TESTING OF ITER-CLASS ECH TRANSMISSION LINE COMPONENTS AT THE JAEA RADIO-FREQUENCY TEST STAND

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iter china eu india japan korea russia usa

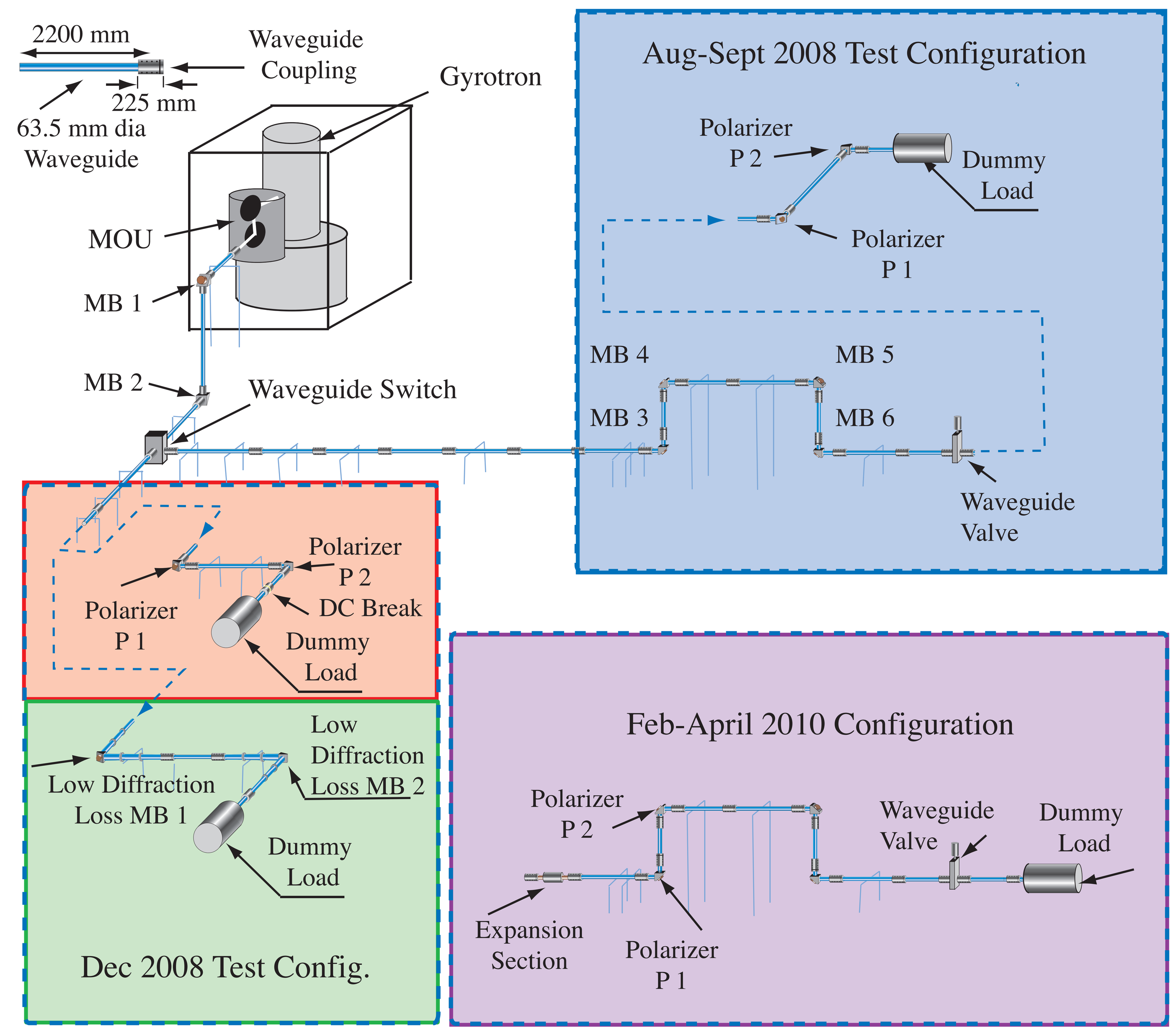
GENERAL ATOMICS

The JAEA RF Test Stand was used under a Joint JA-US RF Technology Exchange Agreement to test ITER Prototype EC Components designed and built by General Atomics

- The tests were to validate the high power performance of the components, under ITER conditions 600 kW, 240 s
- Verify the transmission efficiency,
- Verfy the effectiveness of the thermal management design, projected to 2 MW usage

Components Tested:

- Waveguide Sections
- 90° Miter Bends
- Low Diffraction Loss Miter Bends
- Polarizer Pairs
- Expanssion Section
- DC Breaks



SUMMARY

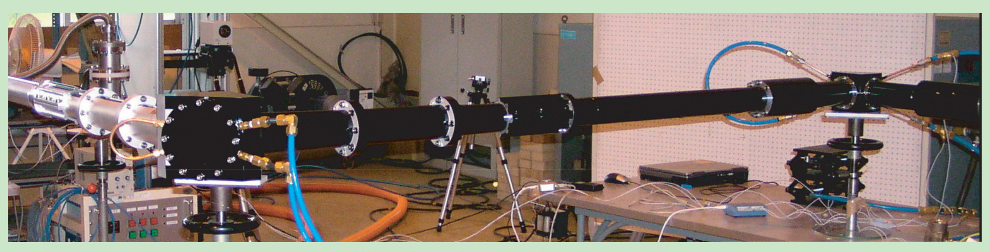
Between 2008 - 2010 tests were performed on several ITER Prototype EC components, (@ ~600 kW, 240 s)

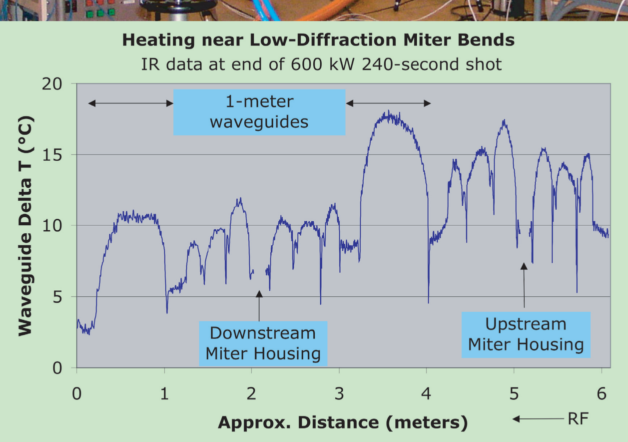
- Most of the components performed as predicted,
  - 90° Miter Bends
  - DC Breaks
  - Expansion Section
  - Low Diffraction Loss Miter Bends
- Ohmic loss in the waveguides greater than predicted
- Ohmic loss in the polarizer mirrors was greater than expected,
  - but was eventually clarified when anisotropic roughness and temperature affects were included in the model
- It will be a challenge to design a polarizing mirror for 2 MW operation, without limiting the polarization adjustment capability

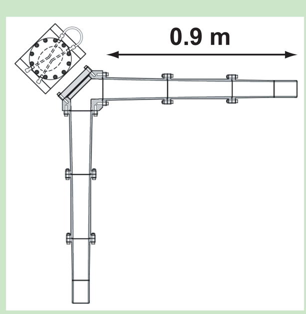
LOW DEFRACTION LOSS MITER BENDS

Main source of ITER waveguide heating is from diffraction losses at miter bends; these losses can be nearly eliminated by converting the HE11 mode to a Gaussian mode and using a slightly curved mirror in an expanded housing

– Uses corrugated tapers 0.9 m long
– Slightly curved mirror in 88.9 mm housing

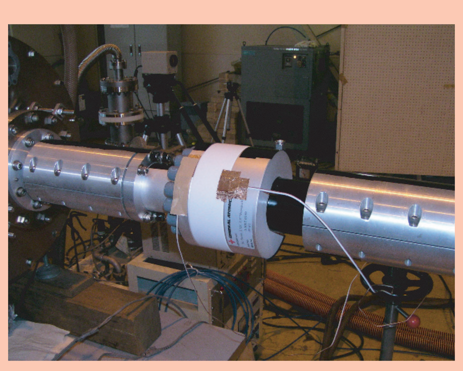






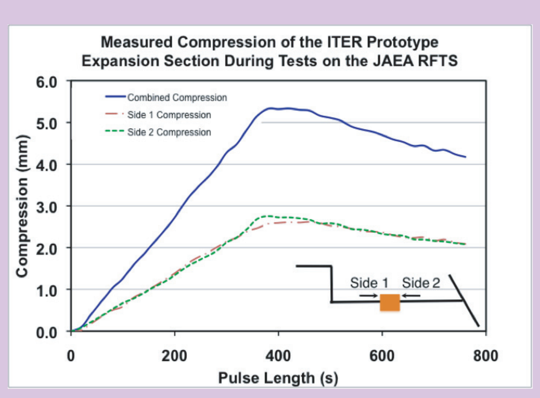
- **Measured increase was about 17.5 °C and 10.5 °C for the 1-m waveguides between the LDLMBs and after the downstream LDLBM, respectively**
- **Measurements from long wavguide lengths indicates that the nominal temperature rise from ohmic losses for the waveguide for ~600 kW, 240s should be 11±1°C.**
- **The higher observed heating in the first 1-m section is attributed to the high order modes generated in the up stream Miter Bends. No high Order modes were obsevered to be generated by the Low Diffraction Loss Miter Bends**

DC Break



- **ΔT of DC break surface ~ 8°C measured at 0.6 MW**
- **Projected ΔT for 2 MW transmission ~ 27°C (vs. safe operating limit of 50°C)**
- **Power detected in a waveguide horn was ≈ 0.2 mW/cm^2 at 50 cm (equiv. to 0.7 mW/cm2 at 2 MW) vs 5 mW/cm^2 safety standard**

Expansion Section



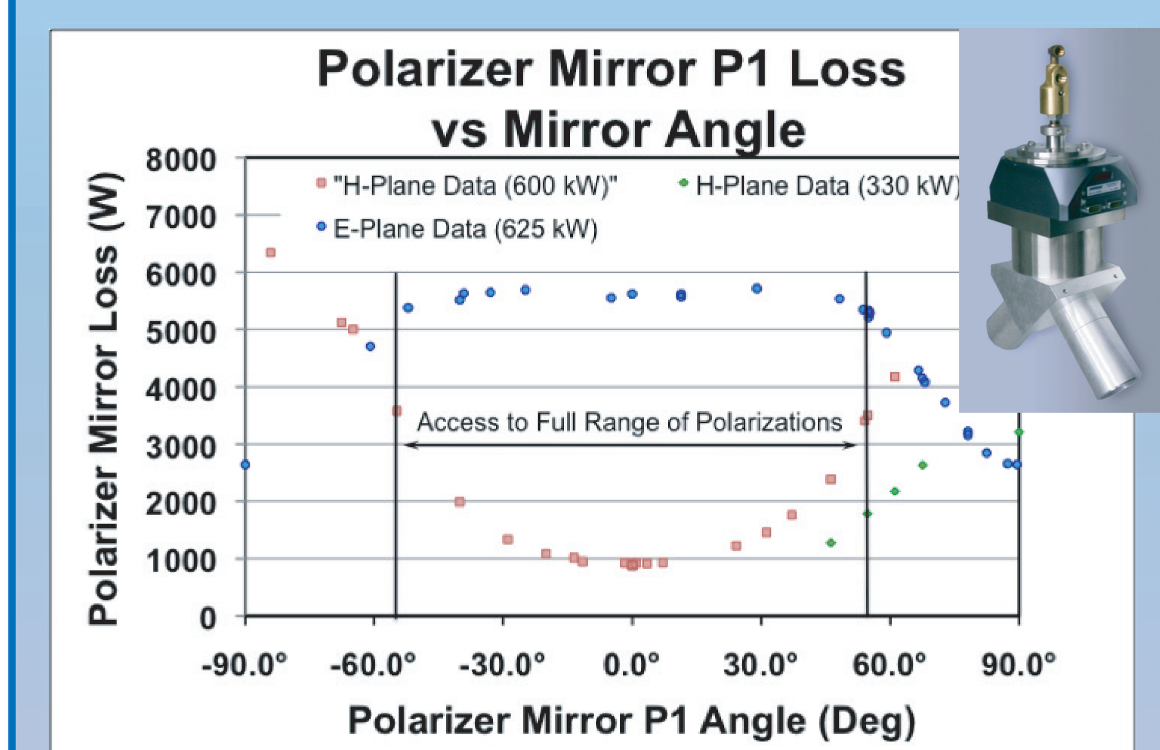
- **Hard copper waveguide for low microwave absorption and high thermal conductivity**
- **30 mm compression stroke achievable**
- **Mode conversion losses ~0.33% (varies with compression)**
- **Tests show a smooth compression during a 367 s pulse**

TABLE I
ITER EC COMPONENT OHMIC AND MODE CONVERSION LOSSES

EC Component	Ohmic† (%) (H-Plane/E-Plane)	Mode Conversion (%)	
		LOM	HOM (Frwd/Rev)
Miter Bend	(0.08/0.161)	0.13	0.0625/0.0625
Waveguide	HE11 - 0.0032 (m^{-1}) LP - >0.012 (m^{-1})		
WG Switch	(0.08/0.161)	0.13	0.0625/0.0625
Expansion Sec.		0.33	
DC Break		0.002	
Polarizer MB	0.1225(SG)(RF)(Ts) H 0.245(SG)(RF)(Ts) E	0.156‡	0.075‡/ 0.075‡
Power Mon. MB	(0.08/0.161)	0.13	0.0625/0.0625
LDLMB	(0.08/0.161)	0.046	0.013/0.013

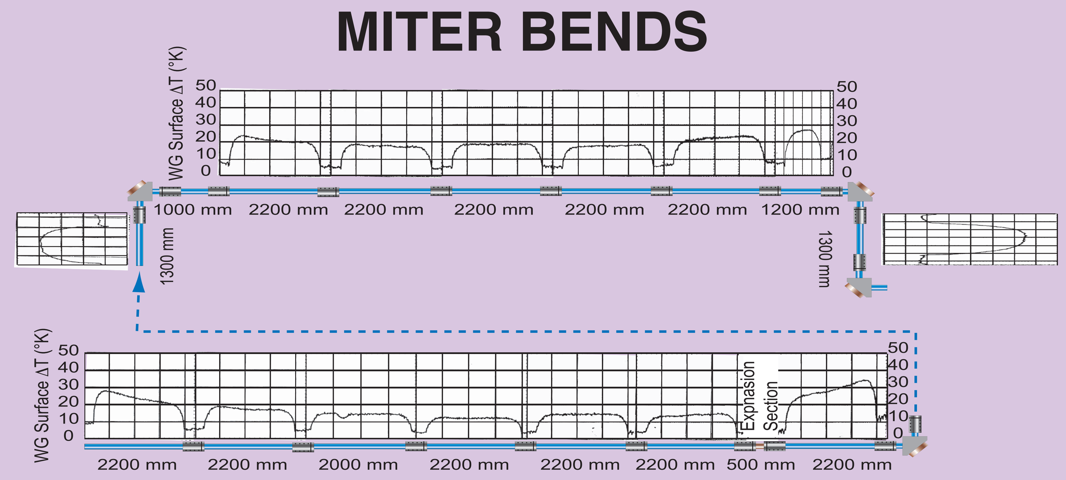
SG = Surface Geometry Factor, RF = Roughness Factor, Ts = Mirror Surface Temp Factor
† All mirror losses are for Room Temperature Smooth Copper, loss needs to be corrected for surface roughness and temperature affects.
‡ The polarizer mode conversion was increased by 1.2 over a standard MB, to account for added diffraction from the grooved mirrors

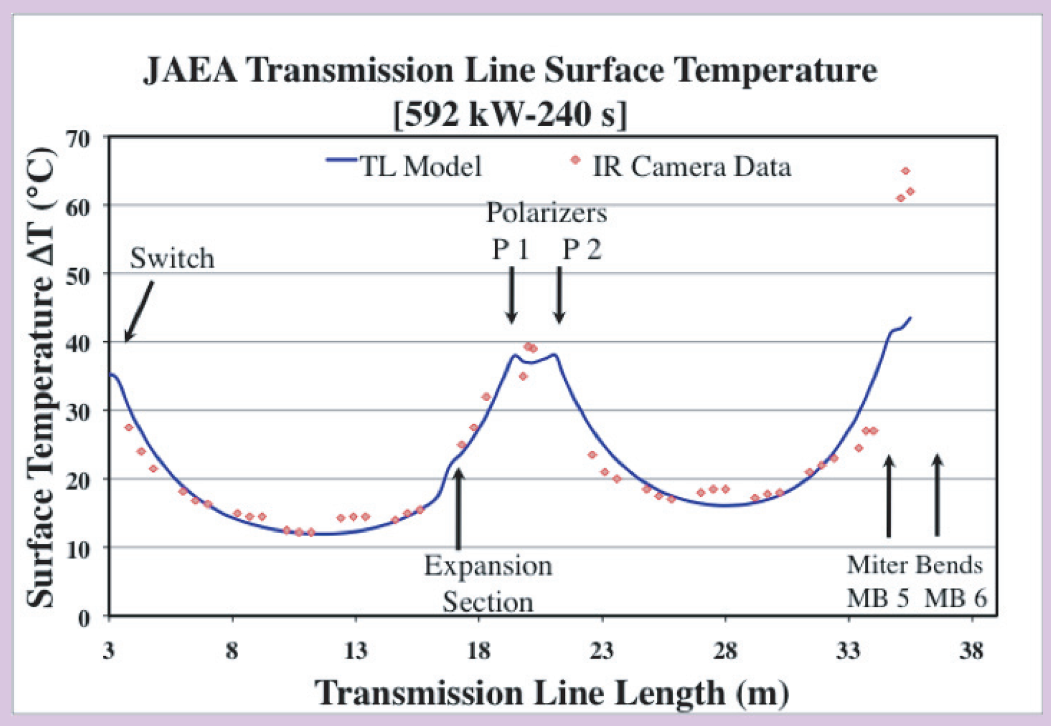
Polarizers



- **Arbitrary polarization angles and ellipticity can be produced from linear polarized RF waves by using pairs of miter bends equipped with rotatable grooved mirrors.**
  - The first Polarizer mirror P1 (having the deeper grooves) mainly rotates the incoming polarization.
  - The second Polarizer mirror P2 mainly changes the ellipticity of the polarization
- **For a given output polarization from the pair, there is normally at least one solution for the rotation angles of these mirrors.**
- **Tests in 2008 had the bend of the Polarizers in the horizontal plane, (E-Plane).**
- **Tests in 2010 were performed with the polarizer miter bend pair in the vertical plane, (H-Plane)**
- **In both tests, it was observed that the ohmic loss was a strong function of the orientation of the grooves with respect to the polarization angle of the RF field.**
  - This was expected, since the electric field sees a different effective surface area depending on the polarization orientation with the mirror groves
- **Another factor that affects the ohmic loss is the surface resistance (Rs), which depends on the surface roughness (Rf) and the surface temperature (Ts).**
- **Thermal analyses indicated that the stresses on the mirrors would be acceptable if the total absorbed power is about 6700 watts or less.**
- **For the 2010 tests, all the desired output polarizations could be achieved with P1 mirror rotation angles of 55° or less.**
- **The maximum measured loss on either mirror in the 2010 tests was 0.42%.**
  - For the 2008 tests, the corresponding maximum loss was 0.69%.
  - We can conclude that with the 2010 orientation of the incident polarization and the present polarizer mirror design, 1 MW CW operation would be achievable, since 4200 watts is comfortably less than the 6700 watt limit. A new design will meet the 2 MW objective

MITER BENDS





- **Calometric measurements of the miter bend mirrors showed an ohmic loss of 1.3 kW (0.22%) vs a 0.95 k W (0.16%) predicted**
  - The higher loss is accounted for by a 1.2 surface roughness factor and a resistivity thermal enhancement of 1.2
- **The WG surface temperature rise can be used to estimate Miter Bend mode conversion losses**
  - The WG temperature increase is caused by the Power Absorbtion of the High Order Modes (HOM) and Low Order Modes (LOM) generated within the Miter Bend
- **The power absorbed from the LOMs and HOMs should follow a simple exponential decay profile**
  - This decay profile can be determined from the DT profile.
  - The waveguide surface temperature T_{WG} should follow an exponential decay, expressed as;

$$T_{WG} = \Delta T_0 \, e^{(-L/D_L)}, \ (°C)$$

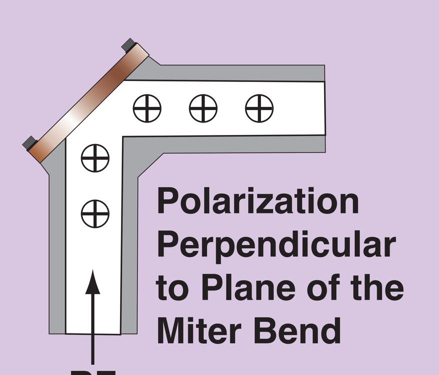
Where ΔT_0 is the peak temperature (°C) rise at the component, L (mm) is the distance from the component, and D_L (mm) is the decay length of the temperature profile

TABLE II
EC COMPONENT LOSS MODEL USED TO PREDICT WG SURFACE TEMPERATURES
Mode conversion rates from Table I

EC Component	Model (HE_{11} ~93%)					
	Ohmic Loss Measured (W/m)	Ohmic Loss Theory (W/m)	P_{abs} LOM (W/mm)	P_{abs} HOM (W/mm)	D_{LOM} (mm)	D_{HOM} (mm)
Miter Bend	1.3 E-Plane	0.95 E-Plane	0.019	0.156	20,000	2,500
Waveguide	85	23				
Expansion Section			0.0065	0.052	20,000	2,500

For linear polarized RF waves the ohmic loss on Miter Bend mirrors depends on the orientation of the polarization to the plane of the arms of the Miter Bend. H Plane Bends have a loss of 0.08%, E Plane Bends have a loss of 0.161%.

H Plane Bend



E Plane Bend