Breakdown in Waveguides and Components

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Outline of Talk

1) Description of the RF high Power System
2) Breakdown Limit due to Waveguide Size and components.
3) Breakdown limits due to Harmonics and

Spurious oscillations and pressurization.

4) Overview of High Power level System and

Specifications for Couplers in main line to achieve breakdown free operation.

5) Conclusions.

1300 MHz RF Power Distribution to Cavities (Typical)

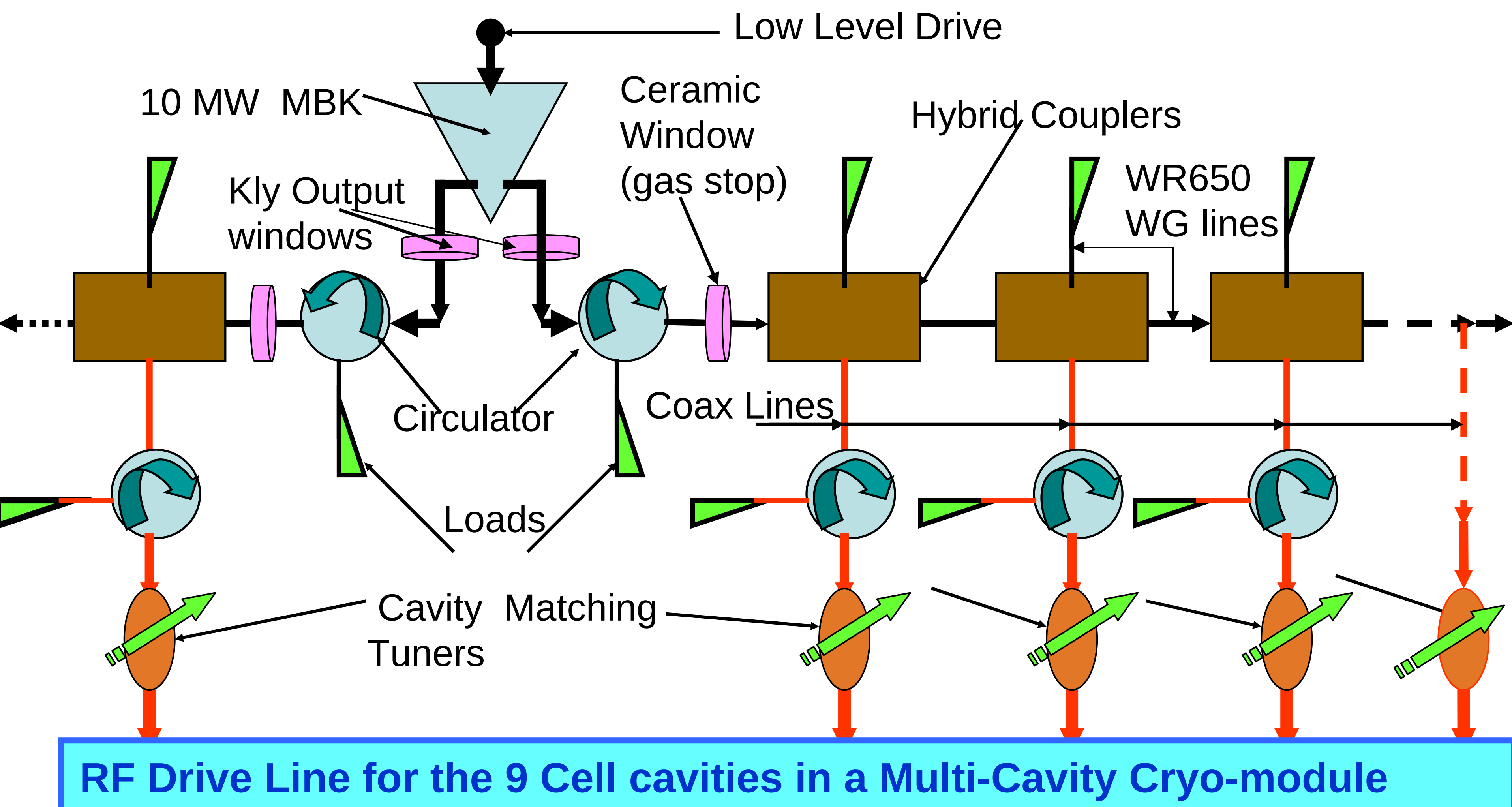


Figure 1. RF Power Distribution

9 cell Superconducting cavity Tesla Design

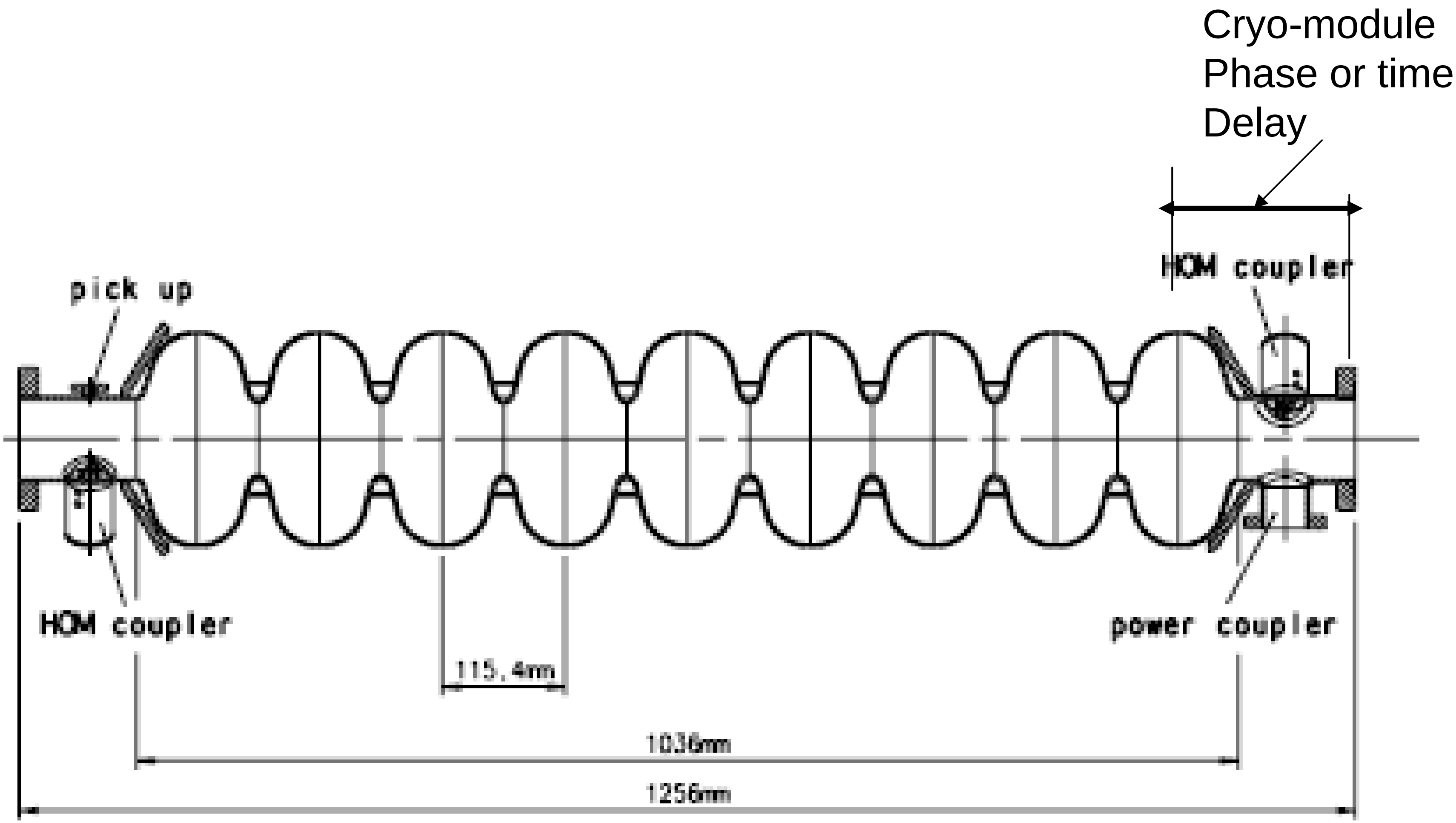
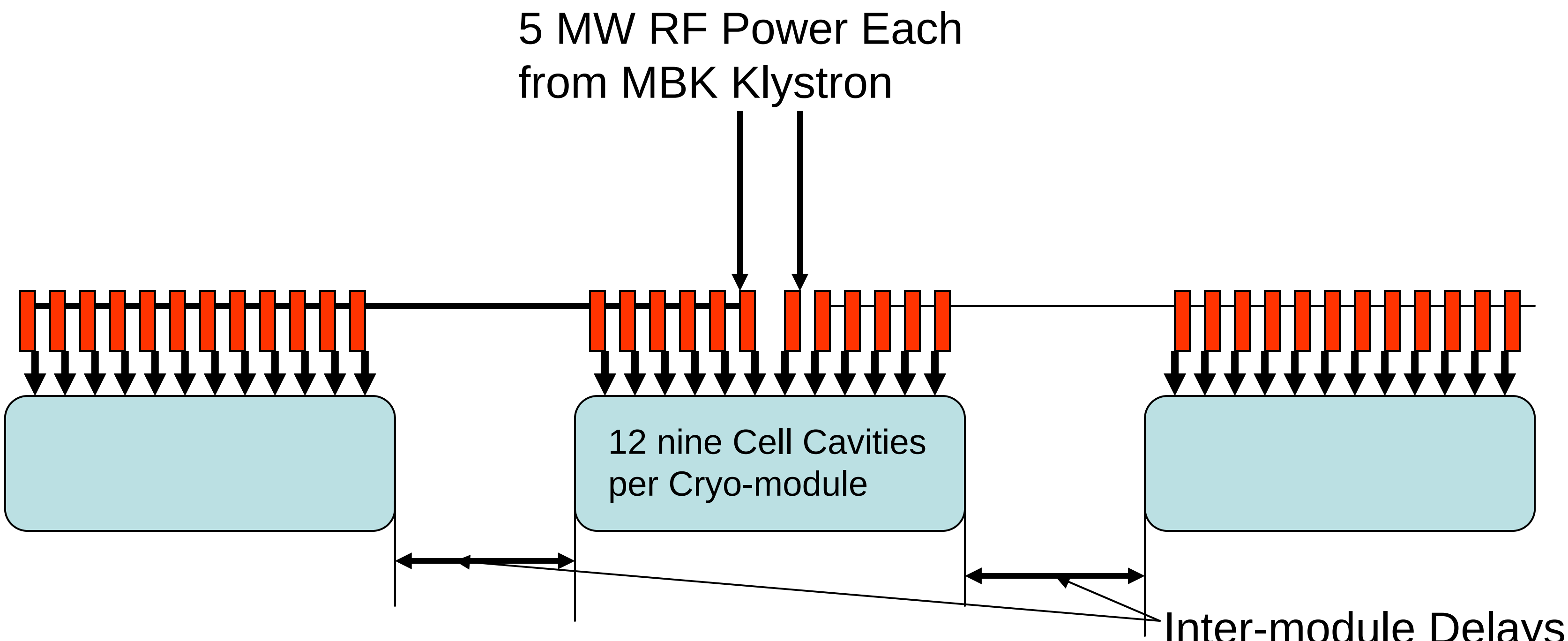


Figure 2. **9 Cell Tesla Superconducting Cavity.**

X-FEl Multi-Cavity Cryo-Modules
12 Cavities in one Module



Symbol = network of Hybrid Coupler,

Circulator and Load and

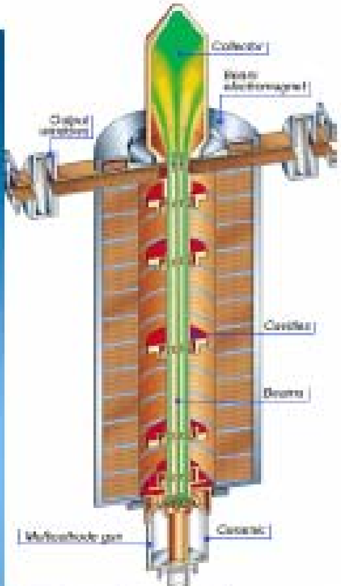
Cavity Matching Tuner

Figure 3. Cryo-Module RF Power Distribution

The Thales TH1801 Multi-Beam Klystron

Measured performance

Operation Frequency:	1.3GHz
Cathode Voltage:	117kV
Beam Current:	131A
Number of Beams:	7
Cathode loading:	5.5A/cm^2
Max. RF Peak Power:	10MW
RF Pulse Duration:	1.5ms
Repetition Rate:	10Hz
RF Average Power:	150kW
Efficiency:	65%
Gain:	48.2dB
Solenoid Power:	6kW
Length:	2.5m
Lifetime:	~40000h



Output Window Pressurization 1.05 Bar SF6 minimum
Output wavegude WR650

RF Breakdown limit of Key Components

The RF power limit of the waveguide components are determined by:

- **Waveguide Size and insertions of dielectrics, ferrites, tuning posts, sharp corners, sharp edges, corrosion of guide and in flanges, cleanliness, condensation.**
- **VSWR of the load and sum of all reflections in the waveguide.**
- **Harmonics and Spurious outputs of the Klystron**
- **Pressurization or lack off and type of gas.**
- **Temperature of guide and components**

Breakdown Limit due to Waveguide Size Bullet #1

- **The bare WR650 Waveguide has a theoretic Power Breakdown limit of 51 MW in 1 Bar Air.**
- **Practical Handbook Rating 11.2 MW in 1 Bar Air.**
- **Insertions of standard hybrid couplers, dielectrics tuners, tuning posts Can reduce ratting to 20 % of Theoretic Limit to 10 MW in 1 Bar Air.**
- **Ferrite Devices can Reduce rating to 10 % Limit to 5 MW in 1 Bar Air.**
- **Temperature rises 80º C (Paschen Curve) to 60% Applied to worse example, Ferrite Circulator, to 3 MW in1 Bar Air.**
- **Corrosion of guide and in flanges, condensation must be prevented and Cleanliness must maintained to keep system near optimum performance.**

Effects of Load VSWR and Harmonic and Spurious VSWR on Breakdown Bullets 2 and 3.

- **Load VSWR (ratio of Maximum to Minimum Voltage along the Line) above 1, reduces the Power rating by a factor proportional to**

$$[(1+VSWR)/(2VSWR)]^2$$

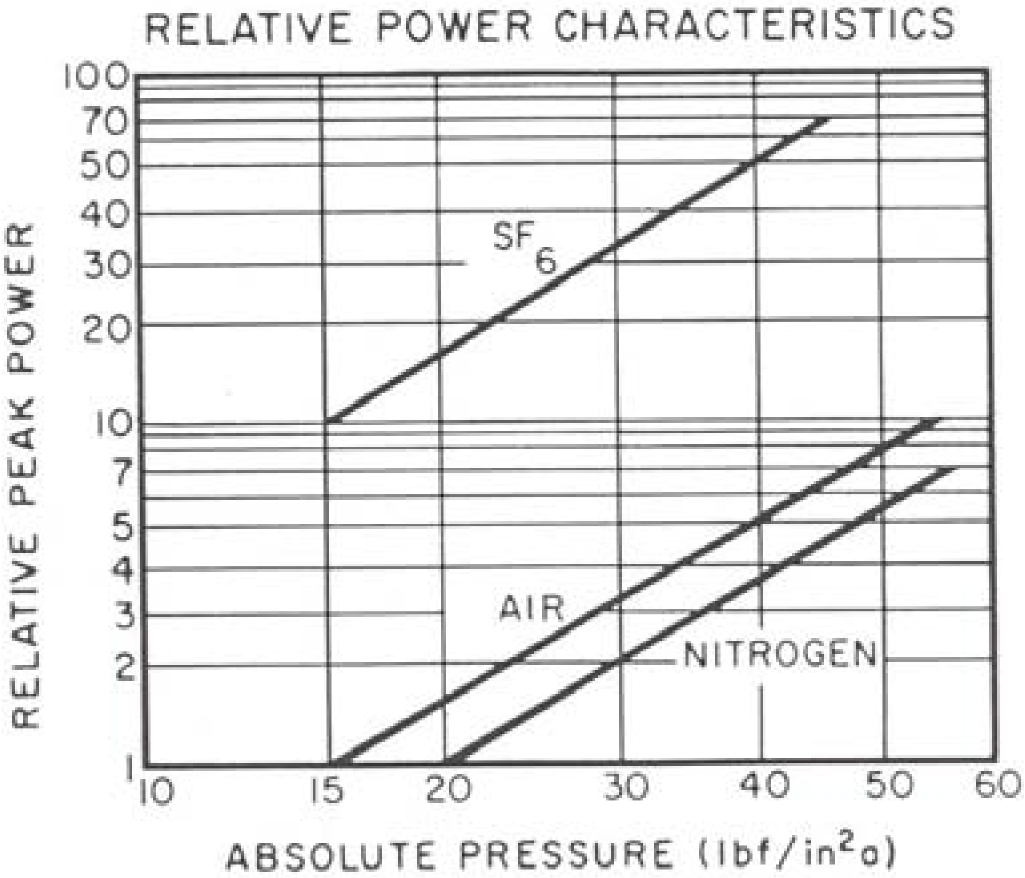
For example a VSWR of 5 produces a reduction factor of 36 %

- **Harmonic and Spurious by adding to the fundamental power or by having a resonance condition in the line reduces the Power rating by a factor proportional to**

$[(1/(1+\sqrt{}(K \times VSWR)]^2$ **where K is ratio of harmonic to Fundamental power and VSWR is for the harmonic or Spurious mode.**

for K=1 % and VSWR=5, the reduction factor is 67 %.

Comparison of Breakdown of SF6, Air and N2



It takes over 3 Bar of Air to be equivalent to 1 Bar SF6

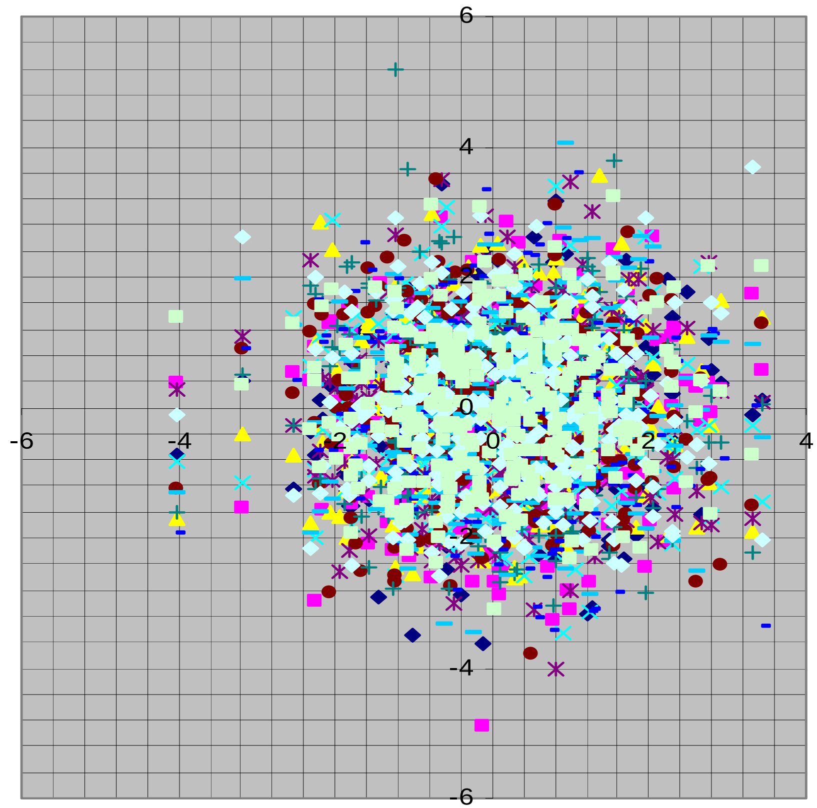
Overview of the RF High Level WG Distribution System

- **The main components, Figure 1, that require pressurization are the Klystron Output window, the 5 MW Ferrite Circulator and the Gas Stop Ceramic Window. It maybe possible with improved design of the Klystron window and gas stop to not require pressurization. But it maybe extremely difficult to design the circulator to not require pressurization.**
- **This leaves two possible choices 1) pressurize the whole system or**

2) pressurize as little as possible.

- **2 is the preferred option. The components downstream of the gas stop in Figure 1 are the hybrid couplers which are isolated by the low power circulators and connect the RF power to the cavities.**

The Effect of 18 Reflections on VSWR Specification of Hybrid couplers in Figure 2.



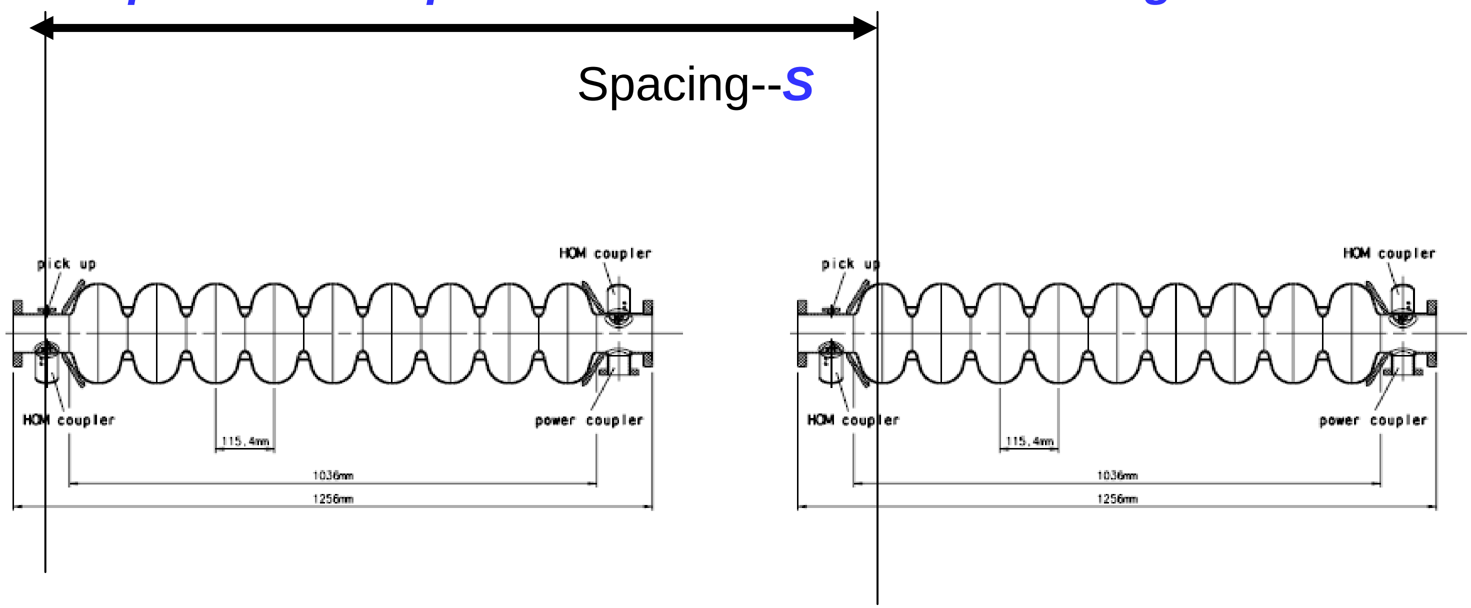
Scatter Plot: Random set of 18 Equal Reflections

- VSWR Specification For the Case of 2.0 % Reduction in RF Power Rating
- Random gives a standard Deviation of 1.21 from zero, gives a VSWR Limit of 1.075 for 5 STDEV
- Worse Case all Reflection add gives a VSWR Limit of 1.0022
- Control of phase delays in Figures 2 and 3; can allow more relaxed specifications on the hybrid couplers and reduce their costs.

Inter-Cavity Spacing of Cavity input Power Couplers for lowest Waveguide Transmission RF power Loss and VSWR

The spacing *S between power couplers* should be made λg/4 longer or shorter than n λg/2 where λg is the waveguide wavelength, i.e.,

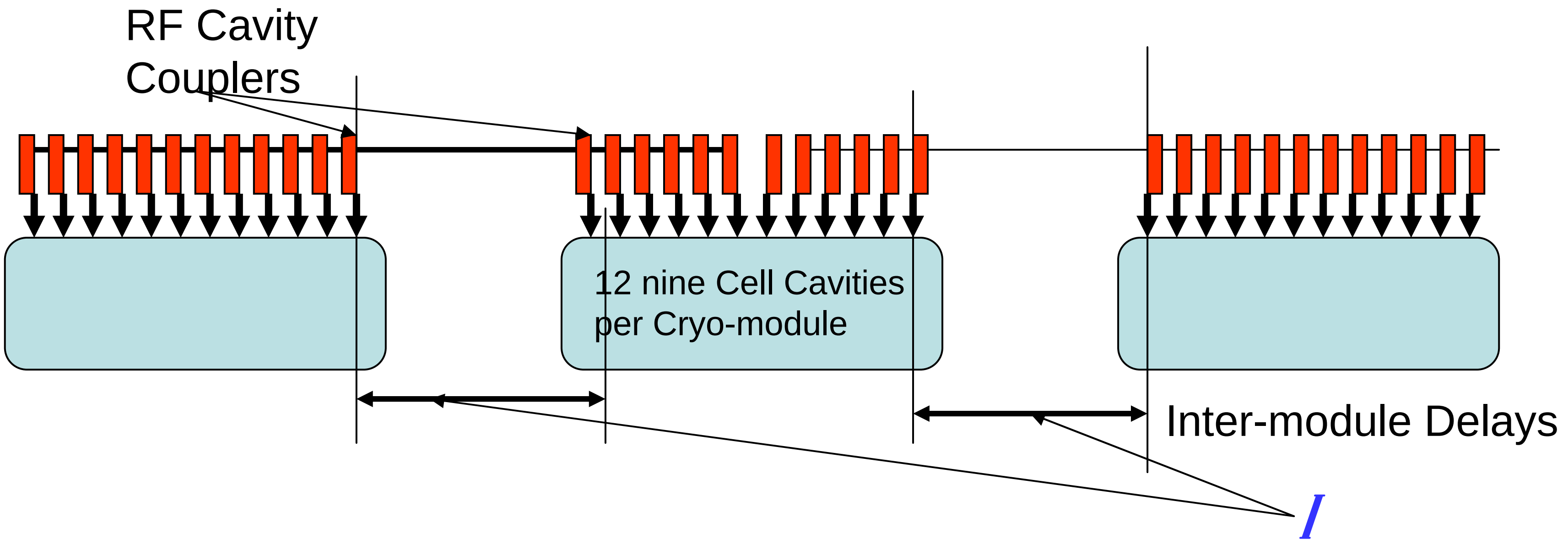
***S=* n λg/2 +/- (λg/4) *for lowest Reflected power buildup in the transmission line Waveguides*.**



Inter-Module Spacing of Cavity input Power Couplers for lowest Waveguide Transmission RF power Loss and VSWR

The spacing *l between Cavity Couplers* should be made λg/4 longer or shorter than n λg/2 where λg is the waveguide wavelength, i.e.,

***l=* n λg/2 +/- (λg/4) *for lowest Reflected power buildup in the transmission line Waveguides*.**



Conclusions

- Currently the only Components needing Pressurization are the Klystron windows, Circulator and Gas Stop.
- Other Components after the Gas Stop can be designed and specified not to require pressurization.
- Attention to detailed design practice must be followed to achieve Breakdown free operation. Resonances, fundamental, Harmonics and Spurious, are most important to control breakdown in long transmission lines. Temperature corrosion, and good flange to flange contacts also must be maintained.
- Advanced R&D, M&S and effort are needed to qualify all components and vendors.
- The X-FEL will be a great component test bed for the ILC.
- For a well Matched system and designed system, the 5 MW Circulator may not be required and may not need pressurization depending on Klystron specification. The Klystron output can be designed to not need pressurization. In this case the whole transmission line can be designed to not need pressurization.