Coupler Electromagnetic Design

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*SNS is a collaboration of six US National Laboratories: Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Thomas Jefferson National Accelerator Facility (TJNAF), Los Alamos National Laboratory (LANL), Lawrence Berkeley National Laboratory (LBNL), and Oak Ridge National Laboratory (ORNL). SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy.

Contents

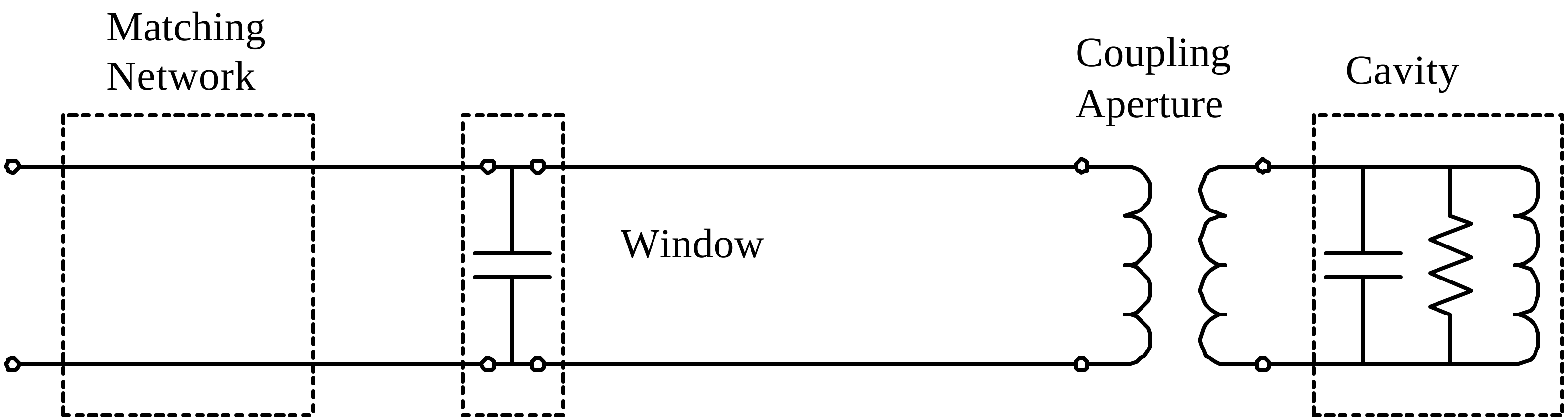
Fundamental Power Coupler

- Functions
  - Transfer RF power to the cavity through a dielectric window vacuum barrier
  - Coupling determines the Q_{ext} of the cavity
- Performance and reliability
  - Low RF reflection and transmission losses with the beam loaded cavity
  - Low cost
  - Mechanical stability
  - RF heating and cooling
  - Arcing and multipacting
  - Low maintenance
- Desired properties of the window material
  - High vacuum seal
  - Good mechanical strength and thermal conductivity
  - Low RF loss

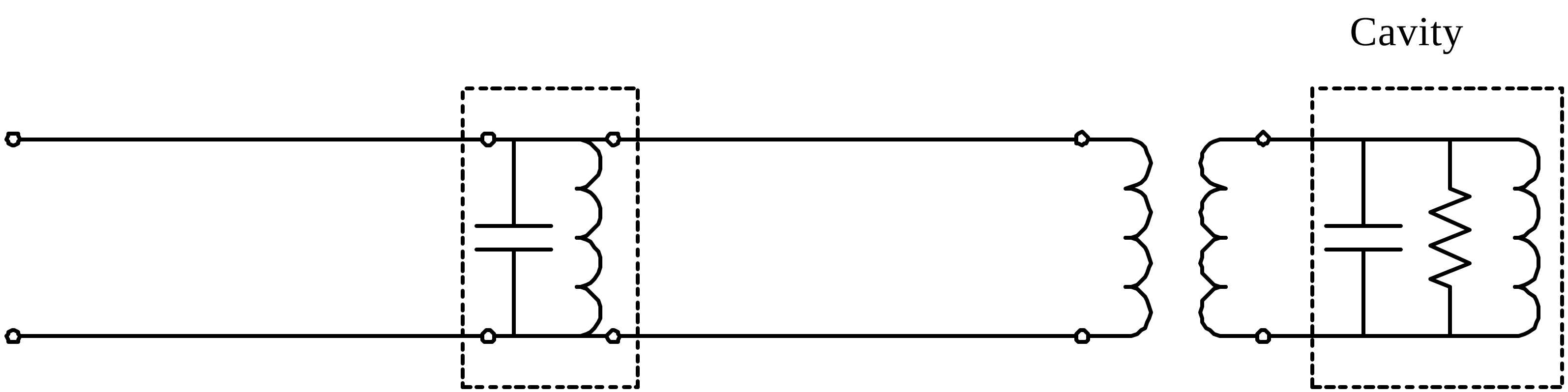
Coupler Design Consideration

- RF frequency, power level (peak and average), cavity design, etc.
- RF matching and adjustment - Impedance matching is made individually at the window, the cavity input, and the transition
  - Variable coupling ?
- Transmission line type – waveguide or coaxial
- Heat dissipation and cooling
- Material selection and processing
- Number of windows
- Coupler conditioning and operation
  - Window protection - vacuum, cooling, arcing, multipacting
  - Control of multipacting and out gassing - DC biasing capacitor
  - Water condensation - heating and temperature control

Coupler Equivalent Circuit and Resonant Matching

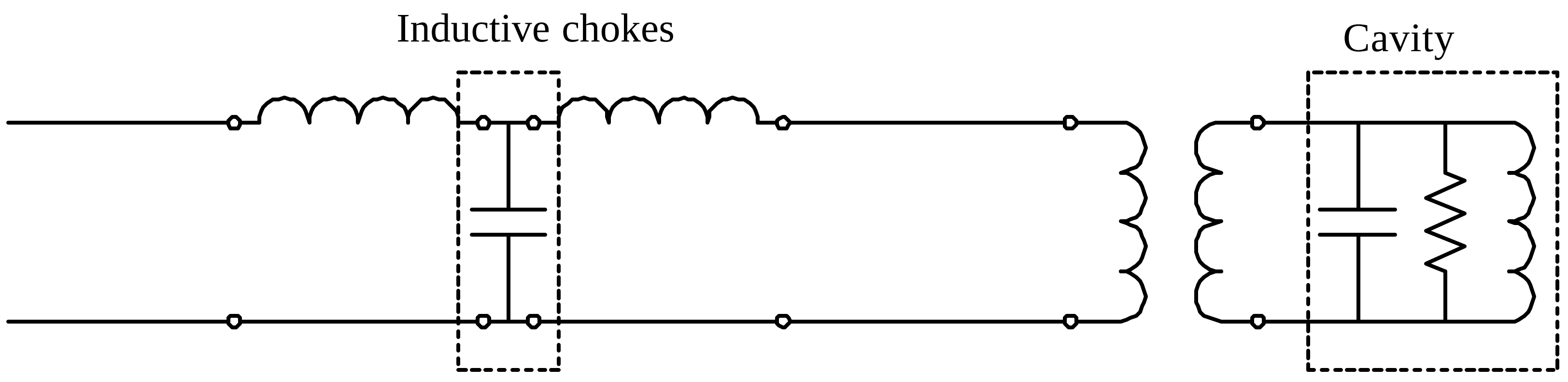


Equivalent Circuit

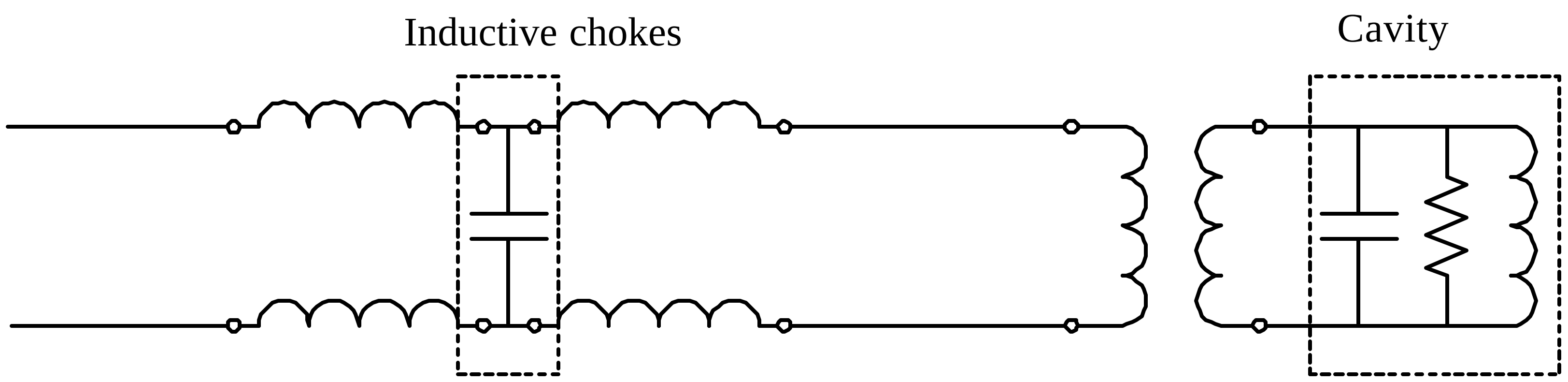


Resonant Matching

Coupler Window Matching with Inductive Chokes



Unbalanced Matching



Balanced Matching

Ceramic Window Matching

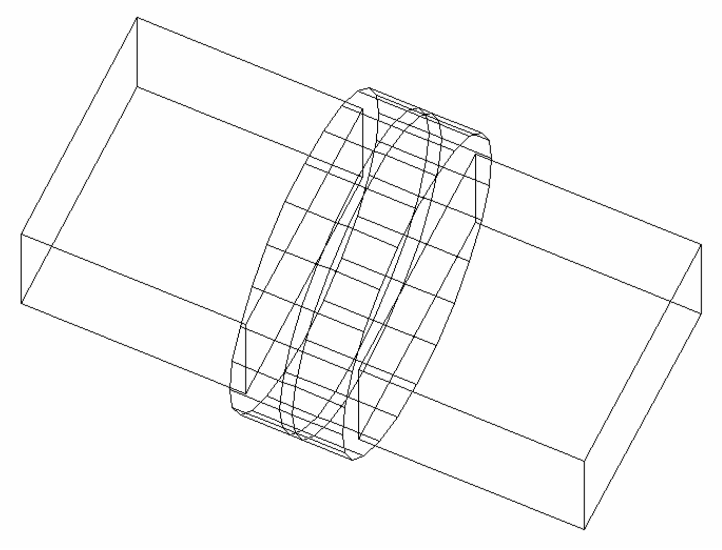
- A thin ceramic window in a transmission line alone has significant return loss (-5 ~ -10 dB) due to its shunt capacitive loading
  - » ex) Return loss of a 0.015λ thick, 95% Alumina window in a 0.25λ diameter 50 Ω coaxial transmission line is about -8 dB
- Tuning out the capacitive loading is required to insure good RF power transmission
- Tuning and matching can be done either locally or globally. Local tuning is more desirable to eliminate resonant standing wave formation in the transmission line.
  - » It is desired that the ceramic window is matched separately to the transmission line. Then, no standing-wave exists between the cavity, window, and transition.
  - » Waveguide impedance transformers can be used separately to match both beam loading and phases of superconducting cavity from a transmitter. This introduces the standing waves in the waveguide.

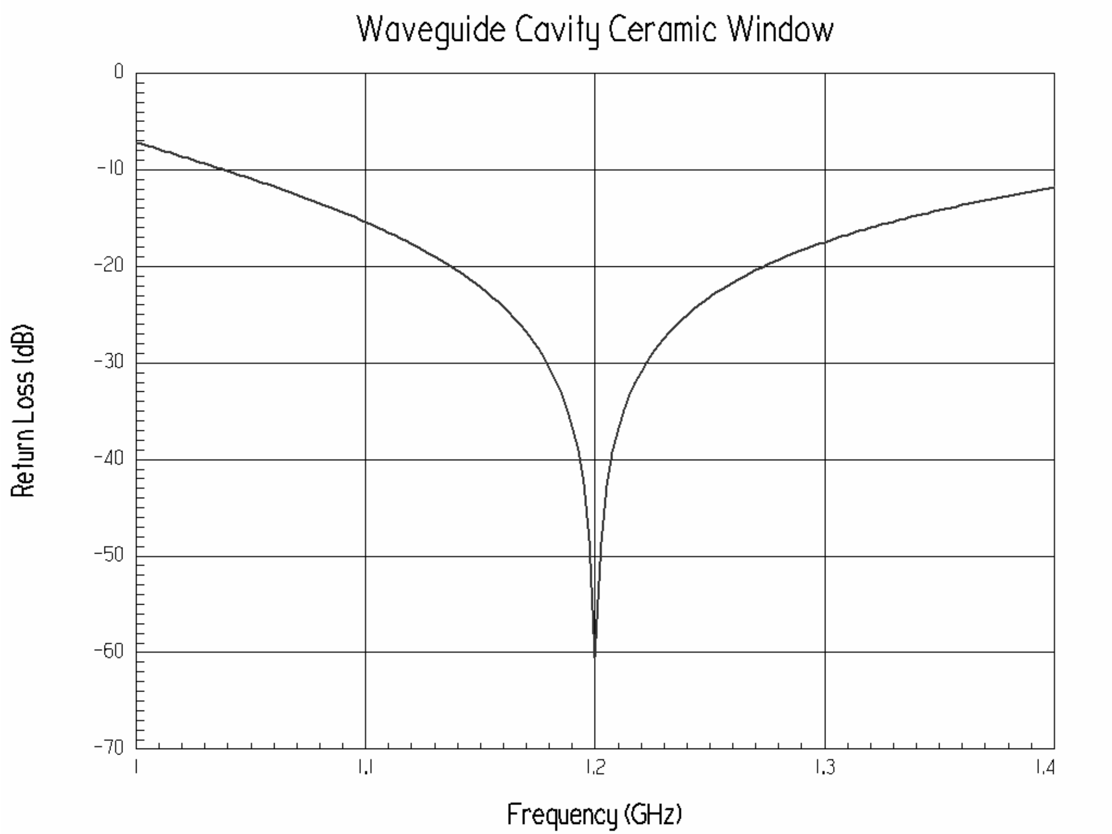
Windows for Couplers

- Window shape
  - Circular or rectangular disks for hollow waveguides
  - Annular disk type for coaxial lines
  - Circularly cylindrical window in waveguide transition
  - Tapered cone
  - Half wavelength thick (λ/2)
- Impedance matching
  - Resonant cavity
  - Resonant window
  - Choke type inductive loading
  - Tapered cone
  - Half wavelength thick (λ/2)

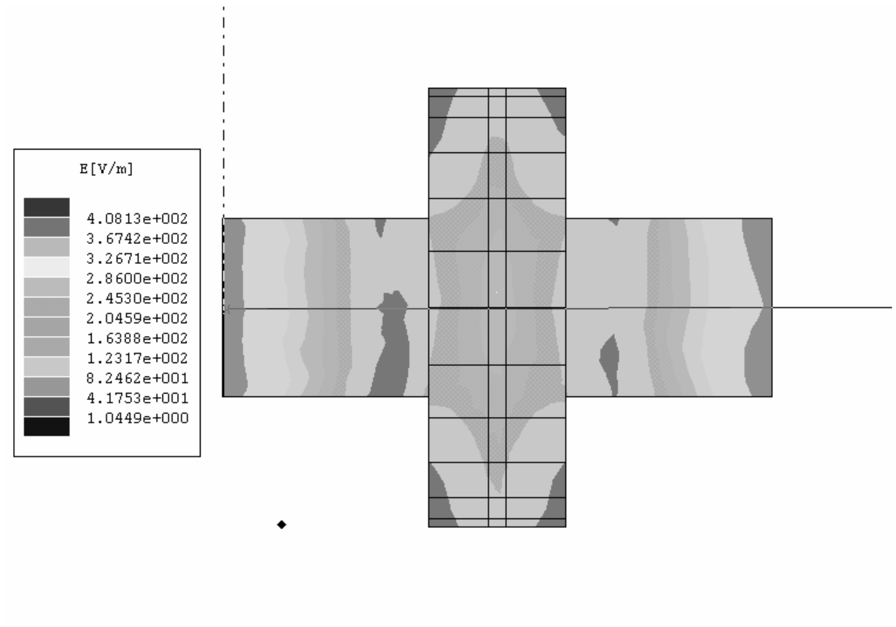
Waveguide Ceramic Window in Resonant Cavity

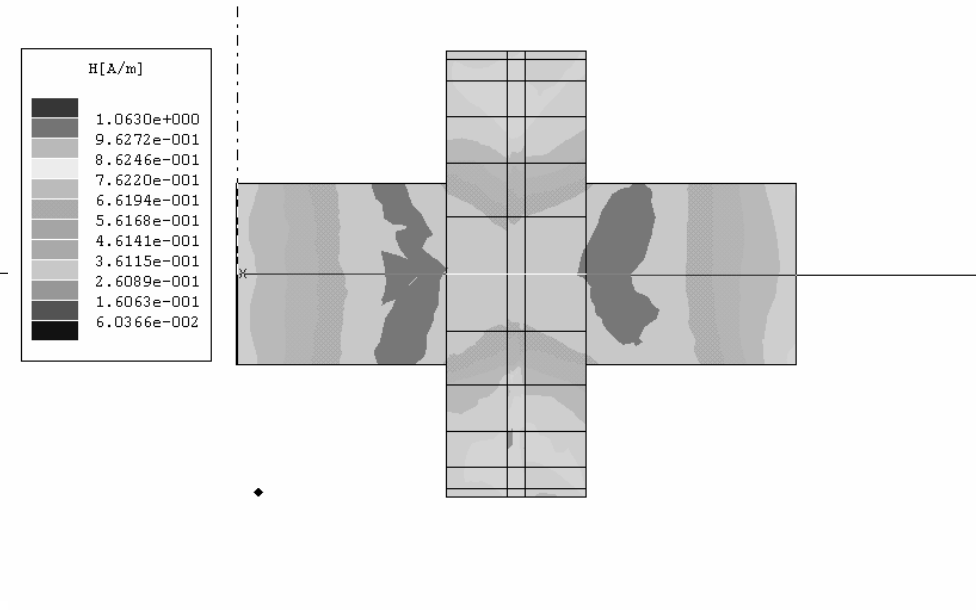
- For a specified operating frequency, both the diameter and the length of the cavity must be optimized
- Cylindrical cavity (and ceramic window) diameter greater than the waveguide dimensions

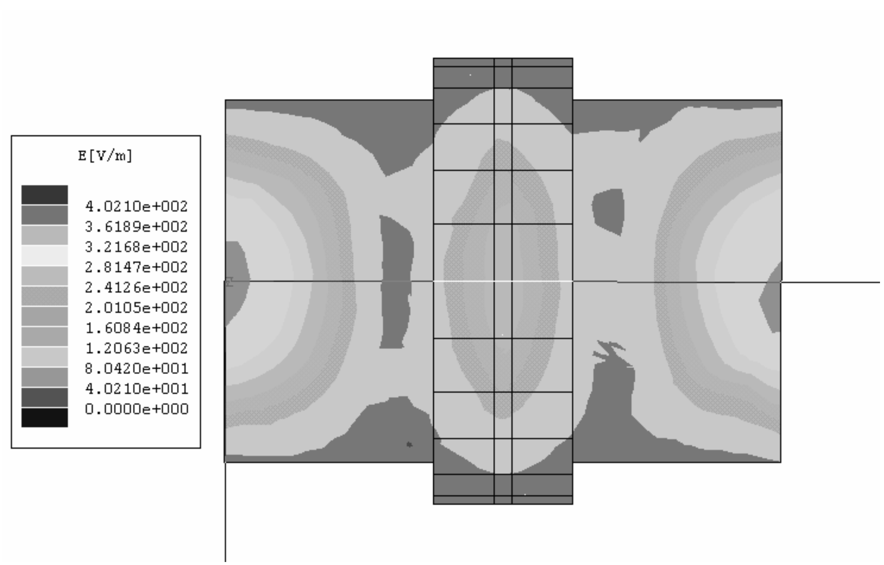


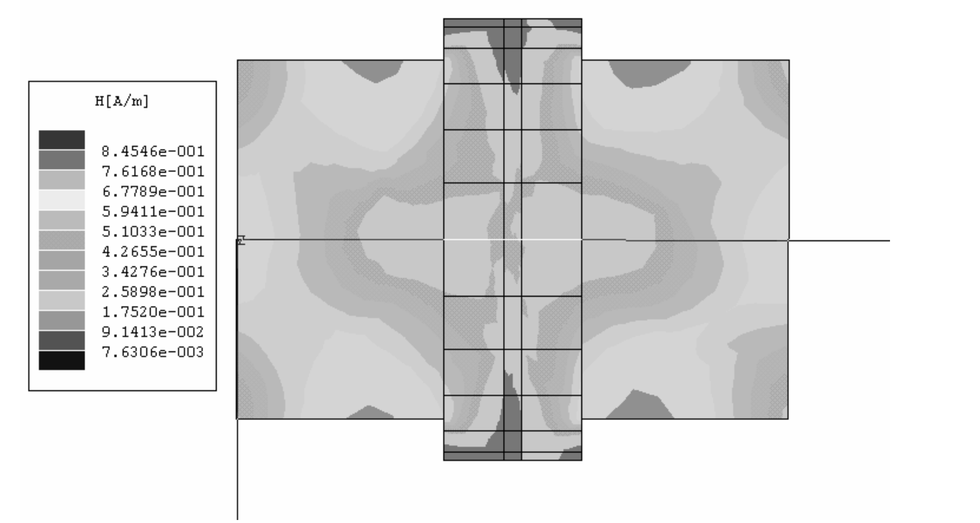


E- and H-fields in Cylindrical Cavity Window



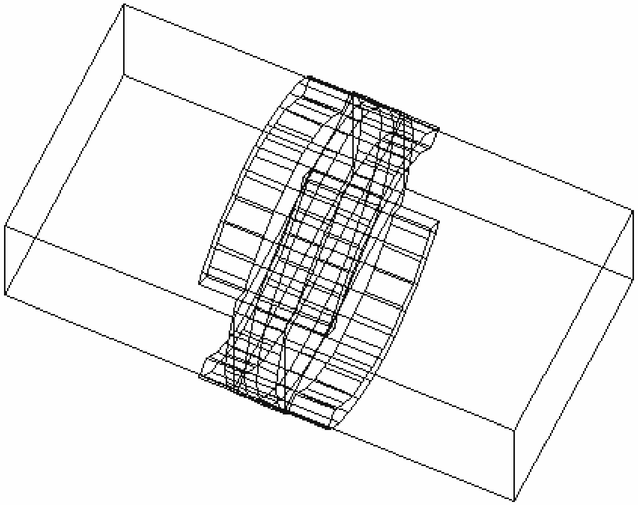


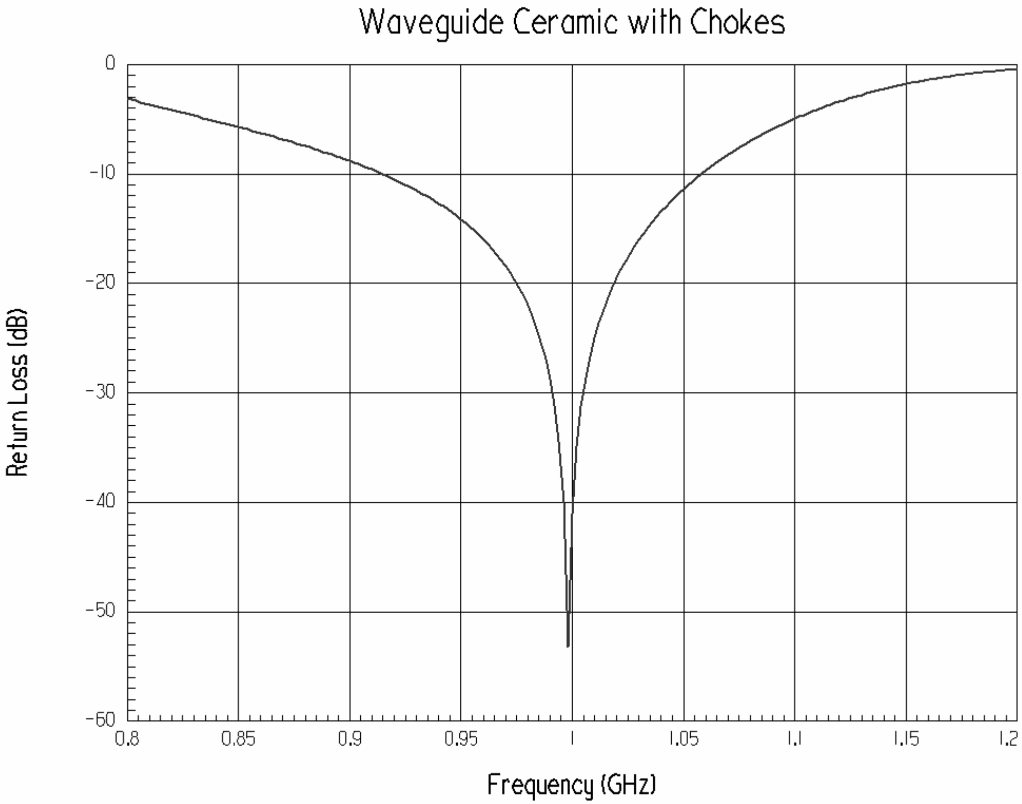




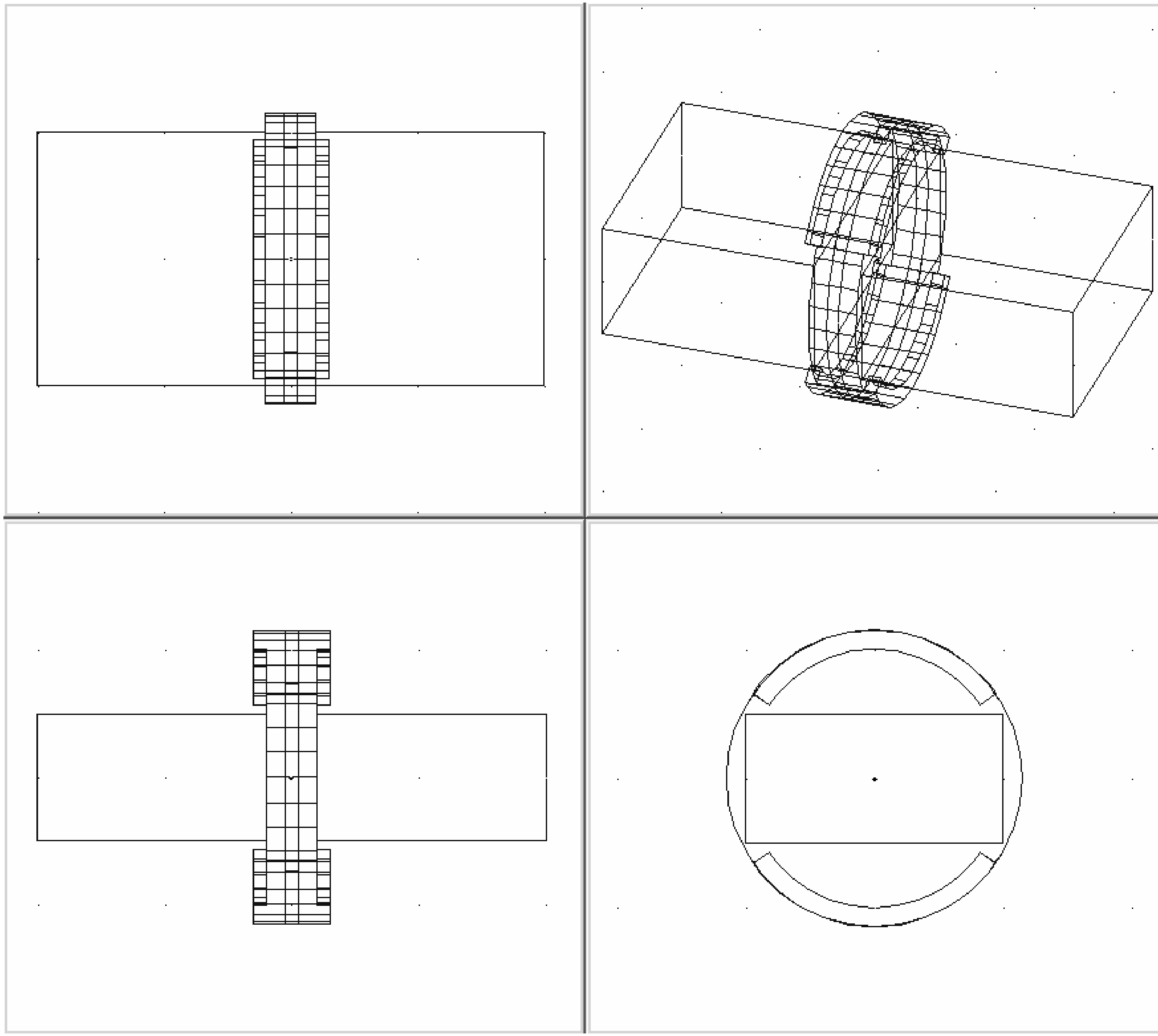
Waveguide Window (WR-770) with Choke Matching

- For a specified operating frequency, only the choke depth needs to be optimized.
- Length and diameter of the ceramic can be arbitrary
- Cylindrical cavity (and ceramic window) diameter can be minimized

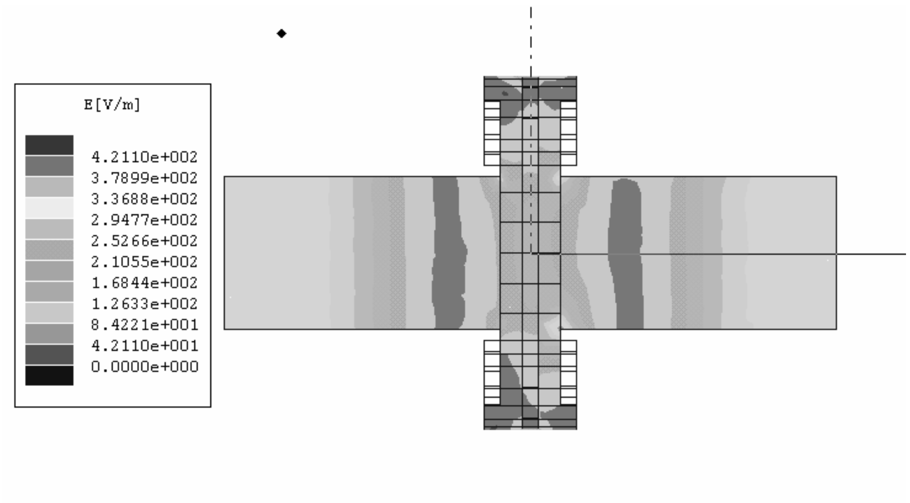


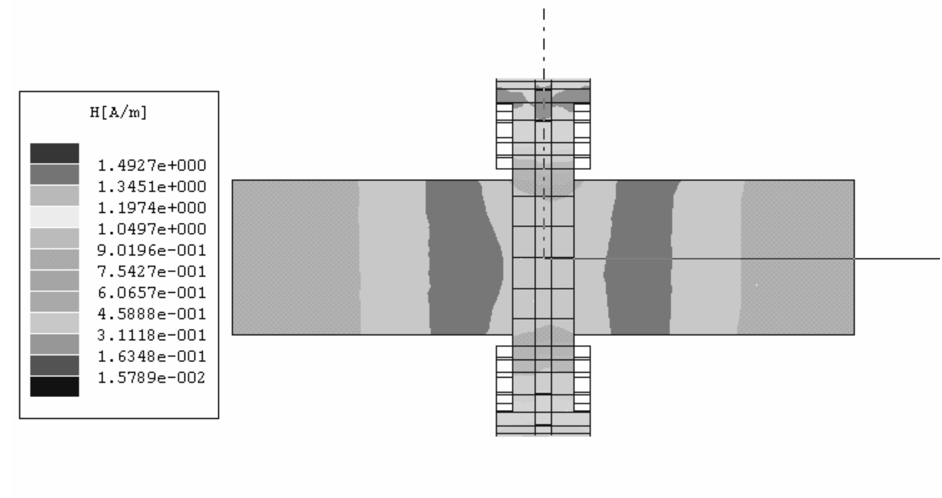


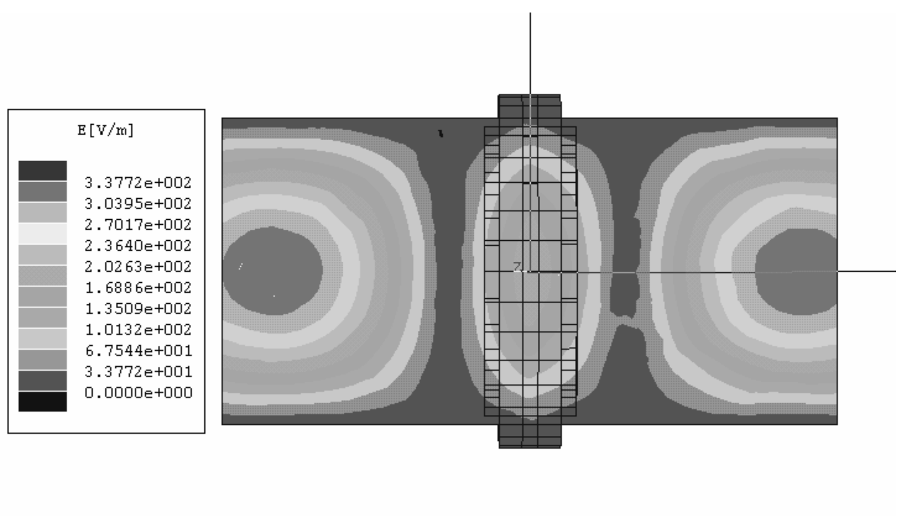
Waveguide Ceramic Window with Chokes

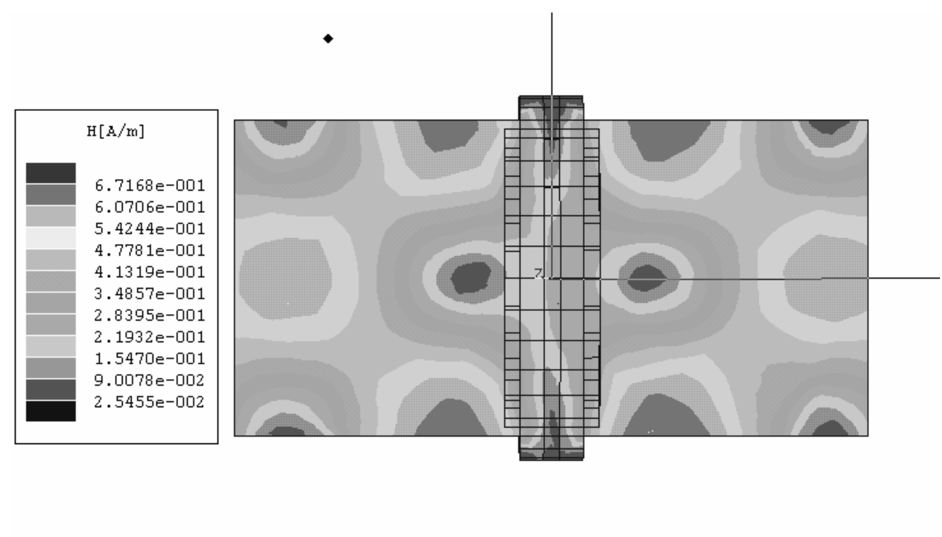


E-and H-fields in the Waveguide Ceramic with Chokes

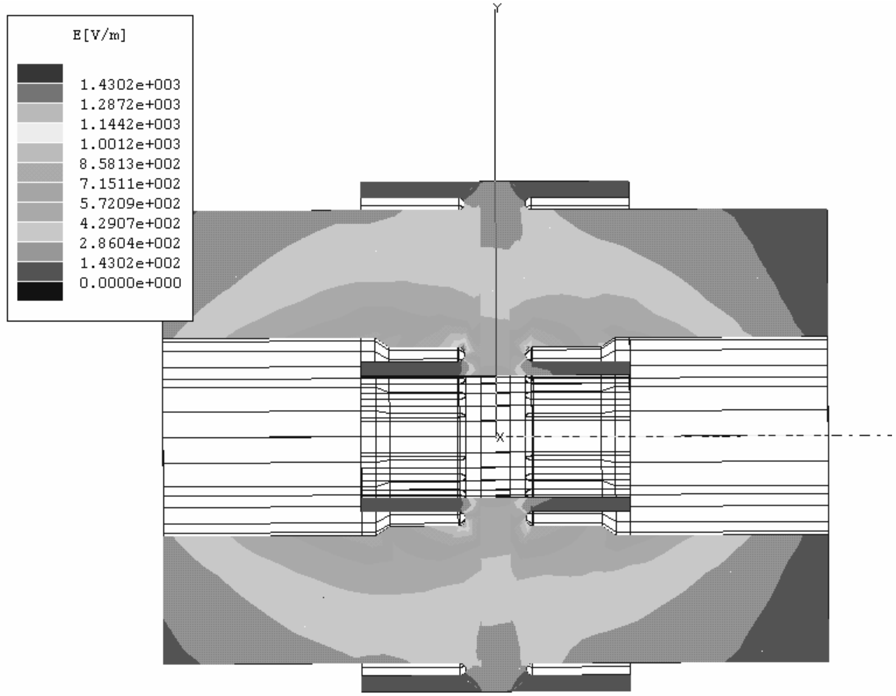


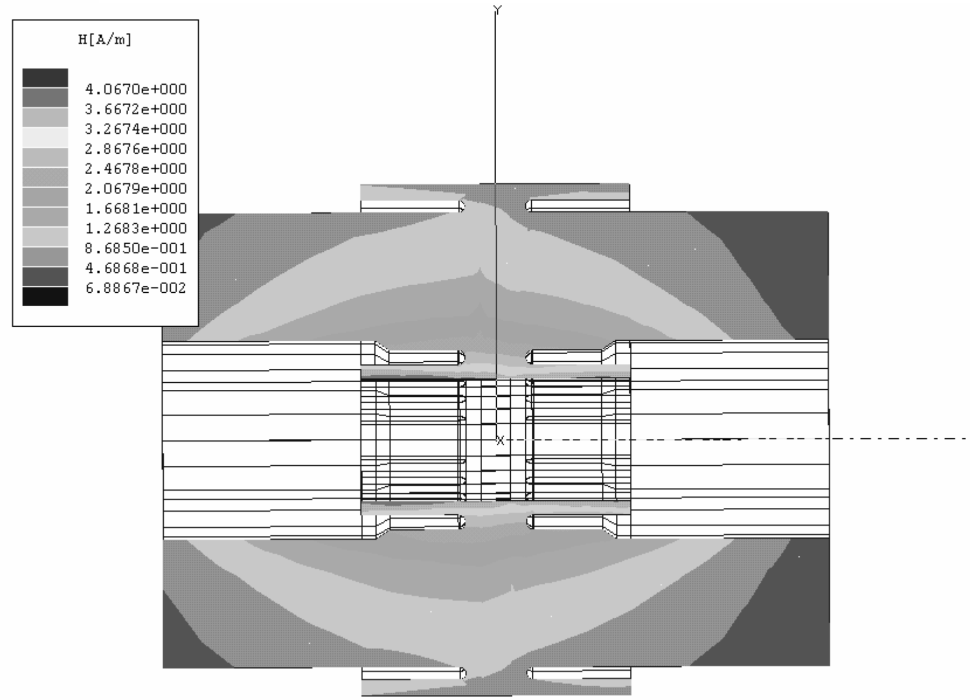




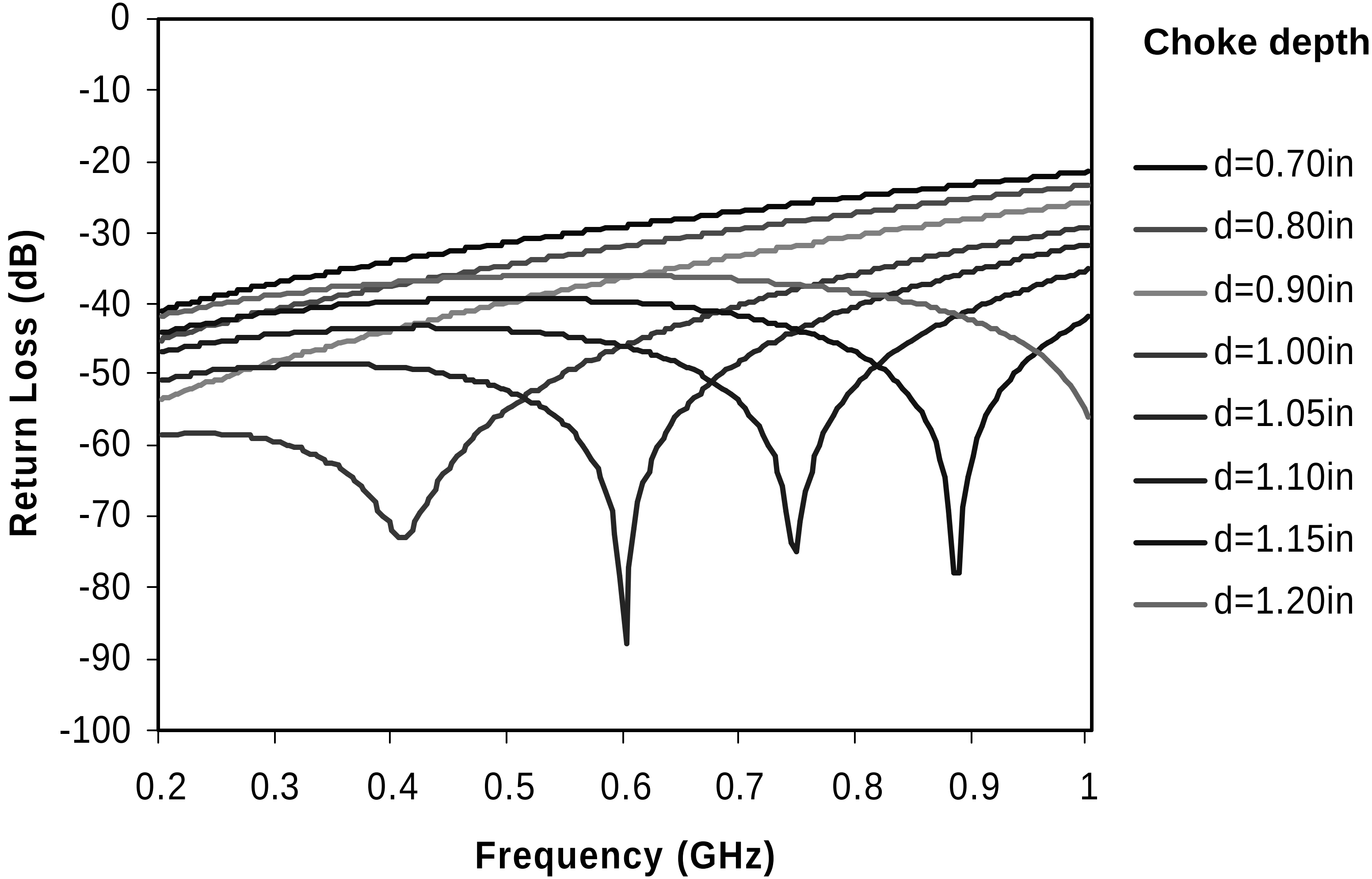


E- and H-fields of Coaxial Window with Balanced Chokes

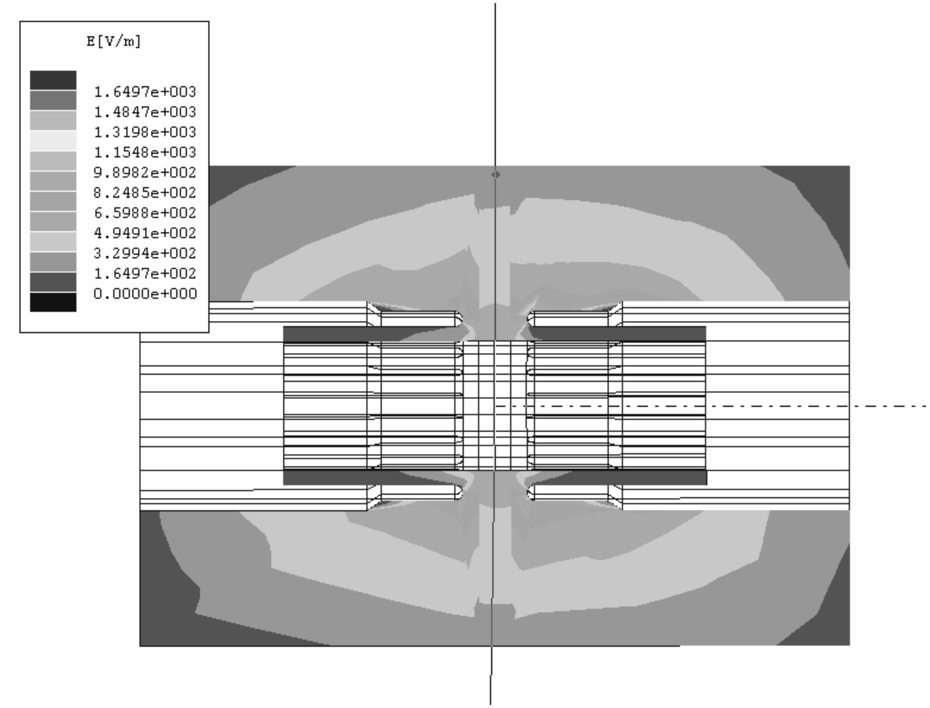


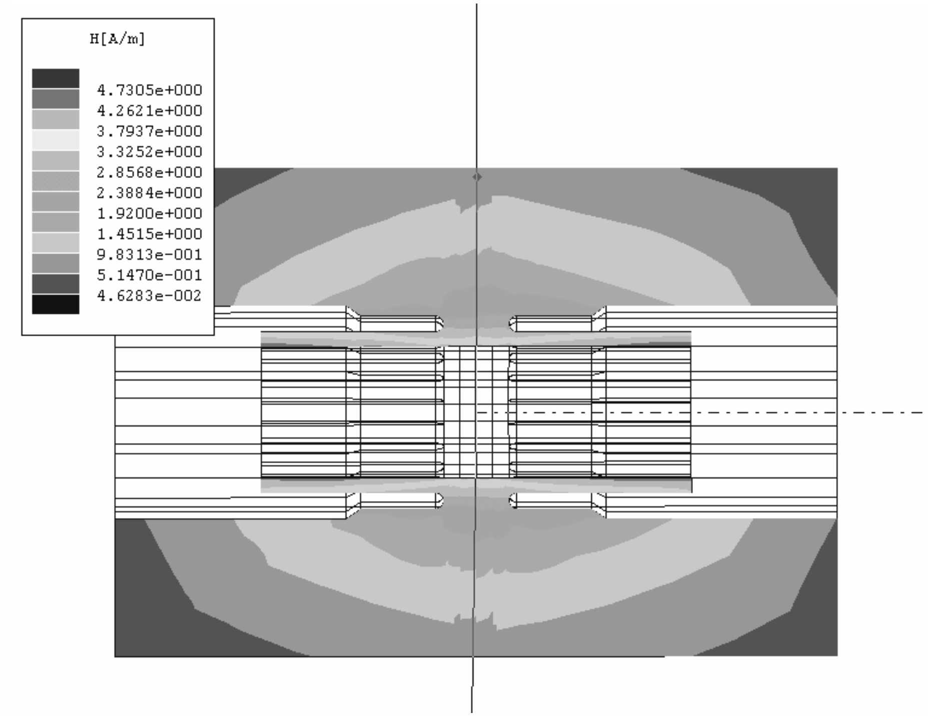


Coaxial Window with Balanced Choke Matching

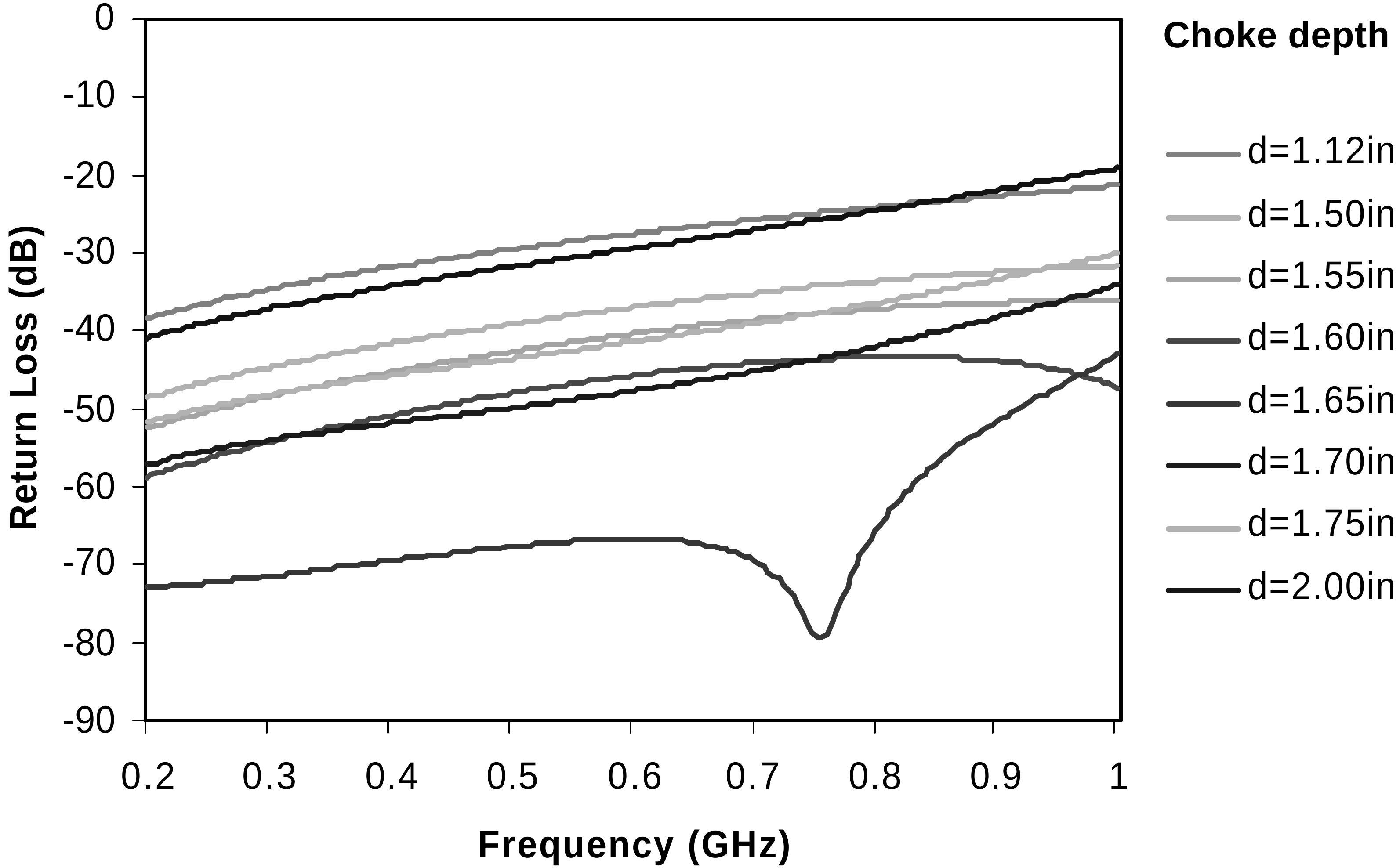


E- and H-fields in Coaxial Window with Inner Conductor Chokes

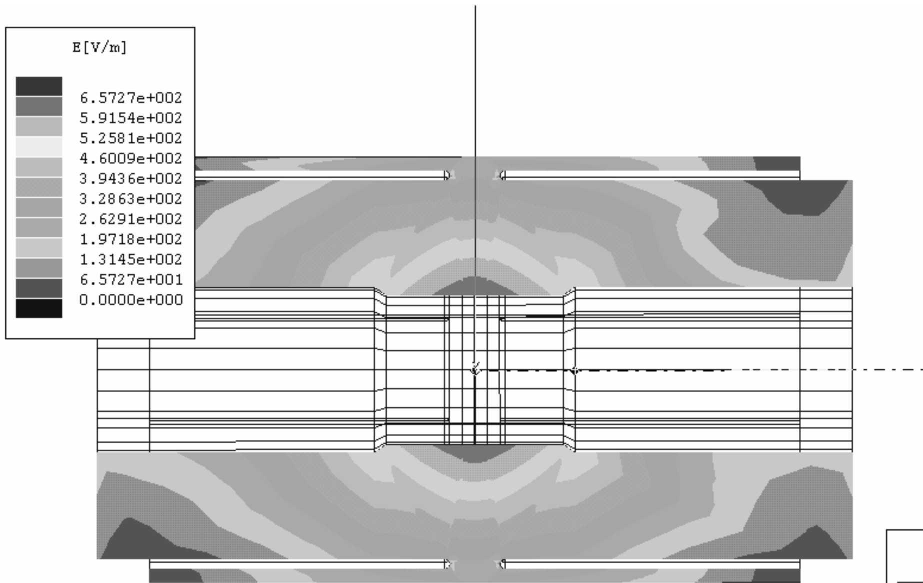


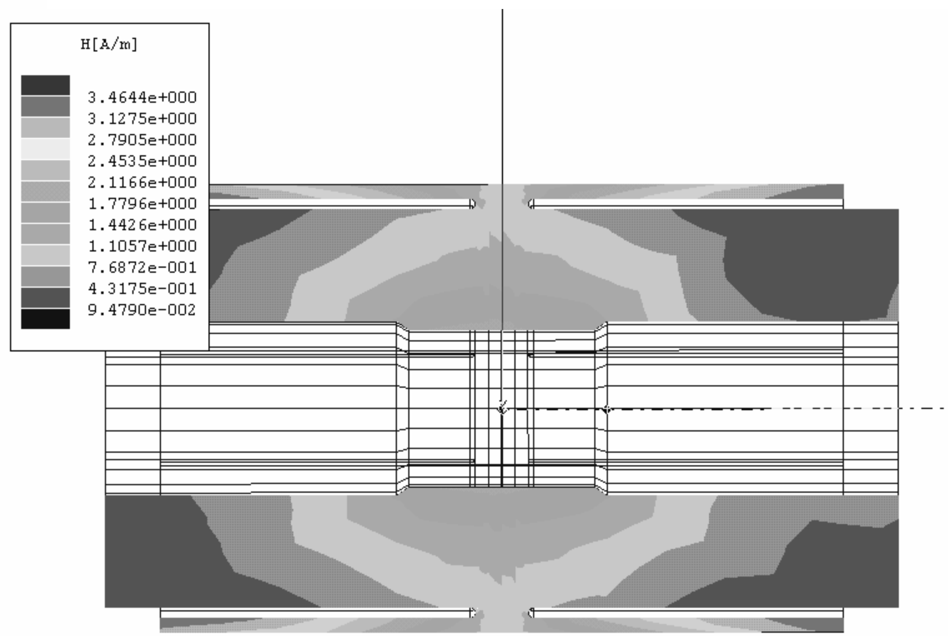


Coaxial Window with Inner Conductor Chokes

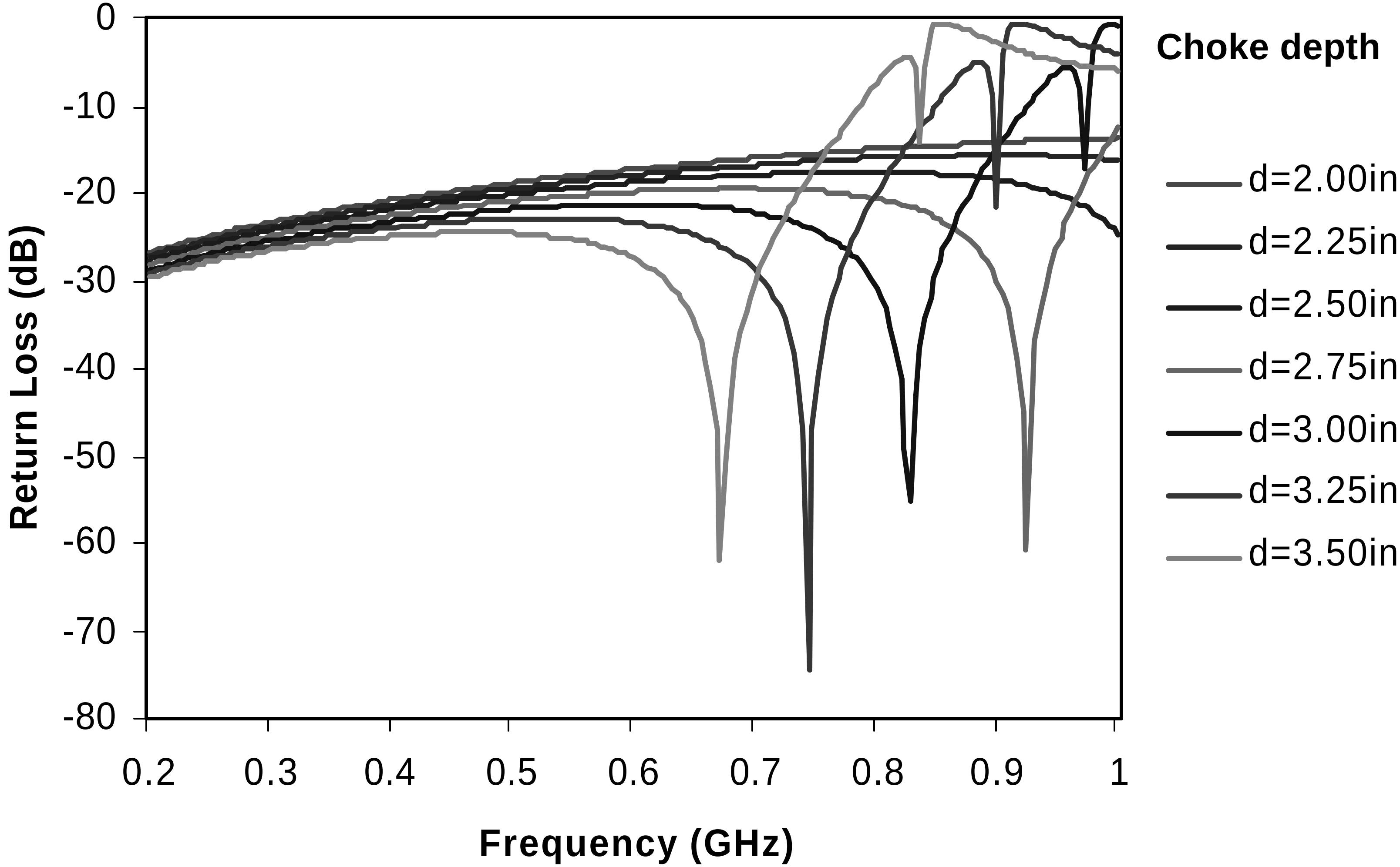


E- and H-fields in Coaxial Window with Outer Conductor Chokes



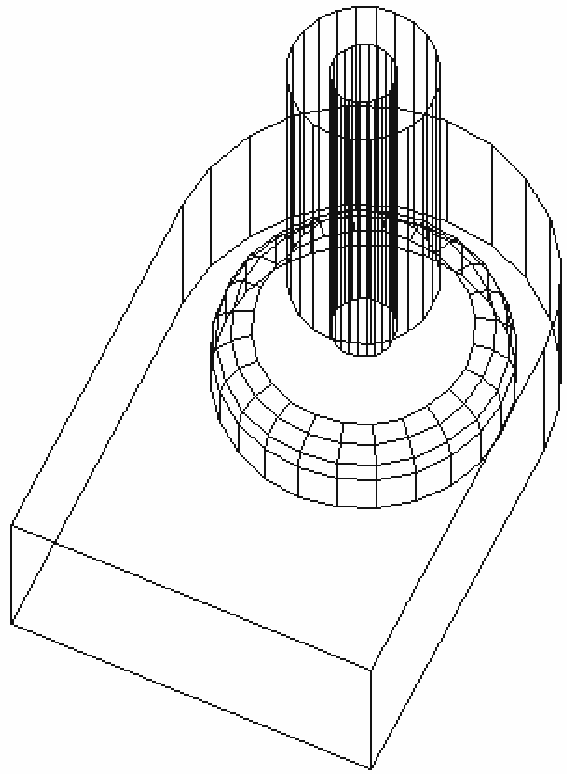


Coaxial Window with Outer Conductor Chokes

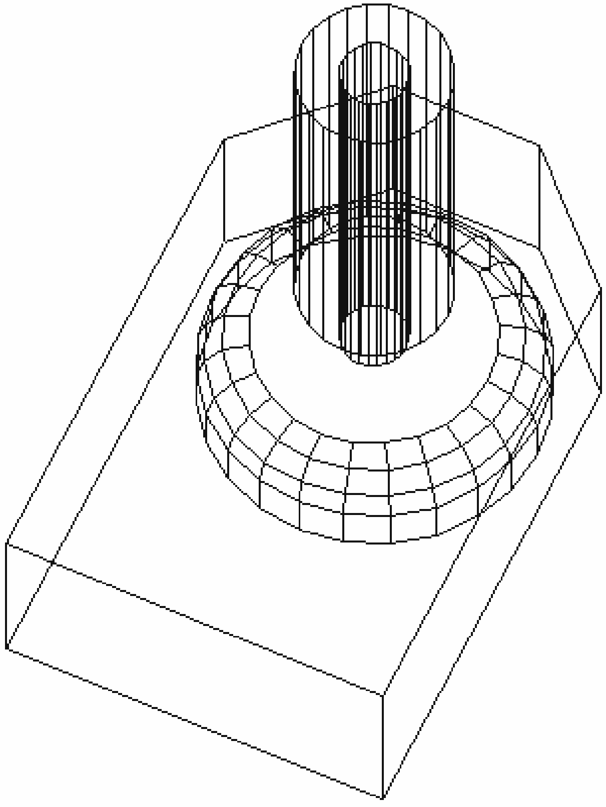


Waveguide to Coaxial Transitions

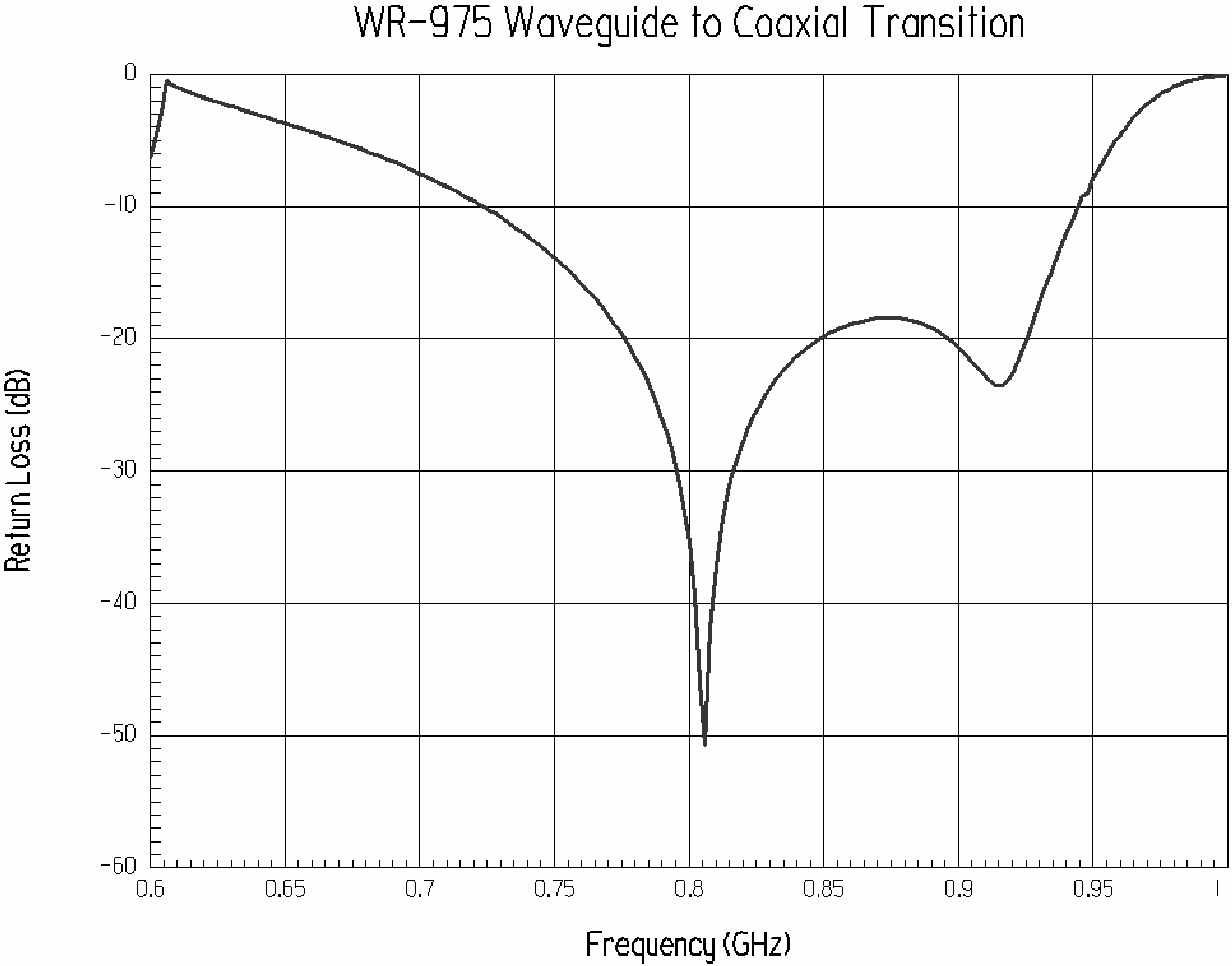
- Semicircular Short



- Miter Short



Return Loss of Transition with Semicircular Short

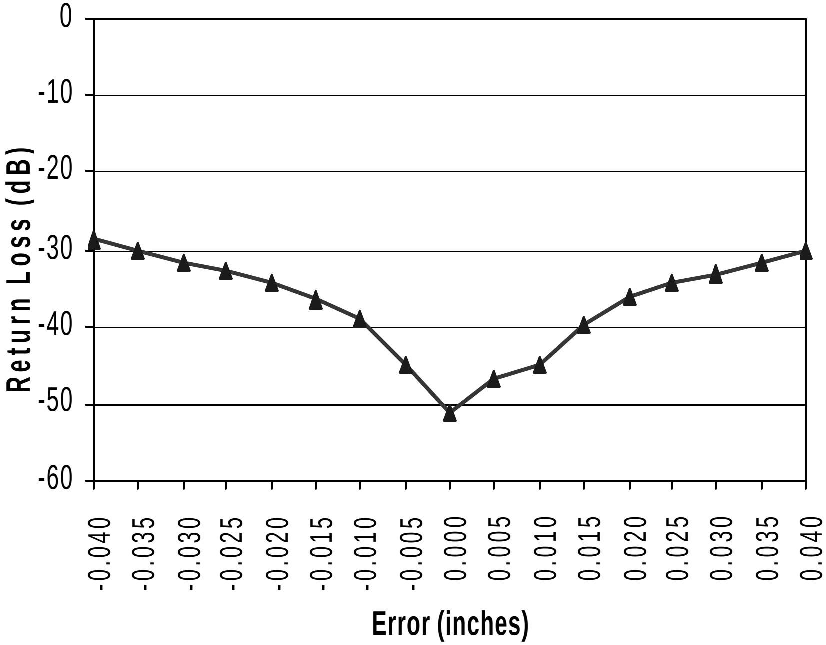


Waveguide Transition with Dimensional Changes

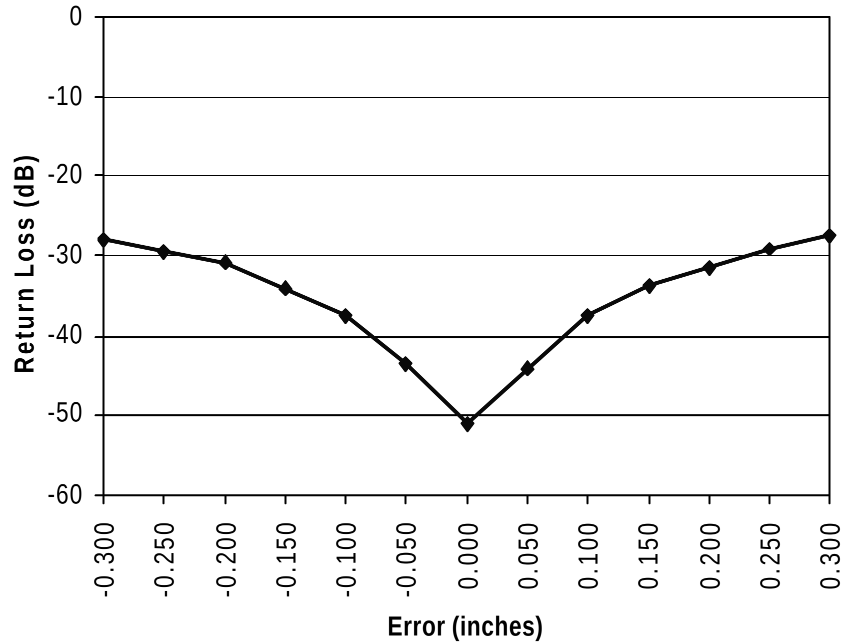
Optimized Transition in WR-975 with Semicircular Short:

- •Doorknob height = 2.6013”
- •Short Location = 0.6752”

Return Loss vs. Doorknob Height



Return Loss vs. Short Location



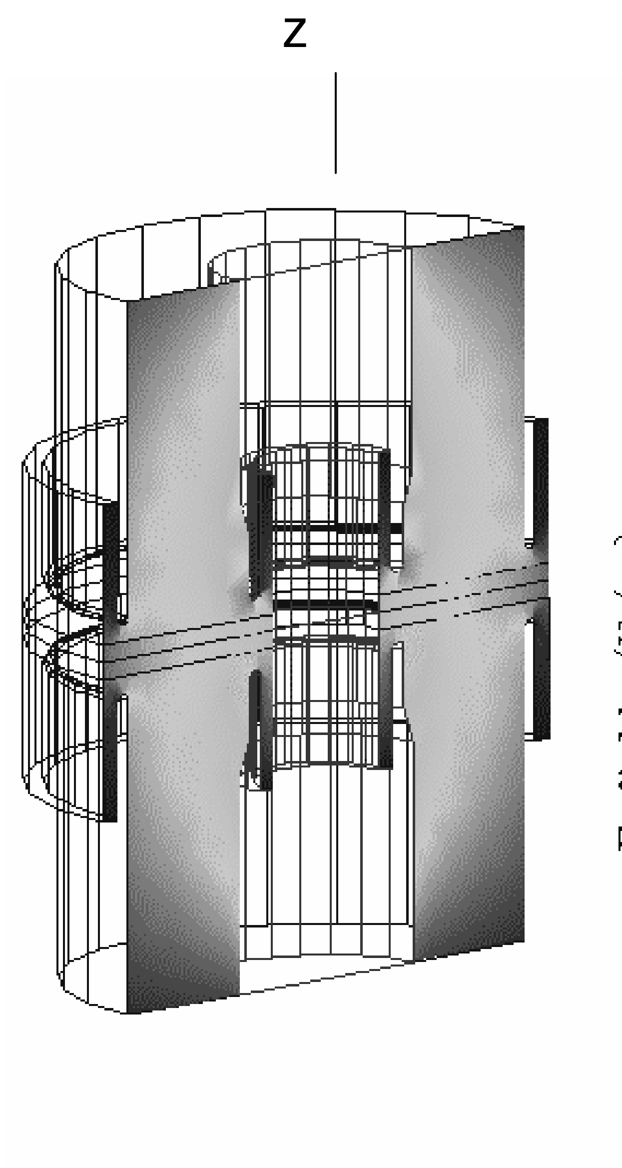
Coupler Design for the SNS SRF LINAC

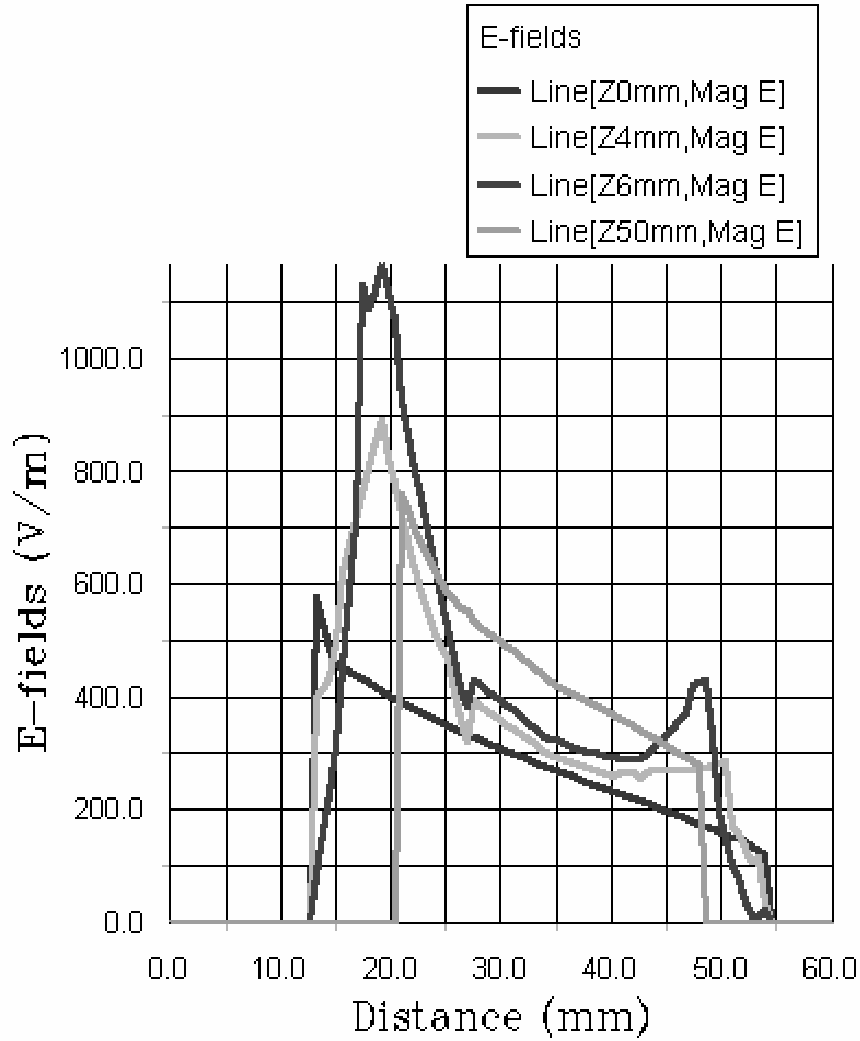
Couplers for the SNS SRF Linac

- Operating frequency = 805 MHz
- Operating power - 1.3ms pulses at 8% duty
  - Peak power = 550kW
  - Average power = 44kW
- Fixed coupling
  - $Q_{ext} = 7.3 \times 10^5$ for medium beta cavities
  - $Q_{ext} = 7.0 \times 10^5$ for high beta cavities
- Coaxial type derived from 508 MHz KEK-B coaxial coupler design
  - Coaxial disk type alumina ceramic window
  - Rectangular waveguide to coaxial to transition

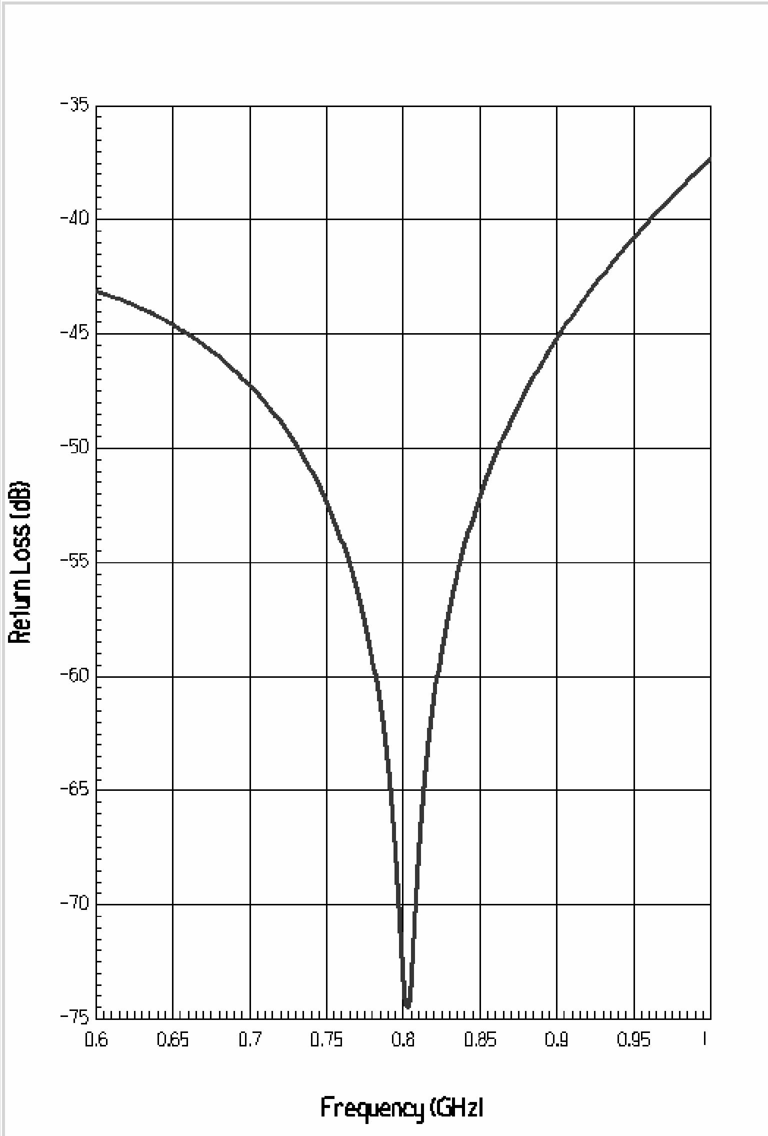
E-fields around Ceramic Window

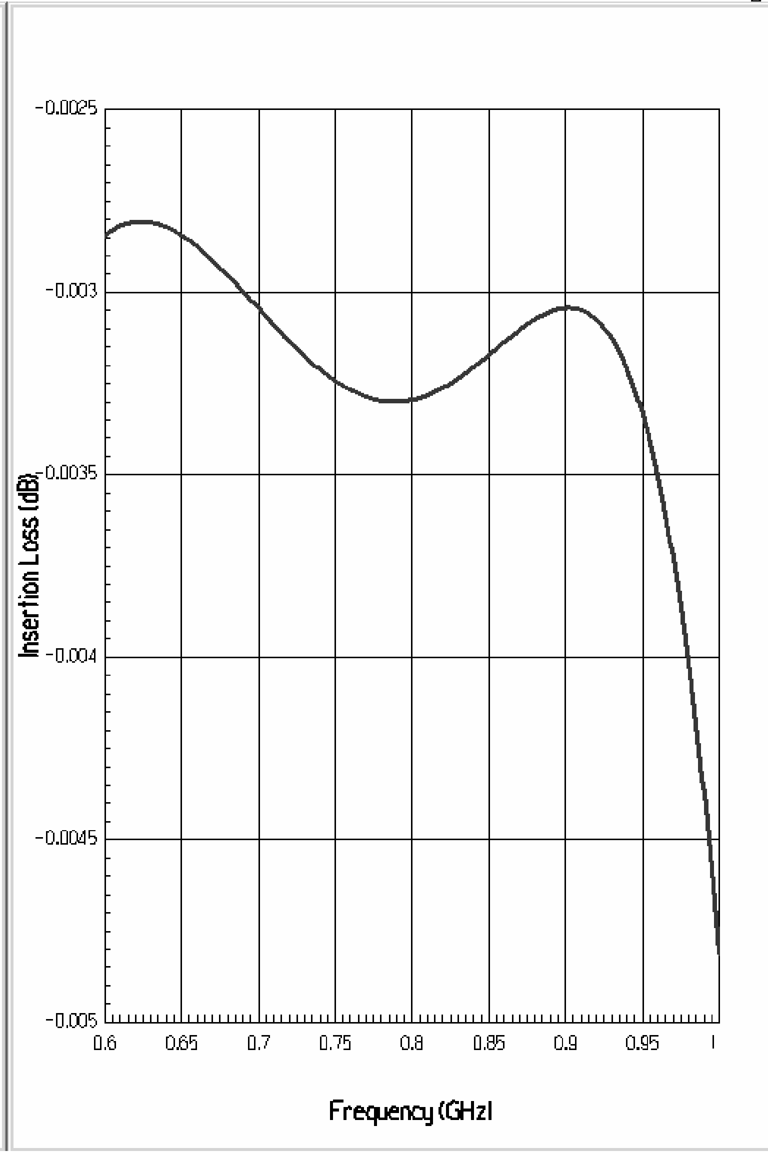
Field strengths normalized to 1W input power



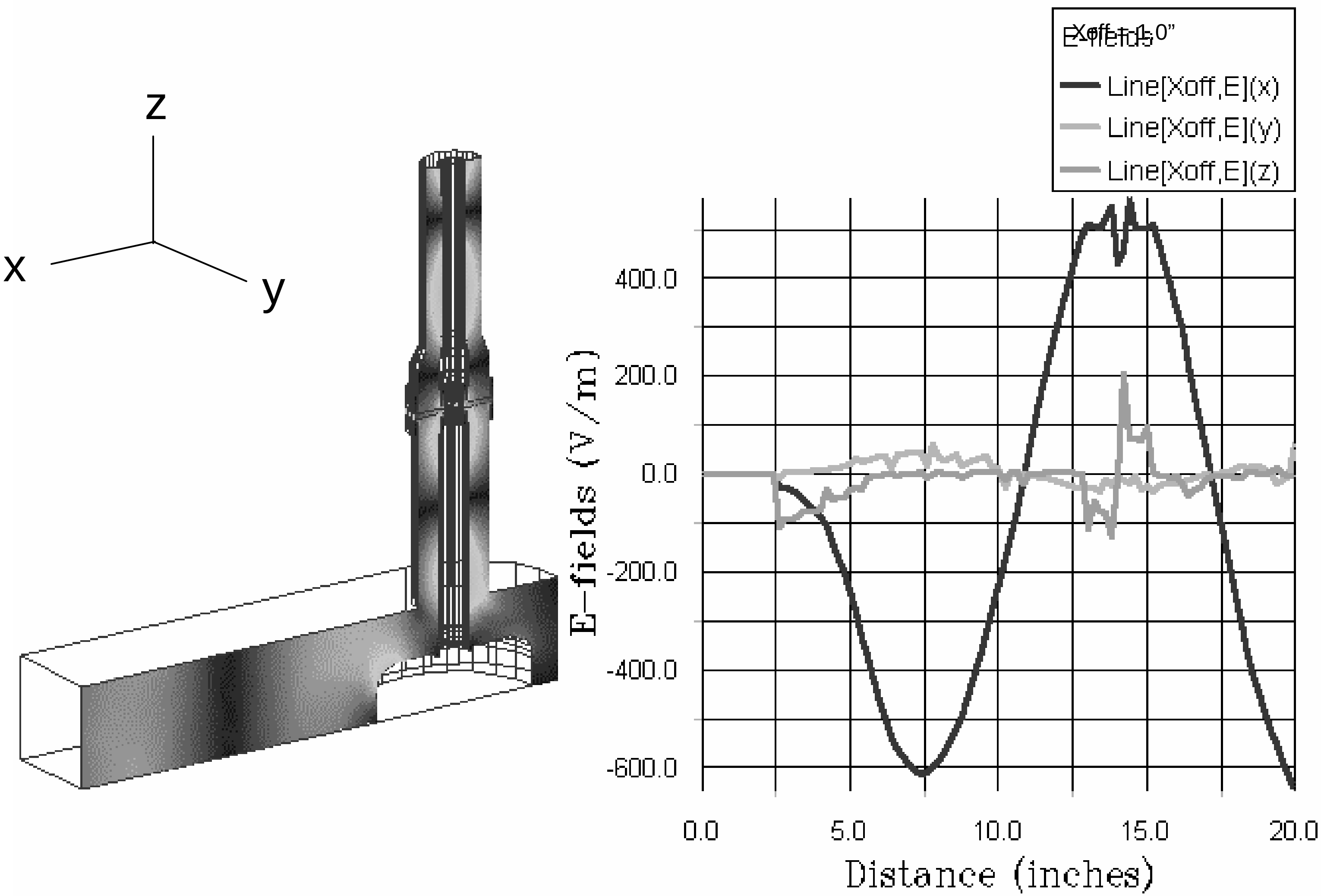


RF Losses of Matched Ceramic Window

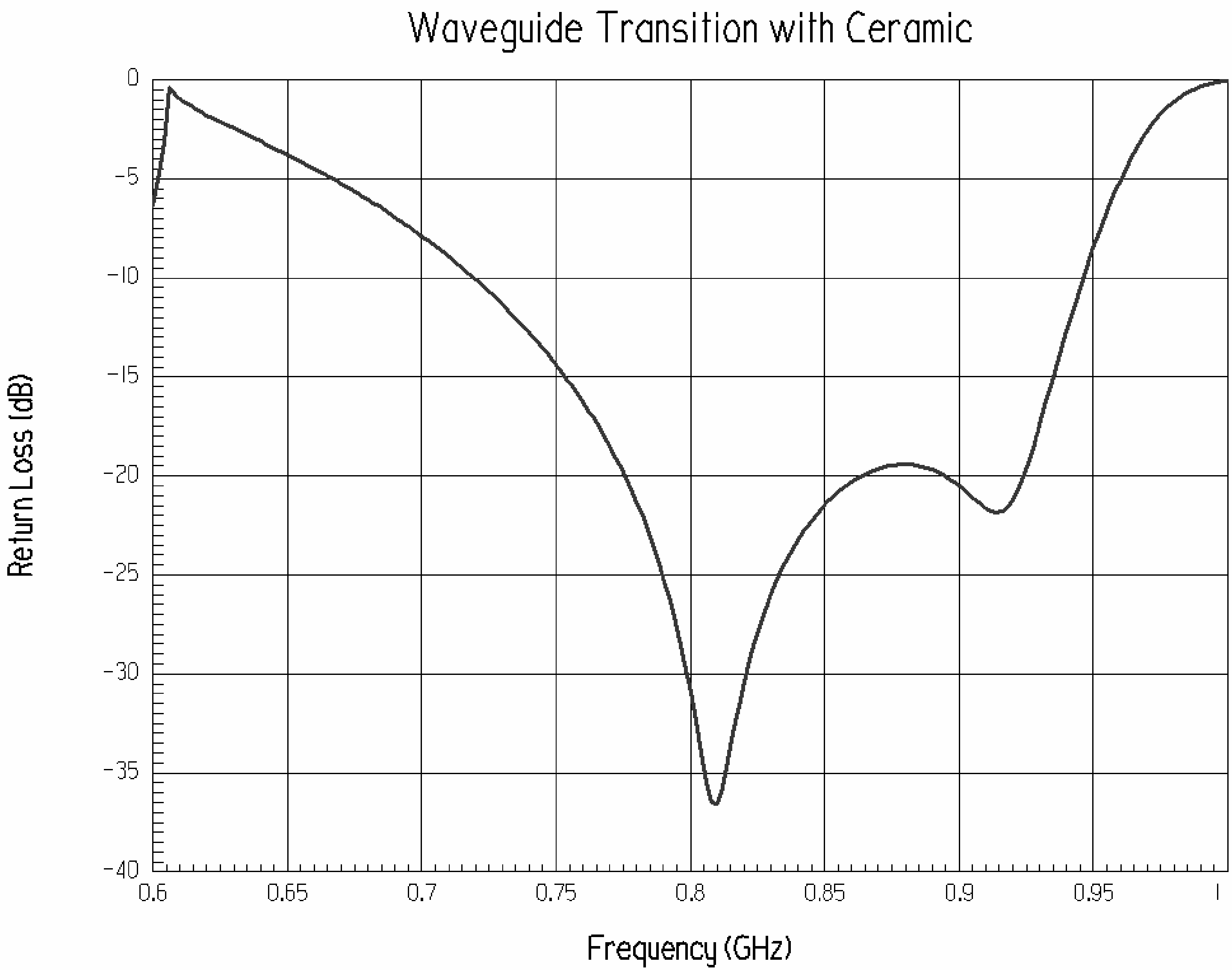




Electric Fields along the Coaxial Structure



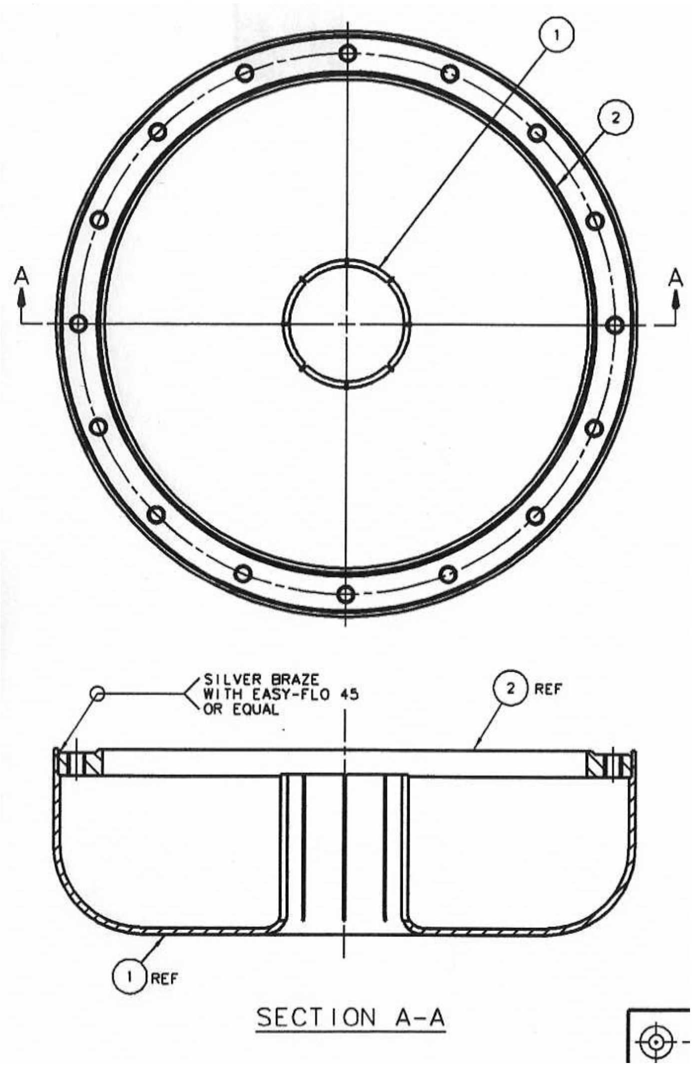
Return Loss of Transition and Ceramic Window

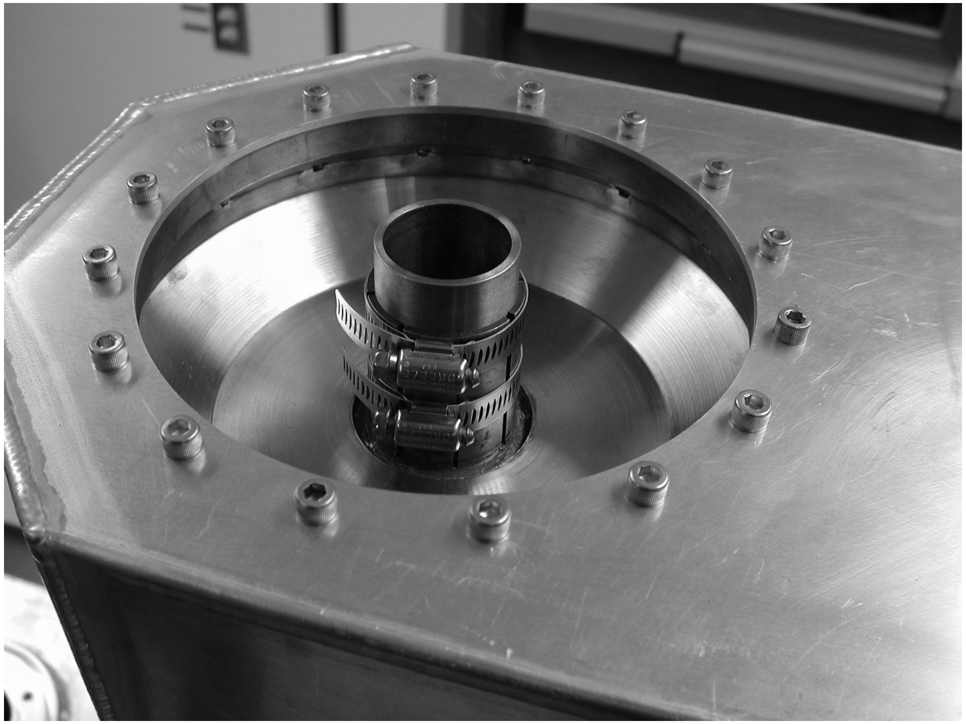


DC Blocking Capacitior for DC Biasing

- Coaxial type couplers allow easy implementation of DC blocking capacitors that are used to DC bias for control of multipacting and RF conditioning
  - » Insulated doorknob in the waveguide transition
  - » Insulated center conductor
- SNS coaxial coupler design uses $\lambda/4$ low impedance coaxial section with 6 mil Kapton film insulated center conductor to realize the capacitior

DC Blocking Capacitor in the Door Knob Transition





Summary

- Inductive choke matching of the ceramic windows is considered simple and efficient solution for good RF matching for both waveguide and coaxial type couplers
- Very good impedance matching can be achieved by careful simulation optimization process
- Non-resonant waveguide type couplers can made using inductive choke matching with smaller window
- Coaxial couplers with simple and cost efficient designs maybe possible using unbalanced inductive chokes
- In waveguide to coaxial transitions, short circuit position error is less sensitive than the doorknob height
- Coaxial DC blocking capacitor can be easily implemented in the waveguide to coaxial transition

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