Clustered Surface RF Production Scheme

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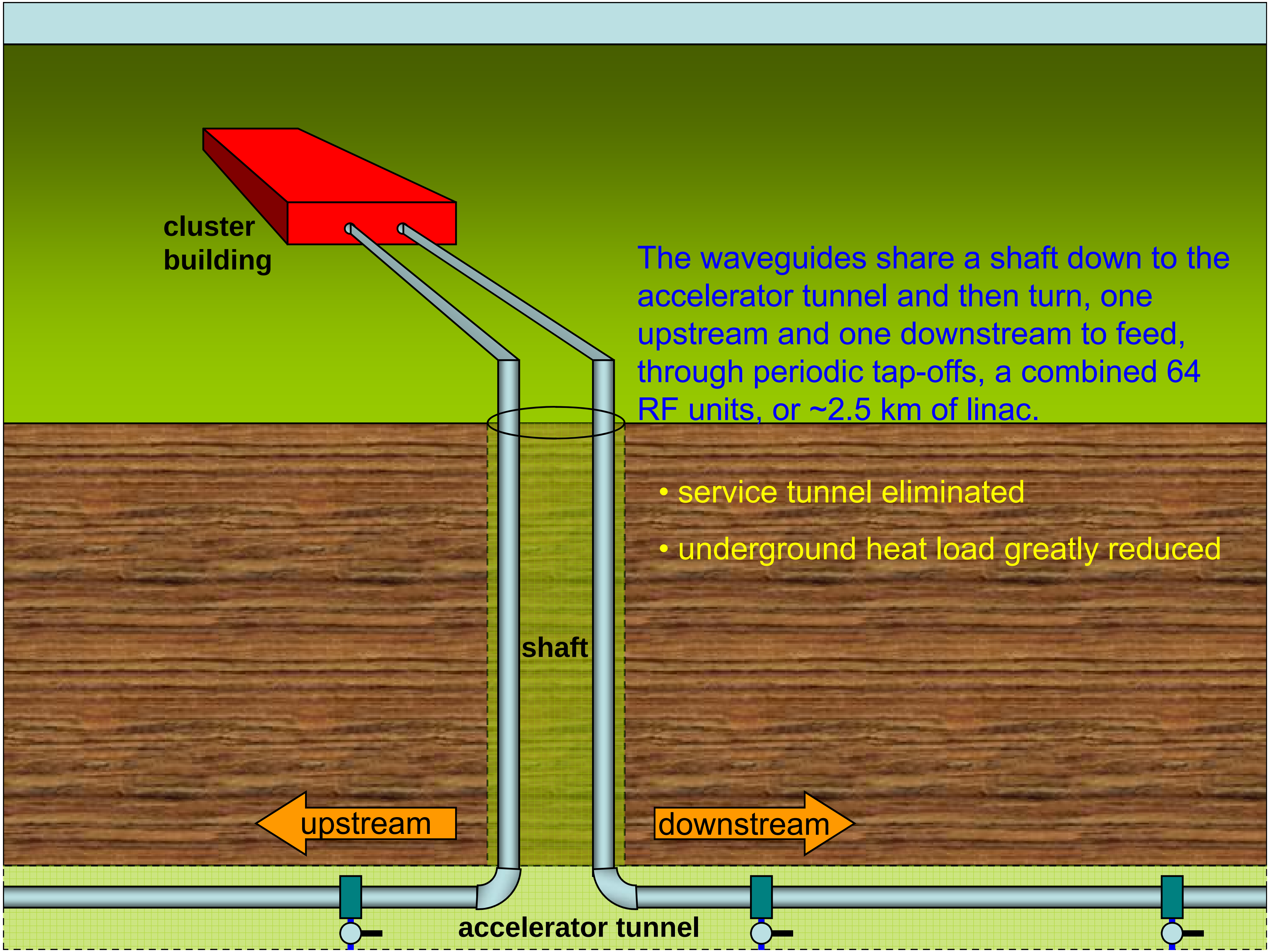
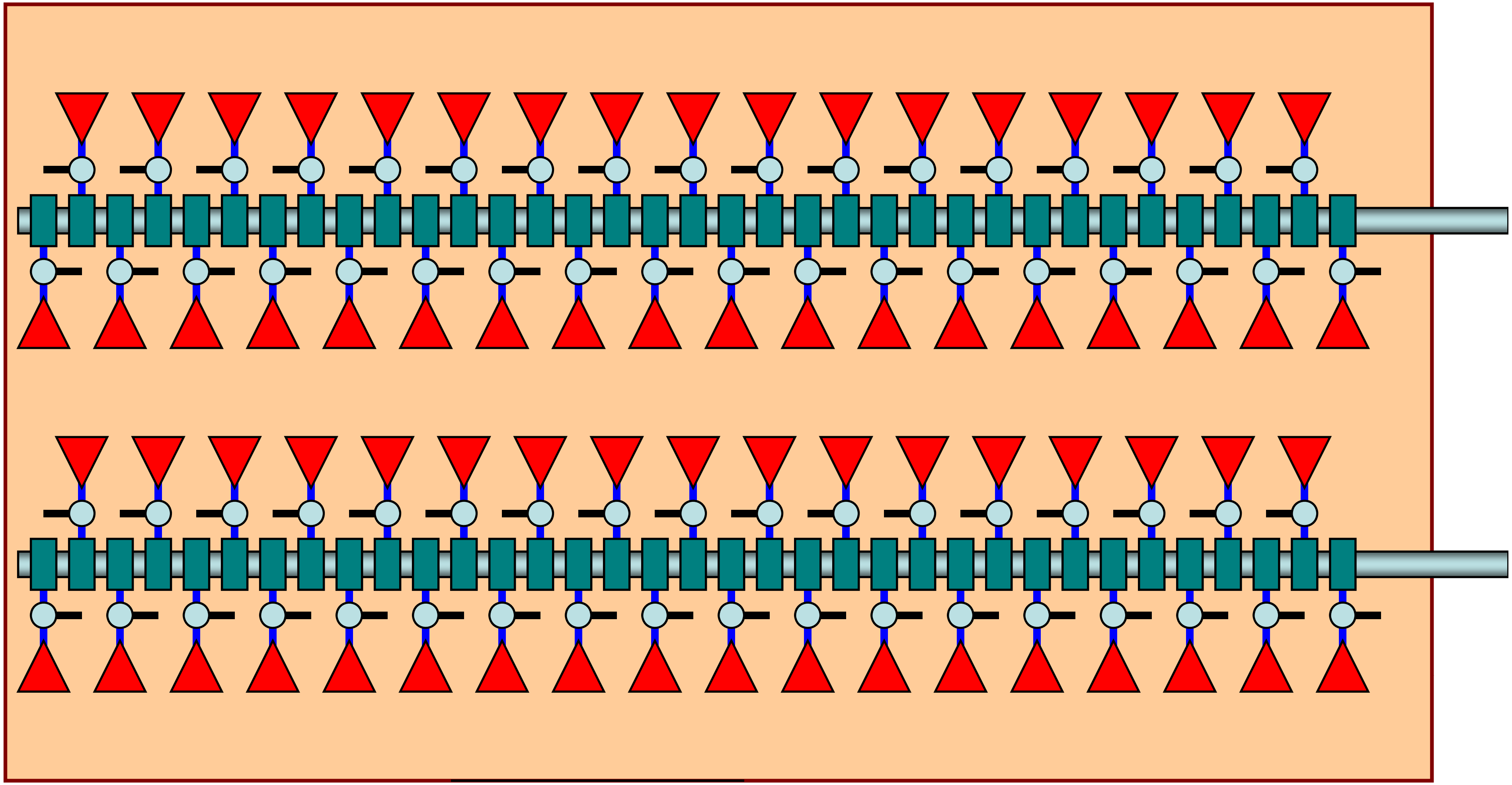
SLAC


cluster
building
The waveguides share a shaft down to the accelerator tunnel and then turn, one upstream and one downstream to feed, through periodic tap-offs, a combined 64 RF units, or ~2.5 km of linac.
• service tunnel eliminated
• underground heat load greatly reduced
shaft
upstream
downstream
accelerator tunnel

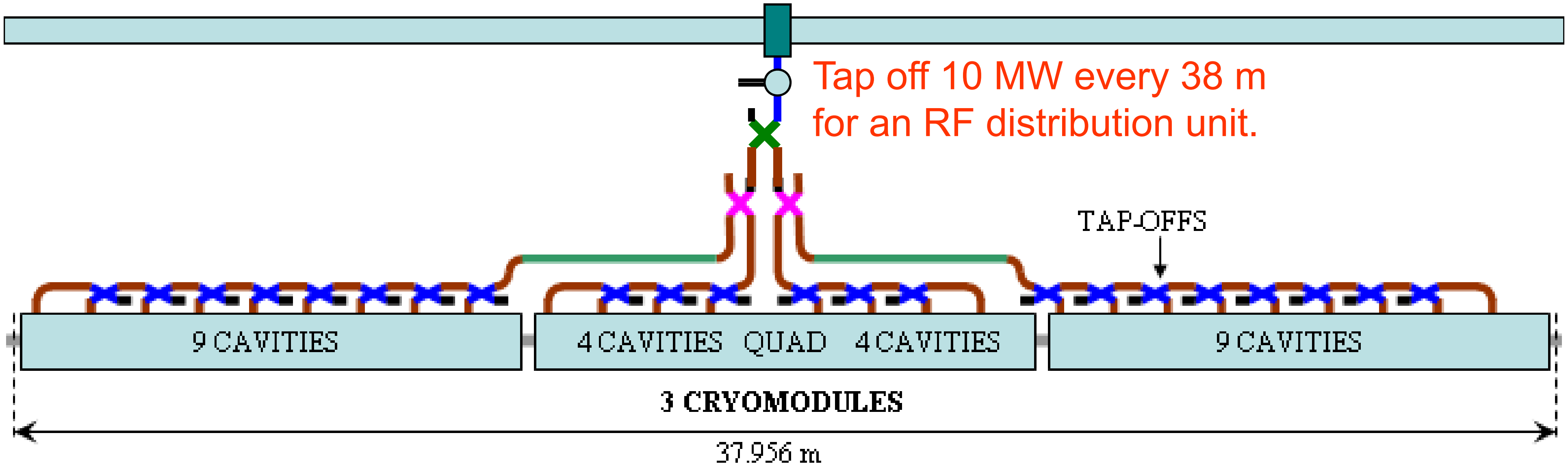
Cluster Layout

Clusters of 70 10 MW klystrons housed, with modulators, in a single building on the surface, feed 350 MW into each of two ~0.5 m diameter evacuated circular waveguides.



Local Distribution
(remains essentially the same)

Each tap-off from the main waveguide feeds 10 MW
through a high power window and probably a circulator or switch
to a local PDS for a 3 cryomodule, 26 cavity RF unit (as shown for baseline).

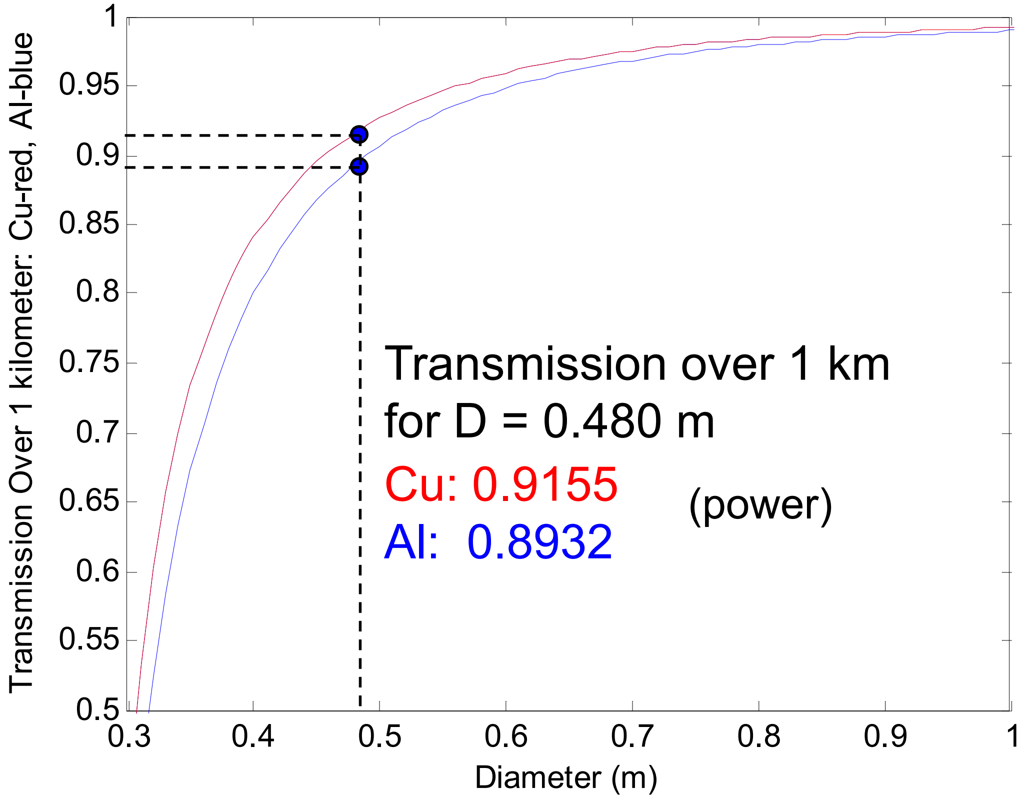


Waveguide Attenuation

Assume smooth copper plated or aluminum walls:

TE°_{01}: $$\alpha = \frac{R_s}{Z_0} \frac{1}{\sqrt{k_0^2 - (\chi_{01}/a)^2}} \frac{\chi_{01}^2}{k_0 a^3}$$

Take D = 0.480 m = 48.0 cm,
between TE_{51} and TE_{22} cutoffs,
6.8% below TE_{02} cutoff



Power Handling

Scaling by pulse width dependence, we should try to keep surface fields below 10 MV/m in couplers.

$$40 \text{ MV/m } (400 \text{ ns}/1.6 \text{ ms})^{1/6} = \sim 10 \text{ MV/m}$$

X-band design goal maximum (40 MV/m) — pulse width ratio (400 ns/1.6 ms) — L-band design goal maximum (~10 MV/m)

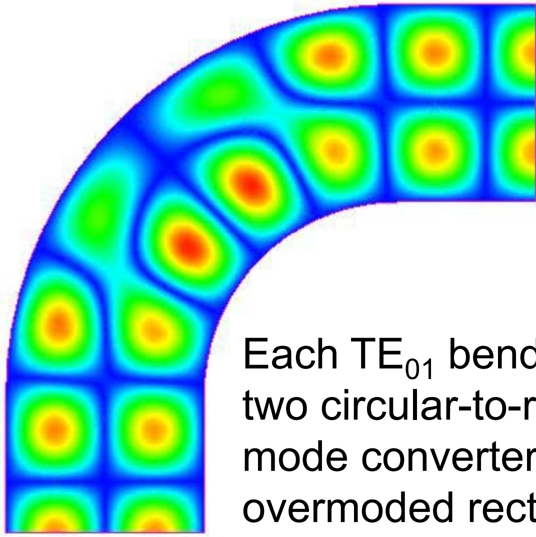
SLAC's 5 cell L-band cavity runs stably with surface fields of 20 MV/m with 1 ms pulses - given the higher power of the ILC system, we are even more conservative by choosing a lower surface field limit (i.e. 10 MV/m).

In the waveguide, 350 MW → ~1.9 MV/m peak, not on wall.

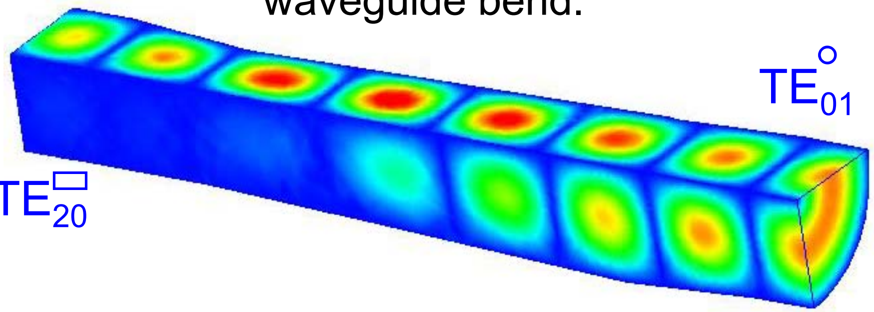
We should be able to keep surface fields below 10 MV/m threshold while coupling in and out 10 MW increments.

Overmoded Bend
(two approaches)

General Atomics high power 90° profiled curvature bend in 44.5 mm corrugated waveguide for TE_{01} mode at 11.424 GHz



Each TE_{01} bend is composed of two circular-to-rectangular mode converters and an overmoded rectangular waveguide bend.



SLAC compact high power 90° bend in 40.6 mm circular waveguide tapered to overmoded rectangular waveguide for TE_{01} mode at 11.424 GHz

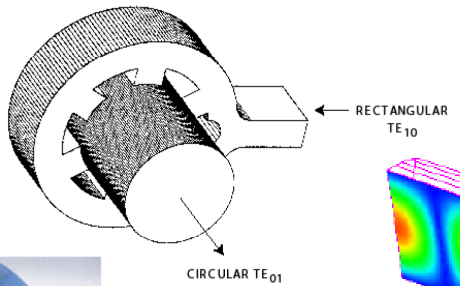
Launchers and Tapoffs

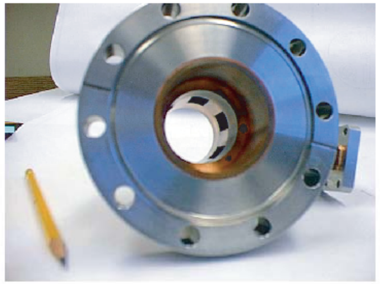
- Need to be designed.
- Could be “wrap-around” based
- 3-port tap-off or 4-port directional couplers?

Co-axial TE_{01} Fractional Tap-offs

X-Band Designs

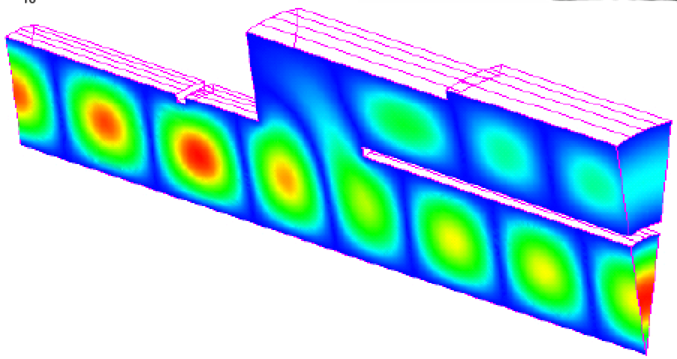
WRAP – AROUND
MODE
CONVERTER

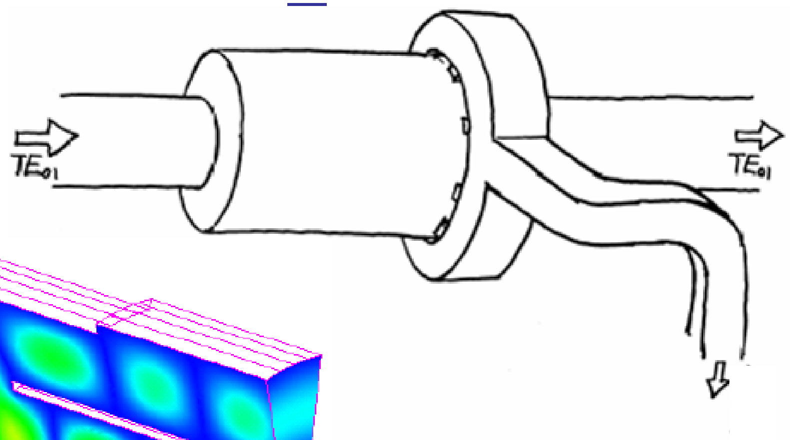


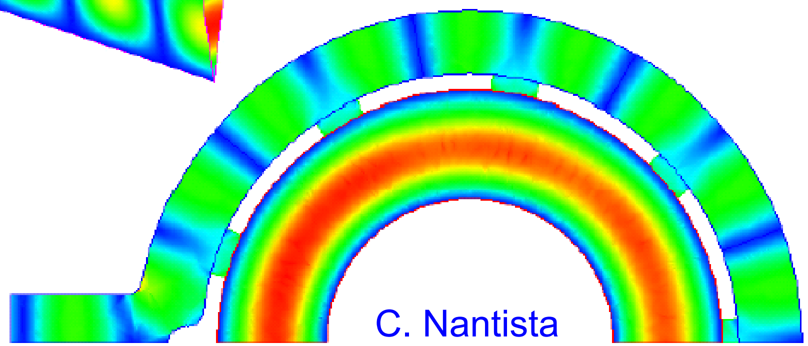


Processed to 485

RF Pulse Length = 1







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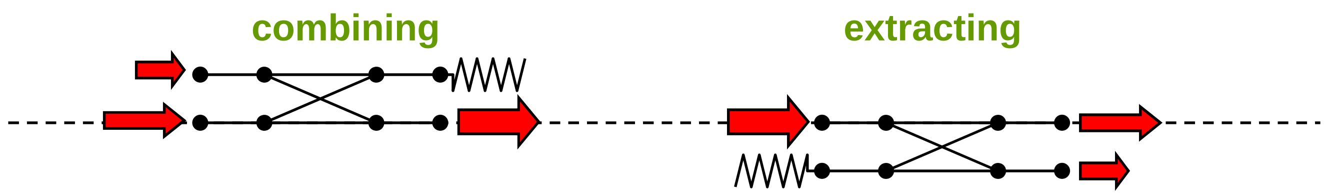
Couplings ranging from 1 to 1/32 are required.

Feeding the power in efficiently at each junction depends on having the right amplitude already flowing in the line and being properly phased relative to it.

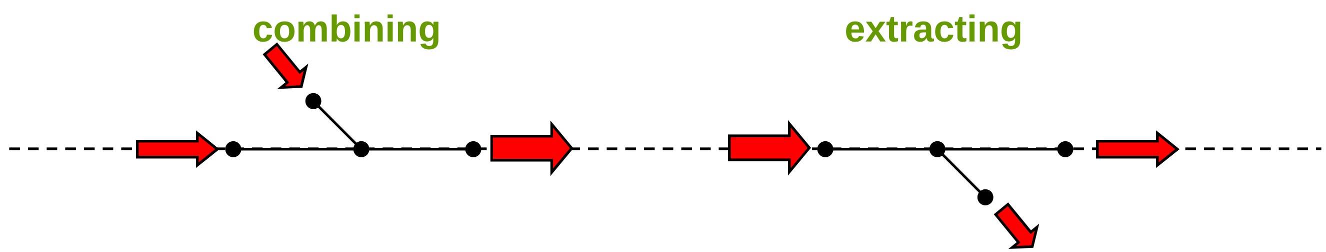
Directional couplers:

more complicated/difficult to design
requires a load on the unused port.



3-port tapoffs:

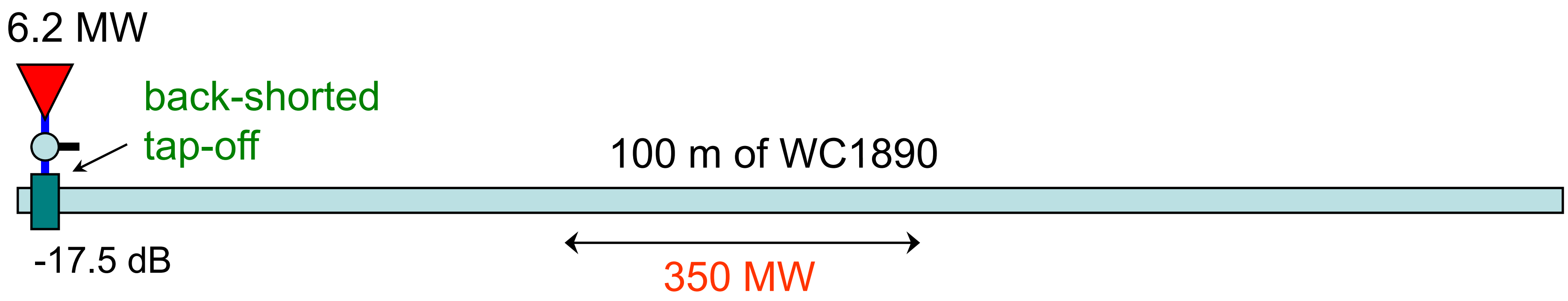
only one port is matched.
for combining, the tap-offs are installed backwards.
reflected/mismatched power goes to circulators.



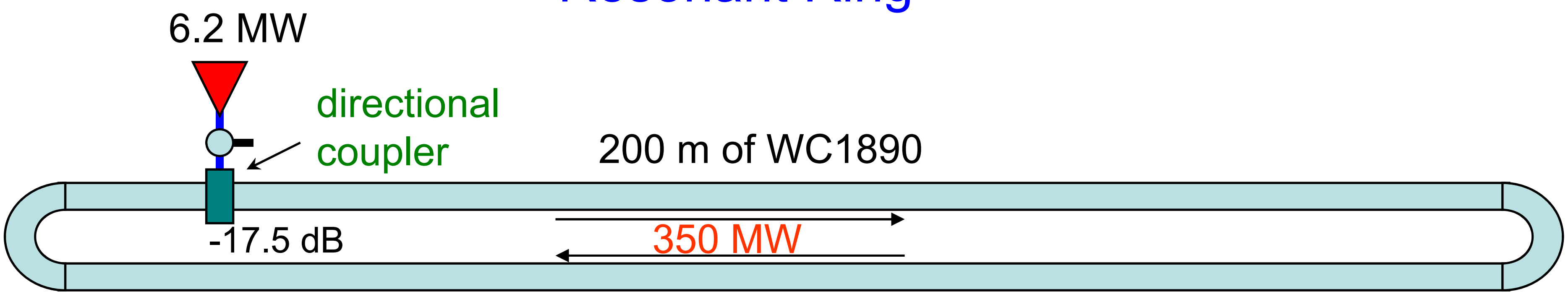
Waveguide (and Bend) Tests

To test the feasibility of the klystron cluster scheme, in terms of power handling, we could build a resonant waveguide and build up the stored energy until it represents traveling waves on the order of 300 MW.

Resonant Line



Resonant Ring



Required Power and Coupling
(for a 100 m line or 200 m ring)

Round trip loss: 1.8 %

Round trip delay time: 823 ns (vs 800 - 9000 ns shutoff time in ILC)

Stored energy: 288 J

Dissipated power: 6.2 MW = input power to produce 350 MW critically coupled

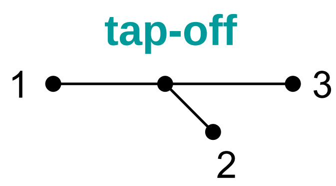
Critical coupling for the emitted field to cancel the reflected field = -17.5 dB.

$T_c = Q_L/\omega = 23.1\ \mu s$

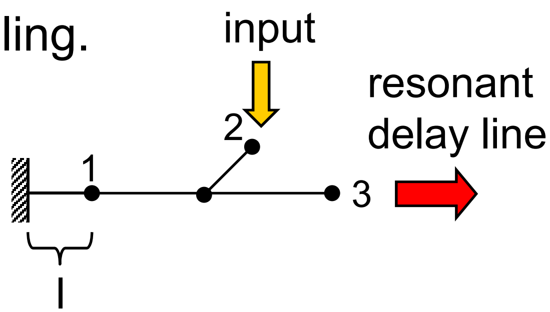
Coupling to a Resonant Line With a 3-Port Tap-Off

The scattering matrix for a lossless 3-port tapoff with coupling C and reference planes chosen to make all elements real can be written:

$$\mathbf{S} = \begin{pmatrix} 0 & \sqrt{C} & \sqrt{1-C} \\ \sqrt{C} & (1-C) & -\sqrt{C(1-C)} \\ \sqrt{1-C} & -\sqrt{C(1-C)} & C \end{pmatrix}$$



Short port 1 at a distance l to reduce to a 2-port coupler at the input of the line and adjust C or l to achieve critical coupling.



$$\mathbf{S}' = \begin{pmatrix} 1-C\left(1+e^{i2\beta l}\right) & -\sqrt{C(1-C)}\left(1+e^{i2\beta l}\right) \\ -\sqrt{C(1-C)}\left(1+e^{i2\beta l}\right) & C\left(1+e^{i2\beta l}\right)-e^{i2\beta l} \end{pmatrix}$$

effective coupling: $\rightarrow C' = \left|\left(1+e^{i2\beta l}\right)^2 C(1-C)\right|$

two knobs, C and l

The smallest coupling distribution tap-off we need is C = 1/32 = 0.03125, or -15.05 dB. From attenuation calculation, we want C' = 0.01783 = -17.49 dB resonant line coupling.

$$(1+\cos 2\beta l)^2 + \sin^2 2\beta l = \frac{C'}{C(1-C)} = 0.5886$$

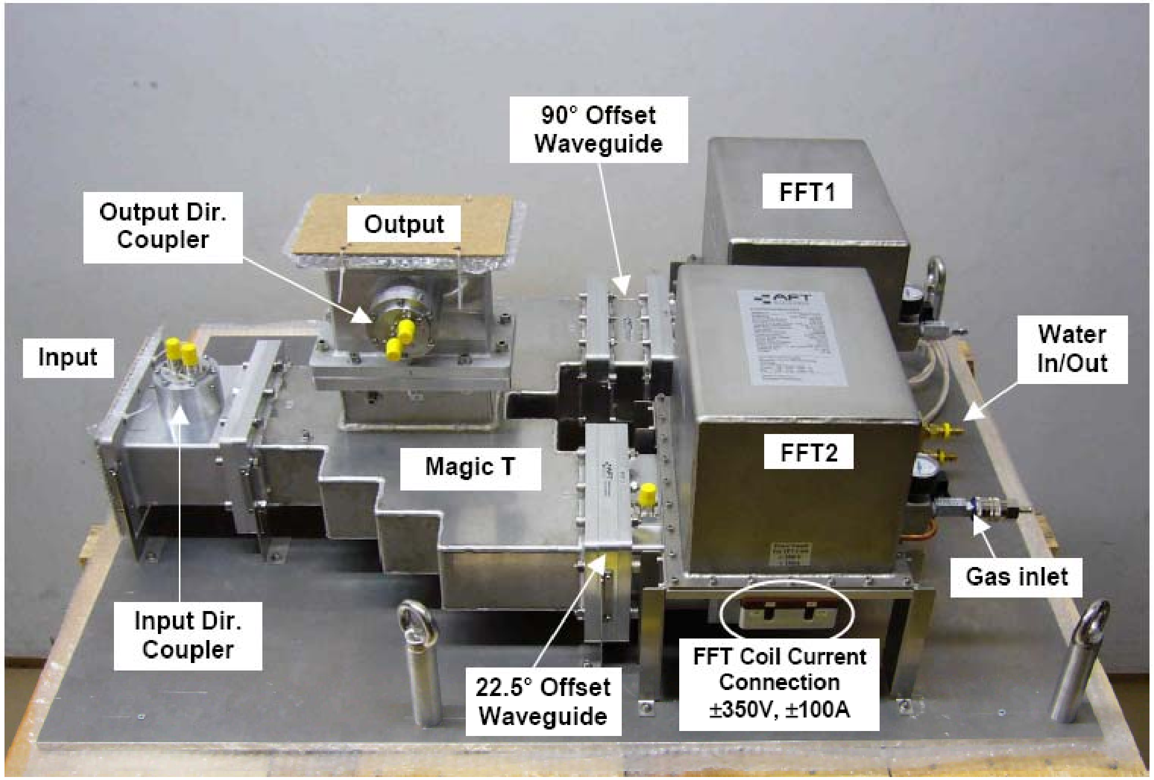
$\rightarrow \beta l$ = 67.65°

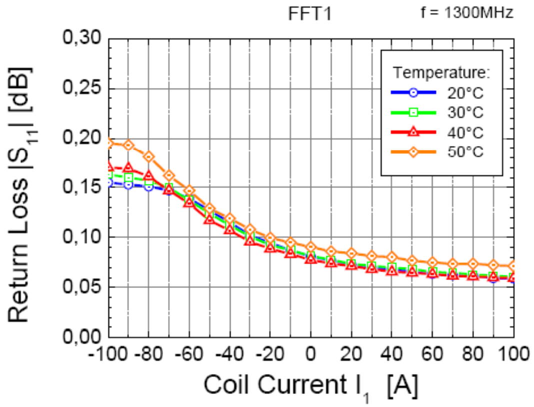
LLRF Control

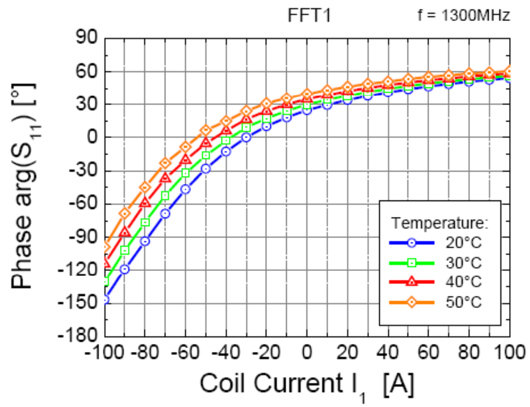
- Use summed vectors from 32*26 cavities (instead of 26) to control common drive power to the klystrons.
- The increased length adds ~ 9 us delay time to the response, so perturbations cannot be very fast (which should be the case as we will know the beam current before the rf pulse in the ILC).
- Assumes uncorrelated, local energy errors are small
  - will investigate by examining FLASH LLRF data during the next accelerator physics run
  - if needed, could add 1 or 2 fast phase/amplitude controllers to each rf unit (to drive the unmatched cavities in the two 9-cavity cryomodules in the ACD scheme).

Fast Amplitude and Phase Control

(AFT prototype for FNAL PD)







Rated for 550 kW at 1.3 GHz and has a 30 us response time