Design and low power test of an electron bunching enhancer using electrostatic potential depression

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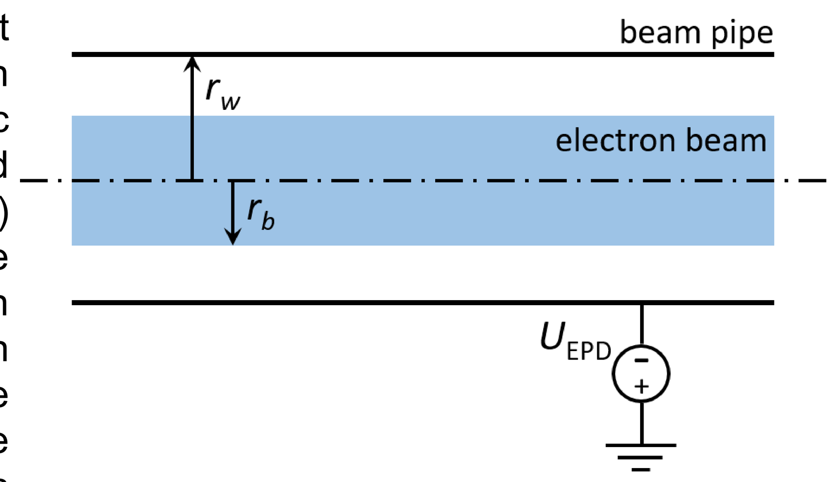
Electrostatic Potential Depression (EPD)

DECELERATION – FAST BUNCHING DEVELOPMENT – RE-ACCELERATION

We present our experimental design and low power test results of a structure for the proof-of-principle demonstration of fast increase of the first harmonic current content in a bunched electron beam, using the technique of electrostatic potential depression (EPD). A primarily bunched electron beam from an inductive output tube (IOT) at 710 MHz first enters an idler cavity, where the longitudinal slope of the beam energy distribution is reversed. The beam then transits through an EPD section implemented by a short beam pipe with a negative high voltage bias, inside which the rate of increase of the first harmonic current is significantly enhanced. An output cavity measures the harmonic current developed inside the beam downstream of the EPD section. Low power test results of the idler and the output cavities agree with the theoretical design.



$$\gamma_{\mathrm{inj}} = \gamma_0 - \frac{eU_{\mathrm{EPD}}}{m_e c^2} + \frac{I_0}{\beta_0 I_A}\left(1 + 2\ln\frac{r_w}{r_b} - \frac{r^2}{r_b^2}\right)$$

FAST DEVELOPMENT OF ELECTRON BEAM BUNCHING

Linear space charge waves – reduced wavelengths inside EPD.
Nonlinear space charge waves – increased bunching development by EPD.

ENHANCED MAXIMAL HARMONIC CURRENT

The first harmonic current reaches a higher value downstream of the combination of an idler cavity and an EPD section, compared to that achieved exclusively by an idler cavity.

IMPROVED ELECTRON BEAM BUNCHING QUALITY

The high level of the first harmonic current downstream of the combination of an idler cavity and an EPD section takes a profile of a comparatively broad plateau.
The first harmonic current peaks over only a very small longitudinal range downstream of an idler cavity by itself.

EPD Applications

HIGH EFFICIENCY AND COMPACTNESS

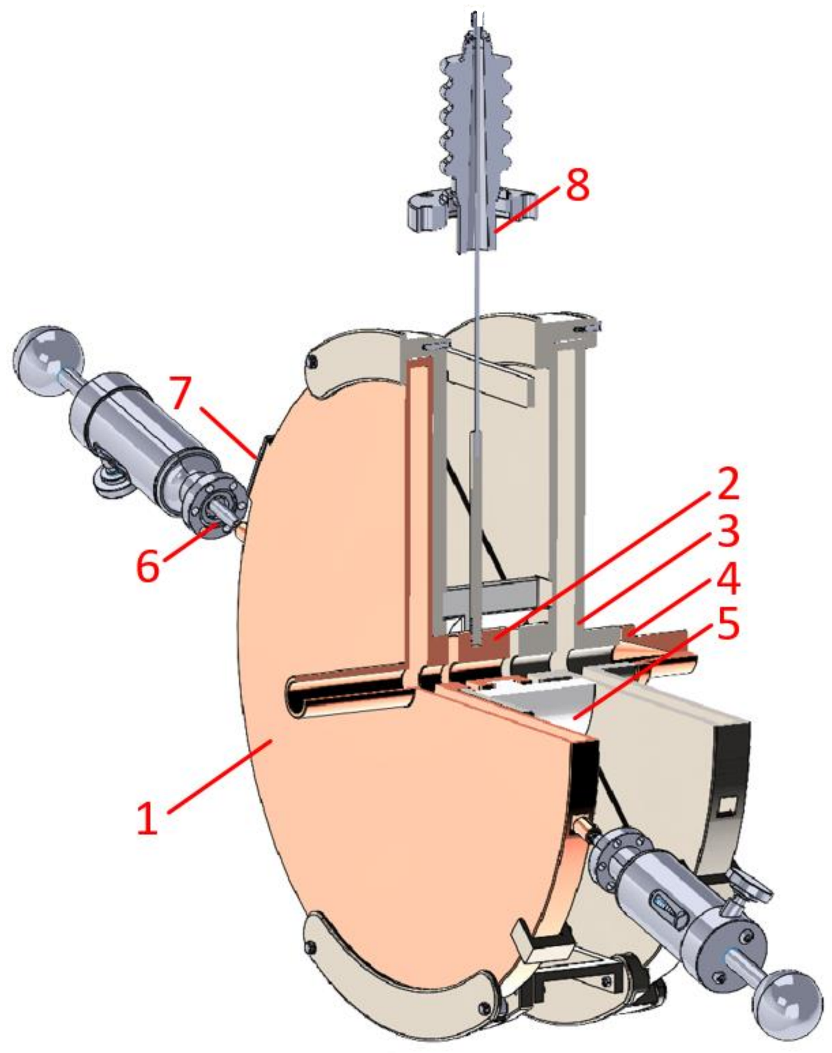
Hybrid inductive output tube.
Compact klystron with iterative EPD sections.

PUBLICATION ON THEORETICAL CALCULATIONS (QR CODE)

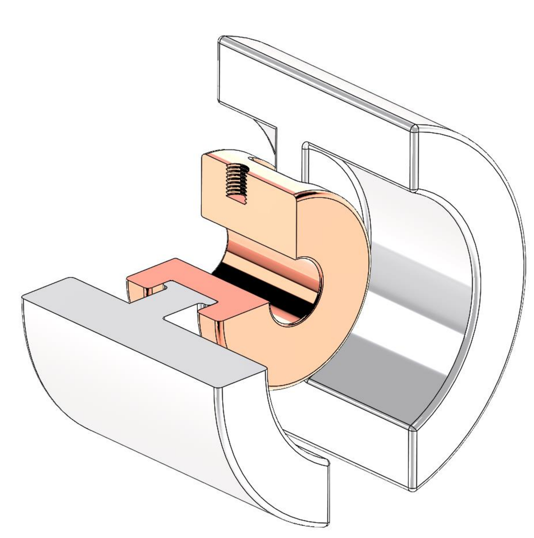
H. Xu, Q. R. Marksteiner and B. E. Carlsten, "High efficiency compact microwave sources using electrostatic potential depression," *IEEE Trans Electron Devices*, vol. 68, no. 4, 2021.

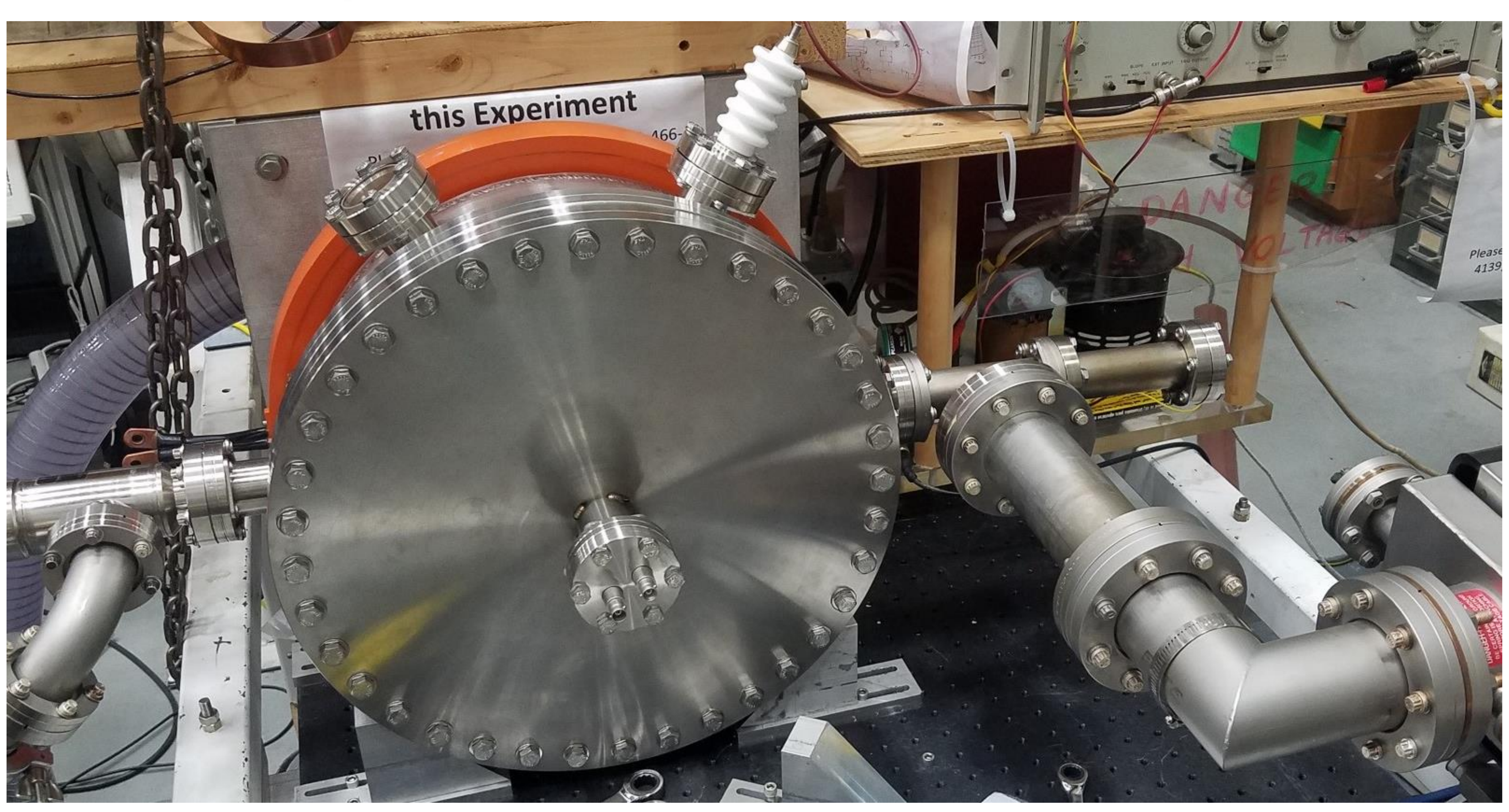
Experimental Structure

ELABORATED EPD GEOMETRY TO AVOID TRIPLE POINT PROBLEM



1 – idler cavity
2 – EPD section
3 – output cavity
4 – current monitor
5 – Macor spacers
6 – linear motion feedthrough and tuner
7 – RF coupler
6 – high voltage feedthrough

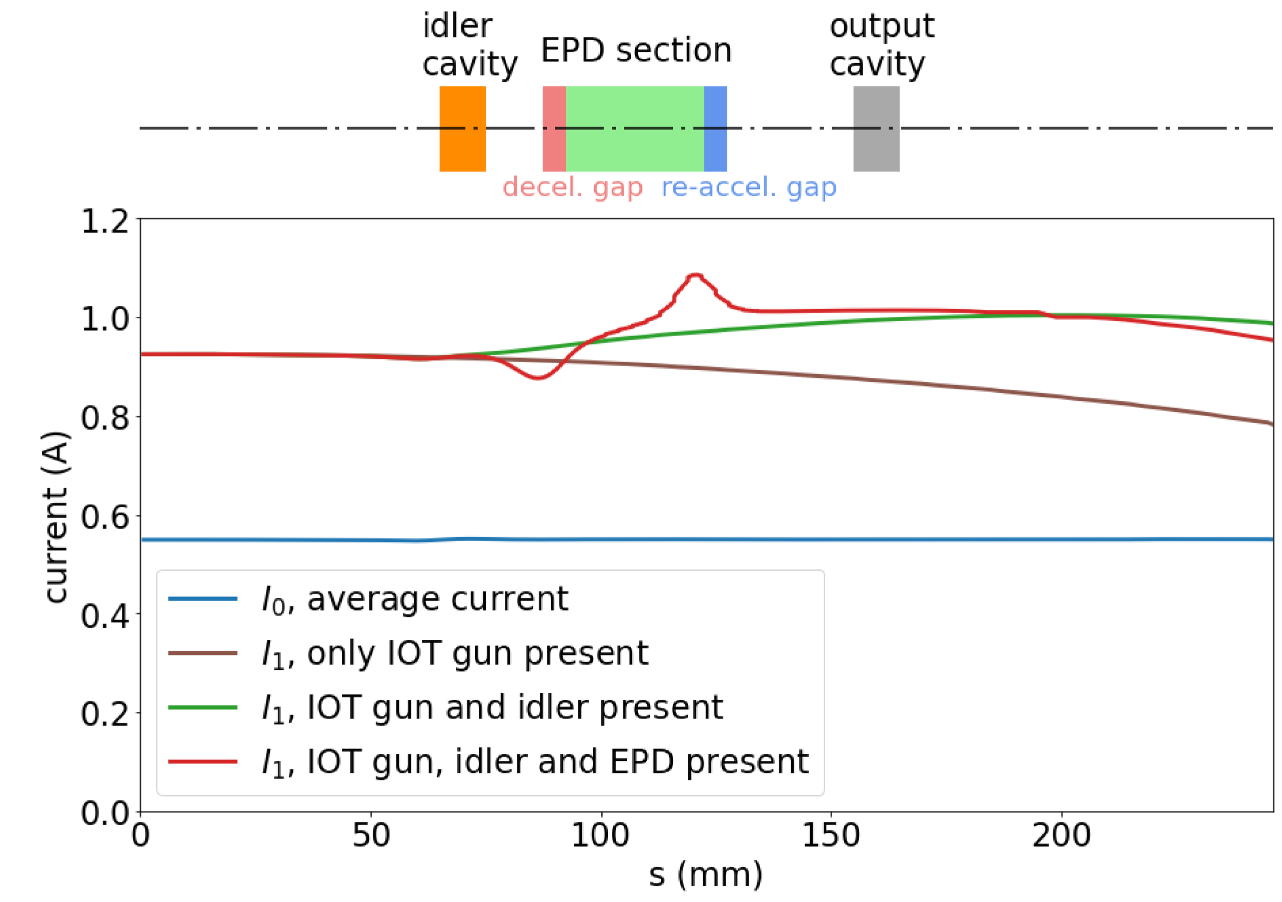




Experimental Setup

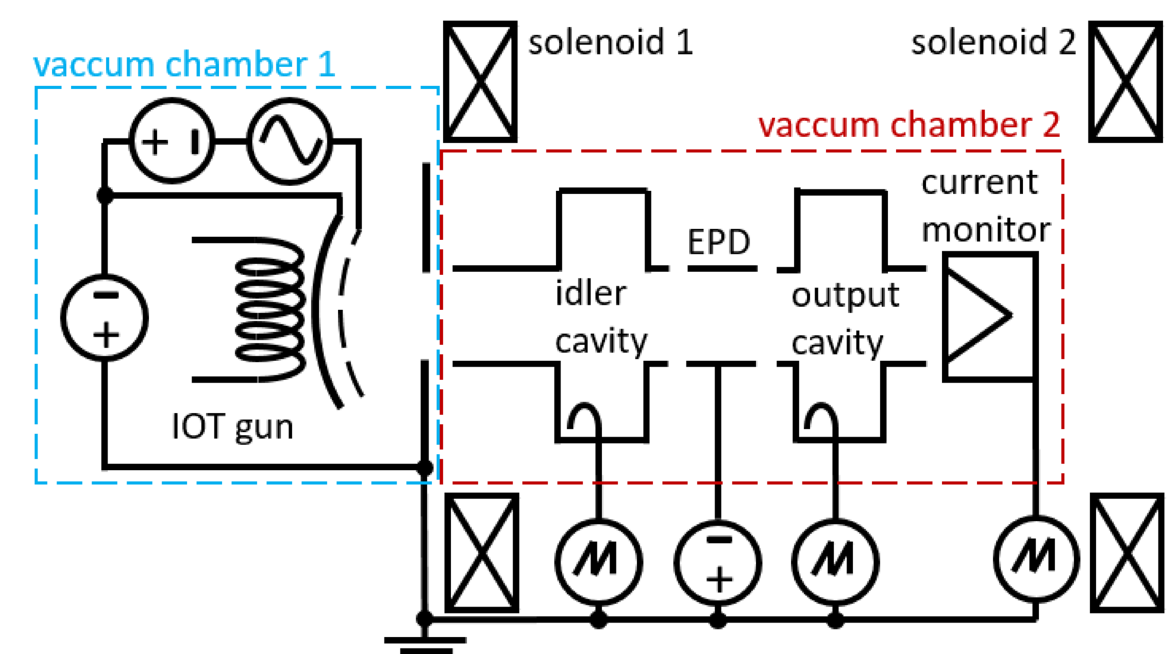
BEAMLINE ARCHITECTURE AND BUNCHING ENHANCEMENT PREDICTION

Simulations performed using the TUBE code.



SCHEMATIC OF DEVICE

The experiment uses the 700 MHz Naval Research Laboratory Inductive Output Tube as the source of the bunched electron beam.



The first harmonic current is measured through the external power measured from the output cavity. Induced current by the electron beam first harmonic current:

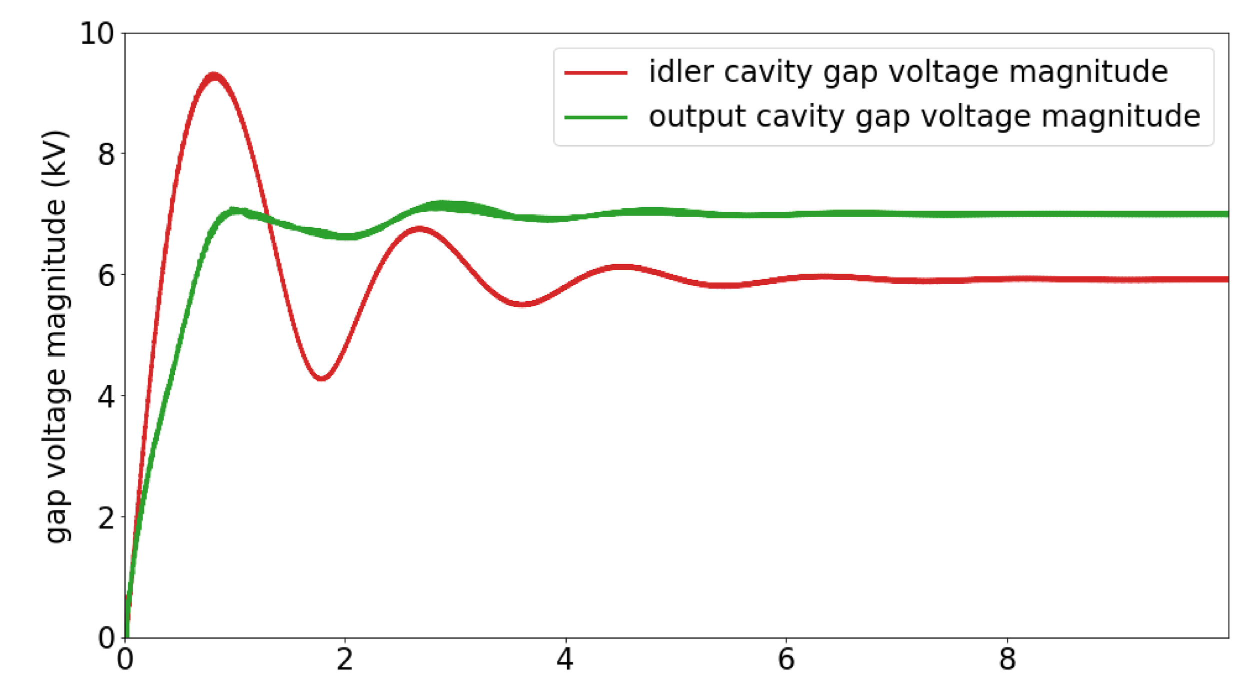
$$i_1 = (1+\beta)\frac{V_{\mathrm{gap}}}{Z_{\mathrm{cav}}}$$

External power coupled from the output cavity:

$$P_{\mathrm{ext}} = \frac{|\beta|}{2}\frac{|V_{\mathrm{gap}}|^2}{|Z_{\mathrm{cav}}|}$$

CAVITY GAP VOLTAGE PREDICTION

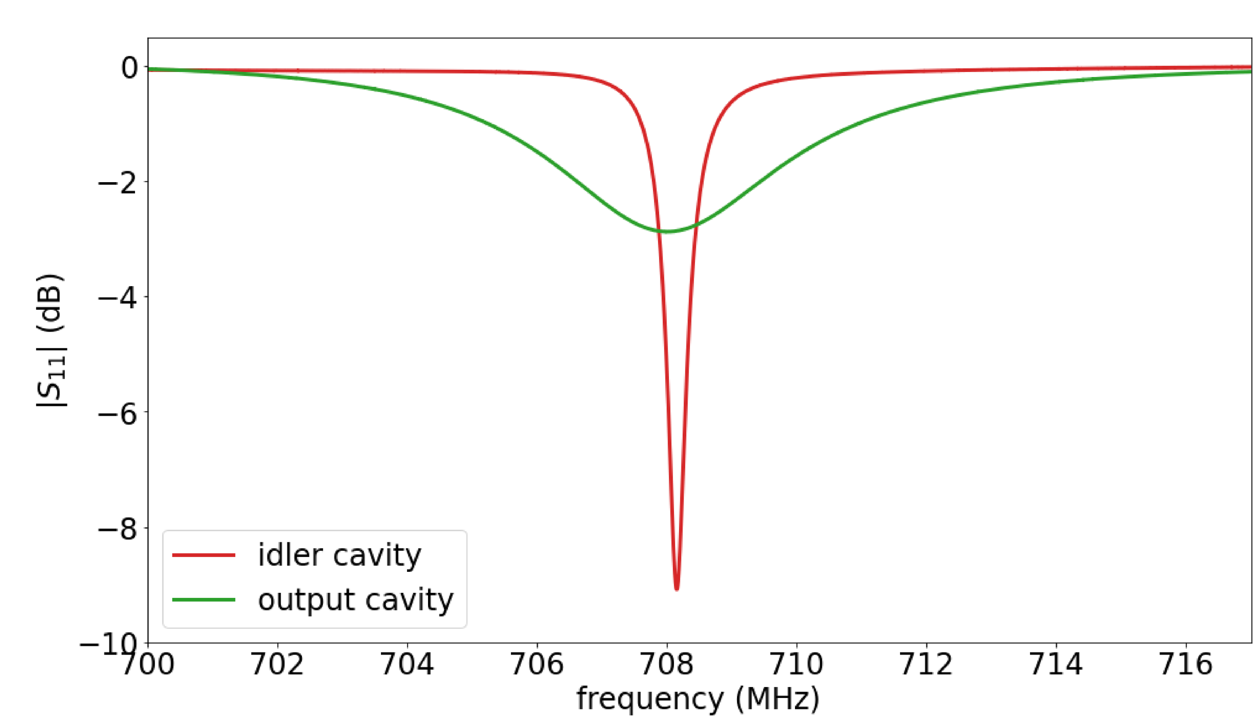
Simulations performed using the CST particle-in-cell (PIC) solver.



Low Power Test Results

REFLECTION COEFFICIENT MEASURED IN SITU ON THE SETUP

To establish the desired gap voltages, the idler cavity resonant frequency should be 0.4 MHz higher than the IOT frequency, which is equal to the output cavity resonant frequency.



Los Alamos NATIONAL LABORATORY

NNSA National Nuclear Security Administration

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