

High-Power Broadband Cascaded-TWT Development

Khanh Nguyen¹, David K. Abe, Lars Ludeking², Edward Wright¹
Baruch Levush, Dean Pershing¹, John Pasour, John Petillo³, and David Chernin³

Vacuum Electronics Branch
U.S. Naval Research Laboratory
Washington, D.C. 20375
Khanh.nguyen@nrl.navy.mil

Abstract: The design of a Ka-band three-beam cascaded serpentine travelling-wave tube (TWT) amplifier is presented. Simulations predict that a peak power of 3.5 kW with saturated gain of 16 dB and an instantaneous bandwidth of 30% can be achieved in a circuit length of ≤ 4.5 cm driven by three 20 kV beams with 0.5-A each. A plan for a proof-of-principle experiment will also be discussed.

Keywords: multiple-beam; cascaded amplifier; TWT; serpentine; broadband; high-power; power booster.

Introduction

In the multiple-beam cascaded travelling-wave tube concept [1], the RF output from each interaction circuit stage is serially connected to the input of the next stage, with each stage driven by a separate electron beam. This configuration provides flexibility for gain, bandwidth, and power trade-offs in high-power, broadband applications, where size and weight are key requirements. The cascaded configuration also provides an advantage in terms of linearity compared to that of a single beam amplifier with multiple stages placed in series [2].

We present a particular amplifier concept as a potential power booster for Ka-band operation. The objective is to achieve a peak power of > 3 kW with > 15 dB of saturated gain over a 3-dB instantaneous bandwidth of at least 20%. The result of an amplifier design study using the MAGIC-3D particle-in-cell (PIC) code is presented. In addition, the design of a high peak power “proof-of-principle” amplifier experiment will also be discussed. This amplifier prototype will be driven by a three-beam, 20-kV gun adapted from a previous eighteen-beam, 42-kV, S-band klystron gun [3]. The gun has been fabricated using spare parts from the 18-beam gun, and the prototype circuit fabrication and cold test are currently underway.

Three-beam Cascaded Amplifier Design

The focus of this design study is to maximize the bandwidth-power product of a three-beam cascade serpentine TWT amplifier to serve as a compact power booster. Consequently, the number of interaction gaps, pitch, and dispersion for each stage in the design are optimized for this

purpose rather than gain. A beam voltage of 20 kV is assumed for the design.

The beam-wave interaction in the resulting design is illustrated in Fig. 1, which shows the particle trajectories in the circuit (top) and the beam kinetic energy (bottom) as a function of axial distance assuming 100 W of input drive power at the center frequency of 37 GHz. Here, the circuit is driven by three 0.5-A electron beams focused by a 2 kG solenoidal magnetic field over a distance of 4.5 cm.

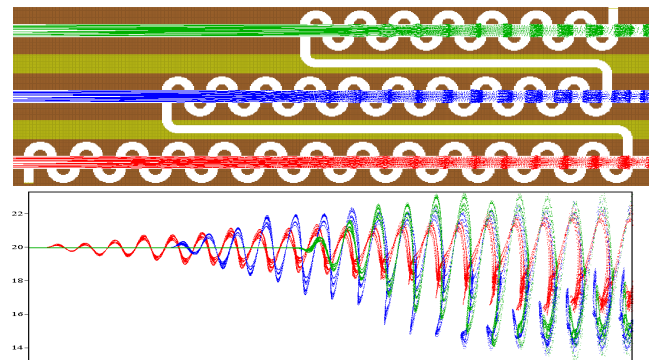


Figure 1: Circuit geometry and particle trajectories (top) and particle kinetic energies (kV) as function of axial distance (bottom). Stages are color coded with red, blue, and green for first, second, and third stage, respectively.

The frequency response for each stage of the circuit at a constant 100 W drive power is as shown in Fig. 2. A peak output power of 3.5 kW is achieved with a 3-dB instantaneous bandwidth of approximately 30%.

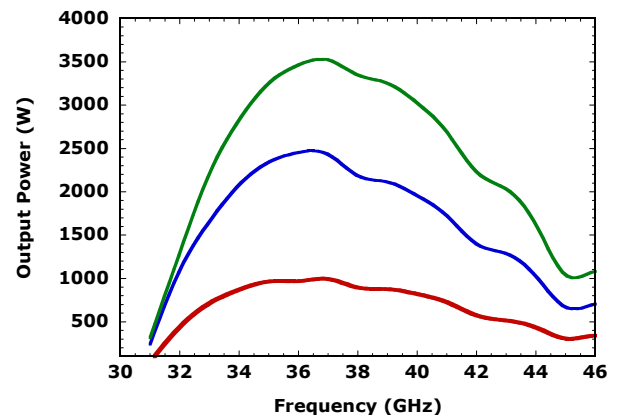


Figure 2: RF power at the end of each stage.

¹ Beam-Wave Research, Inc., Bethesda, MD 20814

² ATK- Mission Research, Newington, VA 22122

³ SAIC, McLean, VA 22102

Careful attention has been paid in the design study to ensure that the circuit is stable against spurious oscillations, in general, and to the 2π -mode backward-wave at around 50 GHz, in particular.

Experimental Demonstration Plan

The amplifier performance as described above will require an optimized beam forming system, which is yet to be developed. For a rapid demonstration of the basic principle of the multiple-beam power booster, we investigated the feasibility converting a previous 18-beam S-band gun into a three-beam gun suitable for use for a Ka-band “proof-of-principle” demonstration. This is illustrated in Fig. 3, which shows the beam-optics from a MICHELLE simulation for three 0.6-A beams at 20 kV. Based on this analysis, a three-beam gun has been fabricated using spare parts from the 18-beam gun. Fig. 4 shows a photograph of both guns.

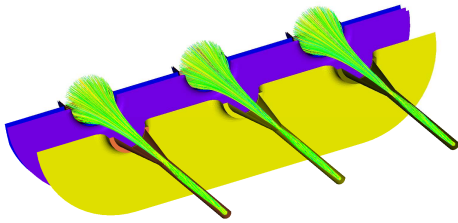


Figure 3: MICHELLE simulation of the three-beam gun.

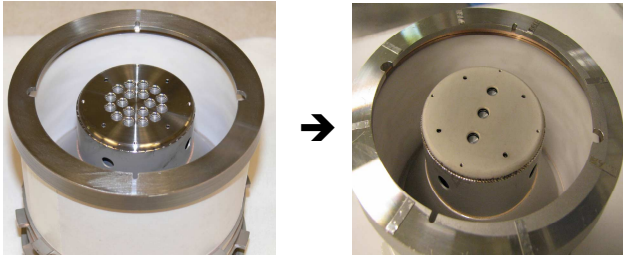


Figure 4: 18-beam S-band klystron gun (left) and modified 3-beam Ka-band cascaded amplifier gun (right).

The amplifier has been designed with MAGIC-3D with beam information imported from the MICHELLE simulation shown in Fig. 3. This is illustrated in Fig. 5, which shows the particle trajectories in the circuit (top) and the evolution of RF power as a function of axial distance (bottom) with 25 W of input drive power at 29 GHz.

The frequency response for each stage of the circuit at a constant 25 W drive power is shown in Fig. 6. Note the lower operating frequency (28 GHz) and narrower bandwidth (12%) relative to those shown in Fig. 2 due to the non-optimal beam optics of the adapted gun. However, even with a non-ideal gun, a design with a peak power of 4.4 kW and saturated gain of 22.5 dB was achieved. The small-signal gain is 29.1 dB with 18.4 dB, 6.9 dB, and 3.8 dB for the first, second, and third stage, respectively.

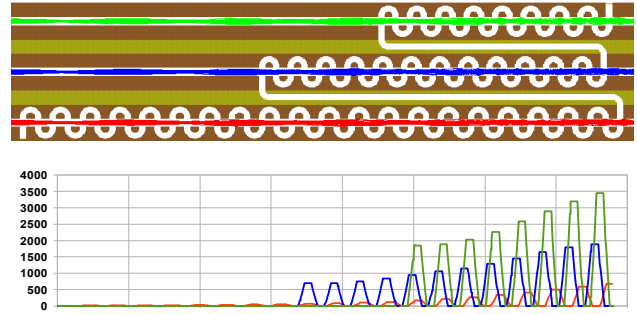


Figure 5: “Proof-of-principle” circuit geometry and particle trajectories (top) and RF power (Watts) as function of axial distance (bottom).

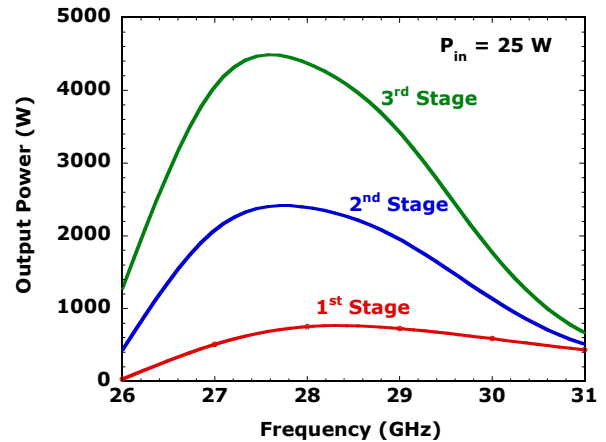


Figure 6: RF power at end of each stage for “proof-of-principle” demonstration design.

Circuit fabrication and cold tests are currently underway. Once implemented and tested, this “proof-of-principle” amplifier will provide valuable information to validate the design methodology and tools; a critical step toward the future development of this new type of amplifiers.

Acknowledgements

This work is supported by the Office of Naval Research.

References

1. K. Nguyen, L. Ludeking, J. Pasour, *et al.*, “Design of a High-Gain Wideband High-Power 220-GHz Multiple-Beam Serpentine TWT,” *2010 IEEE Int. Vacuum Electronics Conf.*, p. 23, May 18-20, 2010 (Monterey, CA).
2. K. Nguyen, J. Pasour, E. Wright, *et al.*, “Linearity Performance of Multi-Stage TWT Amplifiers: Cascade vs. Series,” *2011 IEEE Int. Vacuum Electronics Conf.*, p. 309, Feb. 21-24, 2011 (Bangalore, India)
3. K. Nguyen, D. Pershing, *et al.*, “Eighteen-Beam Gun Design for High Power, High Repetition Rate, Broadband Multiple-Beam Klystrons,” *IEEE Trans. Plasma Science*, Vol. 33, p. 685, April 2005.