Coupling of 84 GHz Microwaves to Waveguide for KSTAR ECH System

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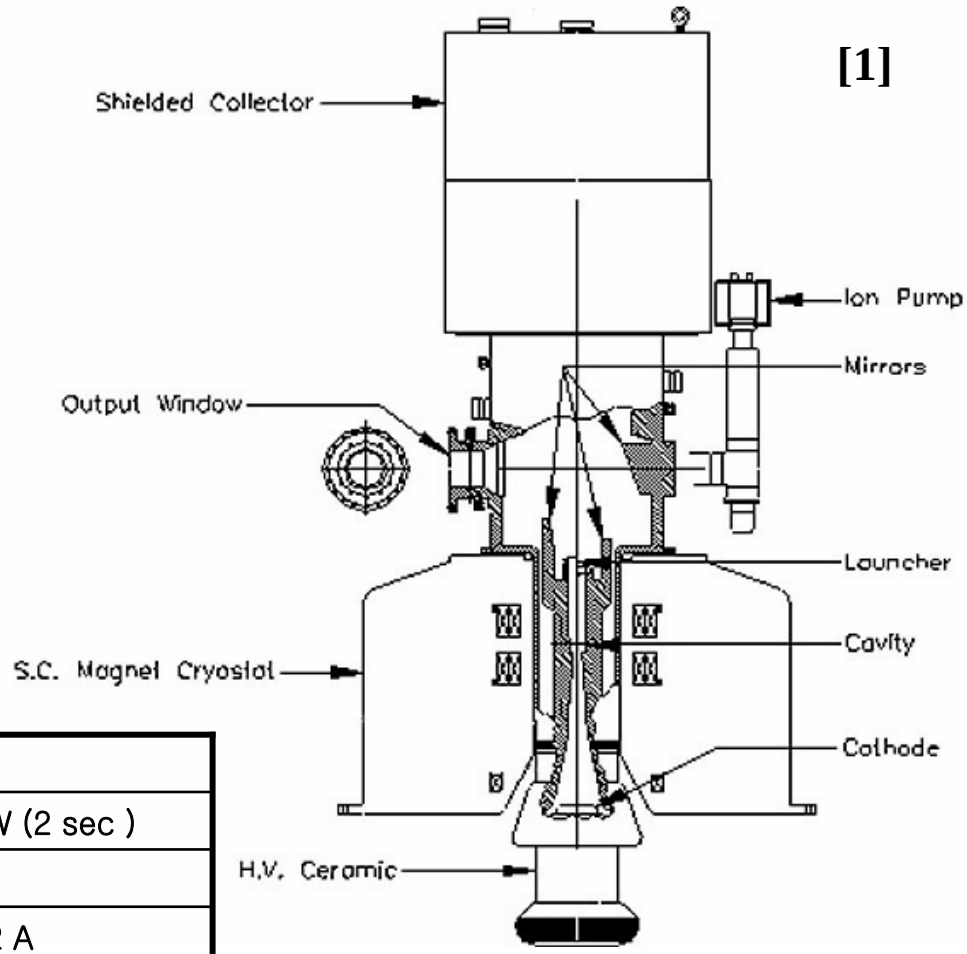
Abstract

- The KSTAR 84-GHz, 500-kW ECH system is installed at National Fusion Research Center, and cathode activation of gyrotron and microwave beam test were carried out with 20-us short pulse prior to long-pulse operation. A 25-A electron beam is accelerated from the cathode to the cylindrical cavity, where 3-T resonant magnetic field is applied, with an energy of 80 keV. The electrons gyrate in the cavity and generate 84-GHz microwave through the interaction between modulated electron beam and microwave. The microwave is converted to TEM_{00} mode Gaussian beam by internal mode converter (phase correct mirrors) and released by CVD diamond window. The big ellipsoidal mirror in L-box focuses the microwave to the 31.75-mm diameter circular corrugated waveguide. In front of L-box and at the waveguide after miter-band, beam size and position were measured with burned paper images and infrared camera images of a paper screen. The beam size and coupling to the waveguide were confirmed through the Gaussian fit of the measured IR image.

Gyrotron



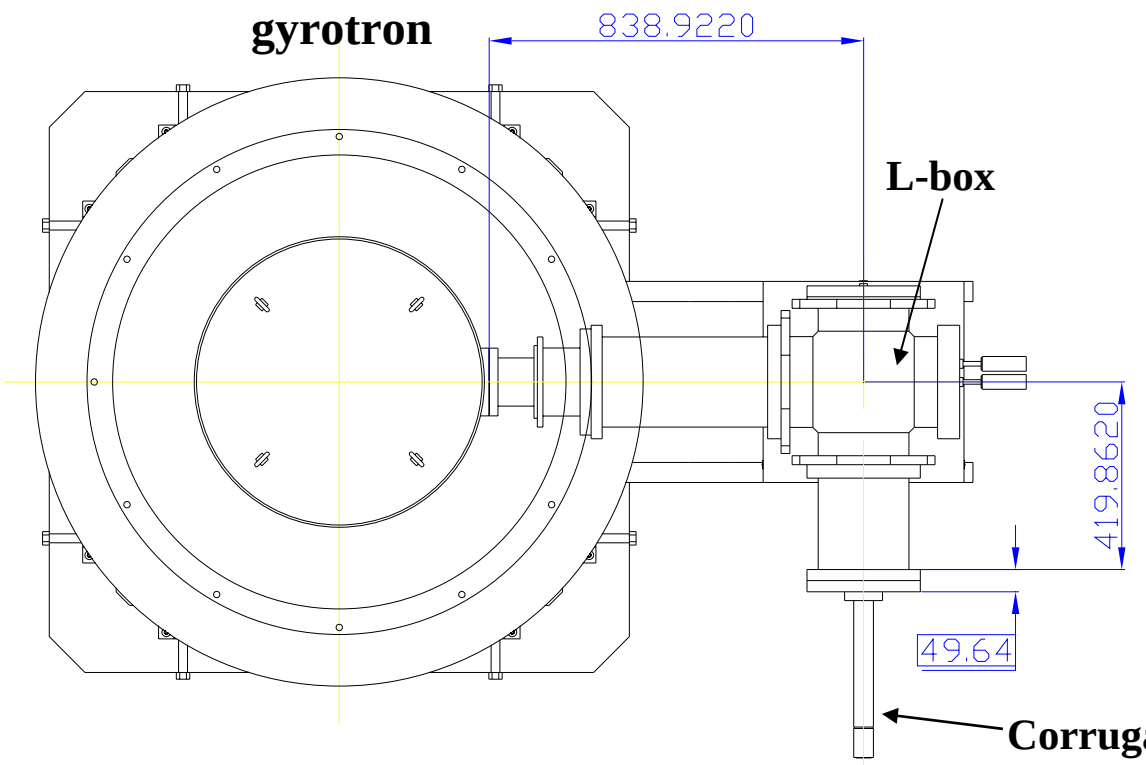
Microwave Frequency	84 GHz
Microwave Power	Max. 500 kW (2 sec)
Resonant Magnetic Field	3 Tesla
Cathode Heating Voltage	27 V_{AC} , 5.2 A
Electron accelerating Voltage	80 kV, 25A
Test Pulse width	20 us, (60 Hz)
Beam mode in free space	TEM_{00} (Gaussian mode)
Beam mode in waveguide	HE_{11}

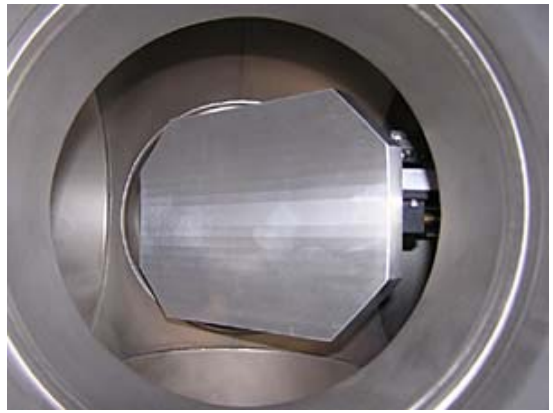
[1] H. G. Lee (2003) KSTAR ECH 장치의 Gyrotron 시운전. M. S. thesis, POSTECH, Pohang.

L-Box

The big ellipsoidal mirror of L-box focuses the microwave beam to the open end of a corrugated waveguide.

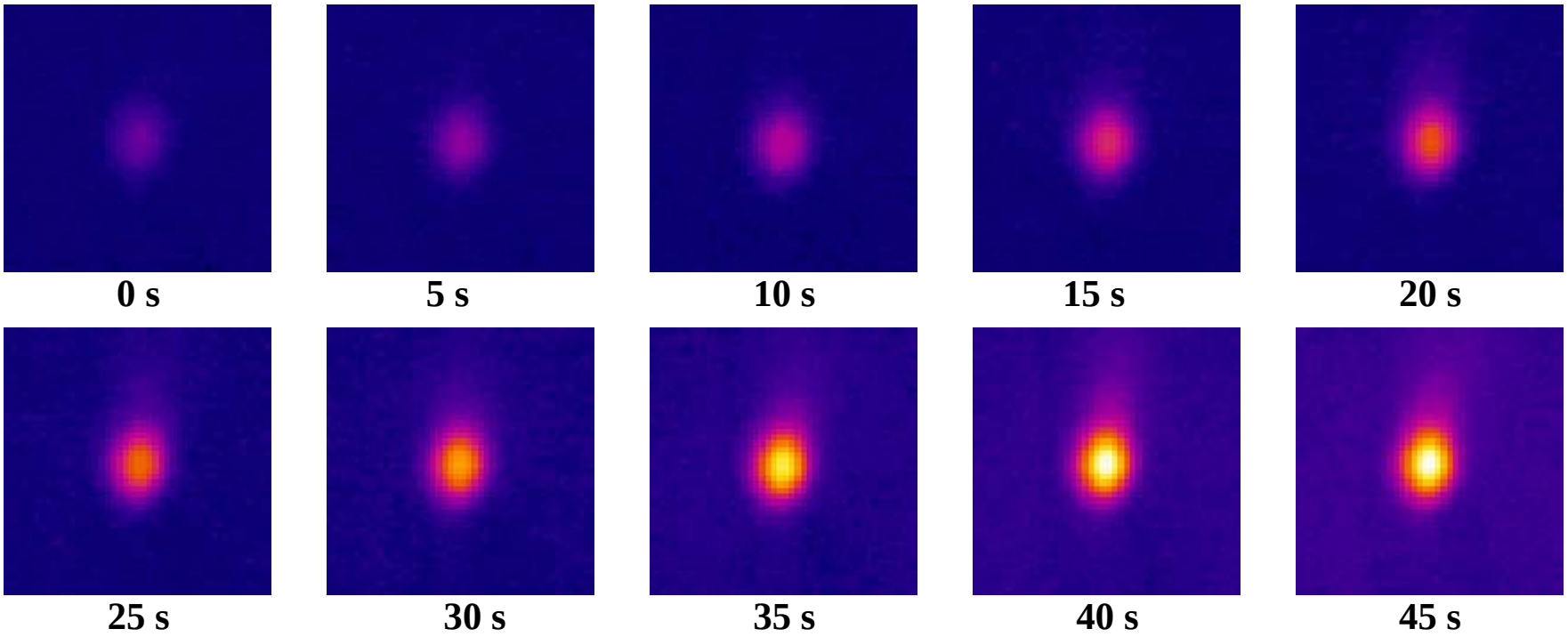
[Top view of gyrotron & L-box]

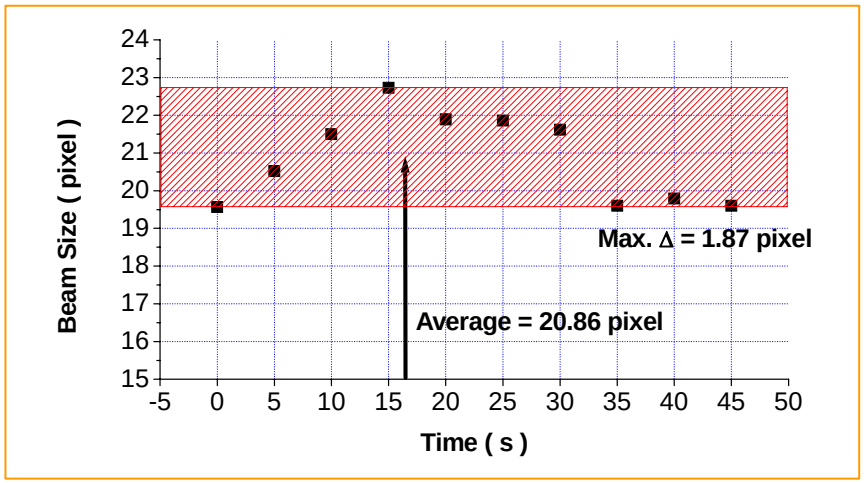




Inside of L-box

Thermal Diffusion Error on Beam Size (06/02/06)





Thermal spread error

= +- 1.87 pixel

+

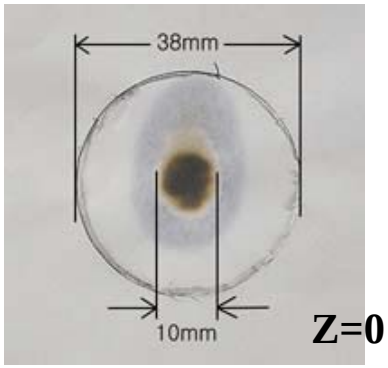
IR camera resolution

= 2 pixel

Total measurement error

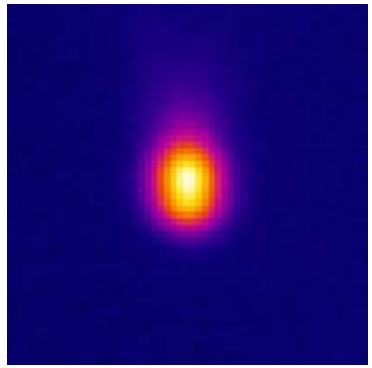
= +- 2.87 pixel

IR Image of Microwave in front of L-Box (06/2/27)

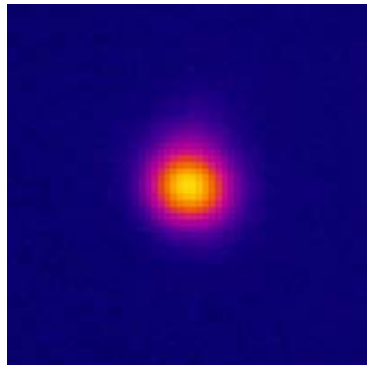


Z=0 cm

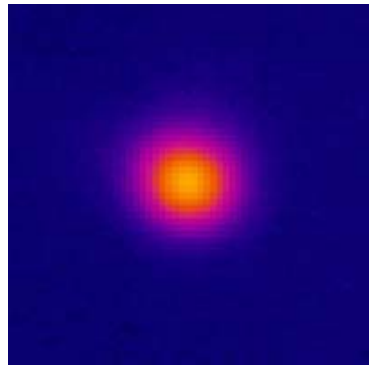
Operation Condition	
Heater voltage	28.5 V
Capacitor voltage	12 kV
Anode voltage	64.8 kV
Anode current	21.2 A
Frequency	10 Hz



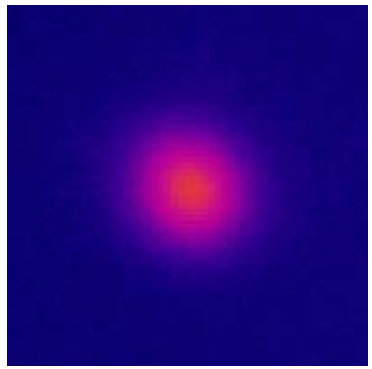
Z = 1 cm



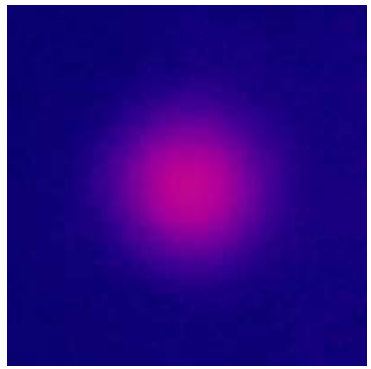
Z = 6 cm



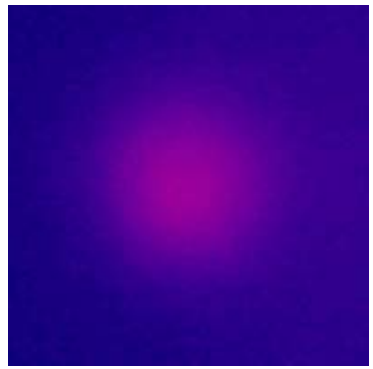
Z = 11 cm



Z = 16 cm

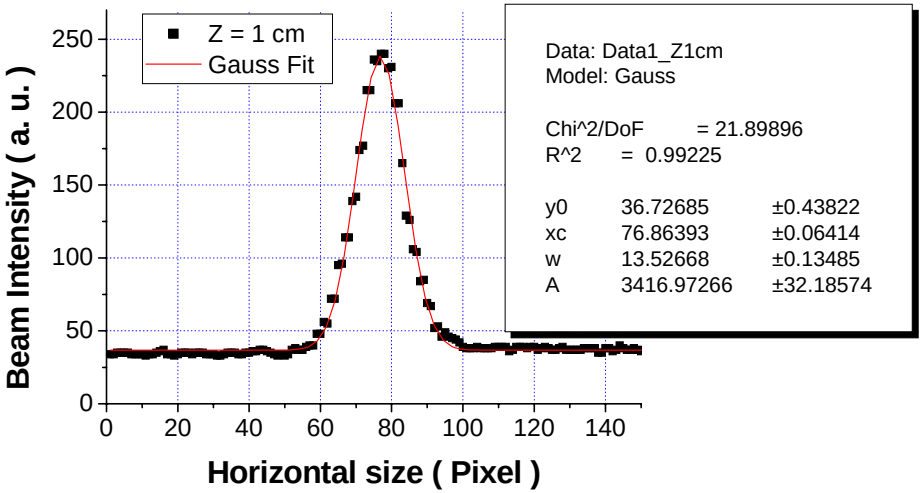


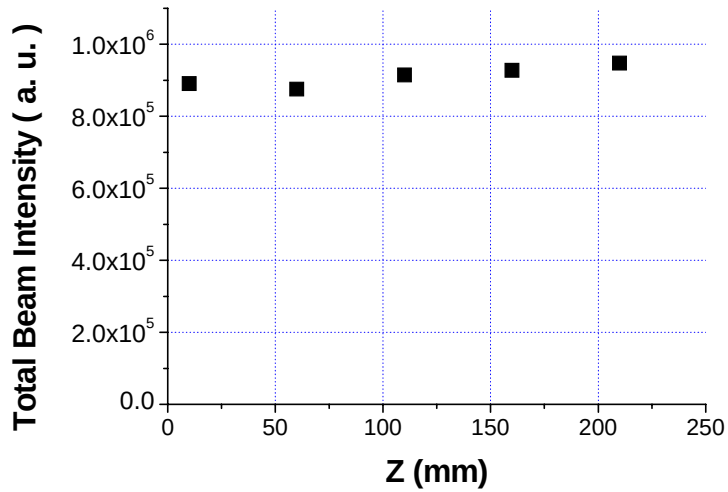
Z = 21 cm

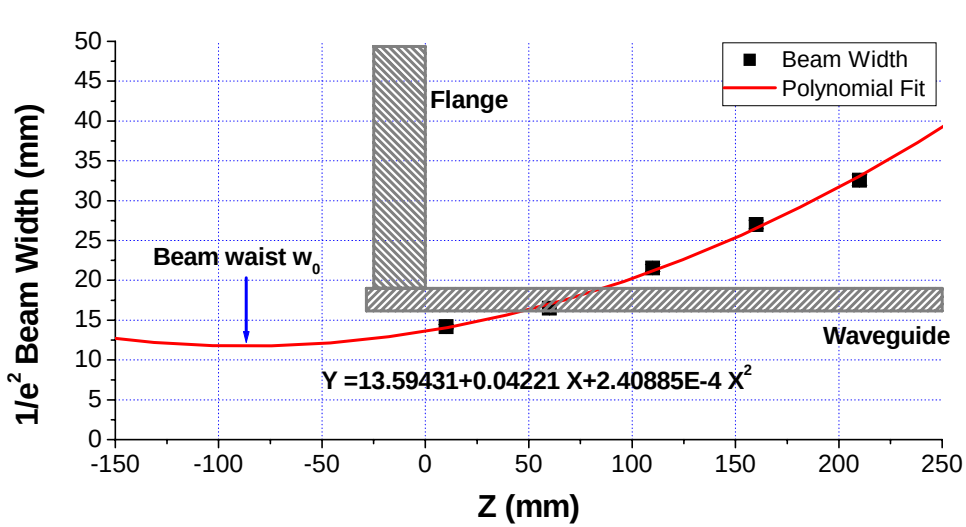


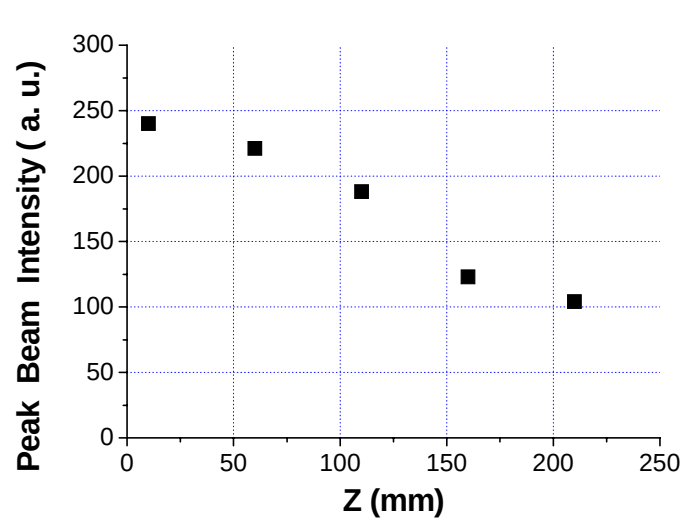
Z = 26 cm

Measured Beam size in front of L-Box









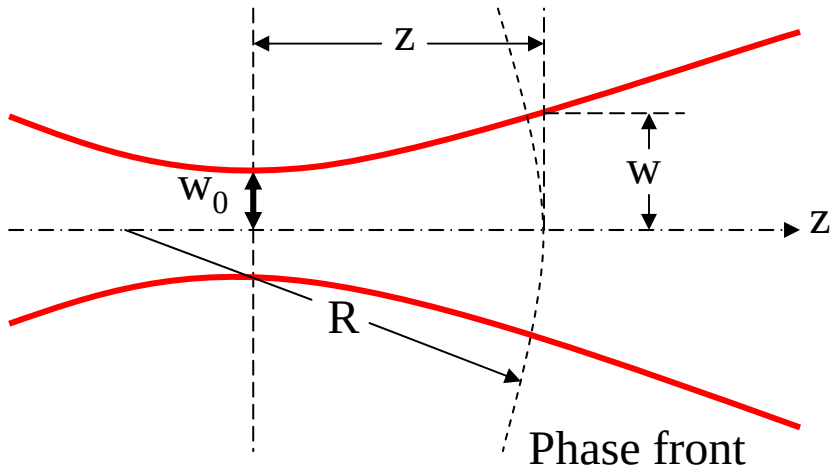
Propagation Laws for the Gaussian Mode [2]

- Gyrotron system designed to have a microwave beam waist (minimum diameter $2w_0$) at the open end of the corrugated waveguide. If one measures z from this waist, the expansion laws tells the beam size and curvature of the phase front at position of z.

$$w^2(z) = w_0^2\left[1+\left(\frac{\lambda z}{\pi w_0^2}\right)^2\right]$$

and

$$R(z) = z\left[1+\left(\frac{\pi w_0^2}{\lambda z}\right)^2\right]$$



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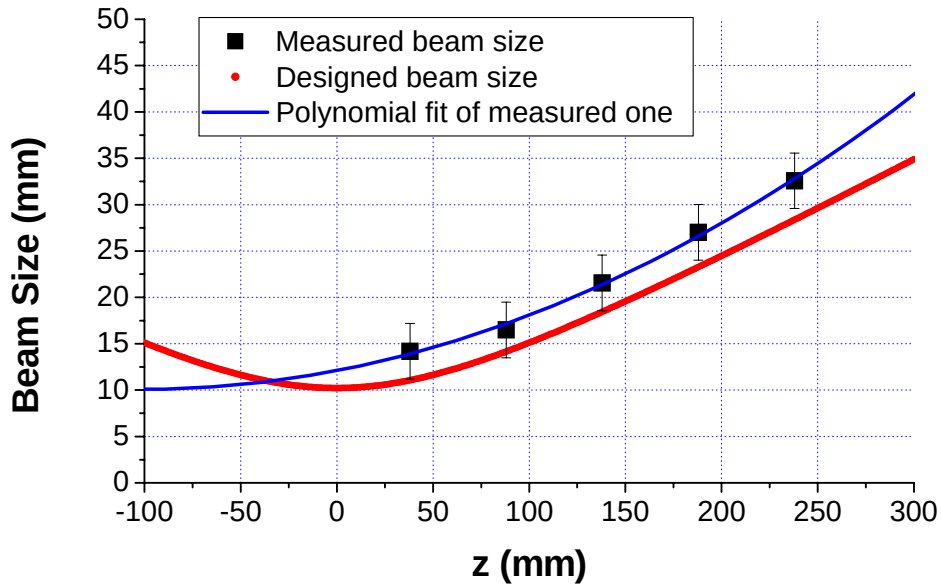
[2] H. Kogelnik and T. Li, Applied Optics, Vol. 5, No. 10 (1966).

Comparison between Designed and measured beam coupling

- For lowest loss of beam power, the optimum condition is $w_0/a = 0.6435$, where w_0 is a beam waist and a is a inner radius of the waveguide. [3]
- Inner radius of 1.25-inch waveguide is 15.875 mm.
- So, design value of w_0 is 10.22 mm.
- The wavelength of 84-GHz microwave is 3.57 mm

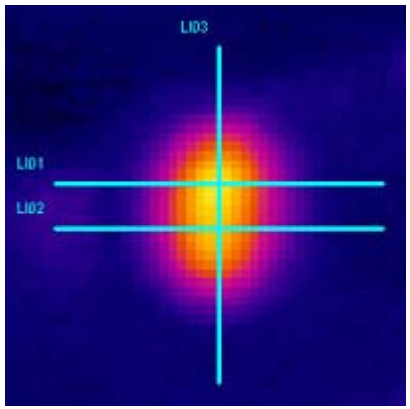
$$\rightarrow \quad w^2(z) = w_0^2\left[1+\left(\frac{\lambda z}{\pi w_0^2}\right)^2\right] = 10.22^2\left[1+\left(\frac{3.57z}{\pi 10.22^2}\right)^2\right]$$

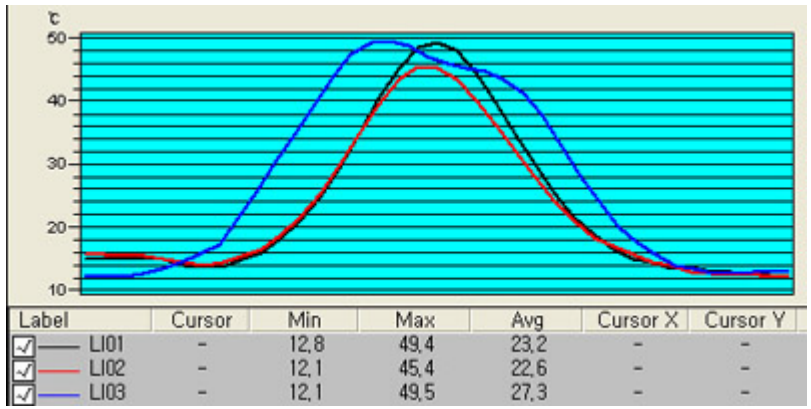
$$= 104.4484 + 0.012363314 \times z^2$$



[3] Richard L. Abrams, IEEE Journal of Quantum Electronics, Vol. QE-8, No. 11, p838 (1972).

IR Image of Microwave at W/G (06 / 3 / 1)





The beam shape is not “Gaussian(TEM_{00})” nor “zeroth-order Bessel function(TE_{11})”!

This could be due to a misalignment between L-box and waveguide or an excitation of higher mode at the mirror of miter-band.

Conclusion

- For lowest power loss when the free-space Gaussian mode microwave beam enters to the corrugated waveguide (inner radius a), the beam waist should be positioned at the open end of the waveguide with the size of $w_0 = 0.6435$ a. Measured beam size is 3-4 mm larger than the designed value and the beam waist places several centimeters back to the open end of the waveguide.
- The infrared beam image at the waveguide after miter-band looks like a peanut shape not Gaussian nor zeroth-order Bessel function shape. This could be due to a excitation of a higher mode at the mirror of the miter-band or a misalignment between waveguide and L-box.
- For the exact measurement of the beam coupling, low transversal thermal spreading material is necessary, and direct measurements inside of L-box should be conducted. This needs a target screen, which has a low transversal thermal conductivity and a longitudinal transparency.