A Versatile Wideband Linearizer/Driver Amplifier for Use with Multiple Millimeter-wave TWTAs

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Abstract: A highly versatile wideband linearizer/driver amplifier for use with multiple millimeter-wave high power TWTAs has been developed. It has a single input, and multiple outputs that have individual phase shift and amplitude adjustments to drive several TWTAs. Only a single linearizer is required for the multiple amplifiers. The demonstration unit operated from 33 to 36 GHz but has the capability of operating over more than 10 GHz of bandwidth.

Index Terms -- multiple TWTAs; millimeter-wave; driver amplifier; phase shifter; linearizer; high power; wideband.

I. Introduction

At millimeter-wave the power level of wideband TWTAs are limited by the diameter of their helixes. To achieve higher power these TWTAs must be combined, often with magic-T waveguide hybrids to multiply the power level available from a single TWTA. The more TWTAs combined the greater the additional power. If an even number of TWTAs are combined with 180-degree hybrids, even order harmonic suppression can be achieved [1]. Second harmonics can be a major problem for wideband TWTAs with greater than an octave of bandwidth. Such high-power amplifier (HPA) systems require not only a driver amplifier with sufficient gain and power to drive the TWTAs to rated power, but also adjustable phase shift and level controls to ensure the amplifiers are balanced for maximum output power; and in the case of even combining, harmonic rejection. To achieve the linearity required for bandwidth efficient communications, a linearizer is also essential. To meet this need, a compact millimeter-wave linearized frontend (CLFE) driver amplifiers have been developed. The linearizer enables the overall HPA to provide greater power and efficiency with multi-carrier and complex digitally modulated signals. Only a single linearizer is required, no matter the number of TWTAs to be combined. Figure 1 shows the block diagram of a production CLFE driver amplifier.

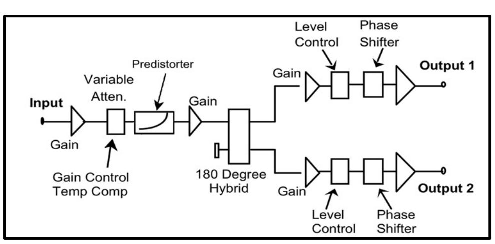

Fig. 1. Block diagram of a CLFE showing case of single input and dual outputs with a 180 degree hybrid.

II. 33-36 GHz CLFE for two TWTAs

A version produced for two TWTAs is shown in Figure 2. This CLFE measures 4.5 x 3.0 x 0.8 inches (114 x 76 x 20 mm). The CLFE shown was designed to cover the 33 to 36 GHz frequency band.

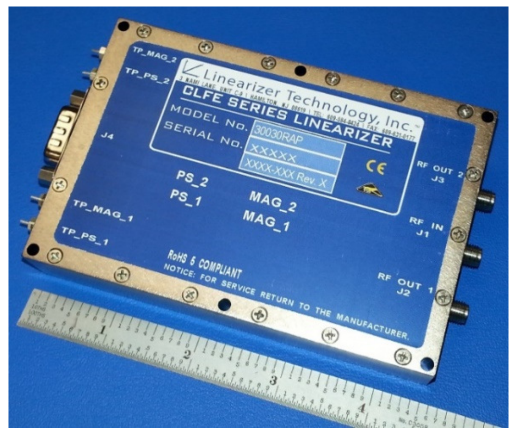

Fig. 2. CLFE, Ka (33 to 36 GHz) dual HPA driver amplifier

III. CLFE Versatile Functionality

The version shown provides more than 36 dB of gain with an output power of +26 dBm and includes a 35 dB input attenuator for system gain control. Typically, the input power is -10 dBm at the single input port. Each path provides greater than 6 dB independent output level adjustment as shown in Figure 1. The individual outputs are 180 degrees out of phase and have an independent path phase adjustment range of greater than 50 degrees.

Although only the combining of two TWTAs was required for this application, the CLFE was designed to be extremely versatile and can be used to combine more than two amplifiers, and function with virtually any HPA technology. A version using the same circuitry for use with radial combined TWTAs is currently under development.

The CLFE can also provide custom frequency tilt equalization. This is an essential feature if the individual TWTAs need frequency compensation for small signal and/or large signal tilt to achieve overall system flatness and satisfactory linearizer performance over a wide bandwidth. Figure 3 shows gain versus frequency as well as the 180-degree phase shift between paths, outputs 1 and 2 of the CLFE in Figure 2. Each path has less than 1 dB of magnitude delta and less than 1 dB of flatness across the operating band.

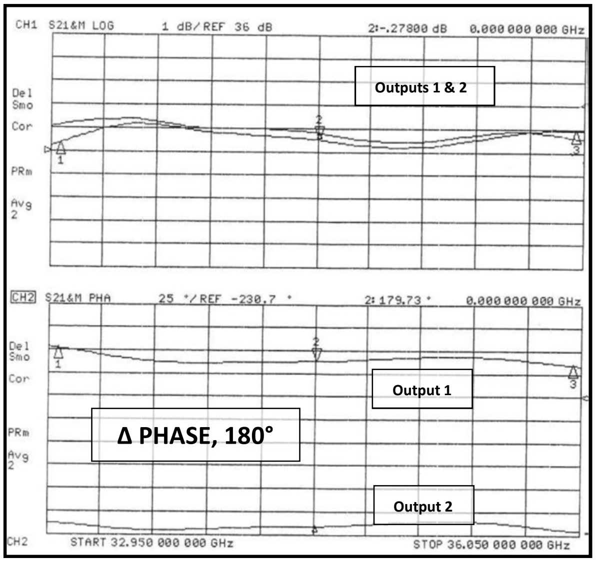

Fig. 3. CLFE Output 1 and 2 magnitude balance, and 180 degree shift between paths.

Figure 4 shows the single path RF performance across the 33 to 36 GHz band. As the phase is adjusted from 0 to 50 degrees, the magnitude level is well controlled to less than a 1 dB change. This is not a problem since each TWTA often requires a different input drive level to achieve the required operating point. The CLFE can provide a significant amount of output power, in this case +26 dBm, but over 1 watt is available. The level control provided is greater than 6 dB and can be adjusted to meet the individual variances of TWTA gain or power to achieve saturation.

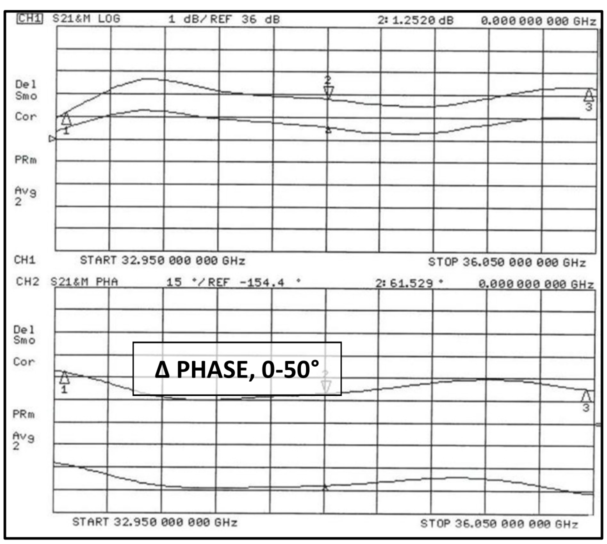

Fig. 4. Output 1 delta level over the 0 to 50 degrees phase adjustment range.

IV. CLFE Linearizer

In the CLFE a predistortion (PD) linearizer is employed to improve the linearity of the TWTAs. PD linearization is favoured at microwave and millimeter-wave frequencies because of its wideband performance, low power overhead and ability to function as standalone units. PD must generate transfer characteristics that are the opposite of an HPA's in both magnitude and phase [2]. The gain increase of the linearizer cancels the HPA's gain decrease, and the phase change of the linearizer cancels the phase change of the TWTA. The desired result is the *ideal amplifier* (limiter) transfer characteristic illustrated by the straight line in Figure 5 [3].

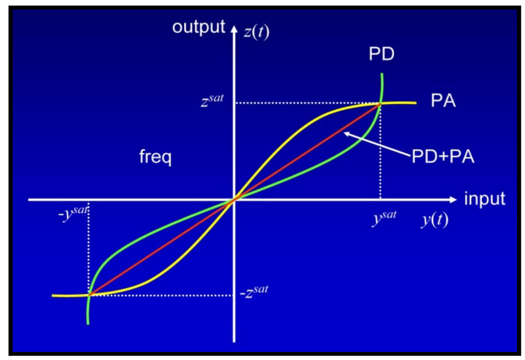

Fig. 5. A PD linearizer generates the opposite of the HPA's response in both magnitude and phase.

Linearizers typically provide 3 to 6 dB of additional output power for TWTAs at the linearities required by uplink SATCOM applications at millimeter-wave. Figure 6 is an example of the correction a CLFE linearizer can provide. It shows the non-linearized and the linearized power, gain, and phase transfer function of a CLFE for a TWTA. (Similar results could have been achieved for SSPAs at millimeter-wave). With the addition of the linearizer, the 1 dB gain compression point was improved from 7.5 dB from Psat to within 0.5 dB of Psat [4].

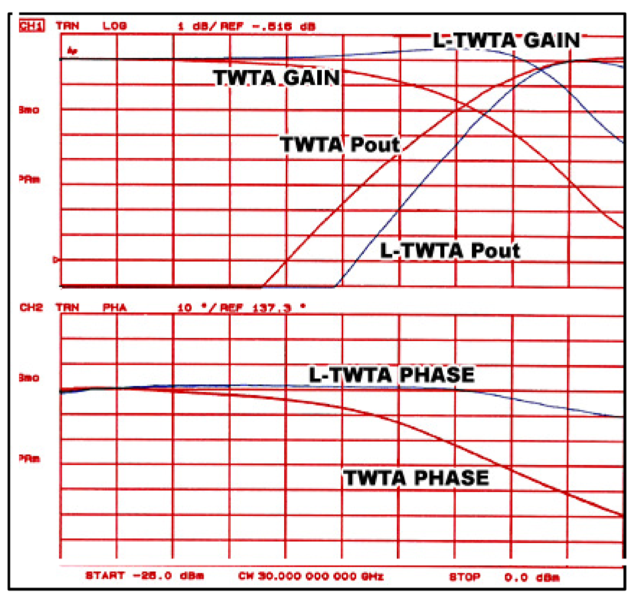

Fig. 6. An example of the AM/AM and AM/PM correction that can be achieved by integrating a linearizer into the CLFE.

The result is an HPA with superior linearity that provides excellent intermodulation performance [5].

The production CLFE provided more than 6 dB of additional linear power over its 33 to 36 GHz operating band. Only a single PD linearizer is required to linearize multiple TWTAs, because the linearizer corrects for the composite (average) gain and phase transfer characteristics of all the TWTAs. Differences in nonlinearity between individual amplifiers do not degrade the linearizer's performance. The individual gain and phase controls of the CLFE does enable both the output power and the linearity to be optimized.

The CLFE's linearizer has the capability to function over more than 10 GHz of bandwidth and operate at frequencies above 50 GHz [6]. To get this very wideband performance, the linearizer's gain and phase transfer characteristics must change over frequency as well as with input level to match the changes of the amplifier's non-linearity at different frequencies. Figure 7 shows the wideband characteristic of the linearizer design used in the production CLFE over a 26 to 36 GHz bandwidth. Figure 8 shows the two-tone C/I performance achieved by a CLFE linearizer over 10 GHz bandwidth. For a 2-carrier C/I of 25 dB, a worst case improvement across the band of 6 dB in output power is shown

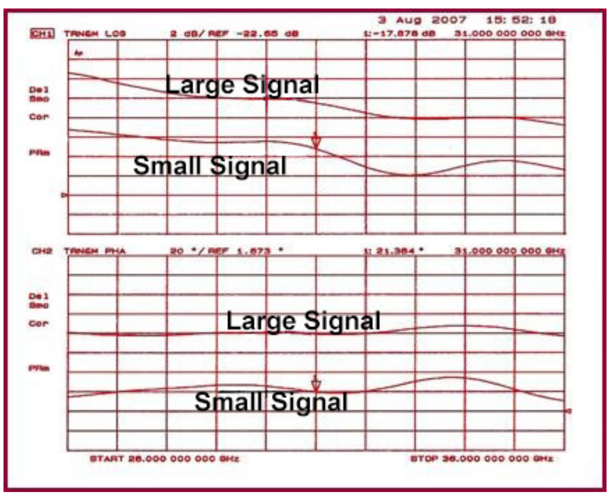

Fig. 7. The 26 to 36 GHz frequency response of a CLFE TWTA linearizer.

V. Overall CLFE

The CLFE can operate over a temperature range of -50 to 85 degrees Celsius. It uses internal temperature compensation networks to maintain the RF performance over this operating temperature range. A TTL Mute function is available to provide a minimum of 60 dB isolation. The CLFE of Figure 1 operates from +12 V at typically less than 1000 mA. The input and output ports of the CLFE are 2.92 mm female connectors. The CLFE user gain control attenuator, and individual HPA phase and magnitude can be manually adjusted via access holes, analog controls or optional I^2C, RS485, or RS232 communications.

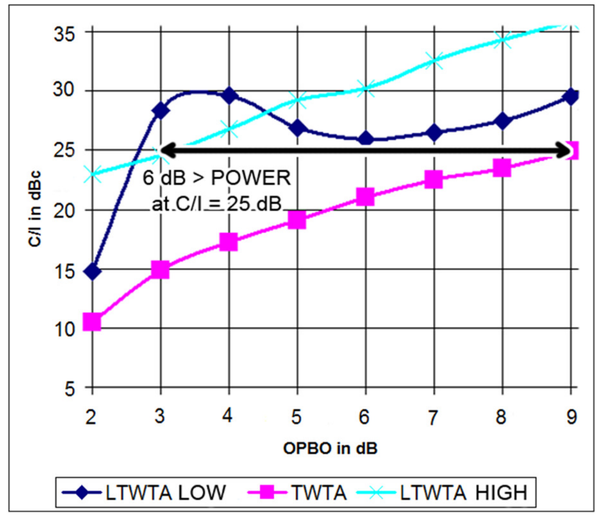

Fig. 8. Wideband CLFE linearizer performance with a TWTA.

VI. Conclusion

Very versatile compact linearized frontend driver amplifiers have been developed to enable multiple millimeter-wave TWTAs to be efficiently combined and economically provide high linearity over very wideband widths. A 33 to 36 GHz version for combining two TWTAs was produced with a single input and dual outputs each having individual phase and magnitude adjustments capable of supplying individual drive powers of up to +26 dBm, and typically more than 10 dB of additional linearity. This design can be scaled to frequencies from below 20 GHz to above 50 GHz and to bandwidths of more than 10 GHz.

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