Advances in Space TWT Efficiencies

D.S. Komm (david.komm@hughesed.com), R.T. Benton (robert.benton@hughesed.com),
H.C. Limburg (helen.limburg@hughesed.com), W.L Menninger (william.menninger@hughesed.com),
X. Zhai (xiaoling.zhai@hughsed.com)
Hughes Electron Dynamics
3100 W. Lomita Blvd., Torrance, CA. 90509
(310) 517-5108 (voice) (310) 517-6873 (fax)

Overall DC-to-RF conversion efficiency continues to be the most significant figure of merit for space TWTs. Improvements in TWTA efficiency immediately translate into potential revenue increases for satellite operators since additional transponders can be carried on board the spacecraft for the same prime power and waste heat handling capacity. The revenue implications of increased efficiency have spurred TWT manufacturers to continue wringing out every possible increase in efficiency. Efficiencies >70% are now routine (at least at Ku-band). This paper will discuss the results of several experiments to improve TWT efficiency.

In order to raise efficiency, a careful analysis of where waste heat is generated in a TWT is required. Then the most beneficial areas for improvements can be identified and a development program generated. Figure 1 shows the power balance for a typical Ku-band space TWT operated at saturation. The largest amount of the total consumed power is converted to RF energy, some 70%. We are concerned with the 30% of consumed power inadvertently converted to waste heat. As is immediately obvious, the largest fraction by far of waste heat is generated in the collector. Thus the primary focus of improving TWT efficiency has been in this area.

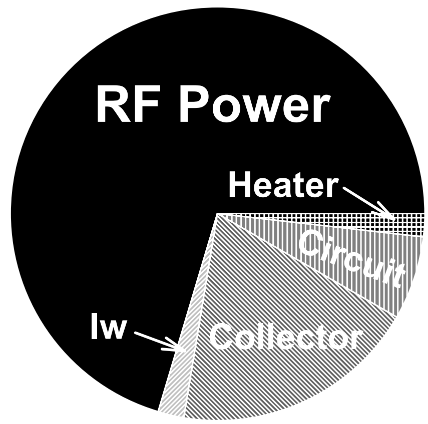

Figure 1. TWT Power Balance

The waste heat in the collector is determined by two primary considerations: The first is that for a given electron distribution function leaving the RF interaction region of the TWT, only a certain fraction of the kinetic energy remaining in the spent beam can be recovered with a finite number of electrode voltages. This fraction is easily calculated for any finite number of available stages. The second consideration is to obtain an electron optics design that comes as close as possible to realizing this maximum theoretical recoverable power. These two considerations are obviously interlinked such that the design of both the RF circuit and the collector optics are closely coupled.

To this end, HED has over the past three years extensively enhanced its proprietary RF circuit design code, QHELIX, and its collector code CCOLLECTOR. The resulting improvements in TWT modeling have allowed dramatic increases in the efficiency of our space TWTs. Specific examples of these improvements follow:

The first example is the C-band 85100H TWT. Typical electrical characteristics are shown in Table 1. In the case of this tube, the efficiency improvement was obtained solely by improving the collectability characteristics of the spent beam distribution function. The TWT collector is the same as used on previous C-band TWTs with no change in optics. Nevertheless, the peak overall efficiency of this design is 65%, a full five percentage points greater than models produced as recently as last year. This dramatic increase is a direct result of improvements in analytical modeling.

Table 1. 85100H Characteristics

F (GHz)	3.7	3.95	4.2
P (dBm)	50.2	50.35	50.2
Iw (mA)	0.44	0.42	0.48
Gain (dB)	51.2	51.5	51.0
Pdc (W)	163	165	164
η (%)	64.1	65.6	63.7

In contrast to the 85100H, the next example is a case where the collector efficiency was improved. This is a Ku-band tube, the 88125H, whose typical characteristics are shown in Table 2. The greater overall efficiency of the Ku-band tube as compared to the C-band tube reflects both the narrower percentage bandwidth at Ku-band as well as size and mass compromises required at C-band. (Optimum efficiency would require a physically longer tube.)

Table 2. 88125H Characteristics

F (GHz)	11.2	11.45	11.7
P (dBm)	51.1	51.2	51.2
Iw (mA)	0.31	0.36	0.47
Gain (dB)	51.2	51.5	51.0
Pdc (W)	176	179	182
η (%)	73.0	73.2	72.4

The final example shows the results of both improving the spent beam characteristics as well as improving the collector efficiency. This example is the 9130H, a 125 W K-band TWT. Previous HED K-band TWTs typically produced efficiencies around 60%. By improving both the circuit and collector, four percentage points were gained in overall efficiency.

Table 3. 9130H Characteristics

F (GHz)	19.7	19.95	20.2
P (dBm)	51.0	51.0	51.0
Iw (mA)	0.56	0.62	0.69
Gain (dB)	51.8	52.0	52.3
Pdc (W)	191	193	195
η (%)	65.8	64.6	64.7

Further improvements in TWT efficiency will continue. While TWT design is a mature field, financially significant gains in overall efficiency remain to be made. Future satellites will carry in excess of 100 transponders per spacecraft. Since each transponder represents a revenue stream of ~$5M/yr, each percentage point increase in overall TWTA efficiency translates into ~$100M over the life of the spacecraft. Given these financial incentives, we fully expect to see TWT designs at Ku-band pass 75% efficiency by 2001 with comparable increases in the other bands.