

# Input Adaptive Linearizer System

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## Abstract:

A novel adaptive predistortion linearizer system has been developed to improve the linearity of high power amplifiers (HPAs). The system was developed for use with TWTAs, but the concept is also applicable to SSPAs. This system can provide near ideal linearizer performance over a wide dynamic range without the complexity of previously proposed adaptive systems. A key feature is the ability to operate as a stand-alone unit. It can be inserted in front of an existing HPA without any interconnections except for the HPA RF drive power.

## Introduction:

The regular transmission of multi-carrier and complex, high data-rate digitally modulated signals at microwave frequencies has created a demand for highly linear amplifiers. One solution to this requirement has been the use of predistortion linearizers to correct for HPAs' inherent amplitude and phase non-linearities [1,2,3,4,5]. Simple predistortion linearizers can provide more than a 10 dB improvement in intermodulation distortion (IMD). Such linearizers still fall far short of the theoretical limit as illustrated in Figure 1. This performance gap is principally a consequence of the inability of most predistorters to provide much more than a 1 to 2 dB/dB rate of gain expansion.

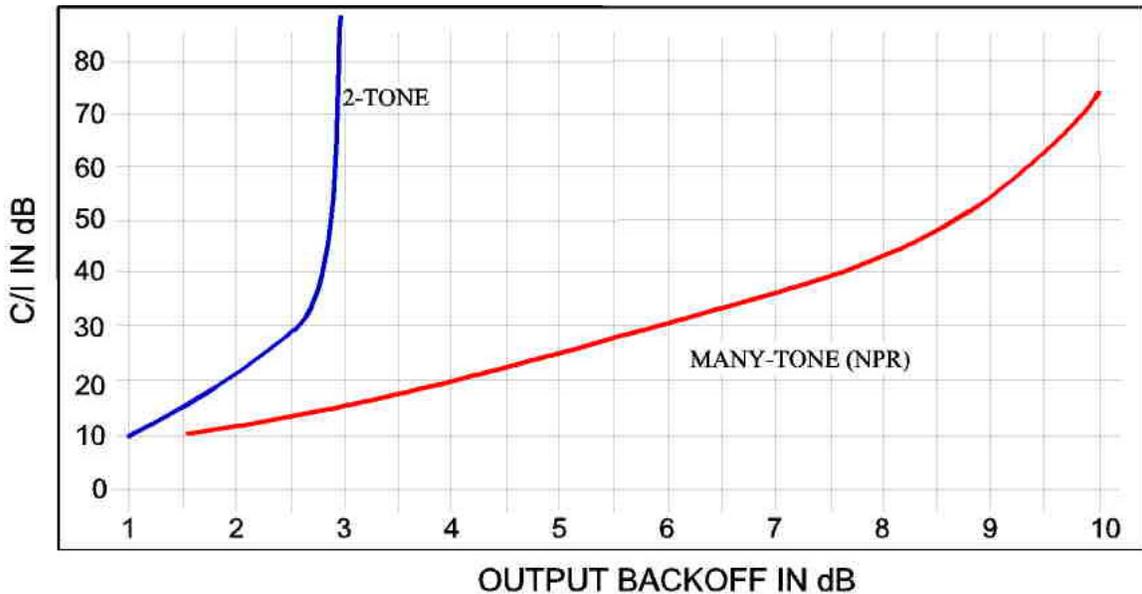


Figure 1. An ideal linearizer can provide many dB of IMD suppression for both 2-tone and multiple carrier excitation.

To ideally correct an HPA near saturation (Sat) in output power ( $P_{out}$ )

$$dG/dP \Rightarrow \infty \quad \text{as} \quad P_{out} \Rightarrow \text{Sat} \quad (1)$$

The ideal predistortion correction required by a typical TWTA is shown in Figure 2.

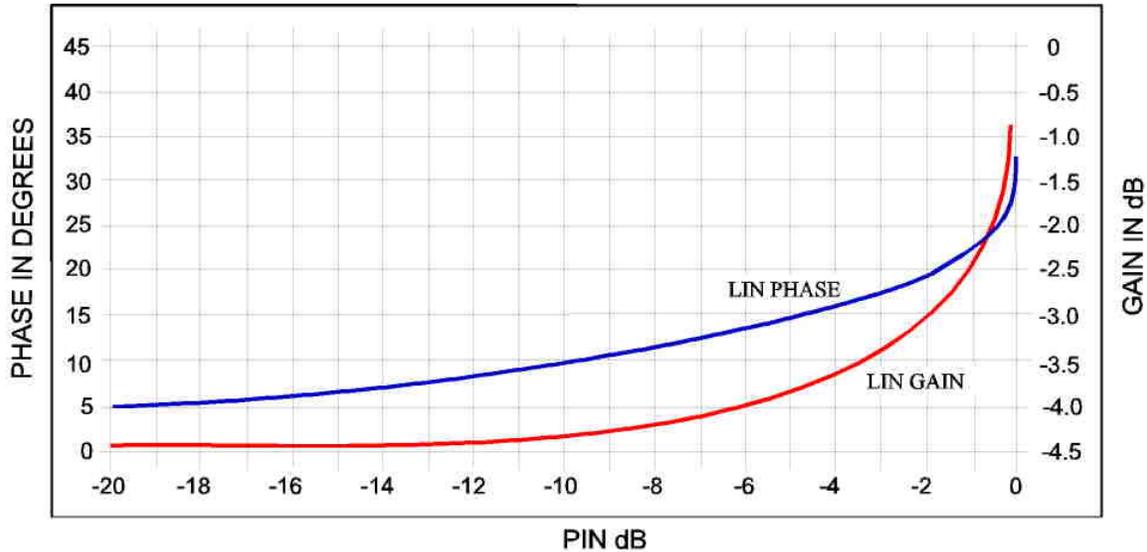


Figure 2. An ideal linearizer must provide a gain expansion that approaches infinite near saturation.

There are a number of ways around this limitation. One approach is to use a linearizer composed of many predistortion elements in cascade. This solution greatly increases predistorter complexity and loss while making wideband performance more difficult to achieve. The most common solution is to neglect correcting the transfer characteristics at saturation. Instead the gain (and phase) transfer response is “overshot” at an output power backoff (OPBO) close to saturation where a sufficient rate of gain expansion exists. The response of a linearized TWTA with *gain overshoot* is shown in Figure 3. This approach produces a narrow region of constant gain where the gain slope

$$k_g = dG/dp \approx 0 \quad (2)$$

An excellent carrier to intermodulation ratio (C/I) can result in this region. As OPBO is decreased further, however, C/I does not necessarily improve as would be expected at higher OPBO, and often degrades. The amount of degradation is a function of the amount of gain overshoot. For C/I values of 30 dB or greater, the overshoot should be limited to 0.75 dB or less. For C/I values of 50 dB or greater, even .1 dB overshoot is too great. A similar effect is observed with phase.

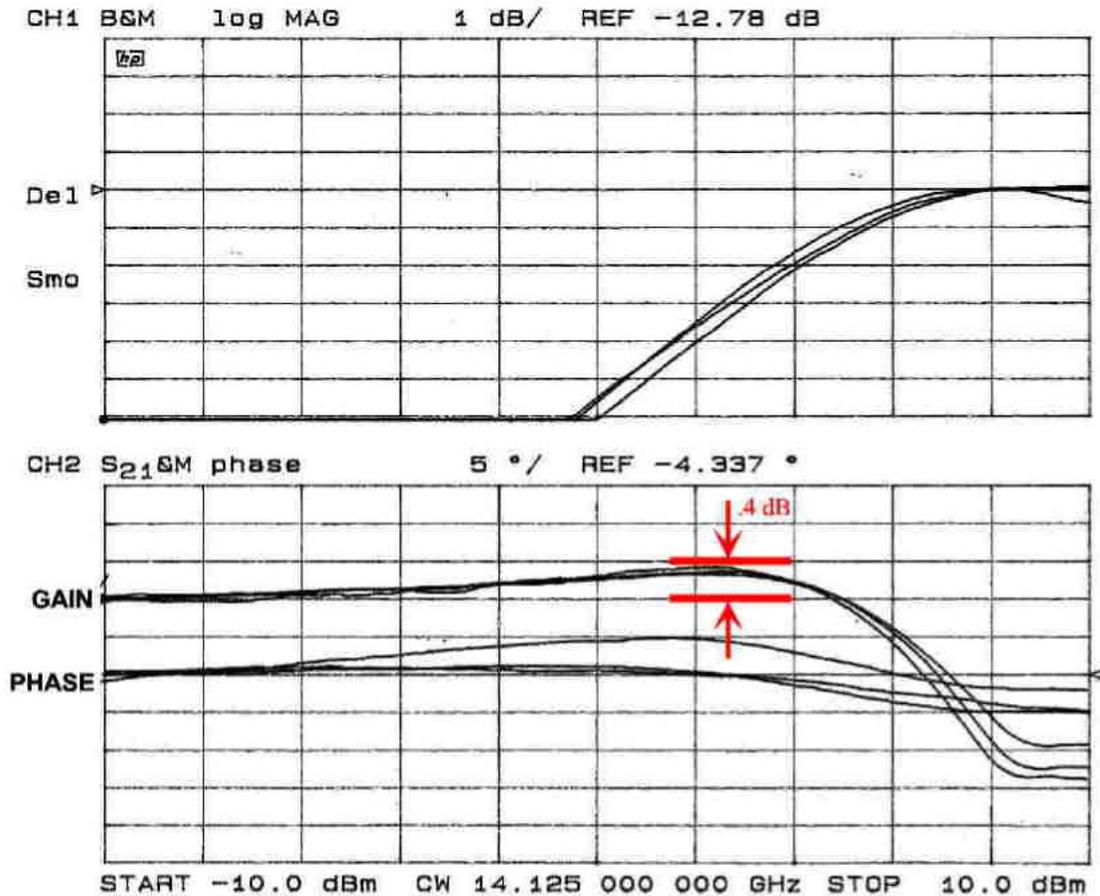


Figure 3. Use of gain (and phase) “overshoot” can create narrow OPBO regions where IMD performance approaches the ideal.

Adaptive predistortion linearization has been proposed as a solution [5,6,7,8,9,10]. In these systems the output of the amplifier is compared with the input and the difference is used to correct the predistortion circuit’s response as illustrated in Figure 4. In systems that correct by following the envelope of the information signal, the time delay of the HPA becomes critical. The correction is always behind in time ( $\Delta t$ ) relative to the input signal. As the envelope frequency increases,  $\Delta t$  also increases. This eventually causes the correction to become out of phase with the input signal and the system fails. In practice such systems are limited to only a few MHz of bandwidth. To avoid this bandwidth restraint, some adaptive systems do not attempt to follow the envelope. They calculate a weighted error signal. This error signal is used to slowly optimize the predistorter’s transfer response over time, usually using a search routine. In either case an adaptive system can become quite complex and is ultimately limited by the flexibility of the predistortion generator.

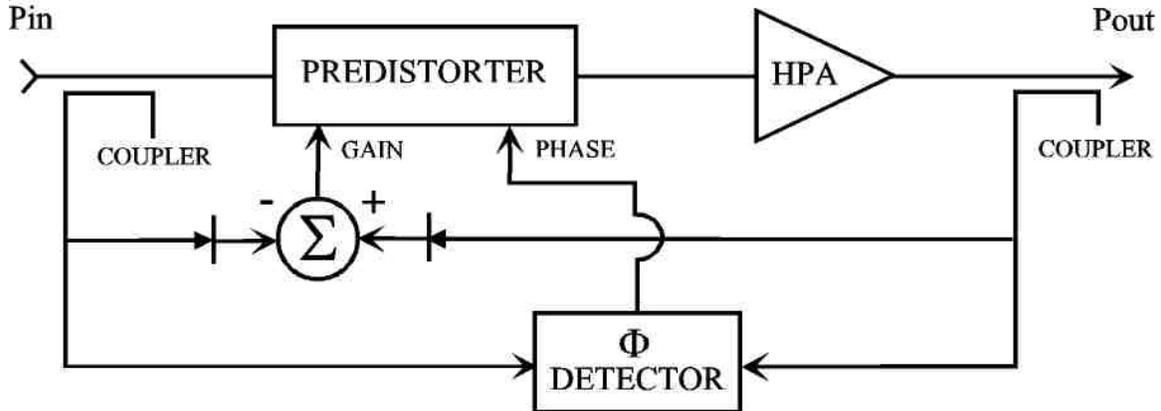


Figure 4. Adaptive linearization systems normally compare the detected output and input signals of an HPA to obtain an error signal used to optimize the predistorter's transfer response.

**Input Adaptive Linearization:**

In an input adaptive linearization (IAL) system, only the level of the input signal to the linearizer is considered. This eliminates the need for detection of the output signal and related connections between the linearizer and HPA.

It appeared that knowing the input level, a predistortion network could be optimized for the appropriate operating point. In essence, the gain (and phase) *overshoot* could be set to a position and level to make  $k_g$  equal zero for the input stimulus. To test this hypothesis, a conventional linearizer/TWTA system was simulated and the predistorter response optimized for a compromise backoff. Experience has shown that an OPBO of about 5 dB works well for this purpose. This level was used in the simulation and subsequent testing. The 2-tone C/I was then calculated over an OPBO range from 2 to 10 dB. This process was repeated, but with the predistorter re-optimized for each OPBO point. Figure 5 shows the results of the simulations. At high OPBO more than 10 dB of improvement can be achieved, while near saturation almost 5 dB of improvement can be obtained.

To show that the IAL system was insensitive to type of traffic, NPR excitation was also investigated. The results are shown in Figures 6 and are similar to those of Figure 5.

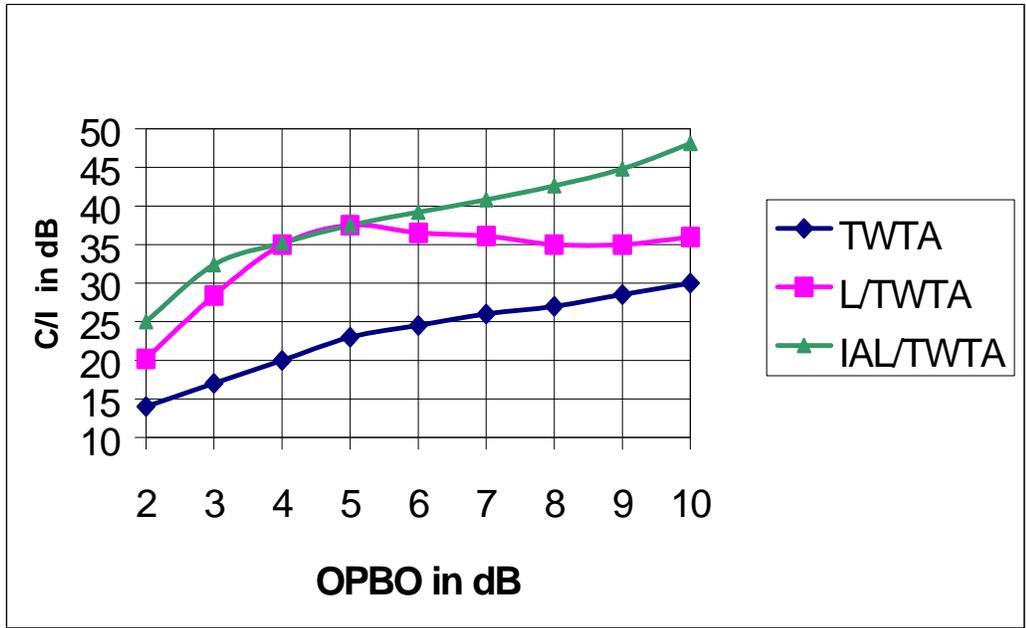


Figure 5. Simulation shows IAL can provide a significant improvement in 2- tone C/I over conventional linearization.

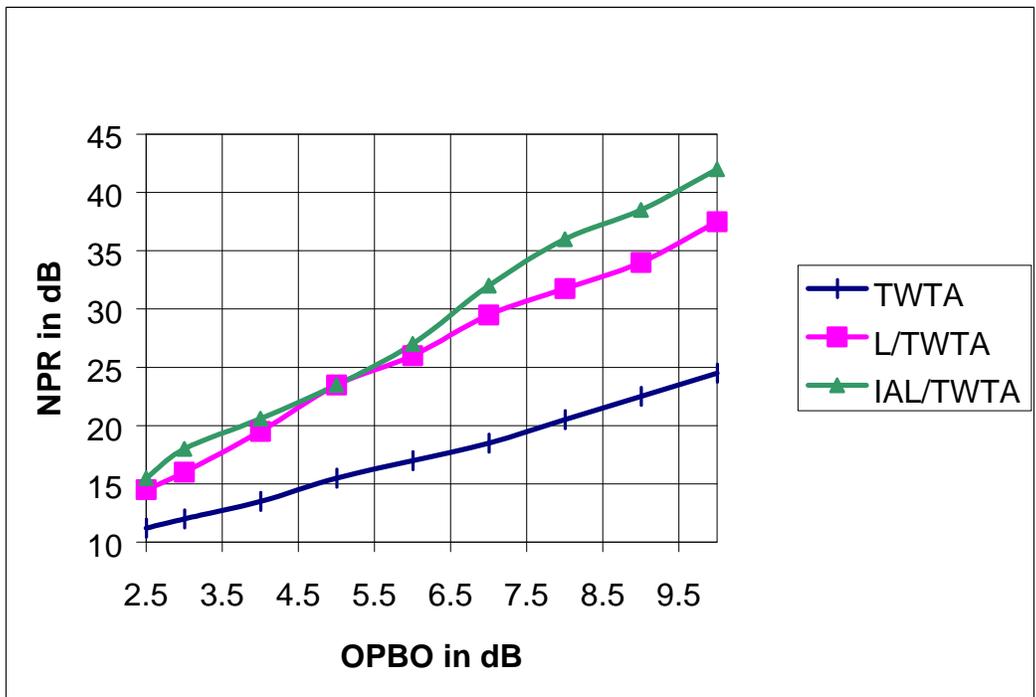


Figure 6. Simulation shows IAL can also provide a significant improvement in IMD for many-carrier (NPR) signal traffic.

### Practical IAL System:

Based on the encouraging simulation results, a practical IAL system was developed for up-link satellite TWT HPAs. A block diagram of the linearizer is shown in Figure 7.

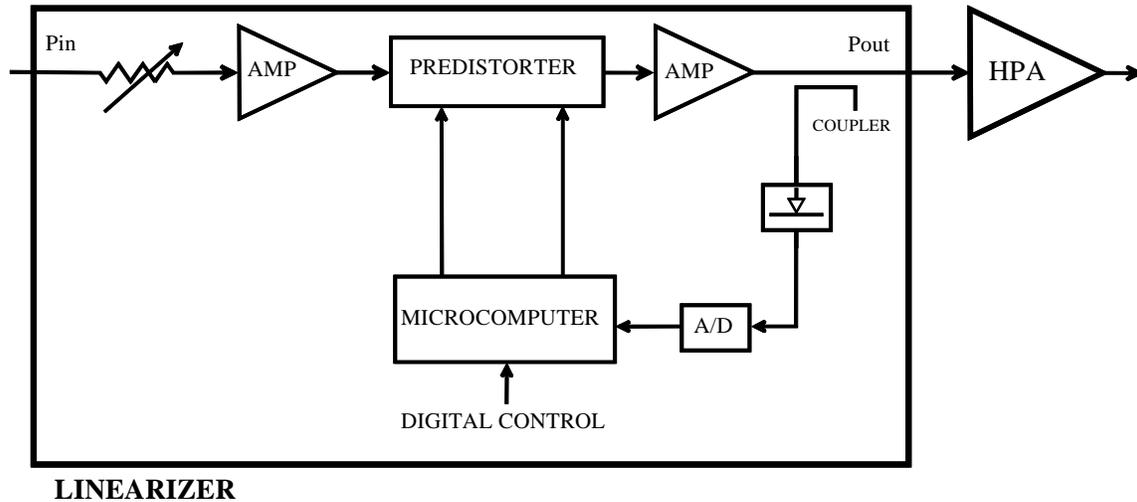


Figure 7. A practical IAL system uses a detector at the output of the linearizer and an onboard microcomputer to determine the optimum predistorter settings.

The input power level is detected at the output side of the linearizer. This is the point where the power is at its highest level and the easiest to detect. The power at this point ( $P_{Lout}$ ) is also correlated to the OPBO of the HPA by a fixed functional relation, i.e.,

$$OPBO = f(P_{Lout}) \quad (3)$$

A balanced detector circuit was used for temperature stability. The voltage from the detector is converted to a digital signal and sent to a small microcomputer chip for processing. The microcomputer compares the power level to values previously stored in a lookup table to determine the optimum control values for the predistorter. The predistorter settings are updated approximately once every 200 milliseconds. The values in the lookup table are normally determined when the linearizer is initially mated with an HPA. Single carrier saturation is first determined. Then under 2-tone excitation, the  $P_{out}$  of the HPA is backed off in one dB steps, and the maximum C/I ratio manually determined. At each power level, the optimum settings are stored in an electrically alterable memory associated with the microcomputer. Since the linearizer is totally digitally controlled, the whole initialization process can take place under the control of an external computer.

A C-band IAL linearizer is pictured in Figure 8. Figure 9 shows the measured 2-tone C/I performance of this linearizer when mated with a TWTA in linearizer off, non-adaptive linearizer and IAL modes. Note the close correlation of simulated and measured performance.

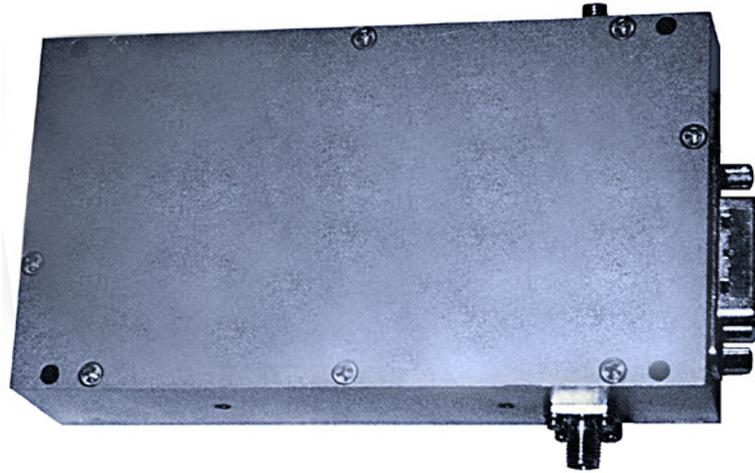


Figure 8. The C-band input adaptive linearizer is 4.8" x 2.6" x .85" in size.

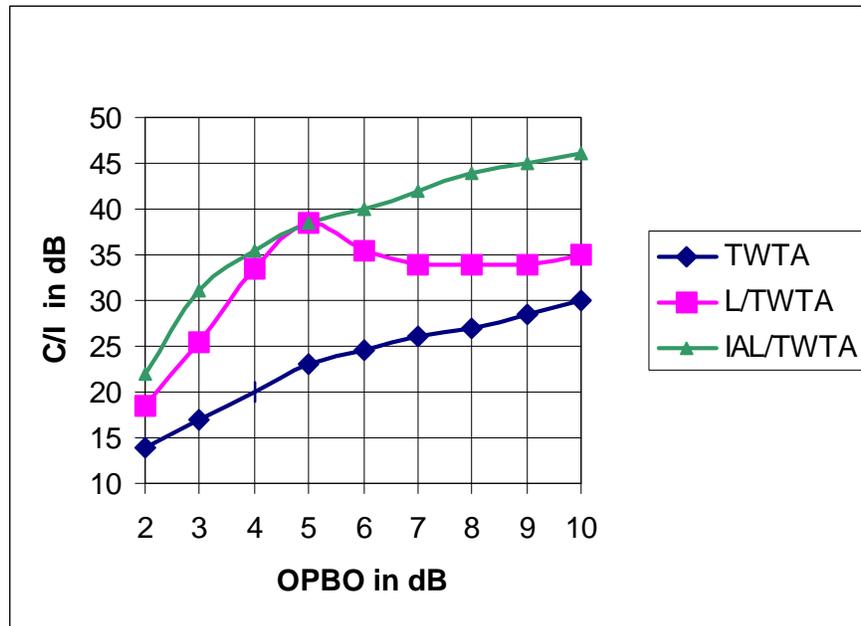


Figure 9. Measured 2-tone C/I performance of linearized TWTA in linearizer off, non-adaptive and input adaptive modes.

## **Conclusion:**

An IAL system has been developed for use in satellite ground station and terrestrial link applications. Commercial linearizers have been produced for use with C and Ku TWTAs, which provide improved IMD performance over non-adaptive units. These new linearizers do not require a special interface to HPAs, and work well with both single carrier digitally modulated signals and multi-carrier traffic. The IAL concept should be applicable to both SSPA and TWTA HPAs.

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