SNS LLRF Reference System

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Oak Ridge National Laboratory

SNS LLRF Reference System

Outline

- Acknowledgement
- What is the SNS LLRF Reference System?
- Specifications and Requirements
- Implementation & Pictures
- Performance
- Future Plans

Acknowledgement

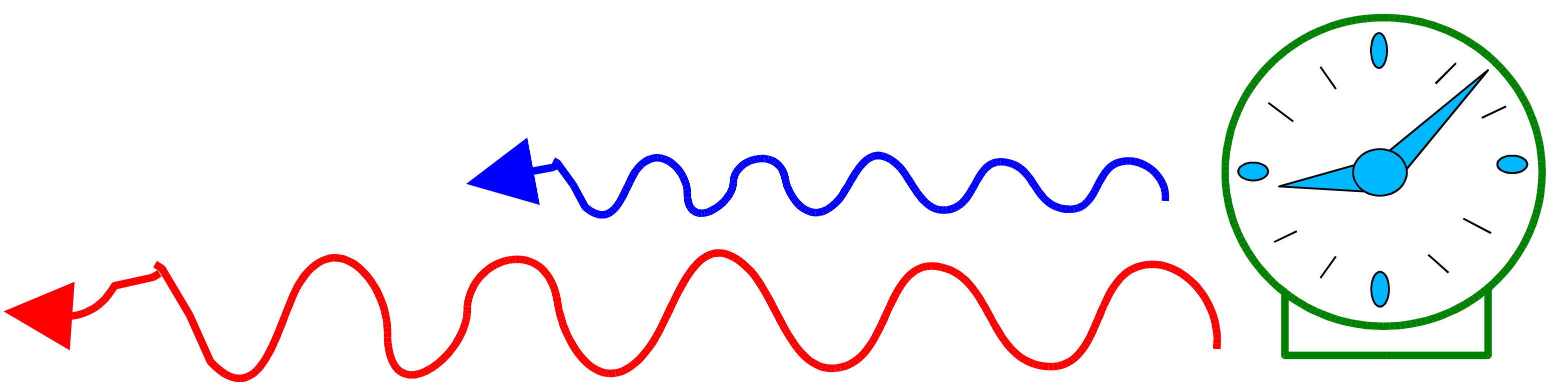
Much thanks and appreciation to the following folks (and others I may have missed):

Mark Champion, Mark Crofford, Taylor Davidson, Ray Fuja, Pam Gurd, Dong-O Jeon, Yoon Kang, Hengjie Ma, Mike McCarthy, Amy Regan, Tony Rohlev, Jim Stovall, Dave Thomson

SNS LLRF Reference System

What is the SNS LLRF Reference System (1 of 2)?

Coherent low noise Reference RF signals provide the ability to control the phase relationships between the fields in the RF cavity structures distributed along the 330 meter long SNS linac.

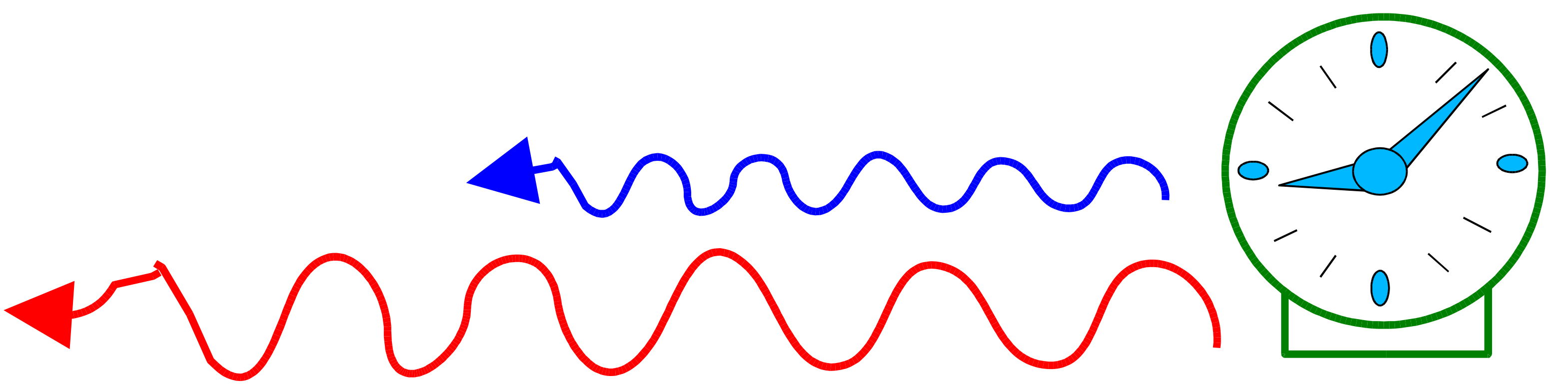


SNS LLRF Reference System

What is the SNS LLRF Reference System (2 of 2)?

The SNS RF Reference System includes:

- Master Oscillator (MO)
- Local Oscillator(LO) distribution
- Reference RF distribution



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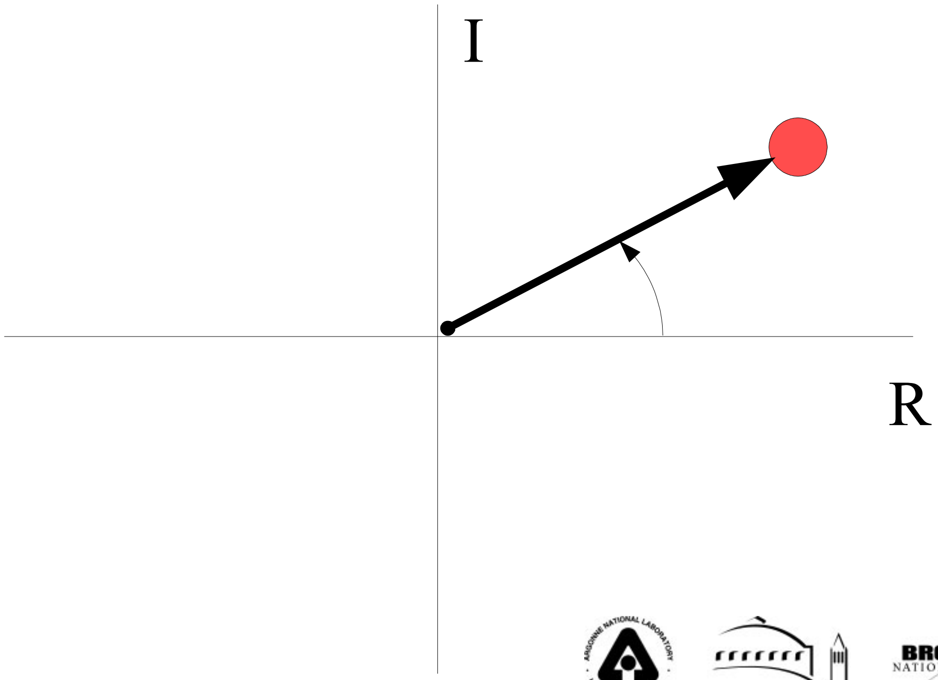
LLRF Specifications (1 of 4)

Cavity Field Control

- Amplitude +/- 1.0 % Max Steady State
- Phase +/- 1.0 degree Max Steady State



(Target 1%, 1 Degree)

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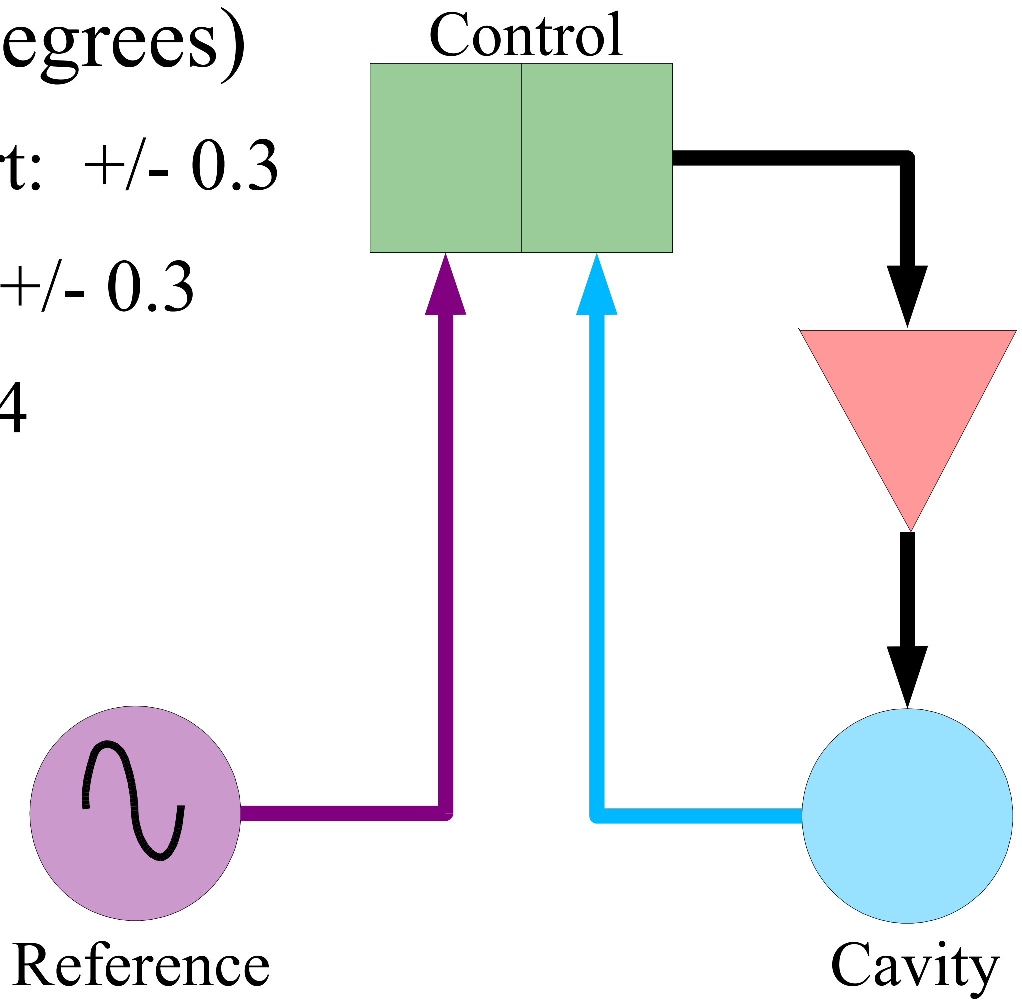
LLRF Specifications (2 of 4)

Phase Error Budget (degrees)

- Reference RF Transport: +/- 0.3
- Cavity RF Transport: +/- 0.3
- Control System: +/- 0.4
- Total: +/- 1.0



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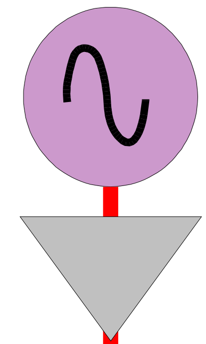
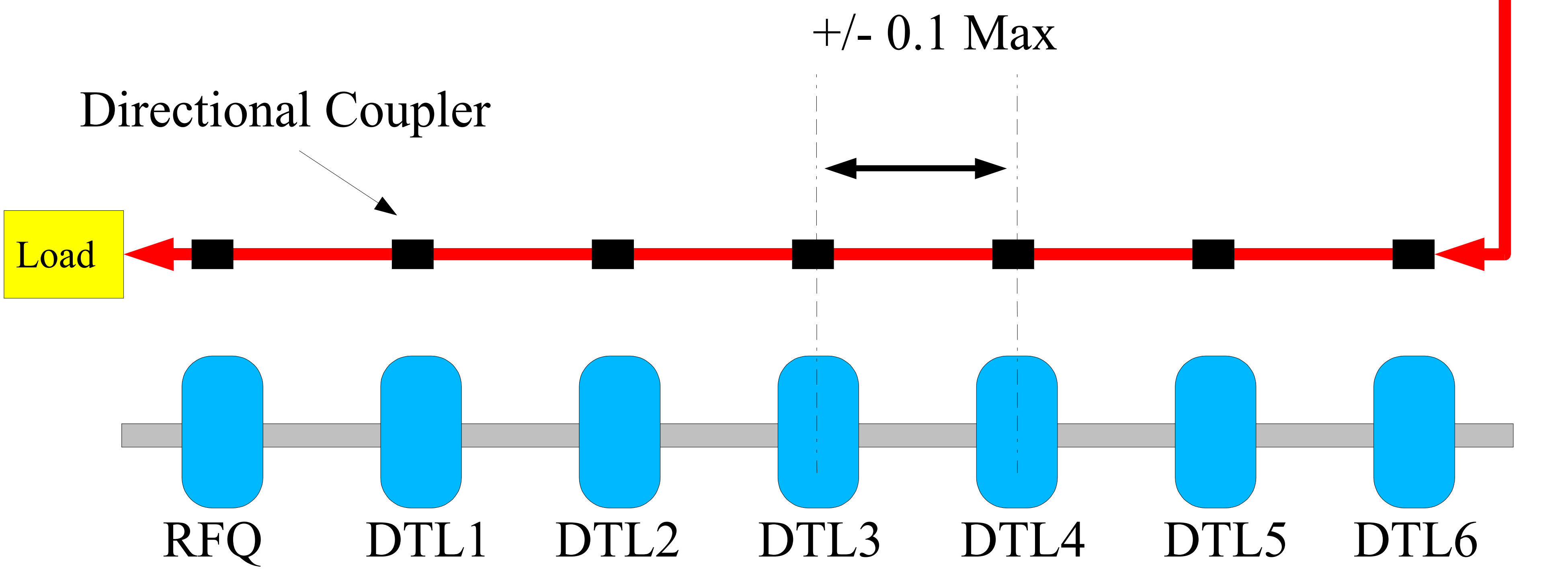
LLRF Specifications (3 of 4)



Reference Line Phase Stability between adjacent cavities +/- 0.1 degree Max, not to exceed +/- 2.0 degrees between any two points in the linac



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LLRF Specifications (4 of 4)

Linac tunnel is a high radiation environment, therefore no Teflon is allowed in the tunnel!

- All LLRF system components in tunnel need to be specified/custom engineered/fabricated without use of Teflon
- Requirement influenced system design

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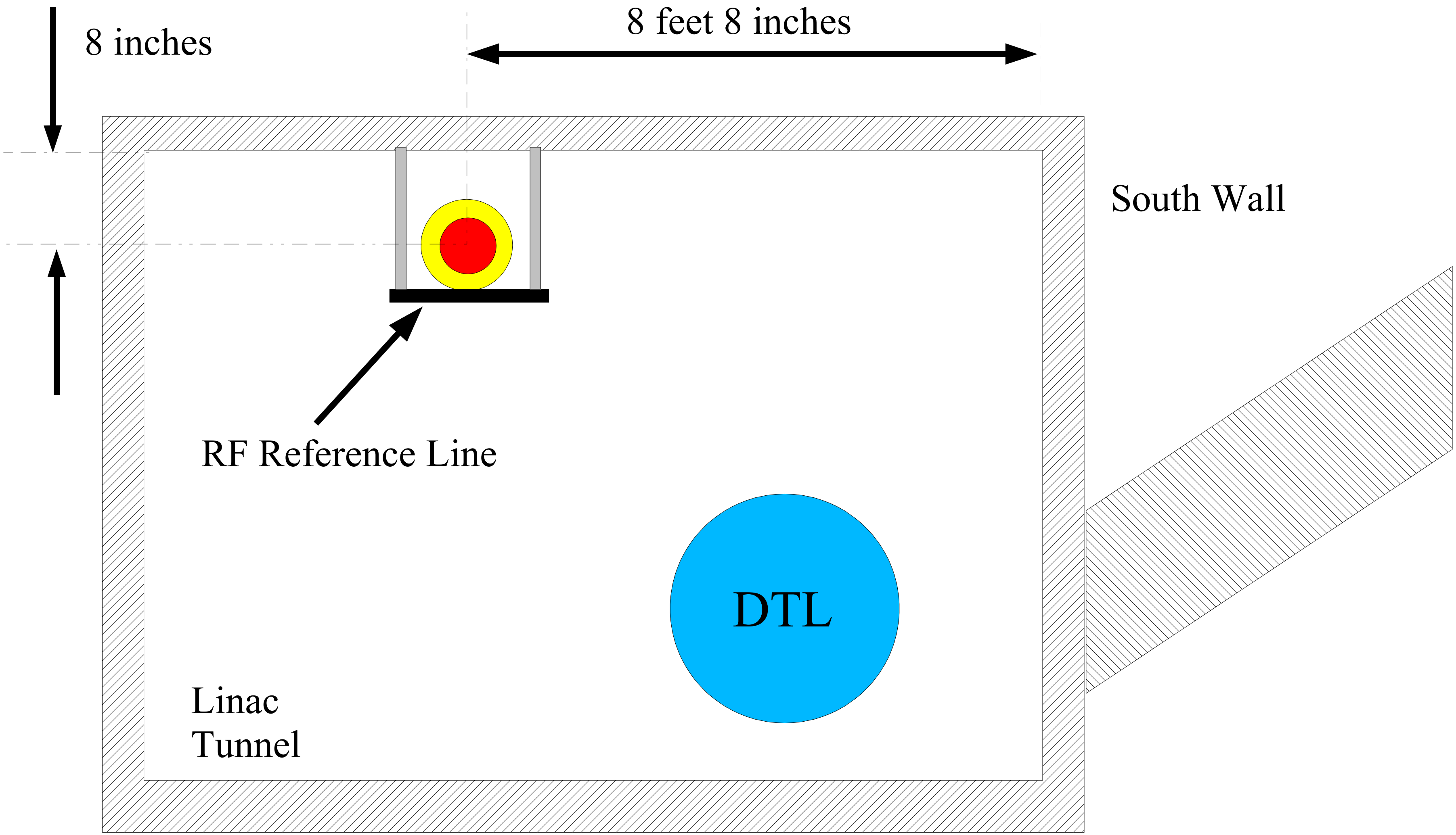
Implementation (1/5)



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Implementation (2/5)

2003

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Implementation (3/5)

2005

BROOKHAVEN NATIONAL LABORATORY

Jefferson Lab

Los Alamos NATIONAL LABORATORY

ornl

BERKELEY LAB

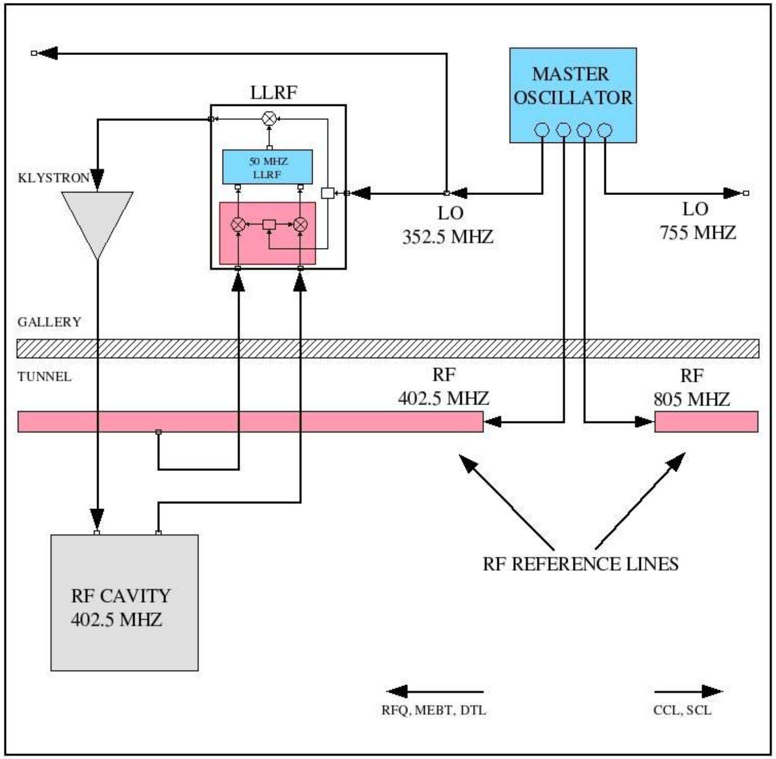
SNS LLRF Reference System

Reference System Complete and Operational

(4/5)

- 402.5 MHz RF Section (11 Systems)
- 805 MHz RF Section (85 Systems)

Successful Linac Commissioning!



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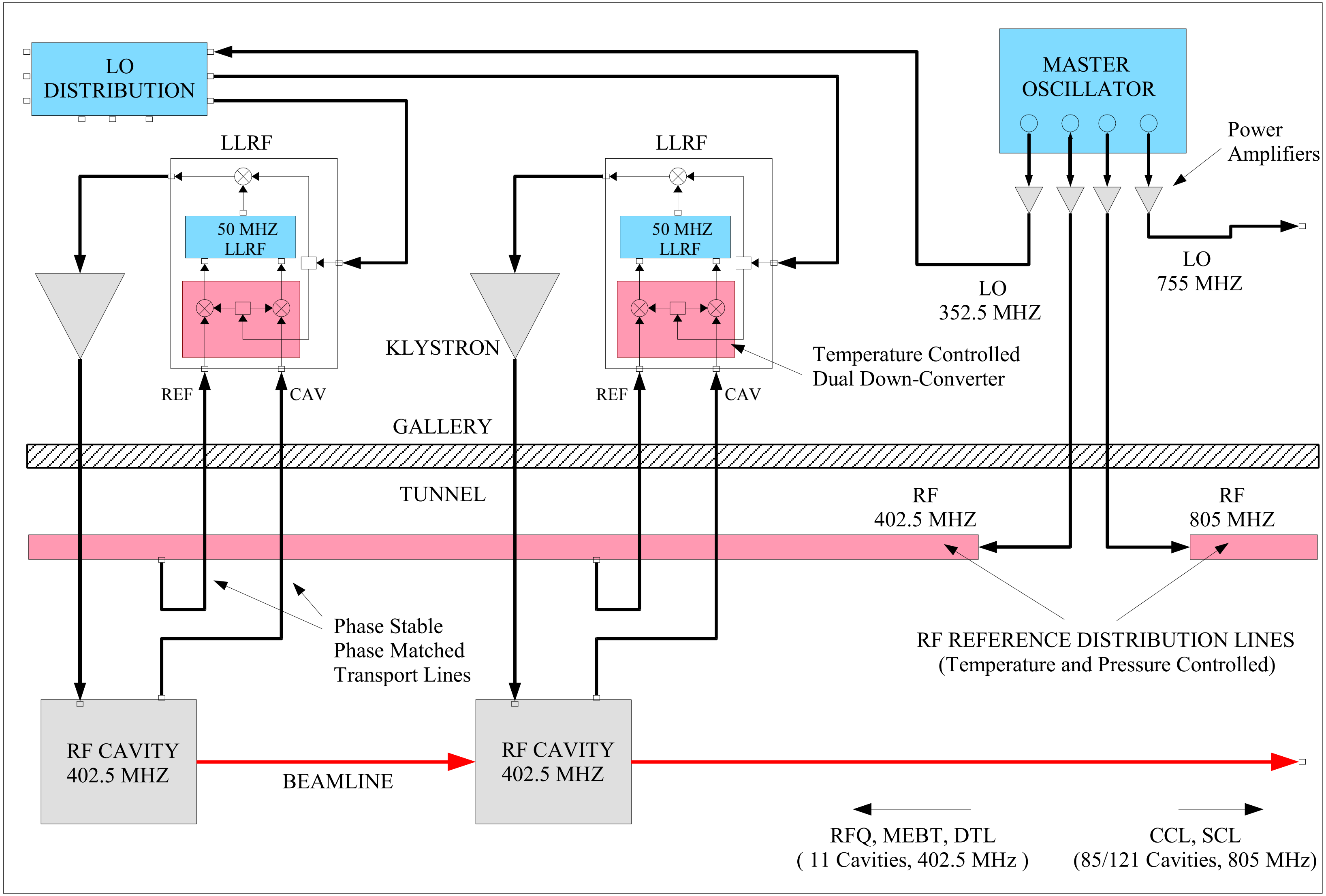
Implementation (5/5)



SNS LLRF Reference System

Master Oscillator (1 of 3)

Produced by Wenzel Associates.

- Direct Analog Design
  - Produces Phase Coherent Output Signals
  - Low jitter, excellent close-in phase noise characteristics
- Rack mount chassis located in Master Oscillator Rack between DTL and CCL

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Master Oscillator (2 of 3)

Internal Reference:	Premium 10 MHz-SC ULN (501-04538E)
Output Frequencies (1 EA):	2.5 MHz, +20 dBm 10 MHz, +20 dBm 352.5 MHz, +20 dBm 402.5 MHz, +20 dBm 755 MHz, +20 dBm 805 MHz, +20 dBm

Phase Noise:	2.5 MHz	10 MHz	352.5 MHz	402.5 MHz	755 MHz	805 MHz
1 Hz	-117 dBc	-105 dBc	-74 dBc	-72 dBc	-67 dBc	-67 dBc
10 Hz	-144 dBc	-132 dBc	-101 dBc	-99 dBc	-94 dBc	-94 dBc
100 Hz	-154 dBc	-142 dBc	-111 dBc	-109 dBc	-104 dBc	-104 dBc
1 kHz	-155 dBc	-147 dBc	-118 dBc	-117 dBc	-114 dBc	-114 dBc
10 kHz	-155 dBc	-147 dBc	-118 dBc	-117 dBc	-114 dBc	-114 dBc

Harmonics:	-40 dBc
Spurious:	-80 dBc

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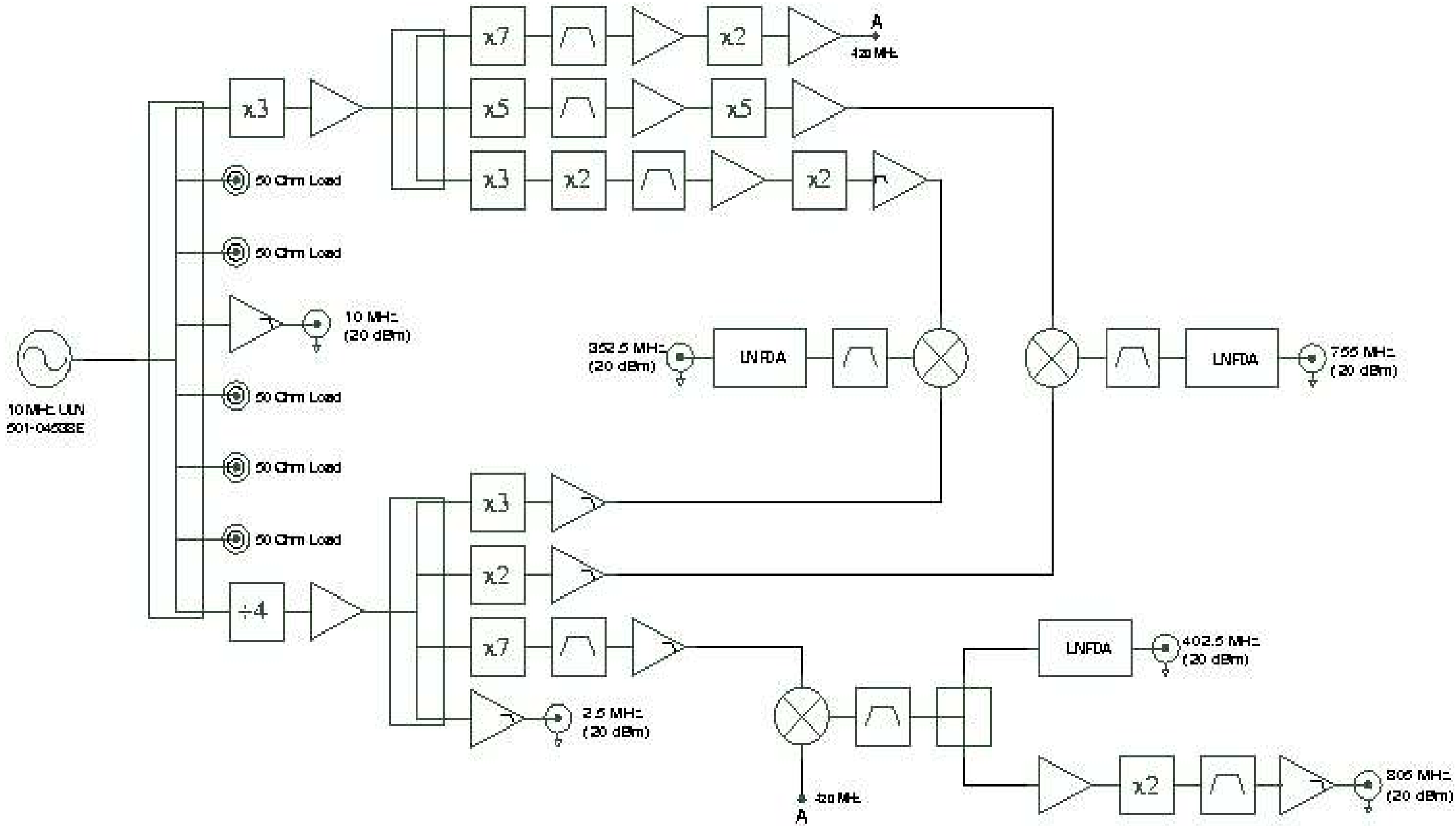
Master Oscillator (3 of 3)



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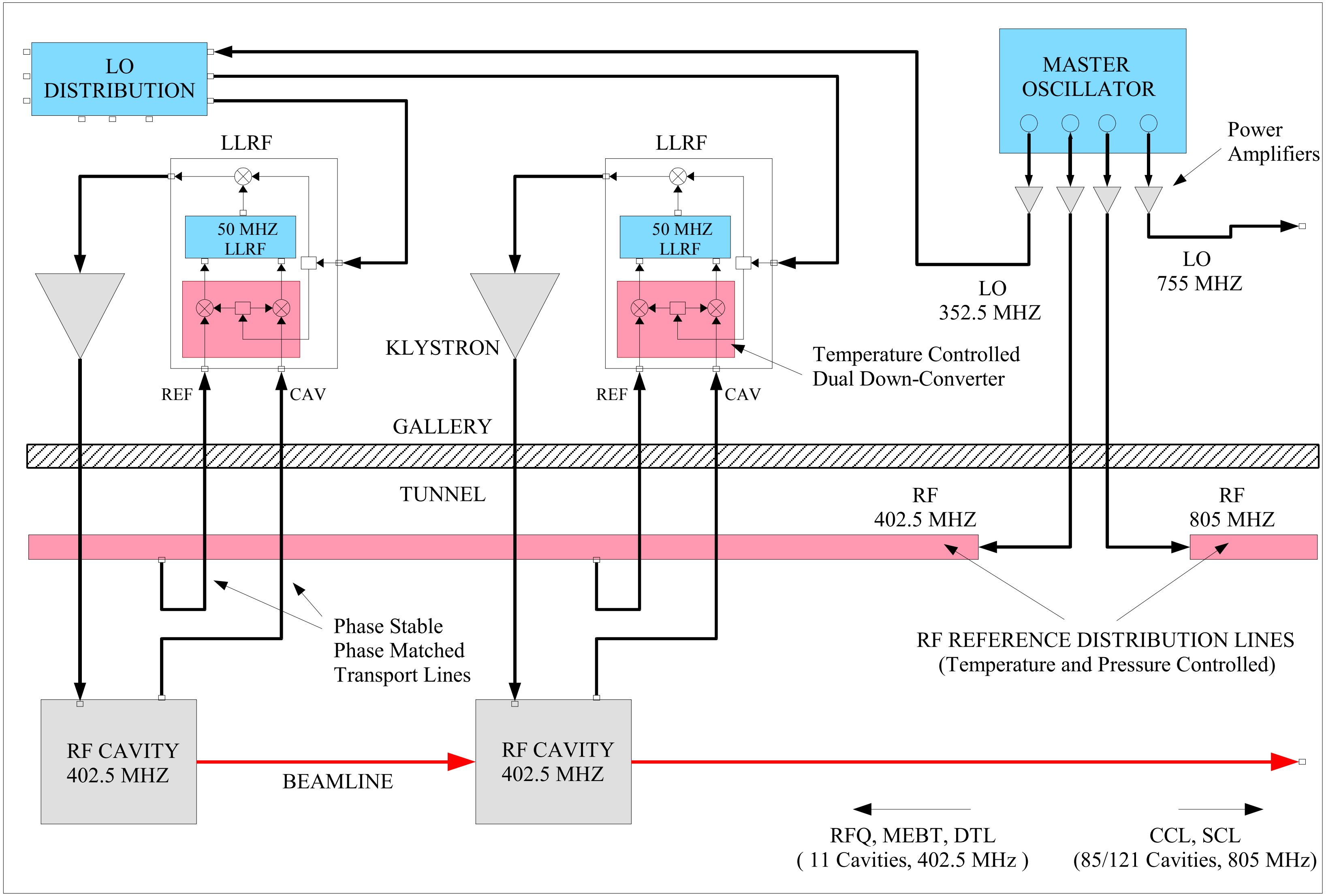
LO Distribution



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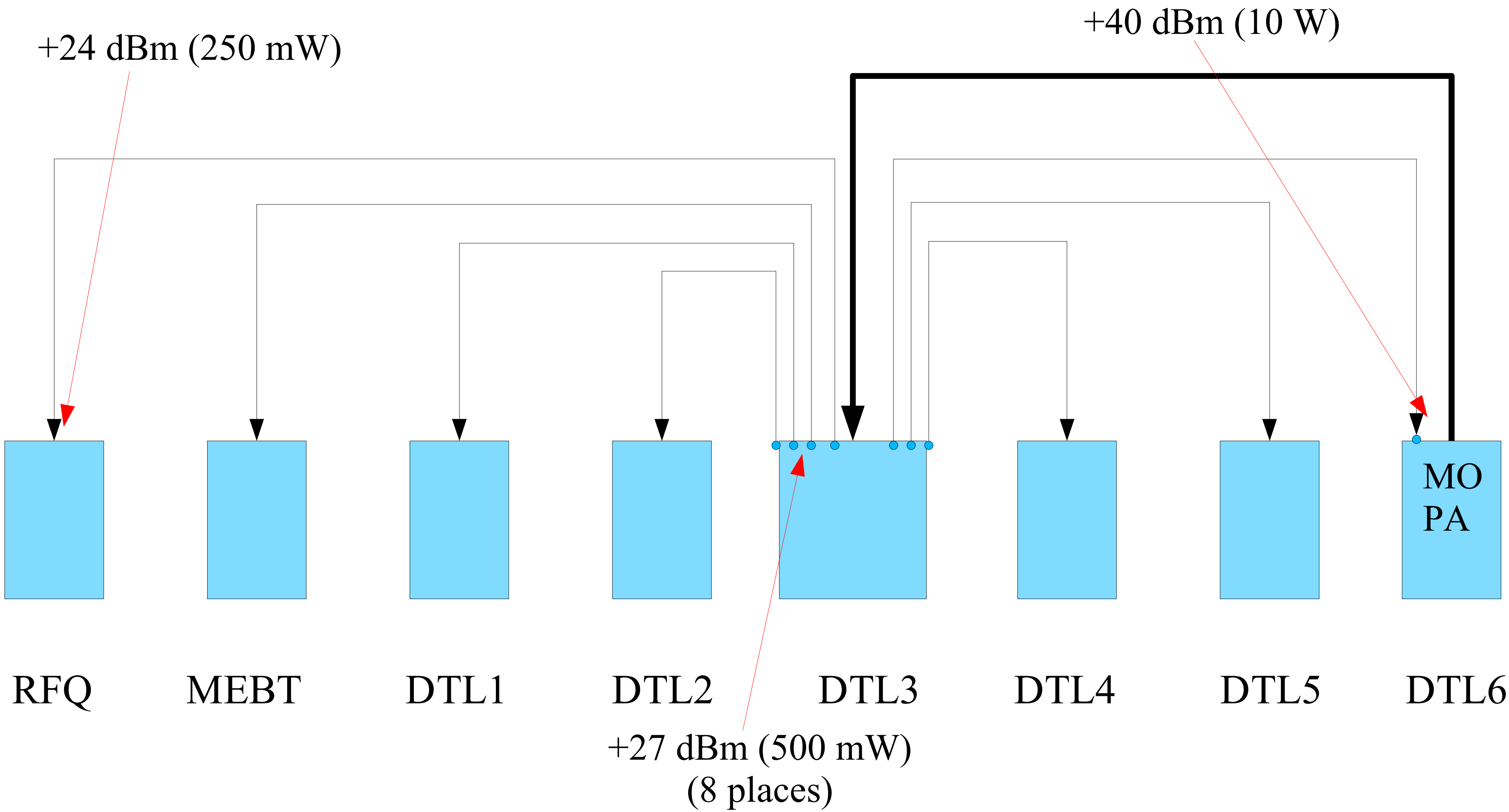
352.5 MHz LO Distribution



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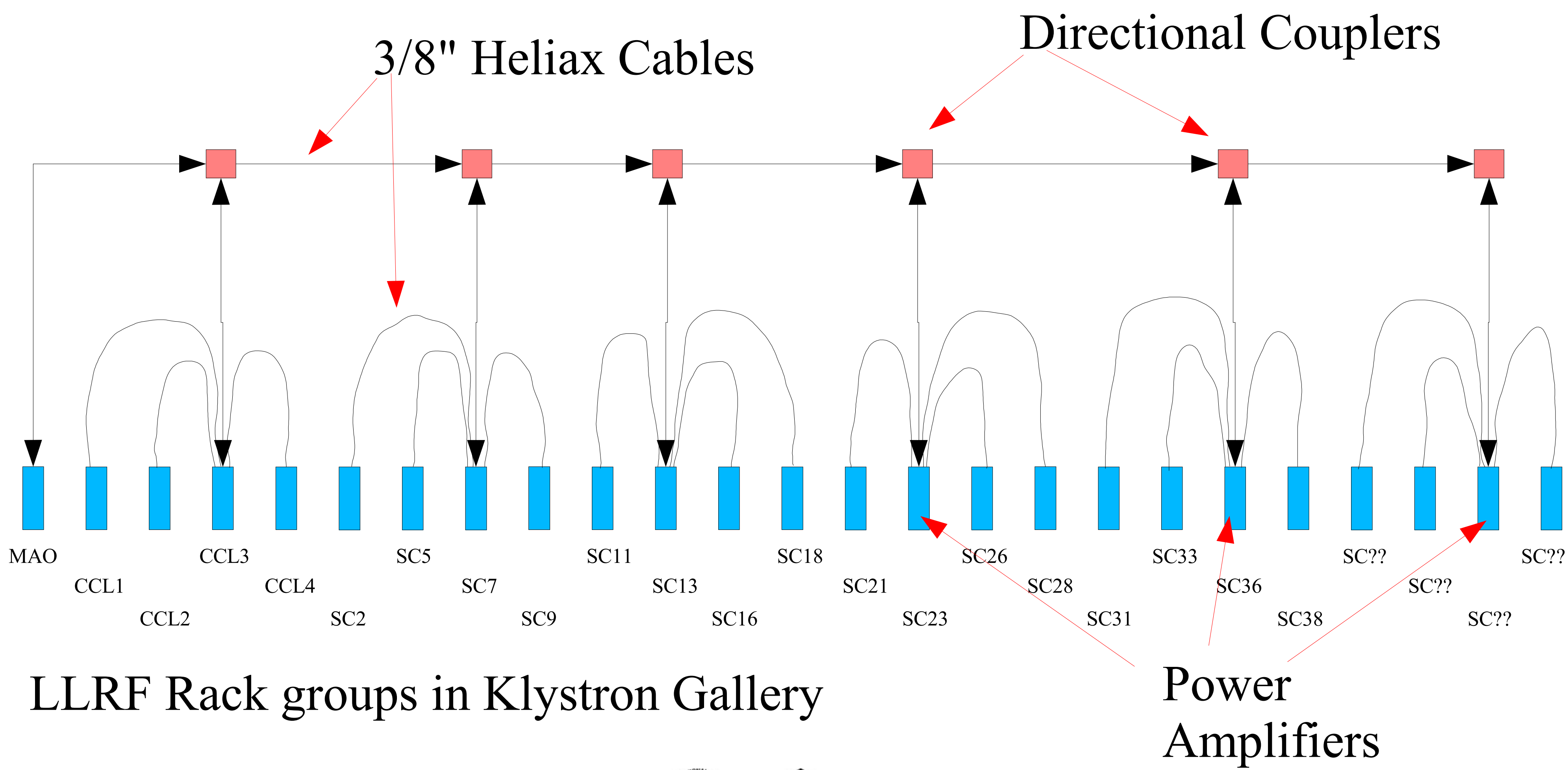
755 MHz LO Distribution

+31 dBm to Each LLRF Rack Group, 3 Way split,
+24dBm to Each Dual Down-Converter



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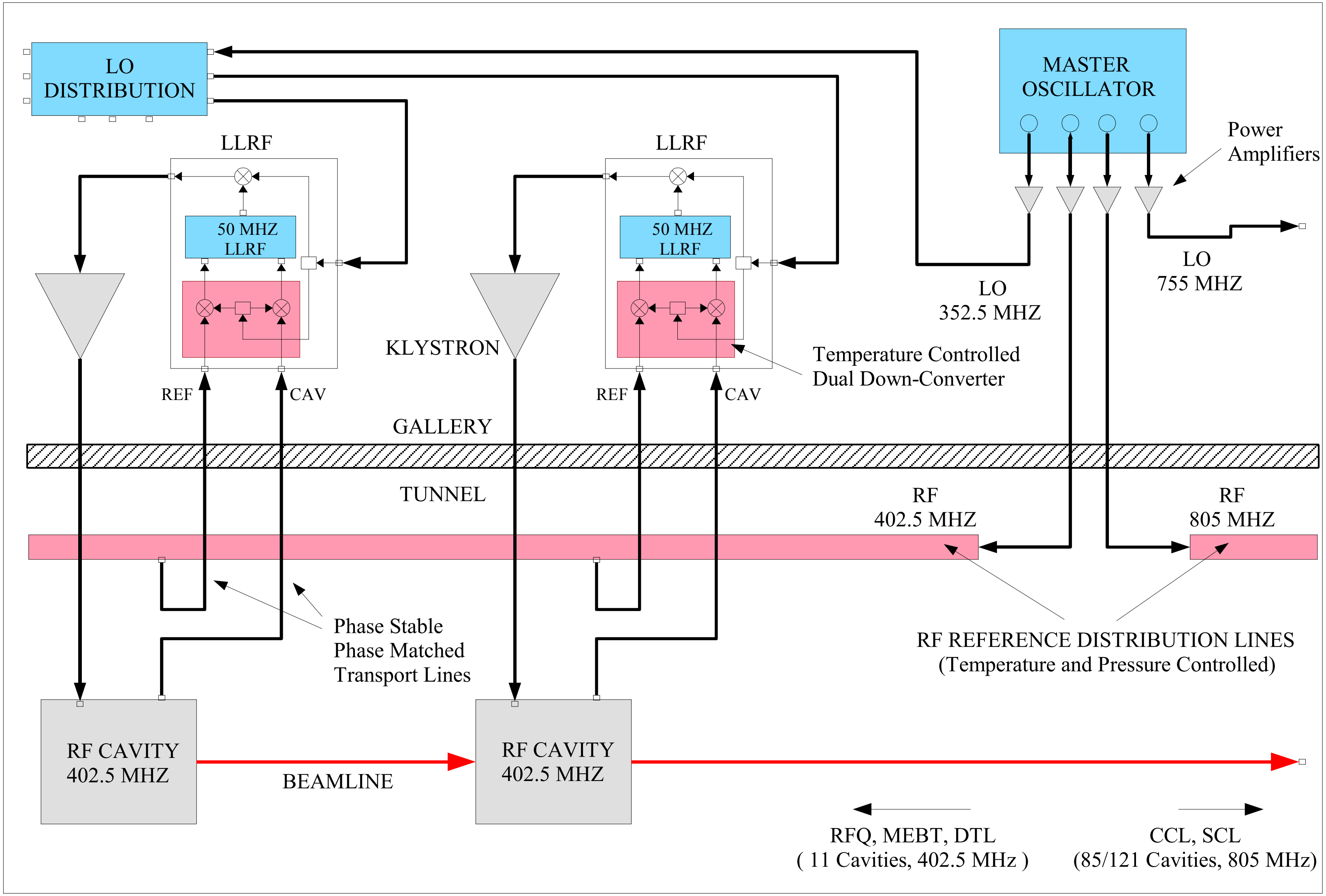
Reference RF Distribution



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805 MHz Reference RF Line in Linac Tunnel

2005

SNS LLRF Reference System

Phase Stable 402.5 and 805 MHz Reference RF Signal Distribution

- Power Amplifiers
- Feed Lines
- Distribution Lines in Tunnel
- Temperature Control System
- Pressure Control System
- Transport Lines to LLRF Control System
- Temperature Controlled Dual Down-Converter

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Phase Stable 402.5 and 805 MHz Reference RF Signal Distribution

Power Amplifiers (PA's)

- Rack mount chassis in Master Oscillator Rack
- Class A, 40 dB Gain
- Noise Figure < 8.6 dB
- 402.5 MHz PA Max Output: 50 Watts
- 805.0 MHz PA Max Output: 200 Watts

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Phase Stable 402.5 and 805 MHz Reference RF Signal Distribution

Feed Lines from Master Oscillator Rack to Tunnel

- Feed Point at DTL to CCL Transition: 402.5 MHz signal goes upstream, 805 MHz signal goes downstream
- 7/8” RFS Cellflex Phase Stabilized Cable (phase temperature coefficient close to zero)
- Minimum Possible Length (20 m) for 805 MHz feed Line

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Phase Stable 402.5 and 805 MHz Reference RF Signal Distribution

Distribution Lines in Linac Tunnel

- 3-1/8” Rigid Copper Coaxial Transmission Line
- Propagation Velocity = 0.99 c
- Multi Point Grounding
- No Bellows or Flexible Joints
- No Teflon

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Phase Stable 402.5 and 805 MHz Reference RF Signal Distribution

Distribution Lines in Linac Tunnel

- One Directional Coupler for each RF Cavity*
  - 11 Cavities @ 402.5 MHz
  - 85 Cavities @ 805 MHz)
- 402.5 MHz Line is 140 feet in Length
- 805.0 MHz Line is 941 feet in Length
- Input VSWR = 1.04:1 for 402.5 MHz Line
- Input VSWR = 1.15:1 for 805.0 MHz Line

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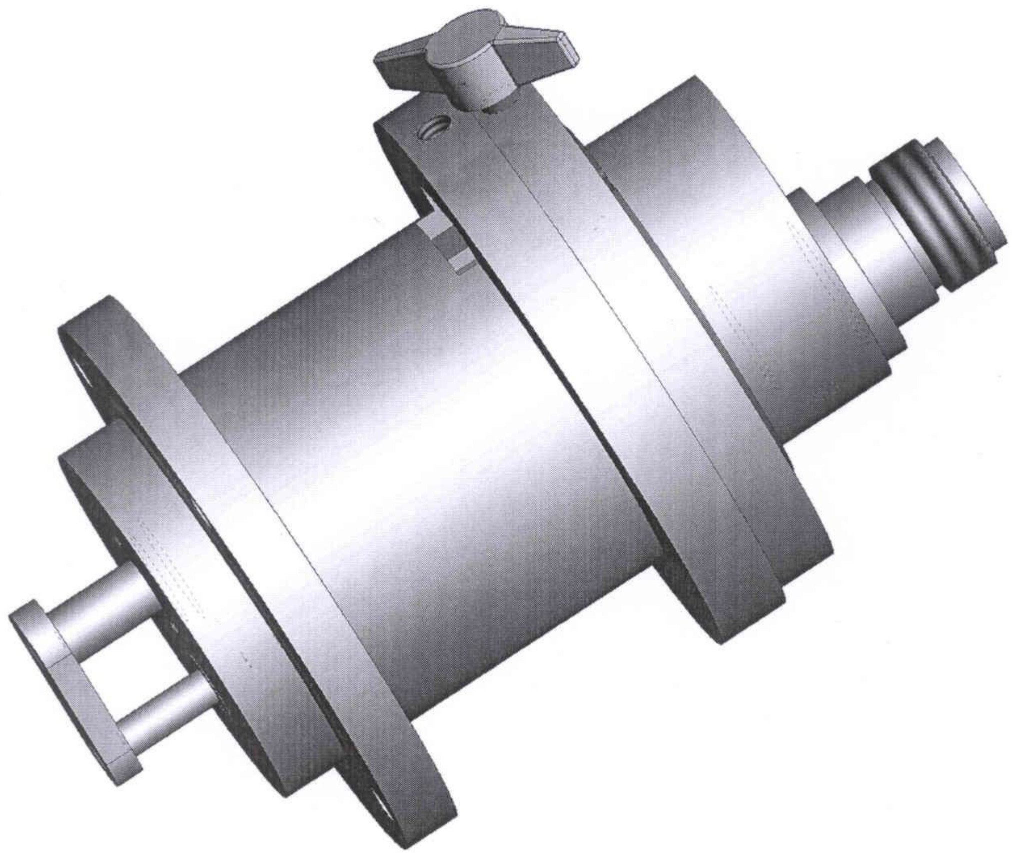
Reference RF Adjustable Single Directional Coupler



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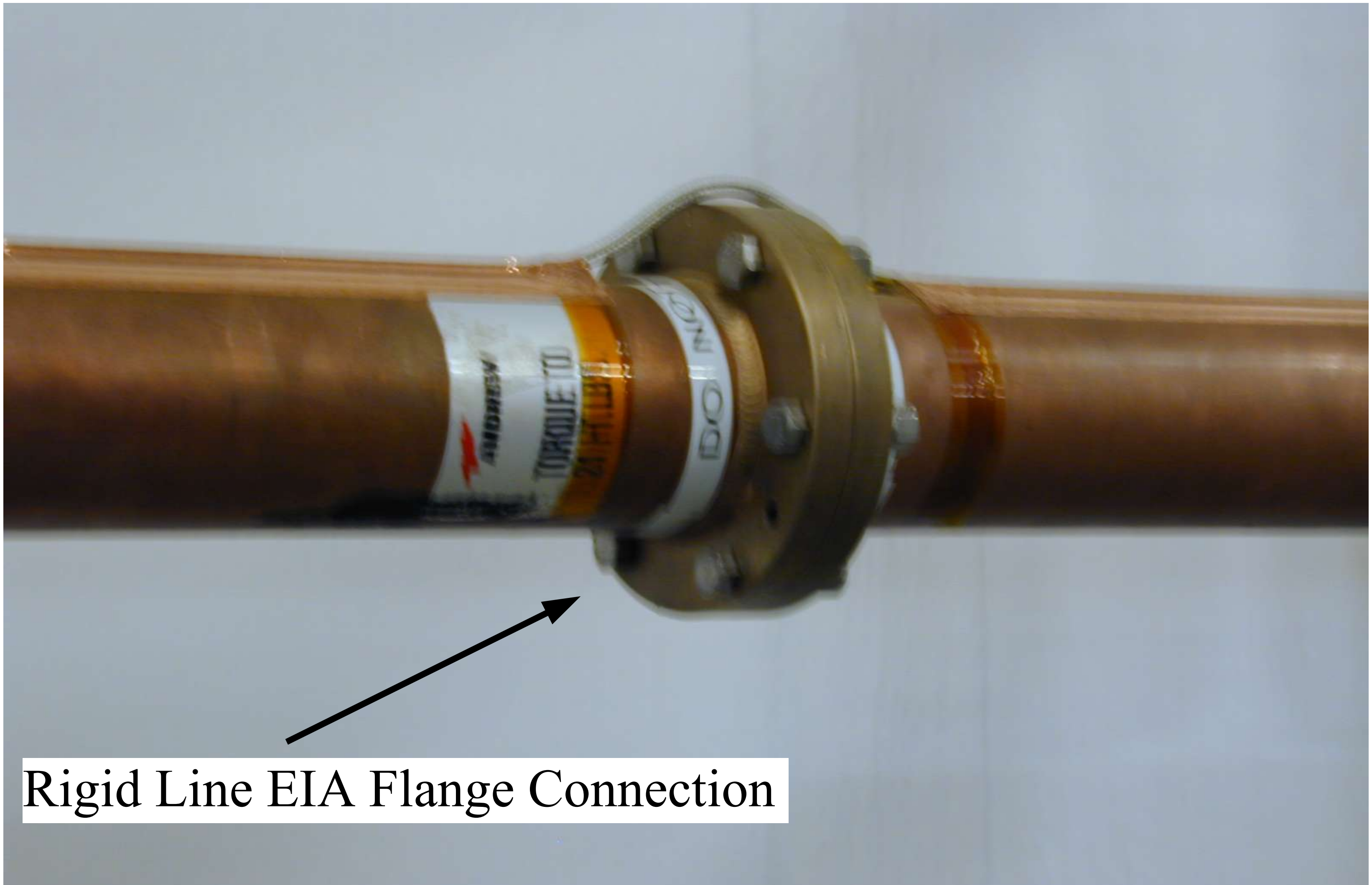
Reference RF 3-1/8” Rigid Coaxial Transmission Line



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Temperature Control System (1 of 3)

- Reference RF Distribution Lines in tunnel are temperature regulated at 100 degrees F +/- 0.1F using PID controllers in LLRF racks
- Reference RF Distribution Lines are divided into 28 separate temperature control zones
  - Each zone is less than 40 feet in length
  - Each zone uses two 4 wire RTD temperature sensors (one for active control, one as a monitor)
  - Temperature Controller Readbacks available in EPICS

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Temperature Control System (2 of 3)

- Heat tape applied with copper tape and Kapton tape
- Rigid Line insulated with commercial 1.5" thick fiberglass pipe insulation sections each 3 feet long
- Visual indicator installed at end of heat tape
- Overtemp protection

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Temperature Control System chassis prototype

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Pressure Control System

- Copper 3-1/8" Rigid Line has air dielectric
- Pressurized to 2.0 psig using Dry “Instrument” Air system (Dew Point -40 C) and Precision Regulator
- Pressure Monitor System uses very high accuracy absolute pressure transducers; pressure readbacks available in EPICS

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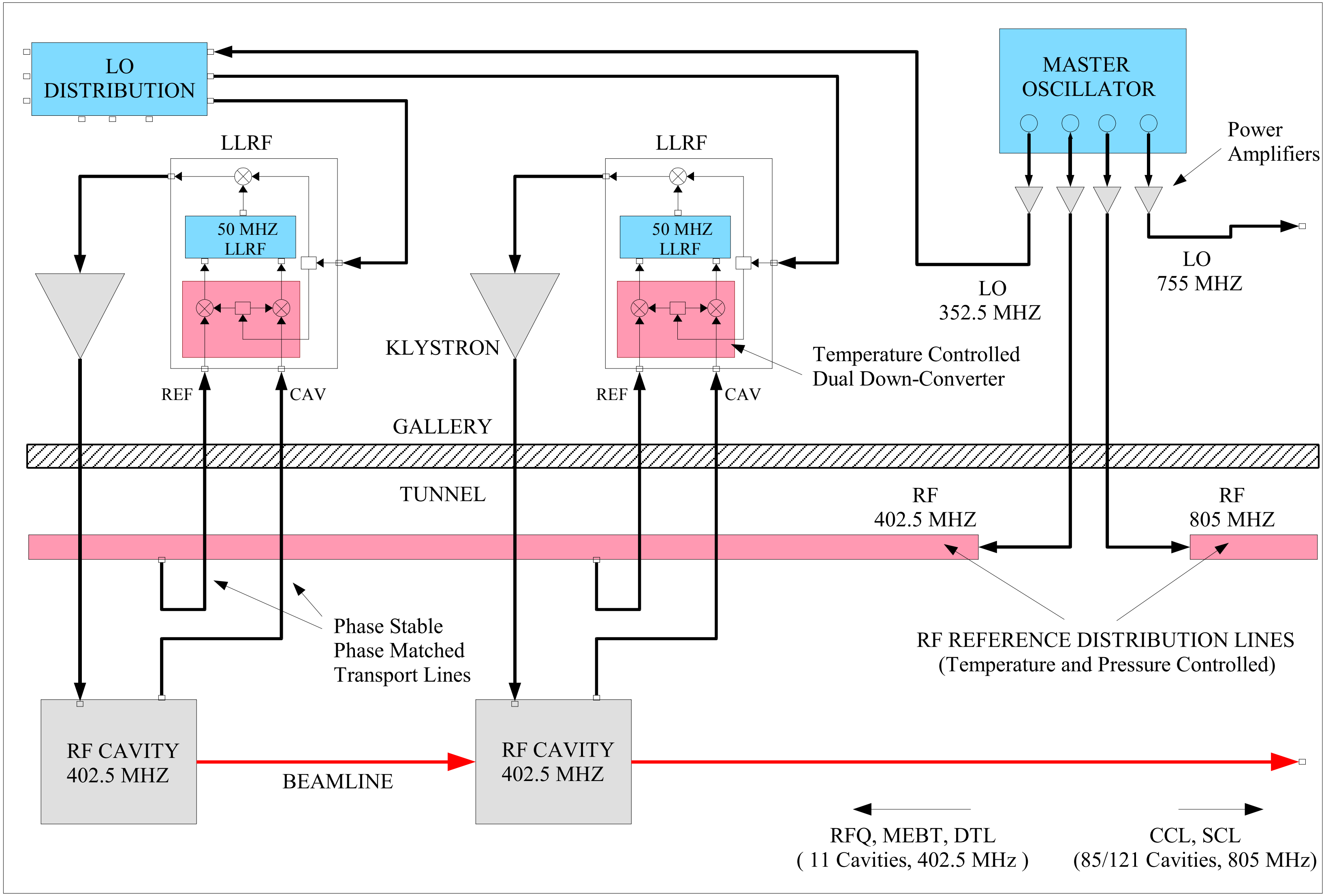
RF Transport



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Reference RF and Cavity RF Transport

- Cavity RF and Reference RF signals Transported from Tunnel to LLRF rack using heat treated phase matched 3/8" Heliax cables.
- Phase/Temperature coefficient is -4 to +3 PPM/C (very stable)
- Propagation Velocity = 0.88 c
- Solid corrugated copper outer conductor provides excellent shielding (> 90 dB isolation).
- Special radiation resistant high quality captivated Type N-F connectors made by Spinner
- Low Differential Phase Errors

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LLRF Analog Chassis

- Located in LLRF racks
- Performs Down-conversion of Reference RF and Cavity RF signals (402.5 MHz) to IF signals (50 MHz) for LLRF control system
- Chassis is Temperature Controlled to minimize phase drifting in analog components
- Uses MiniCircuits ZFM 4H level 17 double balanced mixers

SNS LLRF Reference System

Future

- Reference System is ready for Energy Upgrade (36 additional SCL cavities)
- Multiplexed Single Path Reference system successfully tested using production SNS LLRF system

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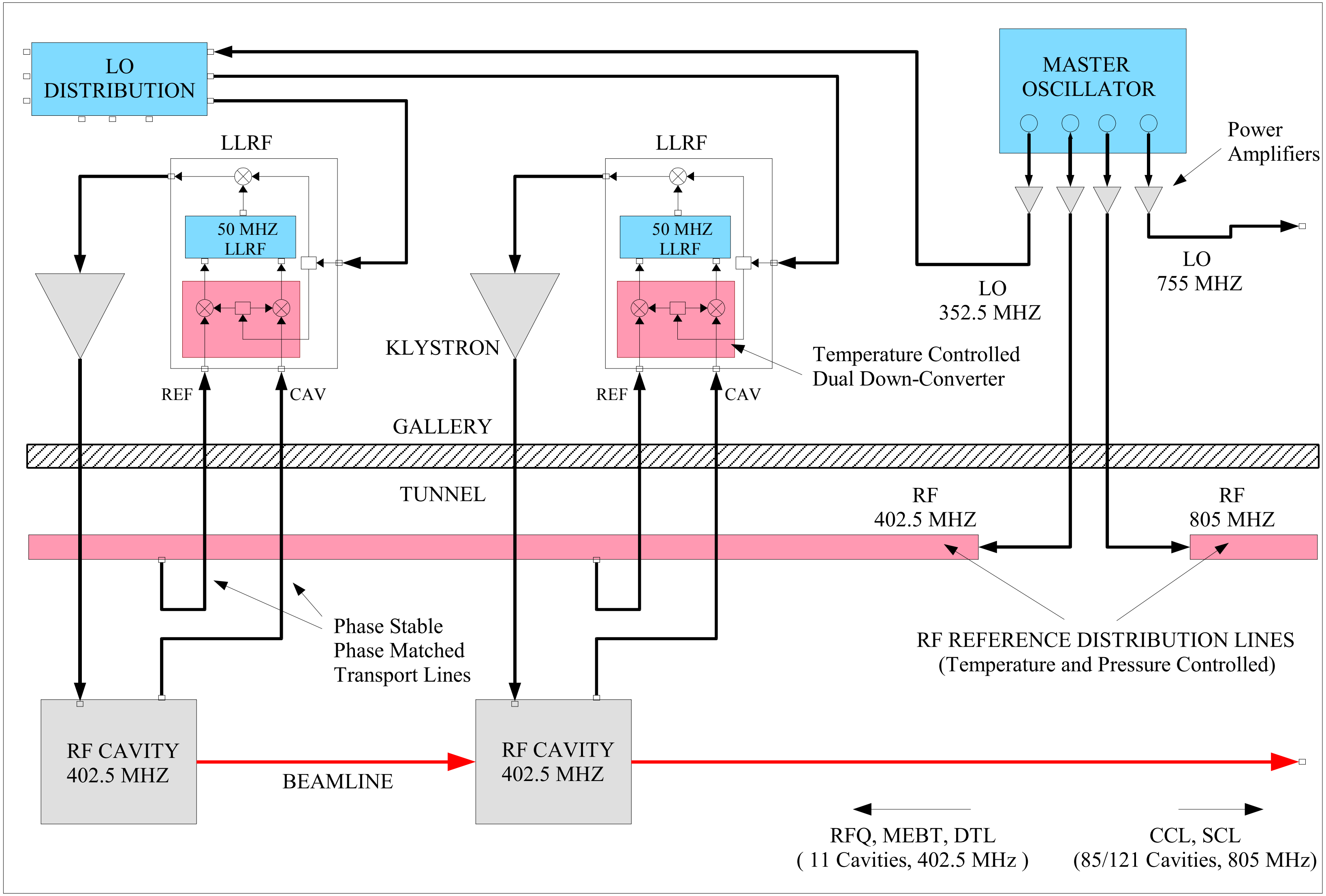
Standard Dual Channel Reference/Cavity Setup



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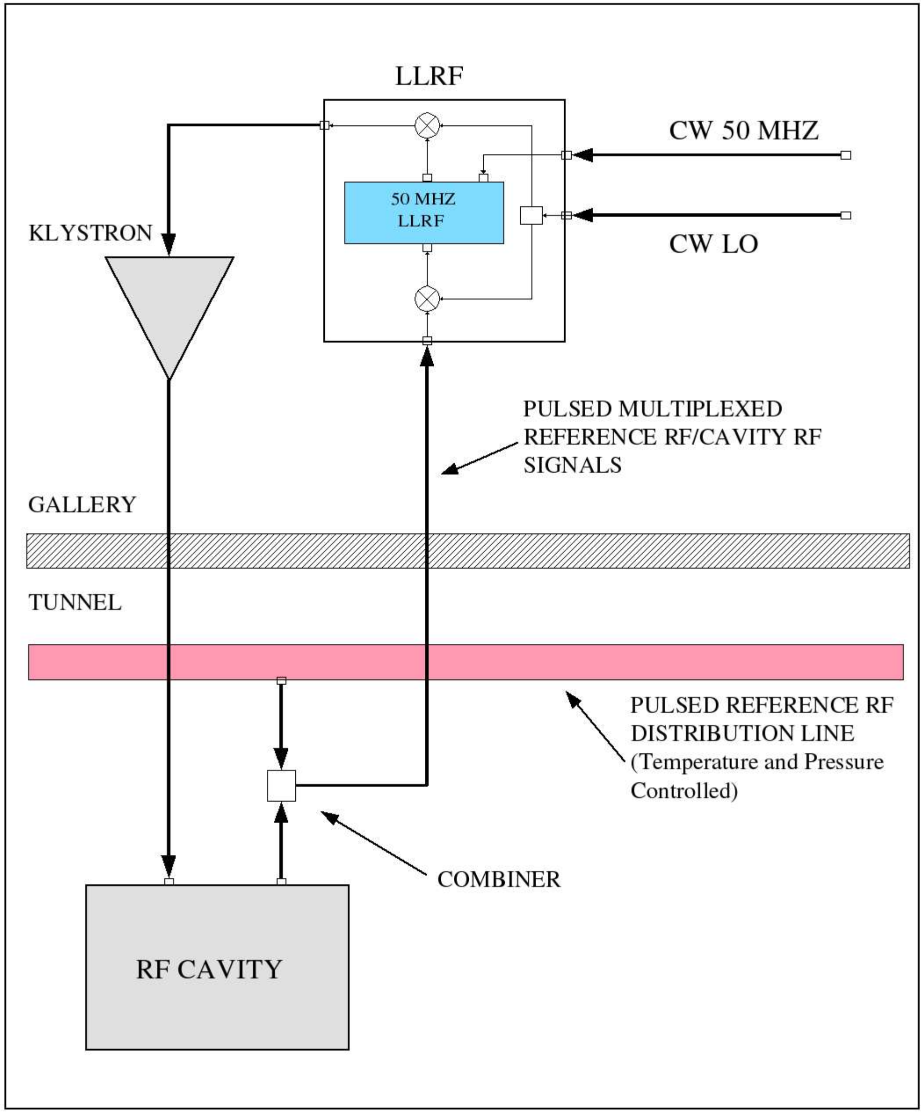
Single Path

Reference/Cavity



SNS LLRF Reference System

Summary

- Reference System complete and operational
- Reference System meets requirements
- Excellent System Performance and Reliability Throughout SNS Linac Commissioning process

SNS LLRF Reference System

Radiation Resistance of Materials (1 of 3)

Material	Total Integrated Dose (MRad)
Teflon	0.1
Nylon	1
Polyethylene	100

- Front End/DTL: 2 Rad/hr, 40 year Total Integrated Dose = 0.4 MRad
- SCL near beamline: 60 Rad/hr, 40 year Total Integrated Dose = 12 MRad

Radiation Resistance of Materials (2 of 3)

Solid Polyethylene (PE) possesses excellent electrical properties

- Dielectric constant = 2.3 (compared to 2.1 for Teflon)
- Dielectric constant is flat vs. frequency
- Material is easily machined
- Heliax cables use low density PE foam as dielectric material

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Radiation Resistance of Materials (3 of 3)

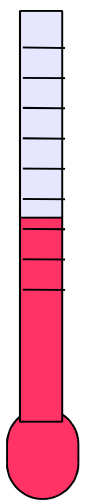
Require Custom Made components for Tunnel

- Polyethylene center conductor supports and bullet connector disks for 3-1/8” Rigid Line
- Heliax connectors with Polyethylene dielectric fabricated by Spinner
- Heat tape and RTD Temperature Sensors use Kapton

SNS LLRF Reference System

Temperature Data (1 of 2)

Expected Temperatures



Device	Temperature
RFQ	24 C (75 F)
DTL, CCL	22-26 C (72 - 79 F)
SCL	??

Local Temperature Information

Location	Temperature	Period
Gallery	+/- 5 F	24 Hours
Chase	+/- 2 F	24 Hours
Tunnel	+/- 2.5 F	12 Months

Global Temperature Information

Location	Beam On/Summer	Beam Off/Winter
Gallery	85 +/- 5 F	75 +/- 5 F
Tunnel	85 +5/-10 F	72 +/- 10 F

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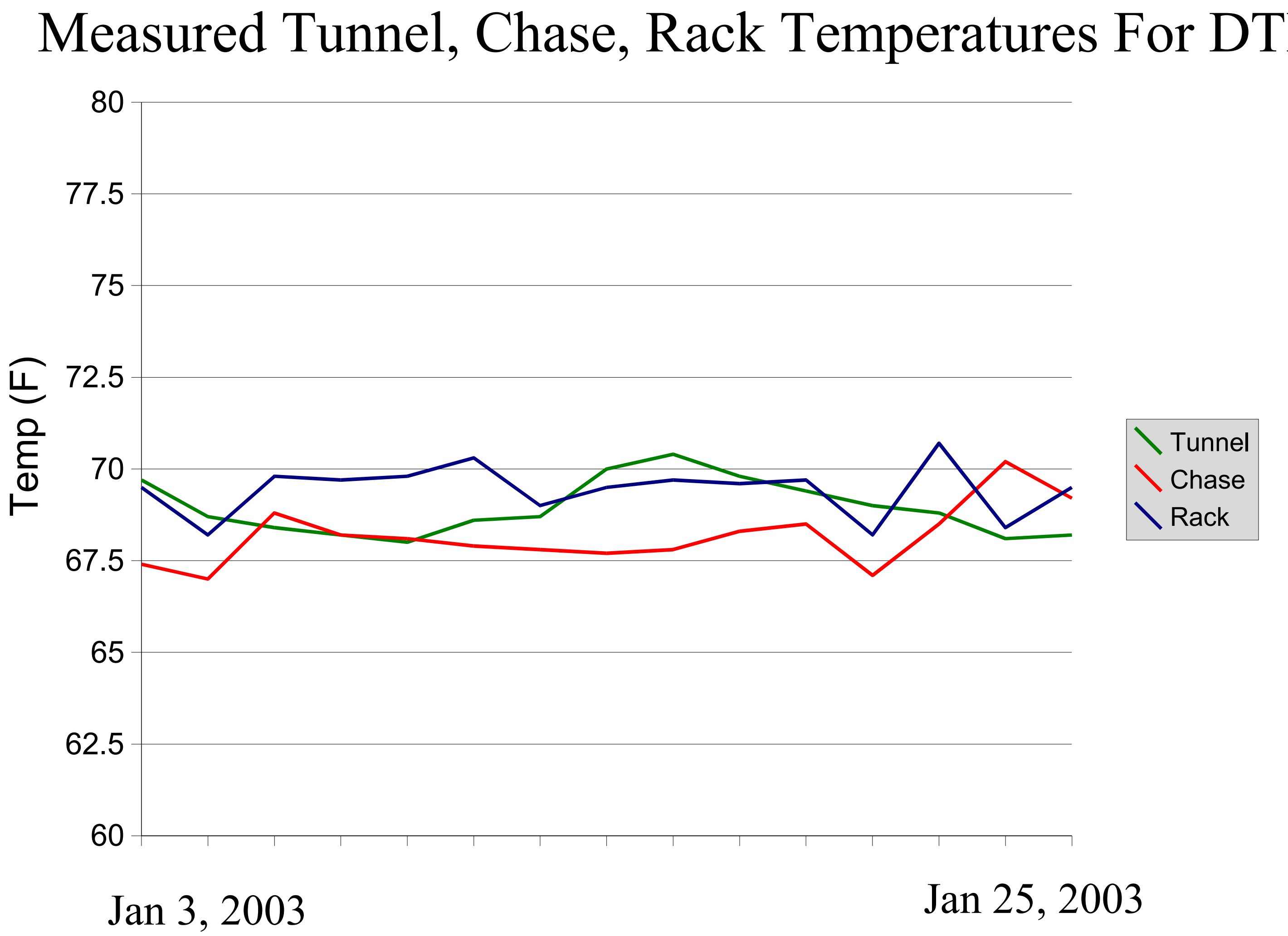
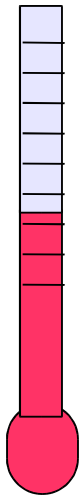
Temperature Data (2 of 2)





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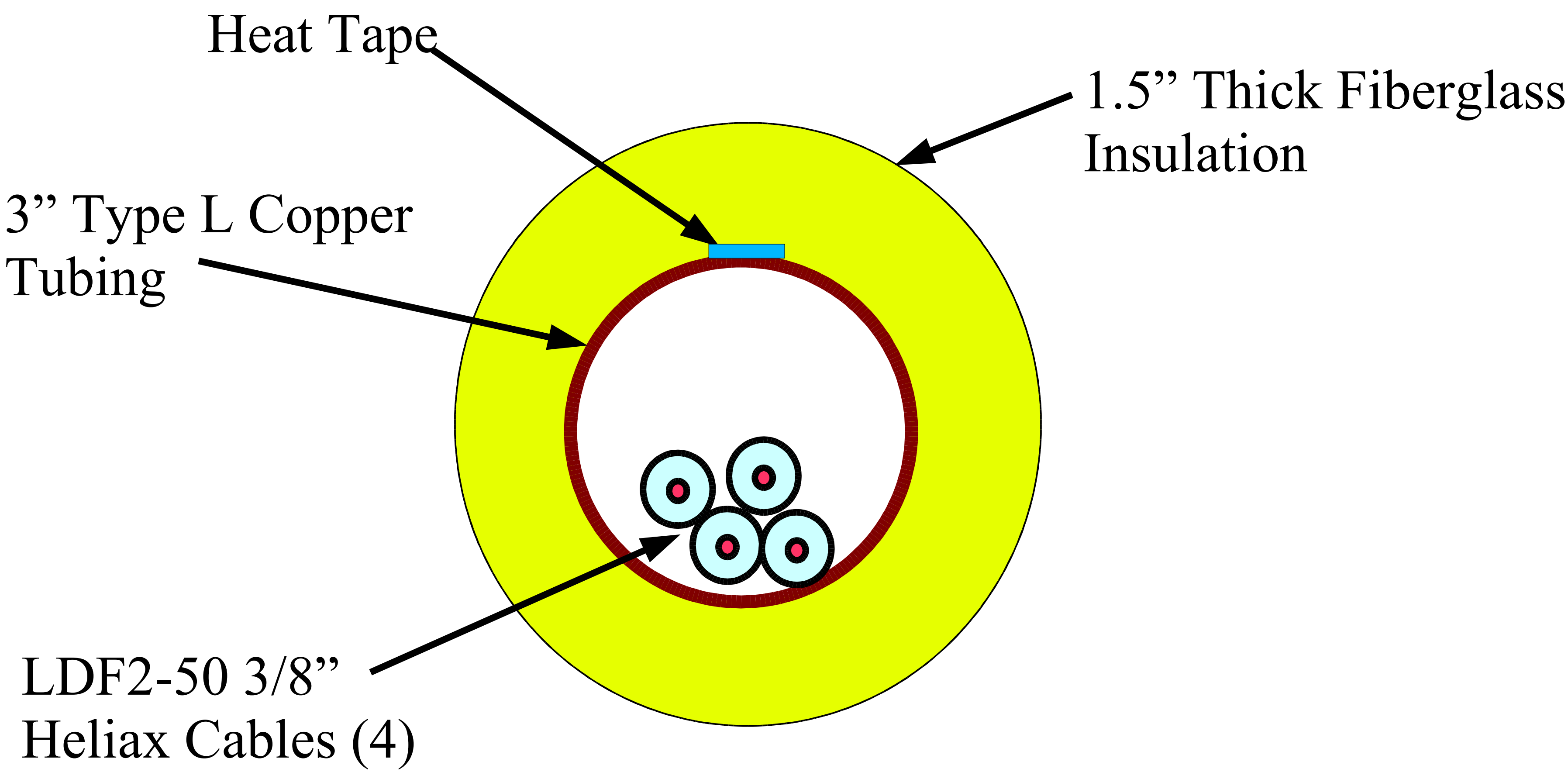
Differential Phase Drift Measurement (1 of 4)

Temperature Chamber Cross Section



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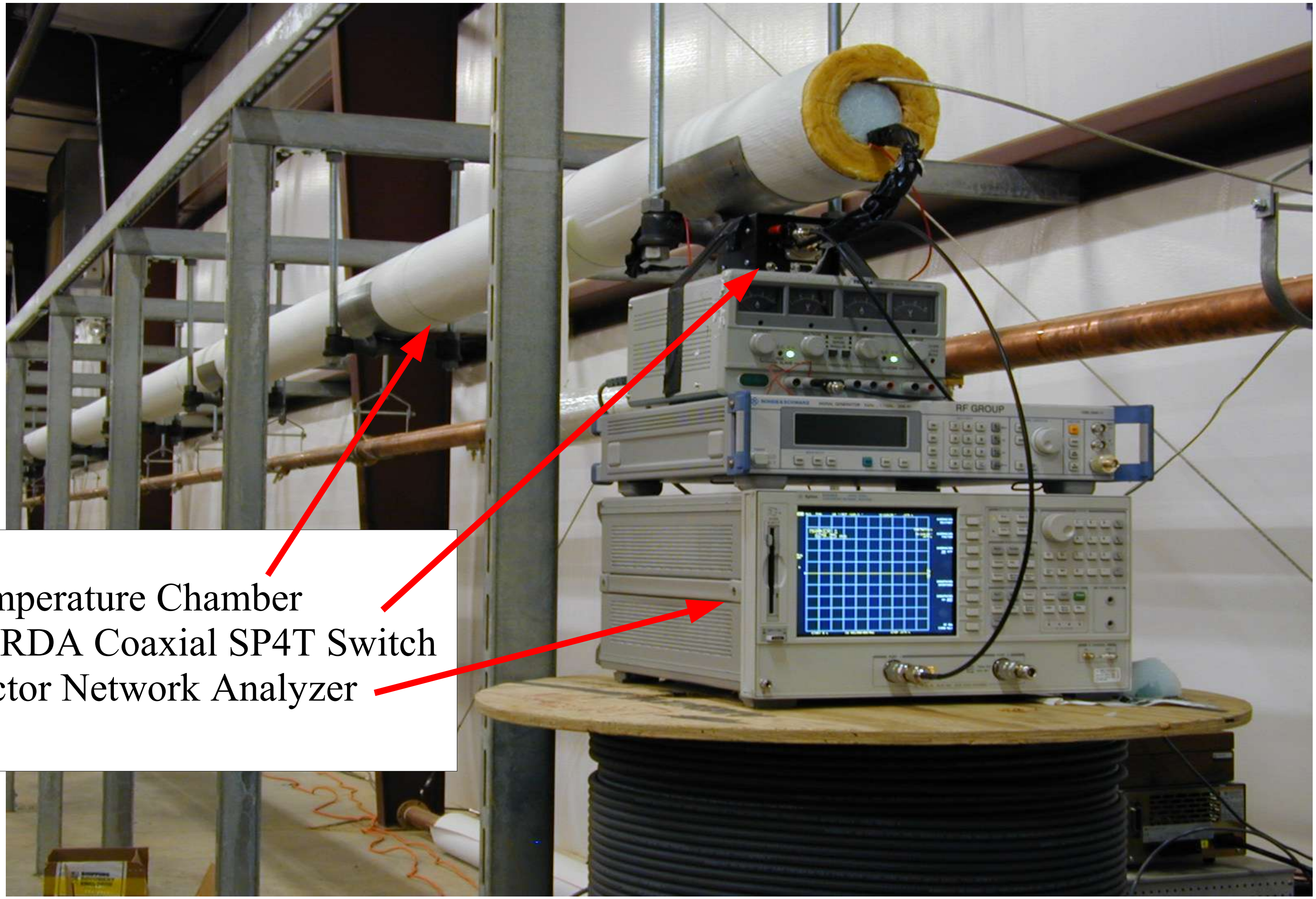
Differential Phase Drift Measurement (2 of 4)



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- Differential Phase Drift Measurement (3 of 4)
- 4 Cables, 402.5 MHz, length 251ns (66m or 217ft). Preliminary data, values in degrees.

	#1	#2	#3	#4		
100F - 80F	2.20	2.85	3.26	2.71		
100F - 70F	3.14	3.98	4.45	3.76		
80F - 70F	0.92	1.13	1.19	1.05		

	#1 - #2	#1 - #3	#1 - #4	#2 - #3	#2 - #4	#3 - #4
100F - 80F	-0.65	-1.05	-0.51	-0.41	0.14	0.54
100F - 70F	-0.85	-1.32	-0.63	-0.47	0.22	0.69
80F - 70F	-0.21	-0.27	-0.12	-0.06	0.08	0.14

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Differential Phase Drift Measurement (4 of 4)

- Cable length in test was 251 ns vs. expected real cable length of less than 136 ns (84% longer than expected)
- Temperature difference in test much greater than measured data or expected temperatures in real machine
- Initial test cables were not phase matched, differential phase drift was lower on the better matched cables.

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Cable	LDF2-50	LDF5-50A	LDF7-50A	MACX350
Size	3/8”	7/8”	1-5/8”	3-1/8”
Loss 400 MHz	7.06	2.49	1.43	0.65 est.
Loss 800 MHz	10.2	3.63	2.13	0.91 est.
(dB/100 m)				
Propagation Velocity	0.88 c	0.89 c	0.88 c	0.99 c
Phase/Temp	-4 to +3	+3 to+7	??	16.5
(PPM/C)				
AVG Power Rating	663 W	2.19 kW	4.52 kW	15 kW est.
(1 GHz)				