Thermal Profiling of PIP-II Radio Wave Distribution

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Motivation

The PIP-II linear accelerator will utilize supercooled electromagnetic resonators, controlled by directed radio signals. These signals must be transmitted, via conduit, from their amplifiers in a gallery building to their corresponding resonators in the accelerator tunnel. The purpose of this analysis is to determine the worst-case power loss due to this transit, as well as the corresponding cooling load and temperature distribution.

Modeling

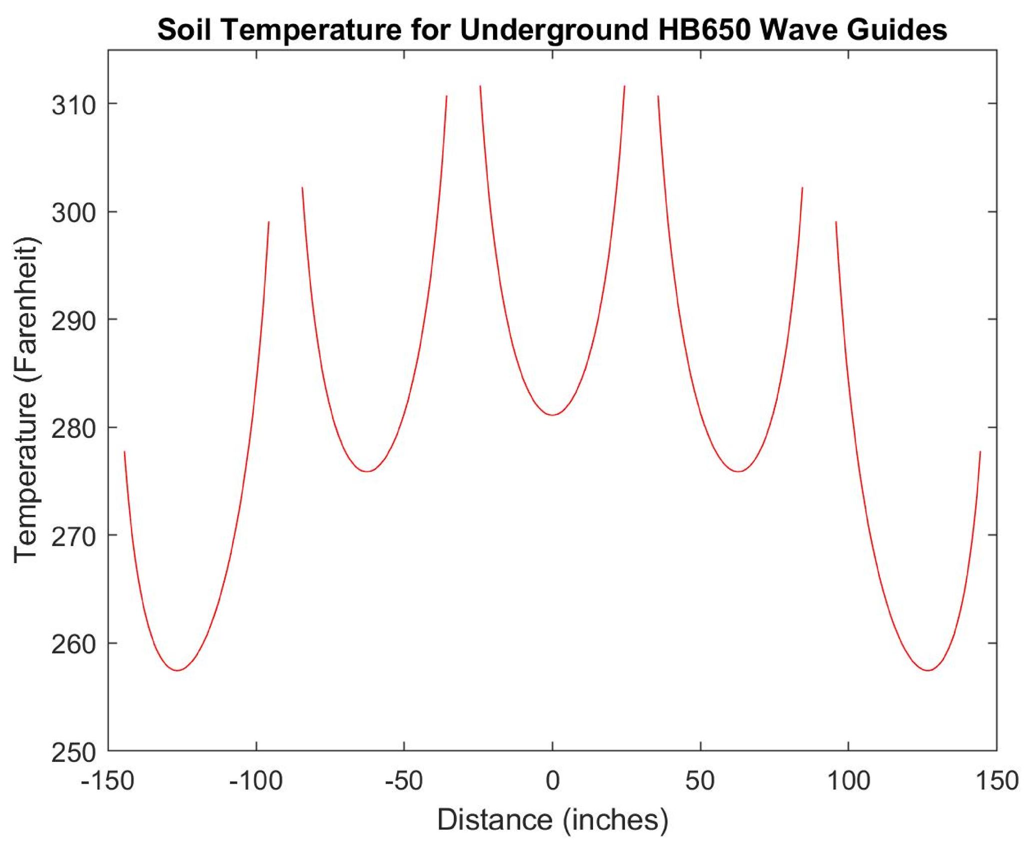
This distribution system includes multiple sections of conduit for each amplifier-resonator pair, some being air-cooled (free) and others passing underground. To develop numerical and analytical models, certain assumptions were required:

- Worst-case losses – maximum input power and attenuation (power loss to conduit)
- Uniform cooling in each section
- Natural convection is dominant cooling mechanism for free sections
- Underground section is cooled by conduction into free sections and soil
- Uniform ambient soil temperature[1] (valid at sufficient depth)
- Constant properties for conduit materials[2]
- Air properties dependent on conduit surface temperature only[3]

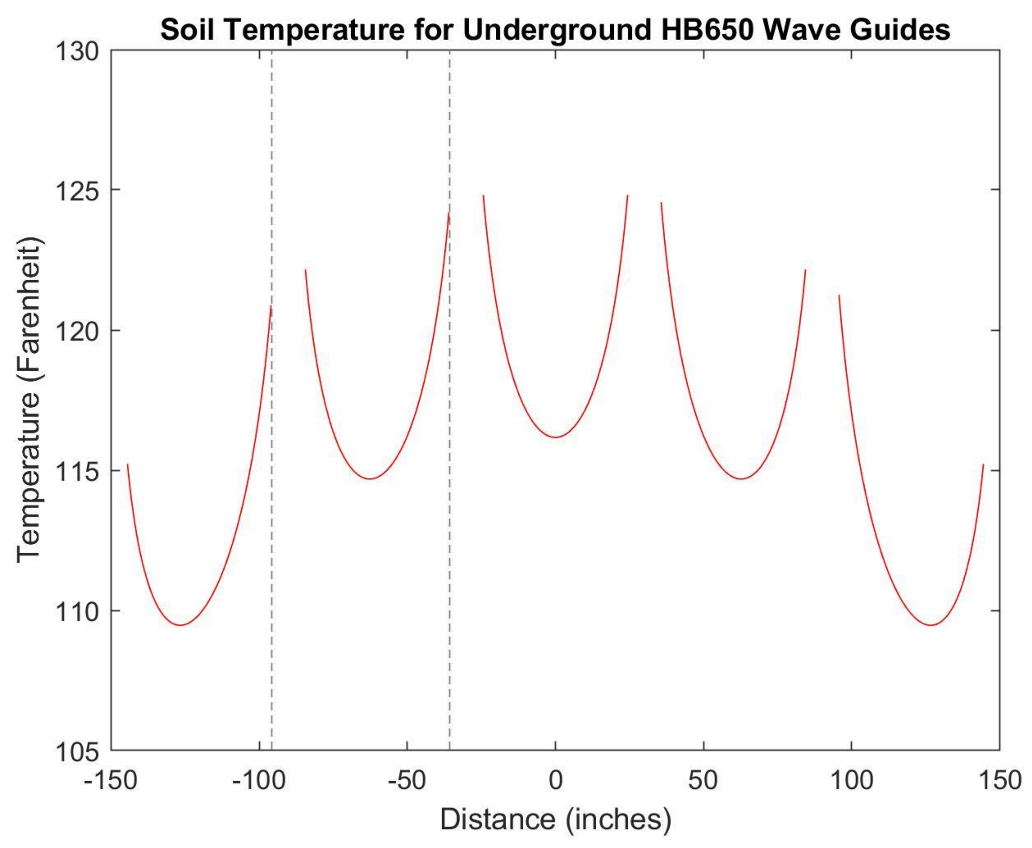
Resonator cavities are clustered into groups called cryomodules. Thermal interactions between conduit lines within each cryomodule were considered, but interactions across different cryomodules were deemed negligible.

Results and Recommendations

The overall distribution system is determined to dissipate a maximum of 158 kW of power to the air in free sections, as well as maintaining a peak temperature range of 98-125 ˚ F. These peak temperatures will be reached at a significant distance from human operators, posing only a minimal safety hazard. Expected power losses will exert a notable load on the air conditioning system, adding to the loads exerted by active machinery and human operators. This load must be considered when designing ventilation and air conditioning for the PIP-II gallery building.



Underground Sections – Disconnected: When these sections can only conduct to the surrounding soil, peak temperatures reach upwards of 310 °F, which can cause damage both to the conduit and surrounding environment.



Underground Sections – Free Sections Attached: Once steady-state conduction into free sections is considered, the peak underground temperature is determined to be a tolerable 125 °F.

Cryomodule	Line # (from end):	1	2	3	4	5	6	7	8
HWR	Load (W):	434.00	442.21	445.87	447.39	447.39	445.87	442.21	434.00
	Peak Temp (F):	116.81	117.42	117.69	117.80	117.80	117.69	117.42	116.81
SSR1	Load (W):	320.13	326.80	329.75	330.96	330.96	329.75	326.80	320.13
	Peak Temp (F):	98.28	98.64	98.79	98.86	98.86	98.79	98.64	98.28
SSR2	Load (W):	685.58	695.13	697.38	695.13	685.58	-	-	-
	Peak Temp (F):	110.65	111.03	111.12	111.03	110.65	-	-	-
LB650	Load (W):	1,227.76	1,238.09	1,238.09	1,227.76	-	-	-	-
	Peak Temp (F):	106.35	106.55	106.55	106.35	-	-	-	-
HB650	Load (W):	2,228.90	2,242.74	2,247.39	2,247.39	2,242.74	2,228.90	-	-
	Peak Temp (F):	124.35	124.58	124.66	124.66	124.58	124.35	-	-

Summary Table: The total power loss to air and corresponding maximum free surface temperature for each conduit line are listed, with groupings showing different cryomodule types.

Sources

1. Olgun, C. Guney. "Introductory Overview of Ground Source Heat Pump Technologies." *Virginia Tech,* https://aeeibse.wp.prod.es.cloud.vt.edu/wp-content/uploads/2015/06/Introduction-GSHP-Olgun-1.pdf. Accessed 06/21/2021
2. "Online Materials Information Resources." *MatWeb,* www.matweb.com/. Accessed 05/28/2021
3. "A-To-Z Guide to Thermodynamics, Heat & Mass Transfer, and Fluids Engineering" *Thermopedia,* www.thermopedia.com/. Accessed 06/21/2021

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