A Lower Voltage W-Band Planar Ubitron (280 kV - 165 A)

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This is the seventh note in a series on the W-Band planar ubitron.

In this note we consider a lower voltage planar ubitron parameter set, based on the studies of the previous notes. The advantage of lower voltage is the eased requirement on the gun. The disadvantage is the lower saturated power output.

Starting with the gun, we assume a 45° half-angle section of a cylindrical diode, of width 30 cm, with cathode current density of 4 A/cm^2, and operating voltage 280 kV. Anode radius of curvature is 0.133 cm, cathode radius is 1.75 cm, gap is 1.62 cm and peak electric field is 231 kV/cm. This is below the nominal 250 kV/cm for 1 μs holdoff. Convergence if 13.2; total current is 165 A, well below the space-charge limit of 415 A. Beam dimensions at the anode plane are 1.9 mm x 15.0 cm. Thus we have spread the beam out in the horizontal by a factor of 7.5 from the previous 480 kV example.

This beam we send into a guide with full interior height of 3.8 mm, and a width of 30 cm. With a wiggler period of 0.76 cm, maximum gain for 91.392 GHz operation is in the 40-60dB/m range for 1-0% energy spread, occuring for peak on-axis wiggler field 3.0-3.5 kG, close to the Halbach limit. With 5 kW of input power, the signal saturates in 150-70 cm, providing 0.2-2 MW with 0.4-4% efficiency, for untapered operation. Beam power is 46 MW or about 32% of that for the higher voltage design previously discussed. To meet the linac scalings, one would require this tube, in tapered operation, to put out 16 MW. Analysis of tapered operation is a significant amount of work that remains to be performed. It will be pursued after further benchmarks of the PIC code. A 1 GeV linac would require 12 such tubes at a minimum.

As a check of the dispersion relation, we may simulate the problem using the code `WUBI1` described in previous notes. The input namelist we employ looks like this,

```
 $INPUTNML
      BWCH=3.17,          !plot P vs z at this Bw (kG), or close to
      BWMIN=0.1,          !kG, if <>0 sets range for Bw scan
      BWMAX=6.0,          !kG, if <>0 sets range for Bw scan
      SCON=1.,            !=0 for spacecharge off, = 1 for on
      EMITON=0.,          !=0 for emittance dgamma off, =1 for on
      VOLTB=0.28,          !beam voltage MV
      DELGP=0.,           !% spread in gamma +-
      XLW=0.761,          !wiggler period in cm
      AGUIDE=30.0,        !guide width in cm
      BGUIDE=0.376,       !guide height in cm
      FREQ=91.392e9,      !frequency in Hz
      CURR=165.,          !beam current in A
      ZMAX=150.,          !max length in cm
      POWIN=1.e3,         !input power W
      SEMIX=0.5,          !0-1,ratio of x semi-axis to half guide width
      SEMIY=0.5,          !0-1,ratio of x semi-axis to half guide height
      EMITNX=1.,          !cm-rad, will adjust focusing to obtain semix
      EMITNY=0.005,       !cm-rad, will adjust focusing to obtain semiy
      SWITCH1=1.,         !=1, or 0 for debugging of dpsi/dz correction
 $END
```

Parameter settings we used were (defined in the common block)

```
   parameter(npart=128*9)
   parameter(nsteps=200,naw=30)
```

This is to say: 1152 numerical macroparticles, 200 steps in z, and 30 wiggler field settings for the detuning scan.We will perform several runs for different energy spreads. The emittance term we set to zero, for clarity. (In practice the main contributor to effective energy spread will be the vertical emittance.)

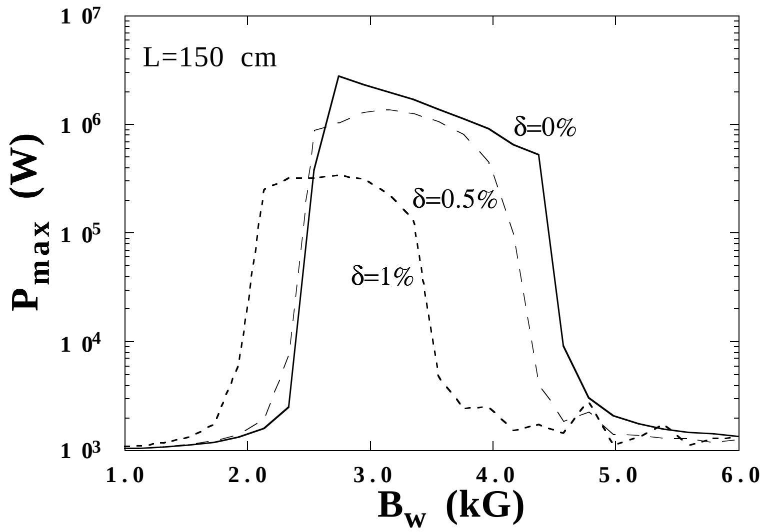

FIGURE 1. Maximum power over 150 cm for three illustrative values of energy spread.

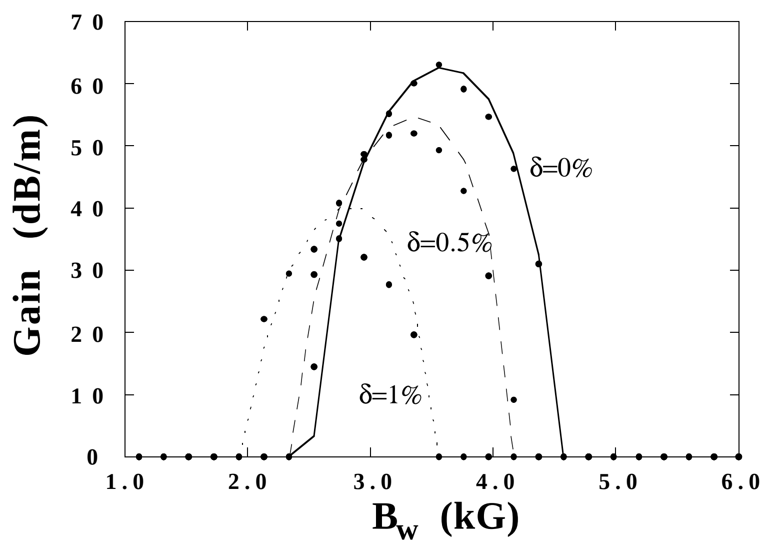

FIGURE 2. Analytic and simulation gain for three illustrative values of energy spread.

Results are illustrated in Figs. 1-3. Deviations between the analytic and simulation gain suggest three possible checks. One is inspection of the exponential fits employed by the code (to arrive at a figure for gain). A second possibility, somewhat unlikely, is that particle number is inadequate. The third possibility concerns the cubic approximation to the dispersion relation. Particle number and the cubic approximation (at this "low" current) turn out to be fine and the deviations seen in the δ=1% case are attributable to the fit procedure (see below).

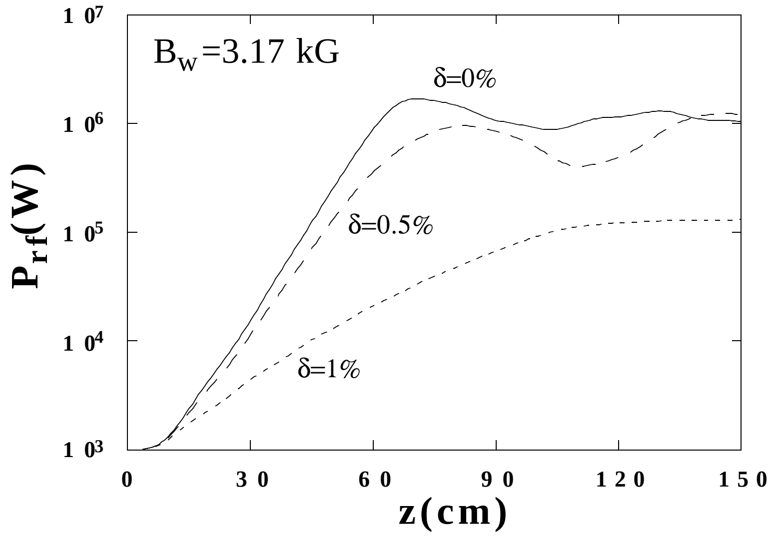

FIGURE 3. Power evolution through the wiggler, for three illustrative values of energy spread.

Deviations in analytic and simulation gain figures are attributable to the fit procedure applied to the case of low gain. As illustrated in Fig. 4, the power evolution in *z* is not a pure exponential. `WUBI1` attempts to account for this by employing a range in power at some level below P_{max}, and above P_{in}. This works better when gain is high, giving 20 dB or more of gain.

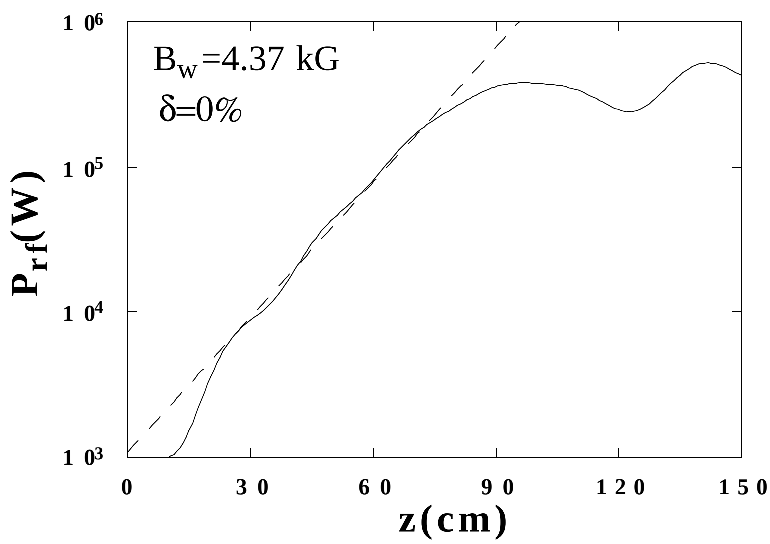

FIGURE 4. Illustration of the exponential fit provided by `WUBI1`.

The portion of the code that determines the fitting procedure begins with the comment

```
!            figure out what the gain was
```
and for these runs proceeded as follows:

(1)examine *P(z)* for $20P_{in}<P<0.1P_{max}$
(2)if 20 or more points satisfy this condition, fit ln*P* to a straightline on this interval
(3)otherwise, examine *P(z)* for $5P_{in}<P<0.5P_{max}$, and fit

This procedure can be improved, but was deemed adequate for the time-being.

As a check of these results, a run was performed with a larger particle number, as illustrated in Figs. 5 and 6, showing good agreement.

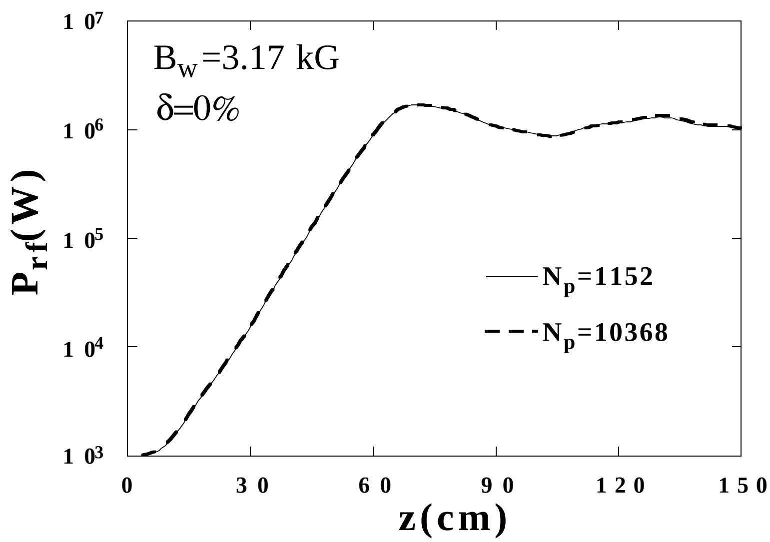

FIGURE 5. Comparison of power evolution in *z* for different particle numbers.

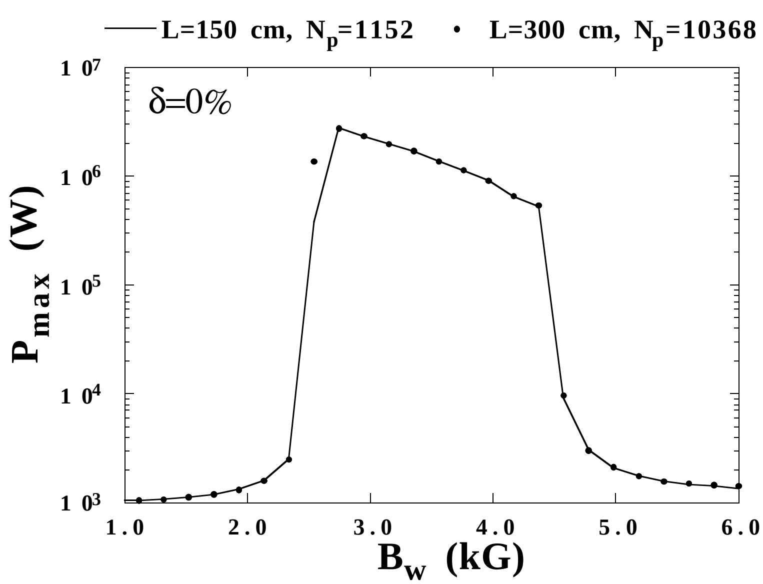

FIGURE 6. Comparison of maximum power for different particle numbers and different simulation lengths.

Conclusions

It appears feasible to design a 280 kV - 165 A planar ubitron delivering 0.5-2 MW in untapered operation. Because of the generally lower gain (40-60 dB/m), results are more sensitive to beam quality, particularly, vertical emittance. Thus a more precised estimate of maximum power will require careful analysis and simulation of the gun, and the tube itself, relying on the PIC code. We will return to this parameter set in a later note. For the time-being, 0.5 MW is probably a better number to keep in mind. For this low-voltage design, tapering will be a critical part of the final analysis.