Design and Evaluation of a Linearized C-Band Helix TWT for Digital Communications Experiments

D.K. Abe (david.abe@nrl.navy.mil), B. Levush (levush@mmace.nrl.navy.mil), T.M. Antonsen, Jr. (antonsen@glue.umd.edu), D.R. Whaley (david_whaley@mail.northgrum.com), and B.G. Danly (danly@nrl.navy.mil)

Naval Research Laboratory, Code 6840
4555 Overlook Ave. SW
Washington DC 20375
Voice: (202)767-0033 Fax: (202)767-1280

Reduction in amplifier distortion is often achieved by backing-off from saturation. While effective, this technique requires trade-offs in output power and efficiency that may have undesirable system impacts such as higher prime power requirements or a larger antenna to maintain a desired EIRP. With the ever increasing demand for information, there is a push to higher microwave and millimeter-wave frequencies to take advantage of greater fractional bandwidths and to the use of more spectrally-efficient digital modulation schemes to make better use of existing spectrum allocations. Multi-level, multi-phase digital modulation schemes such as m -ary QAM and m -ary PSK are placing greater demands on the linear and nonlinear distortion characteristics of communications amplifiers, while the move toward higher bandwidths complicates the design of equalizers and linearizers.

As an alternative to aggressively backing-off in output power to meet new demands of linearity, this work explores techniques to optimize the pitch profile of TWT helices to reduce distortion. A C-band helix TWT circuit optimized for linearity was designed at NRL and subsequently built by Northrop Grumman (Rolling Meadows, IL); we will describe the circuit design and the design methodology, and compare the measured TWT performance with model predictions.

Optimized pitch profiles were developed with the large-signal codes CHRISTINE 1-/3-D using three different optimization criteria: efficiency maximization, AM-PM distortion minimization, and complex gain distortion minimization; as a baseline, a constant pitch circuit was also modeled. The four designs were evaluated for their output characteristics – gain, power, bandwidth, and efficiency –

as well as for their linearity, as measured by analog standards such as gain compression, phase distortion, and intermodulation products. The output performance at mid-band (5 GHz) predicted by the 1-D code is summarized in Table I below.

Optimization Type	$P_{out,sat}$ (dBm)	S.S. Gain (dB)	Sat. Gain (dB)
Constant pitch	52.0	31.6	24.5
Efficiency	53.3	28.2	23.3
AM-PM	49.1	30.3	21.6
Complex gain	52.6	32.1	20.1

Table I: Predicted performance at 5 GHz.

The predicted gain compression as a function of the output power at a driven frequency of 5 GHz is plotted for the four helix circuits in Fig. 1a. At an output power of 50 dBm, the gain compression is -1.3 dB and -1.9 dB for the constant pitch and complex gain optimized circuits, respectively (the AM-PM optimized circuit produced a maximum output power of less than 50 dBm). On the other hand, the efficiency optimized circuit exhibits a gain expansion of $+0.5$ dB, which is typical behavior for high efficiency devices.

The predicted AM-PM distortion is plotted in Fig. 1b. Unsurprisingly, the AM-PM optimized circuit exhibits the lowest phase distortion. However, the circuit produces considerably less output power compared to the other designs. On the other hand, the complex gain optimized circuit has the second lowest phase distortion and possesses better overall output characteristics. For example, referring to Fig. 1b, the complex gain optimized circuit has a predicted AM-PM distortion of 2 deg/dB at an output power of 48.5 dBm; to achieve the same level of distortion, the output power of the con-

stant pitch and efficiency optimized amplifiers would have to be backed-off in output power by 1.7 dB and 2.6 dB, respectively.

The predicted C3IM as a function of output power is plotted in Fig. 2. All cases were driven by two equal-amplitude tones spaced 20-MHz apart with carrier frequencies of $f_1 = 5.5$ GHz and $f_2 = 5.52$ GHz. To compare C3IM performance, consider a hypothetical application that requires a minimum C3IM of 20 dB in response to drive tones at f_1 and f_2 . Referring to Fig. 2, we see that the complex gain optimized circuit meets this specification while producing an output power of 44.8 dBm. By the measure of intermodulation performance, the complex gain optimized circuit is clearly the most linear of the four circuits under consideration and is the circuit that was incorporated into a C-band TWT by Northrop Grumman. The measured single- and multi-tone performance of this TWT will be compared with the simulations.

It is also interesting to examine the C3IM performance of the other circuit designs. For example, while the AM-PM optimized circuit produces only 38% of the single-tone peak power of the efficiency optimized circuit (Table I), it still outperforms the efficiency optimized circuit in terms of two-tone power and linearity: to achieve a C3IM of 20 dB, the efficiency optimized circuit has to give up almost 1-dB in output power to match the AM-PM circuit. Thus, the traditional design method of maximizing for peak power and then backing-off in output power to meet linearity specifications may not always result in the best solution for applications requiring low distortion.

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Fig. 1: Gain compression and AM-PM distortion versus output power (1-D model).

Fig. 2: Carrier-to-third-order intermodulation products versus output power (1-D model)