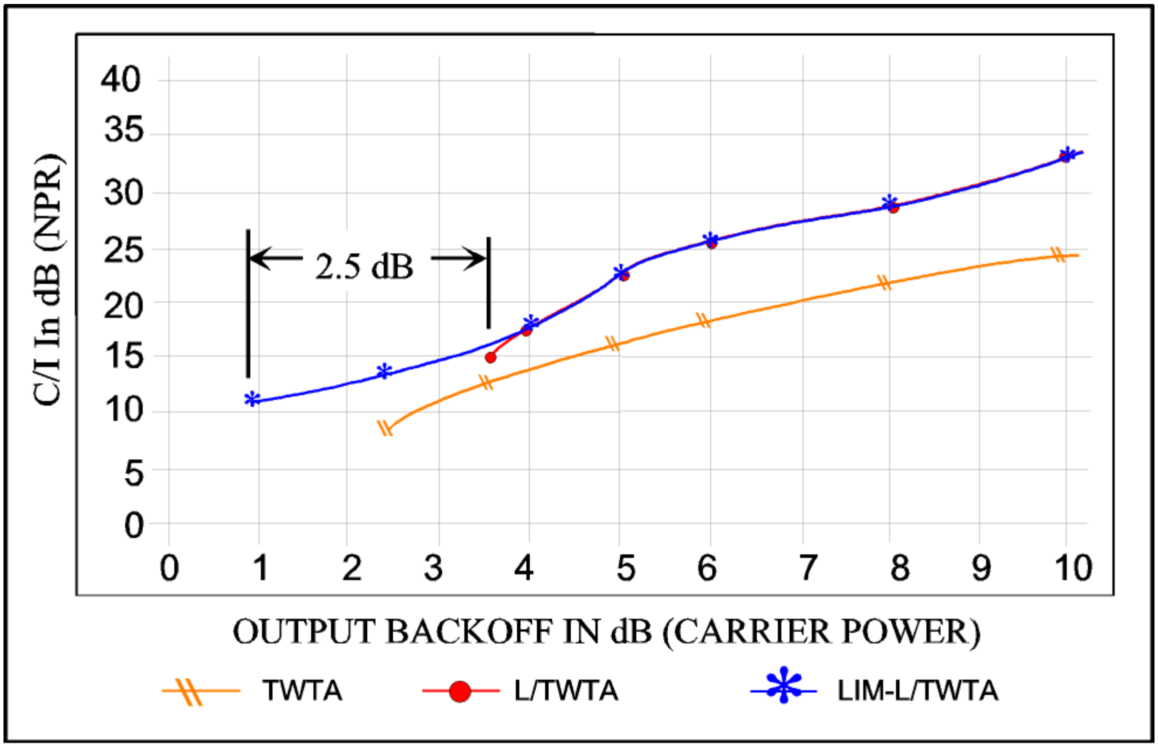

Figure 7. The addition of a limiter increases both near saturation carrier power and NPR.

V. CONCLUSION

The use of a limiter in conjunction with a linearized TWTA (and some SSPAs) can increase multi-tone saturated power from 1 to 2 dB depending on carrier number, and post saturation transfer characteristics. It can also provide several dB of C/I improvement near saturation (at OPBO < 3 dB). However, the addition of a limiter to a L/TWTA appears of little or no value for single carrier QPSK modulated signals, where no significant reduction in spectral regrowth was observed.

IV. REFERENCES

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