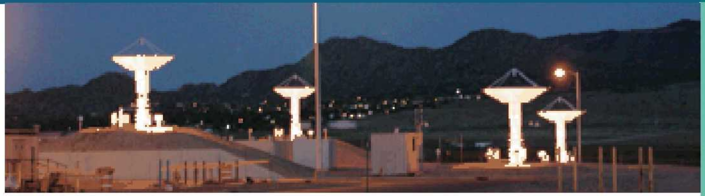
SAND2020-3274C

Systematic CMA of the U-slot Patch with FEKO



PRESENTED BY

John Borchardt, org. 5333 jjborch@sandia.gov

SAND2020-XXXXC

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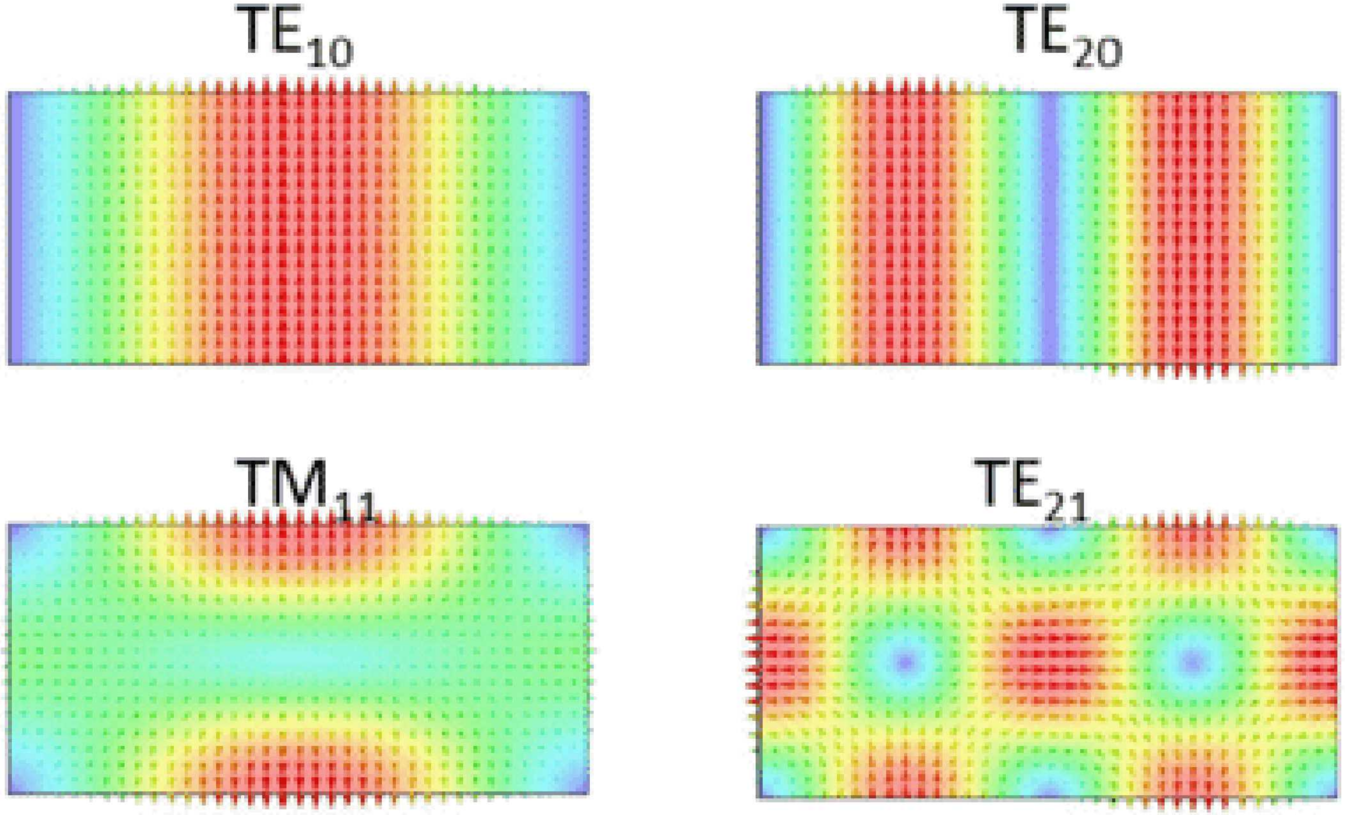
Outline

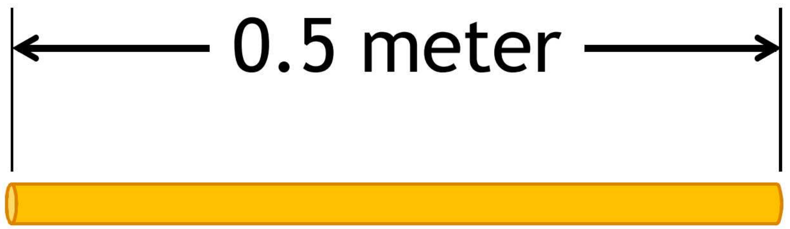
- Characteristic Mode Analysis/dipole example
- Systematic Analysis Steps
- Multimode patches & Coupled Mode Theory
- Apply systematic analysis steps to the U-slot patch

Conceptually similar to waveguide modes, but suited to radiation & scattering problems

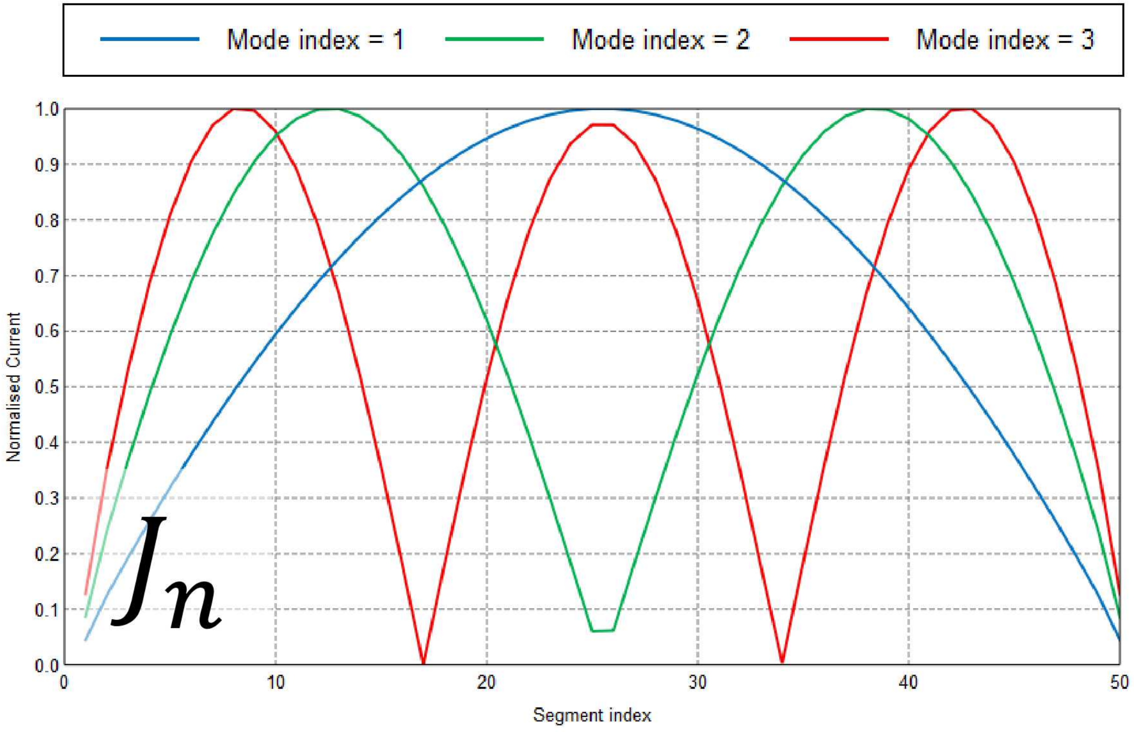
$$\nabla_t^2 e = -\beta^2 e$$

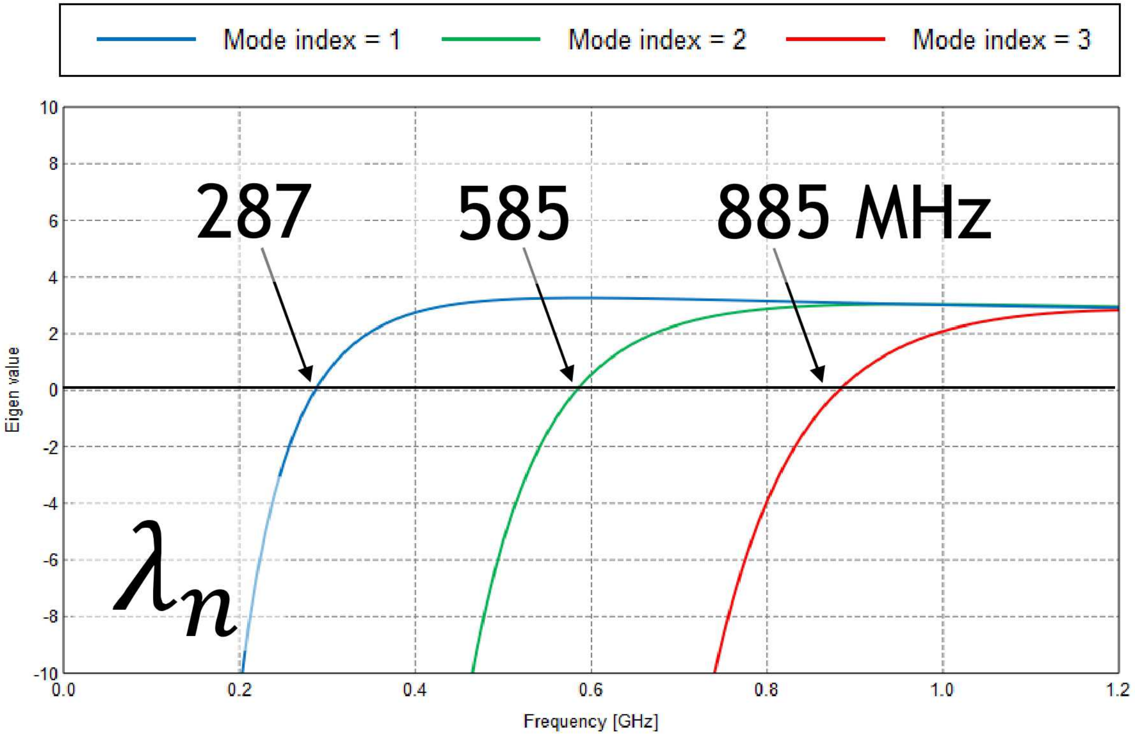


CMA Eigenvalues and Eigenvectors



$$[X]\,J_n = \lambda_n\,[R]\,J_n$$

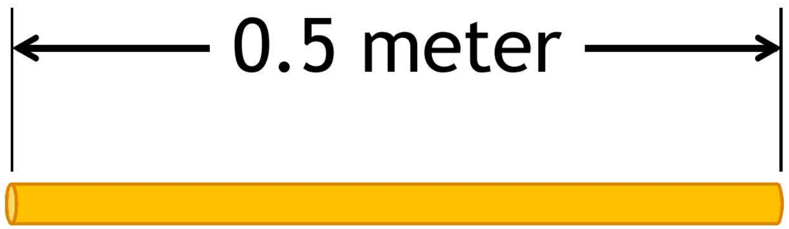


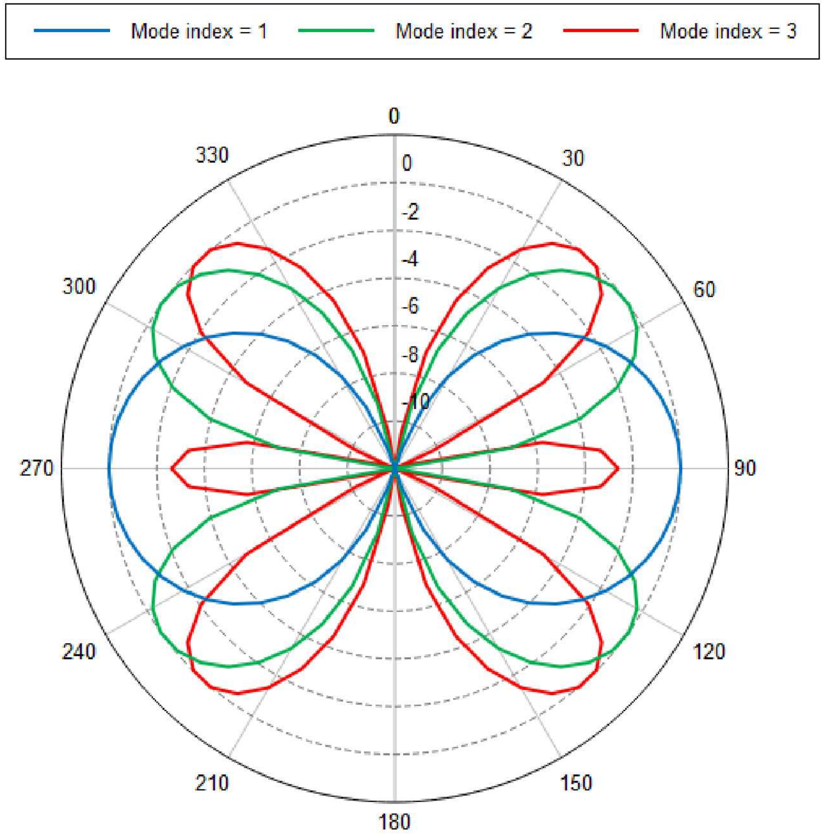


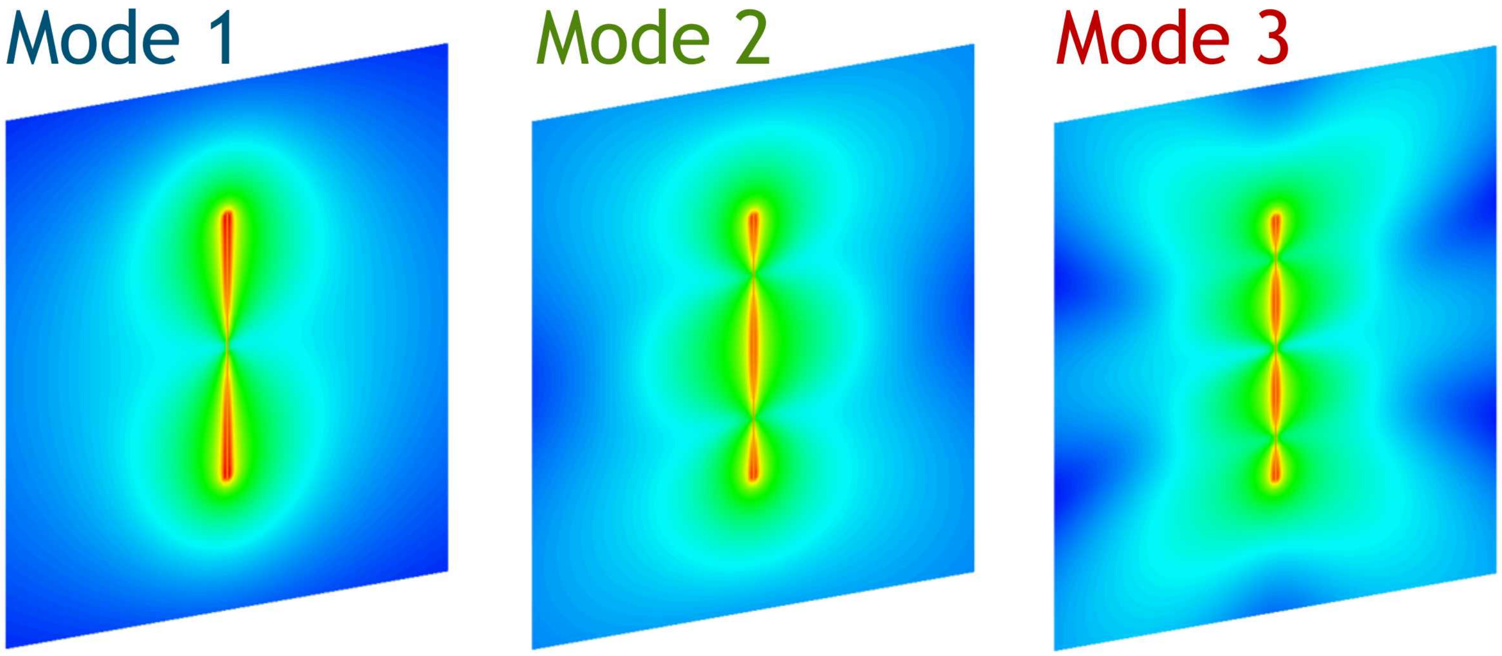
Eigenvectors are currents J_n

Mode resonant when $\lambda_n = 0$

Modal Near- and Far-Fields



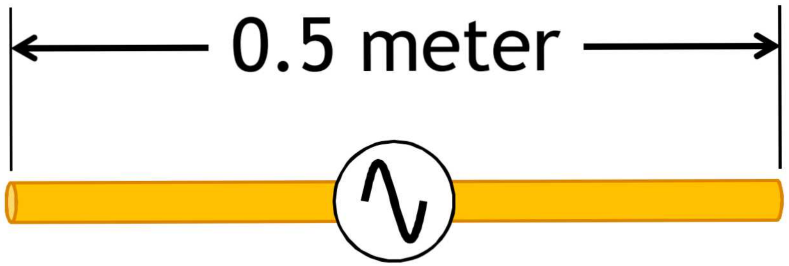




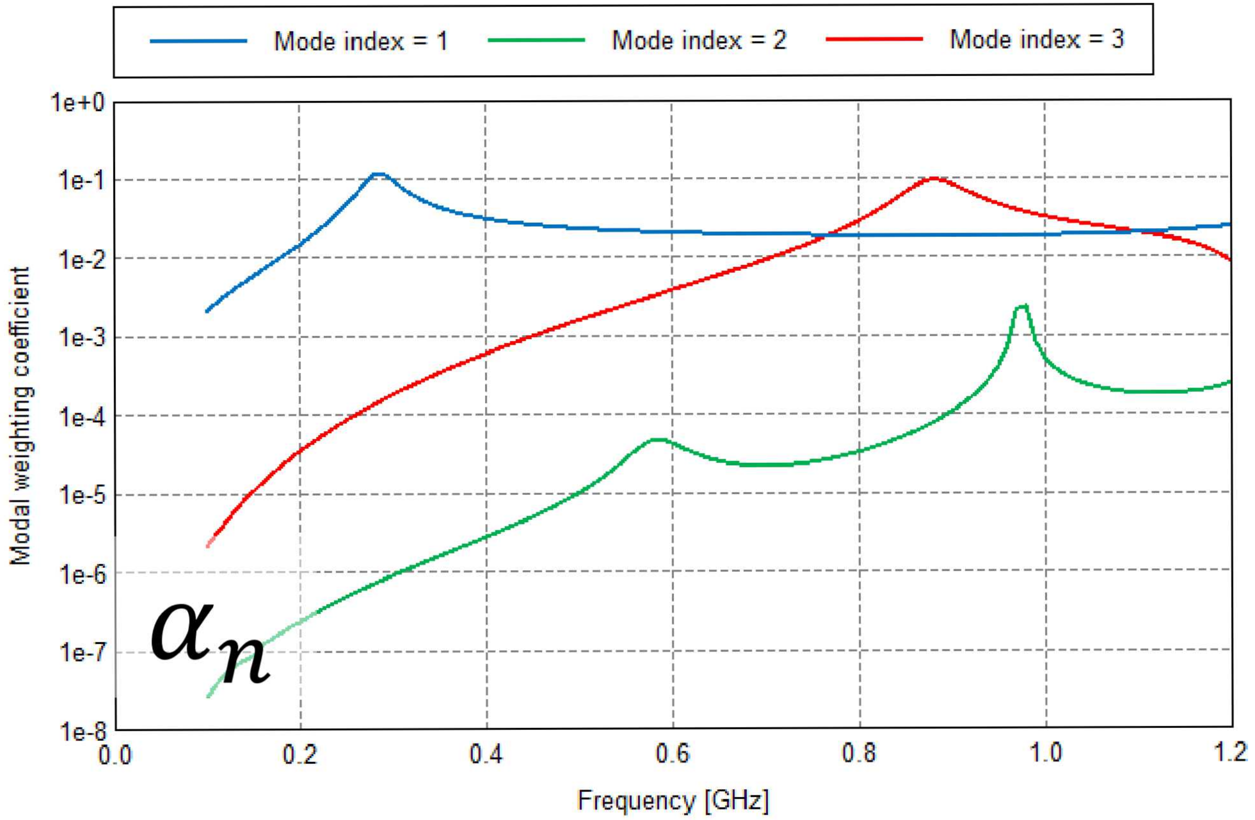
Near- and far-fields are associated with each mode

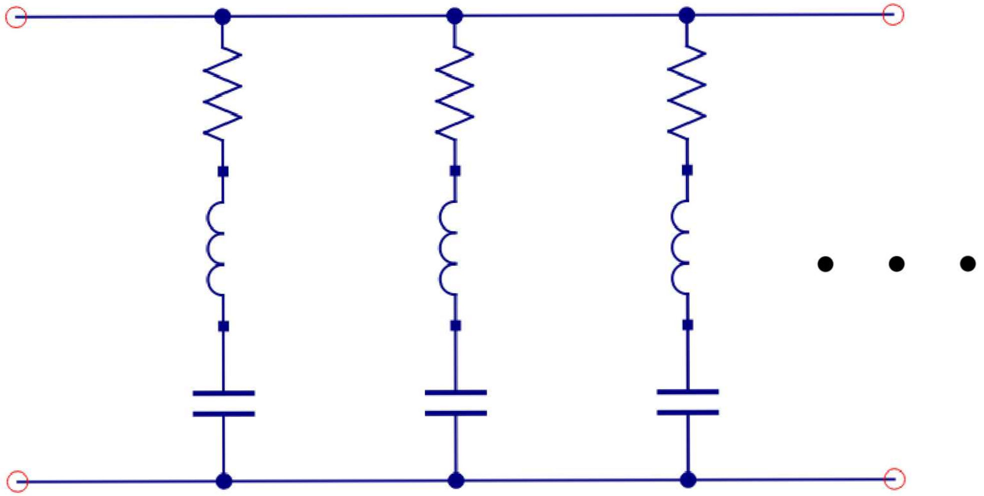
CMA *with an Excitation*

$$J_{tot} = \sum_n \alpha_n J_n \qquad \alpha_n = \frac{\langle J_n, E^i_{tan} \rangle}{1 + j\lambda_n}$$



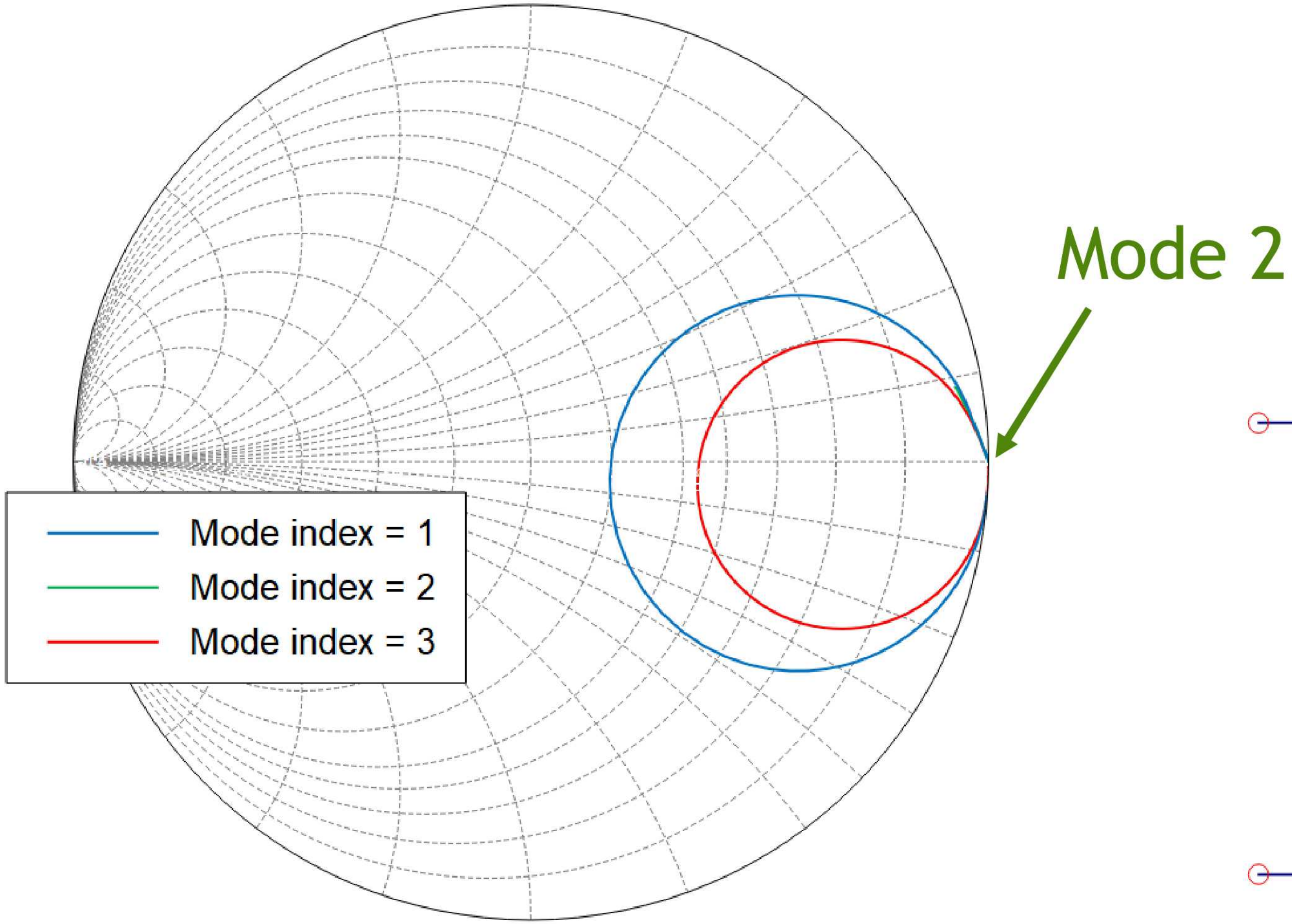
$$Y_{tot}[i] = \sum_n \frac{J_n[i]^2}{1 + j\lambda_n}$$

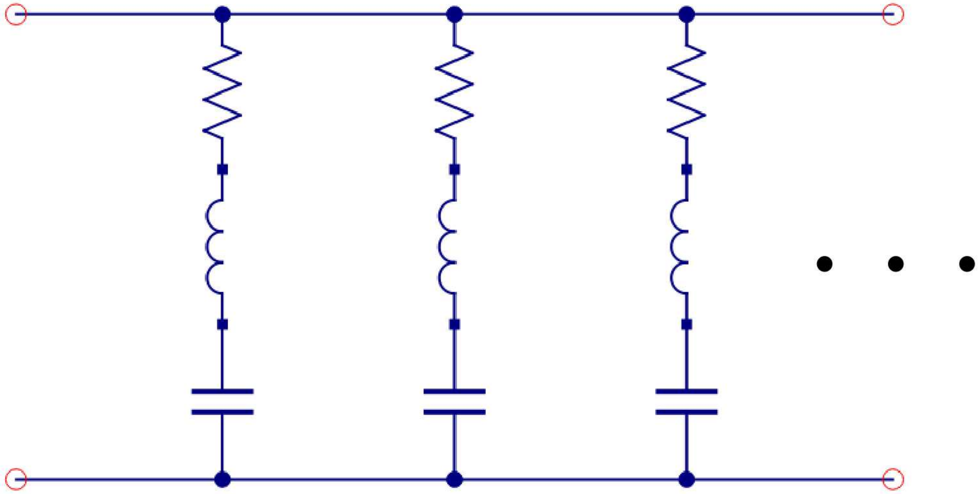




Modal Admittances

$$Y_{tot}[i] = \sum_{n} \frac{J_n[i]^2}{1 + j\lambda_n}$$





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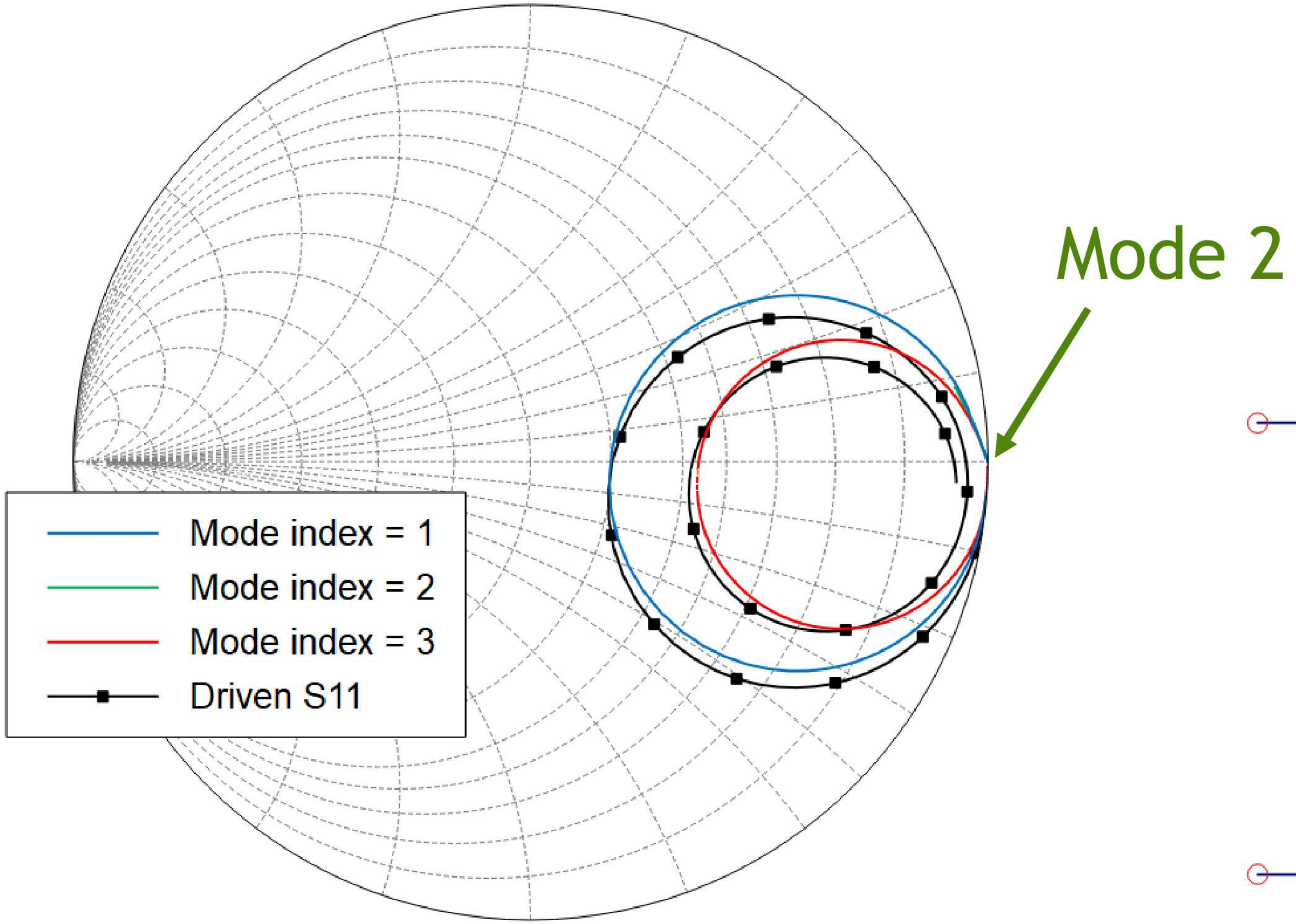
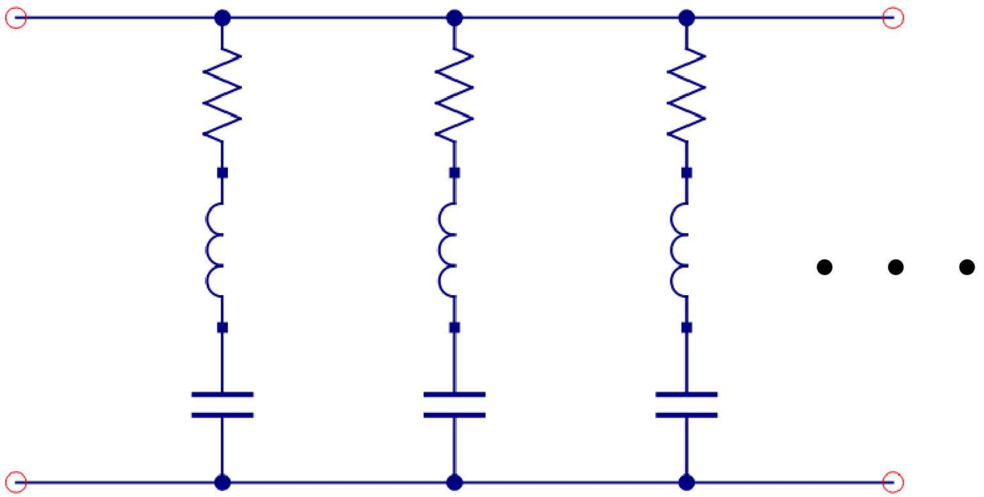
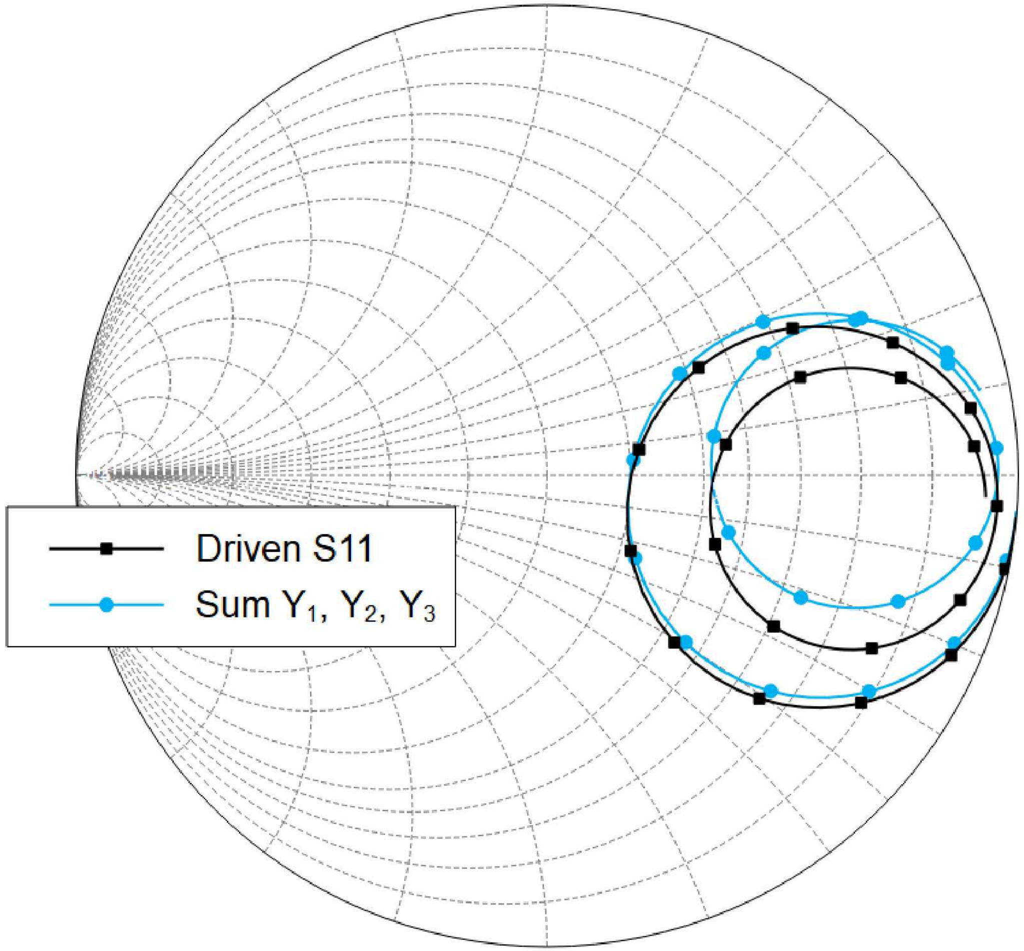
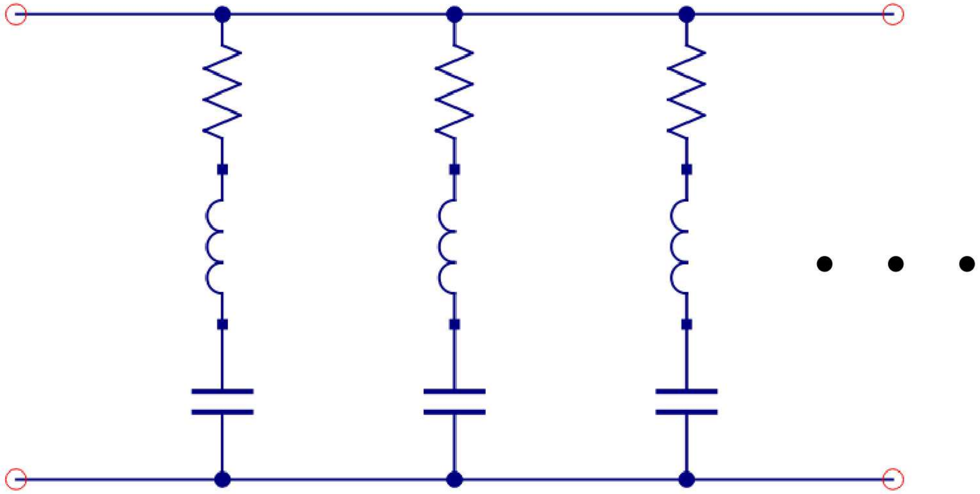




Sum of Modal Admittances



$$Y_{tot}[i] = \sum_n \frac{J_n[i]^2}{1 + j\lambda_n}$$



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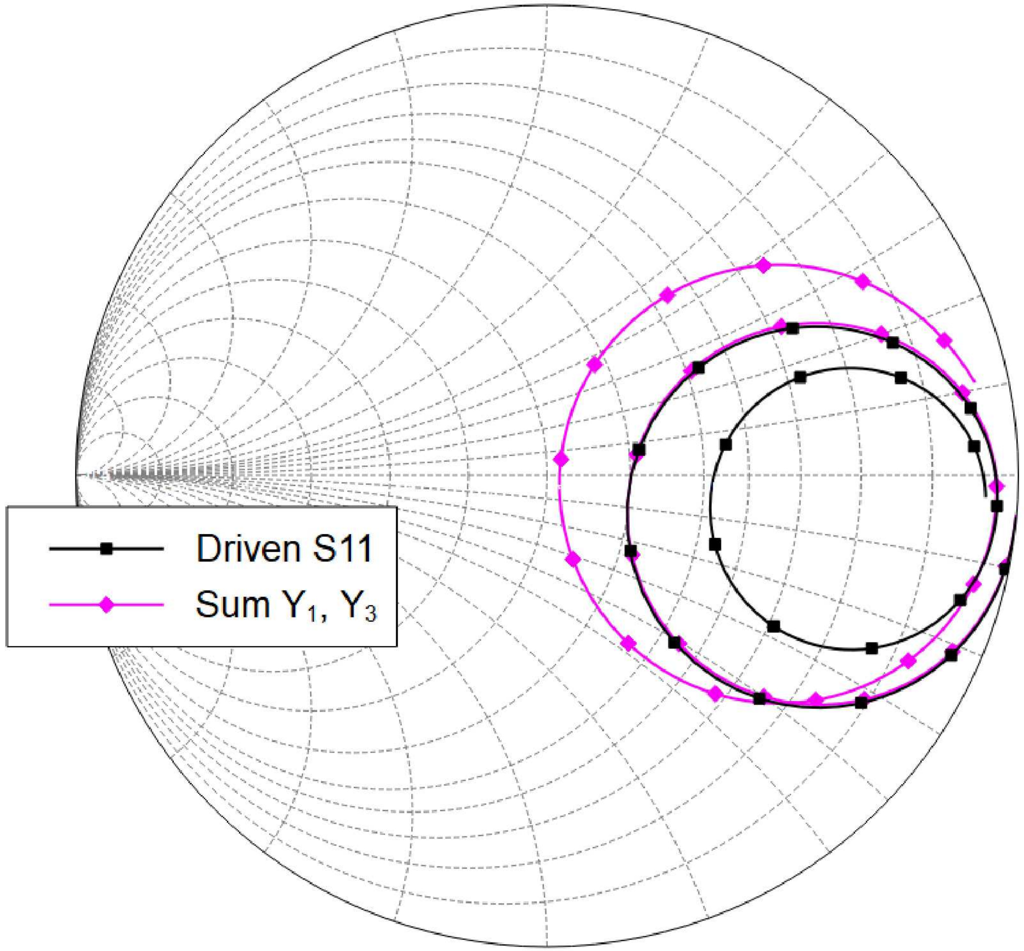
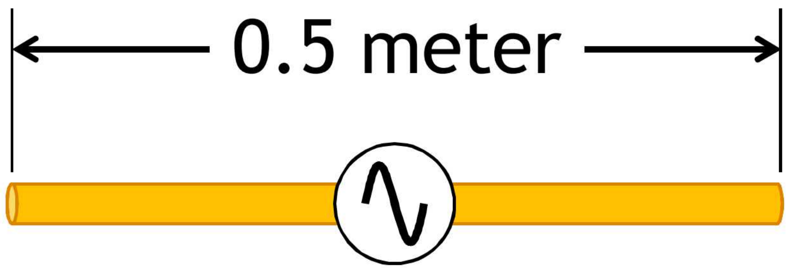
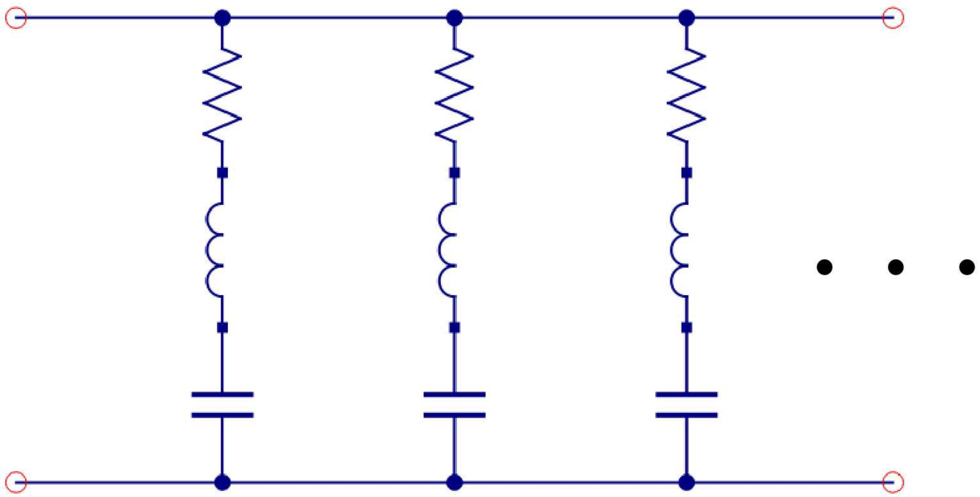




$$Y_{tot}[i] = \sum_n \frac{J_n[i]^2}{1 + j\lambda_n}$$



Systematic Analysis of Antennas with CMA

(1) include the excitation and run driven MoM problem alongside CMA

(2) select resonant modes/select modes with significant MWCs

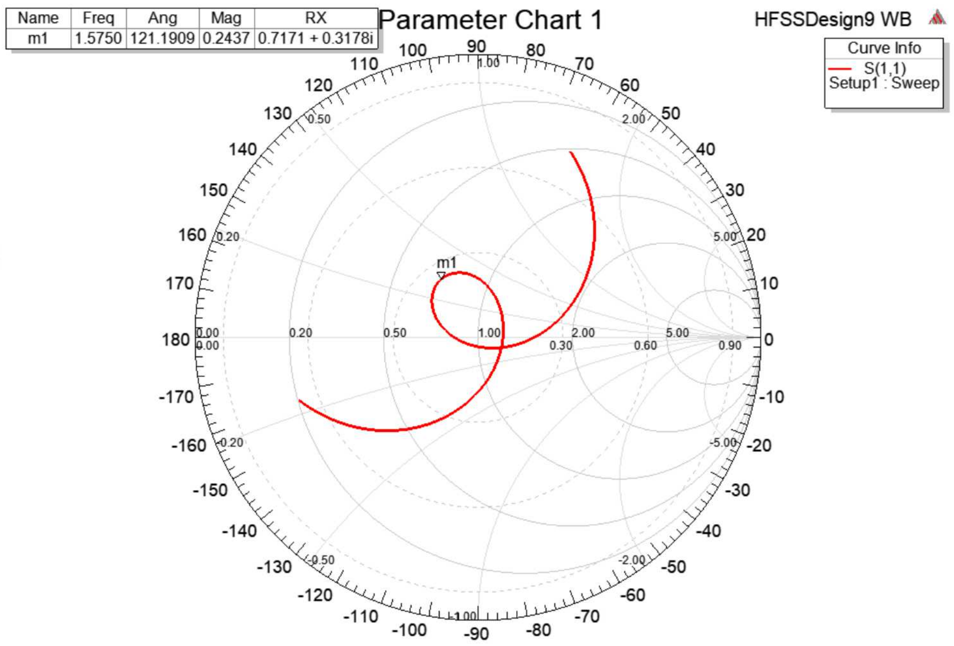
(3) replicate driven admittance with sum of selected modal admittances

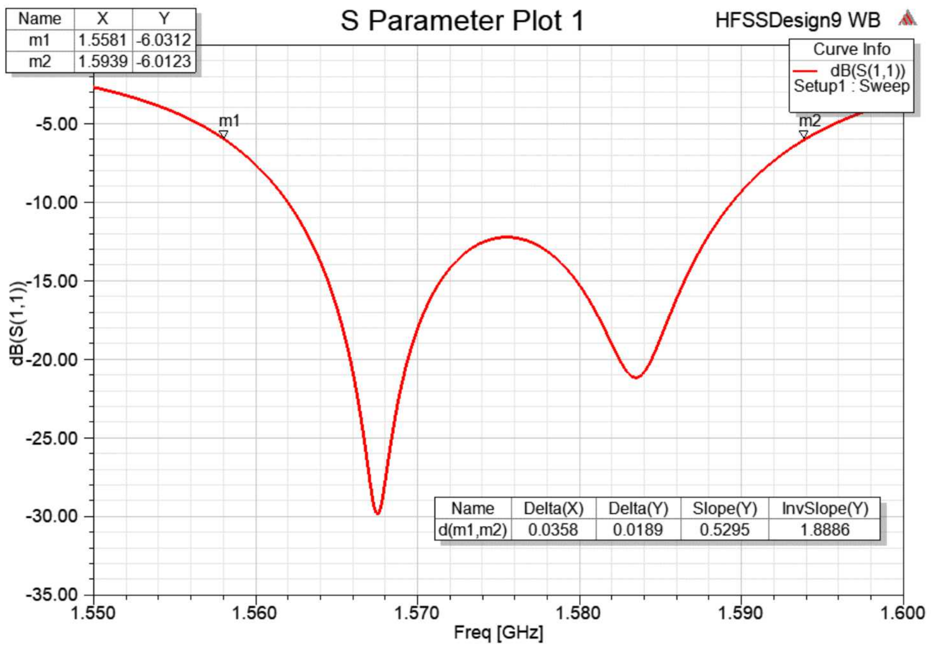
(4) use CMA current and charge distributions to obtain physical insight

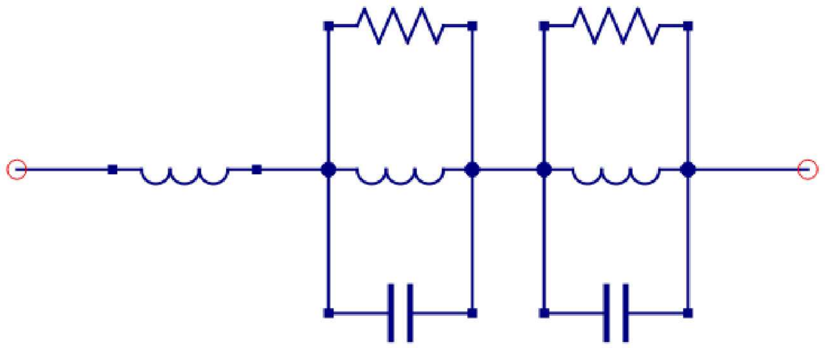
(5) for multi-modal antennas establish uncoupled resonator geometries and calculate coupling using near-fields

Patch impedance bandwidth and multi-moding

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$







$$Z \sim R(1 + j2Q\,\Delta\omega/\omega_0)$$

Classic U-slot patch

Huynh and Lee, 1995

BW about 30%

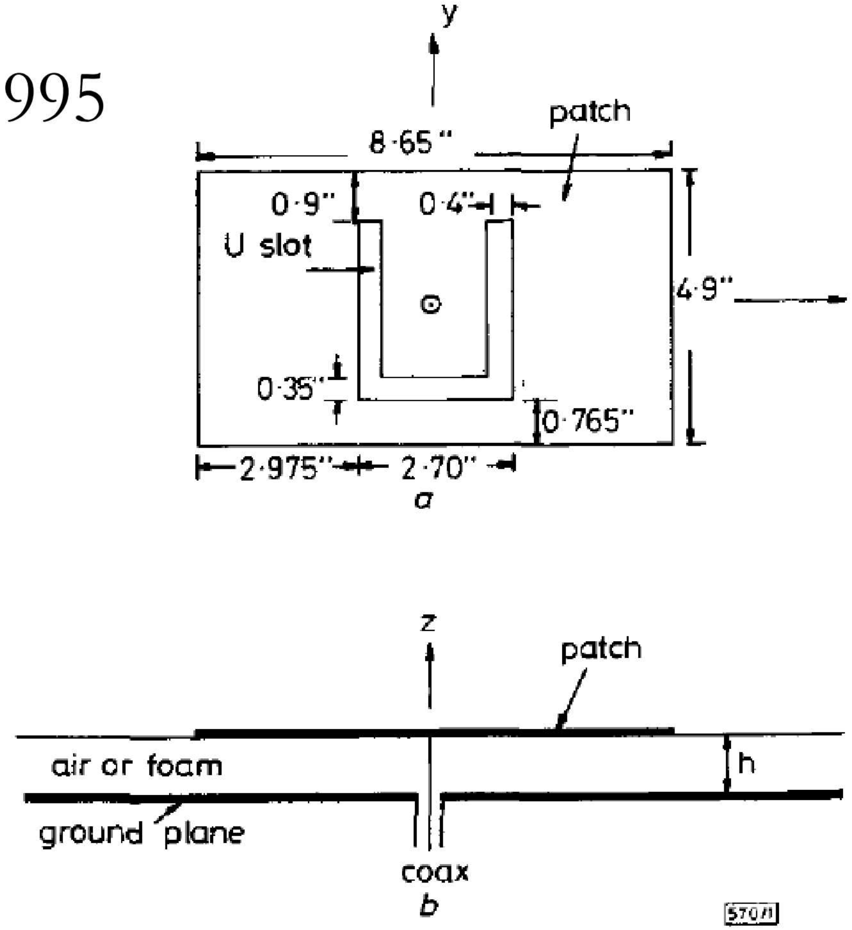


Fig. 1 *Geometry of coaxially-fed rectangular patch with U shapec*

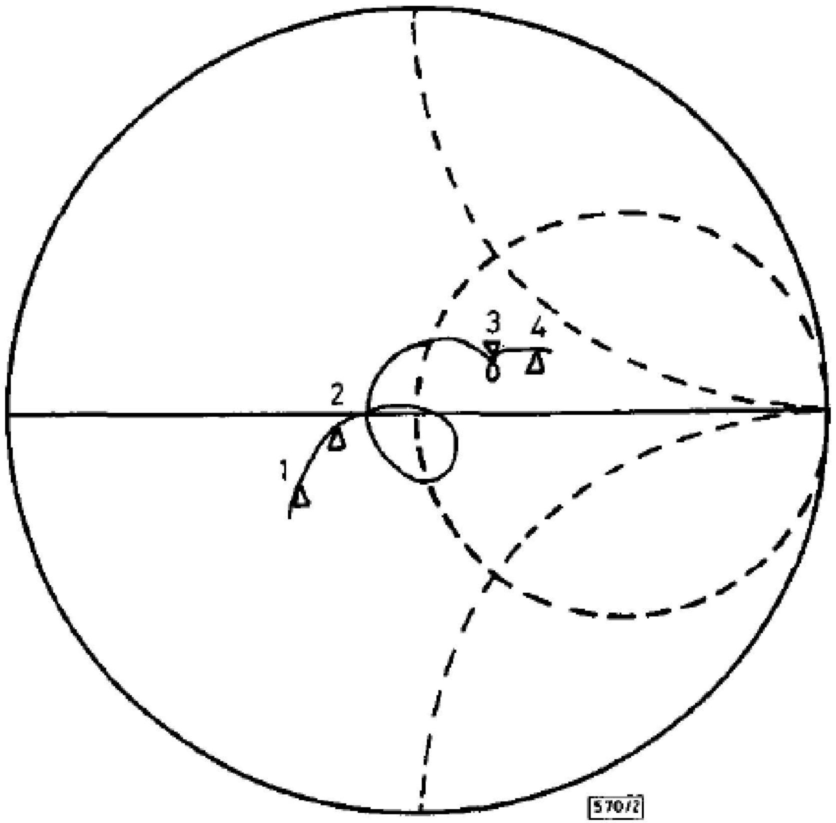
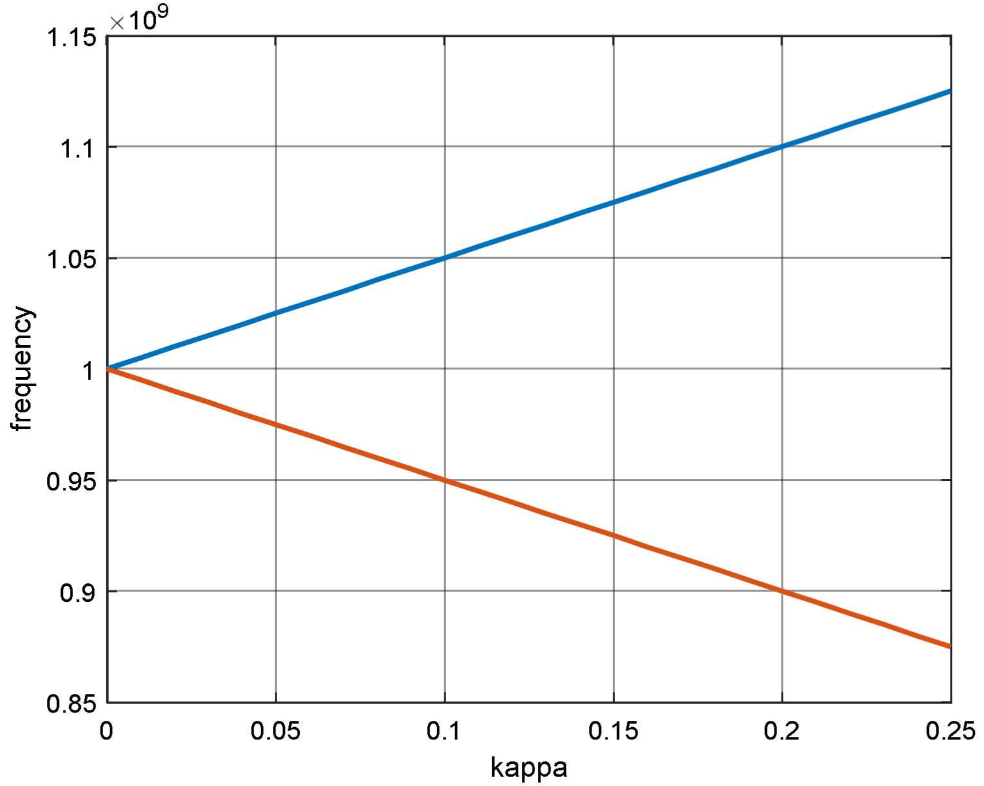


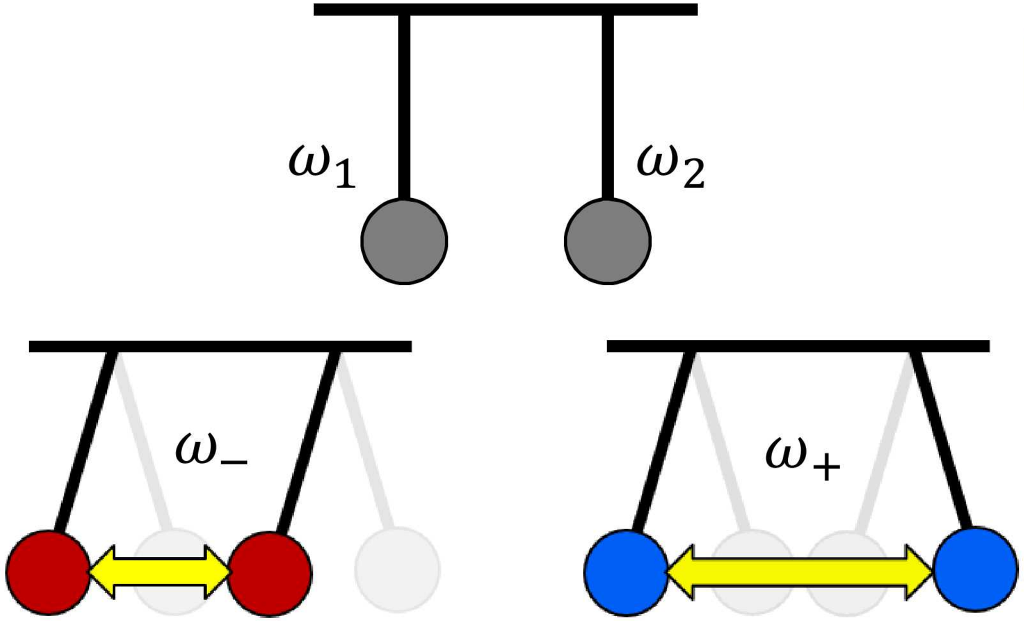
Fig. 2 *Measured impedance loci for h = 1.06" (≃0.08λ at 900 MHz)*

T. Huynh and K. F. Lee, "Single-layer single-patch wideband microstrip antenna," in *Electronics Letters*, vol. 31, no. 16, pp. 1310-1312, 3 Aug. 1995.

Coupled Mode Theory

CMT analyses the motion of a system of two coupled resonators as the combination of in-phase and anti-phase modes of motion





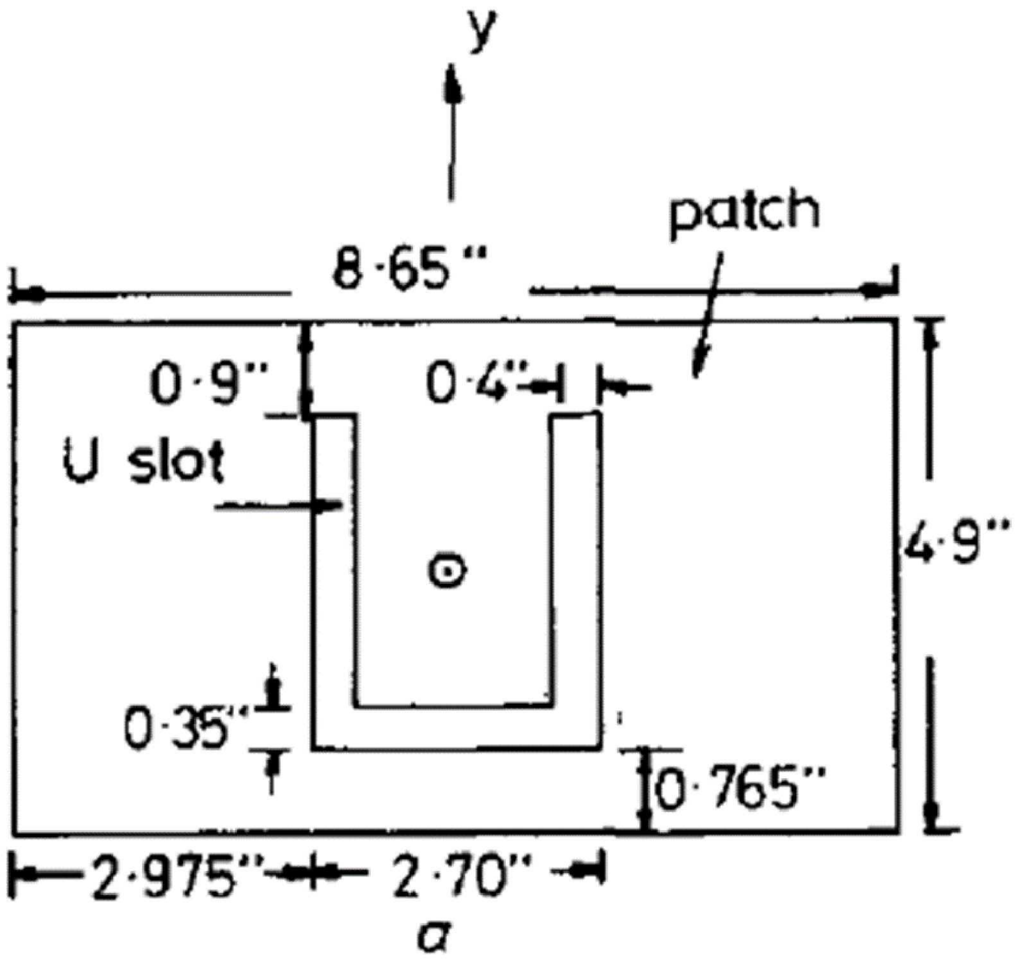
$$\omega_\pm = \left(\frac{\omega_2 + \omega_1}{2}\right) \pm \sqrt{\left(\frac{\omega_2 - \omega_1}{2}\right)^2 + |K|^2}$$

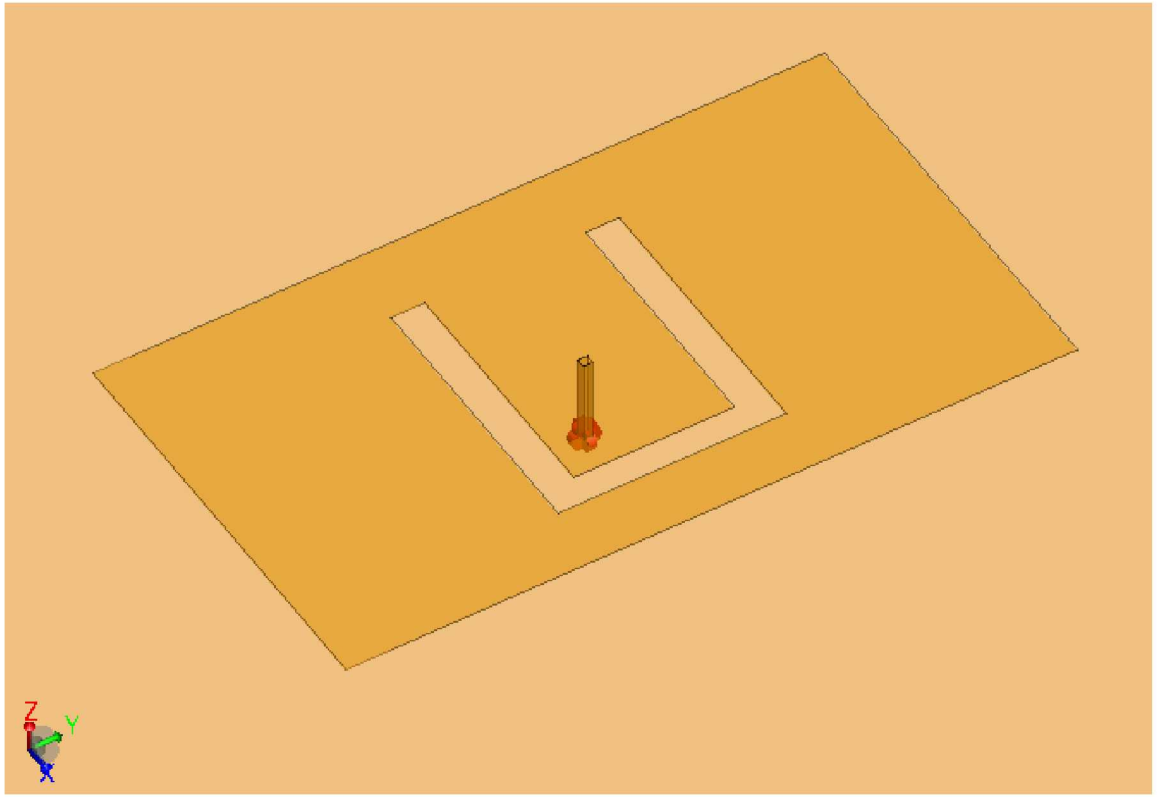
$$\omega_2 = \omega_1 \;\rightarrow\; \omega_\pm = \omega_0 \pm |K|$$

$$\omega_0 = (\omega_2 + \omega_1)/2$$

S. L. Chuang, Physics of Optoelectronic Devices, 1st ed., New York, NY, USA: Wiley, 1995, ch. 8, sec. 2.2, p. 291.

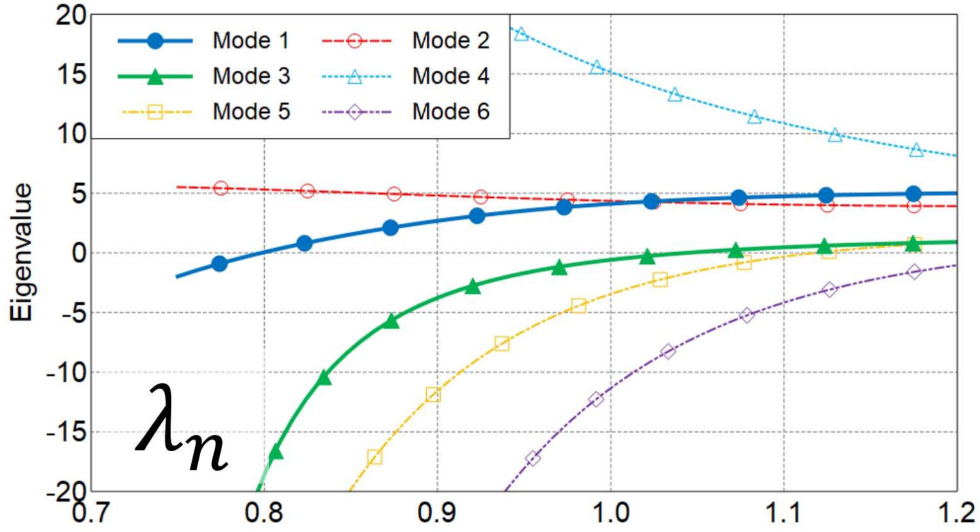
CMA of the U-slot Patch

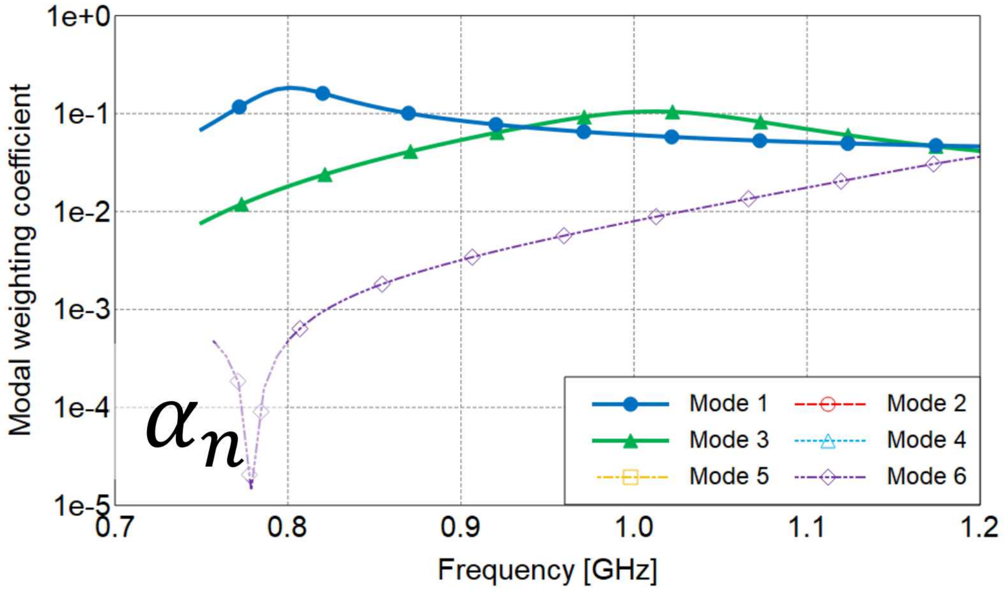


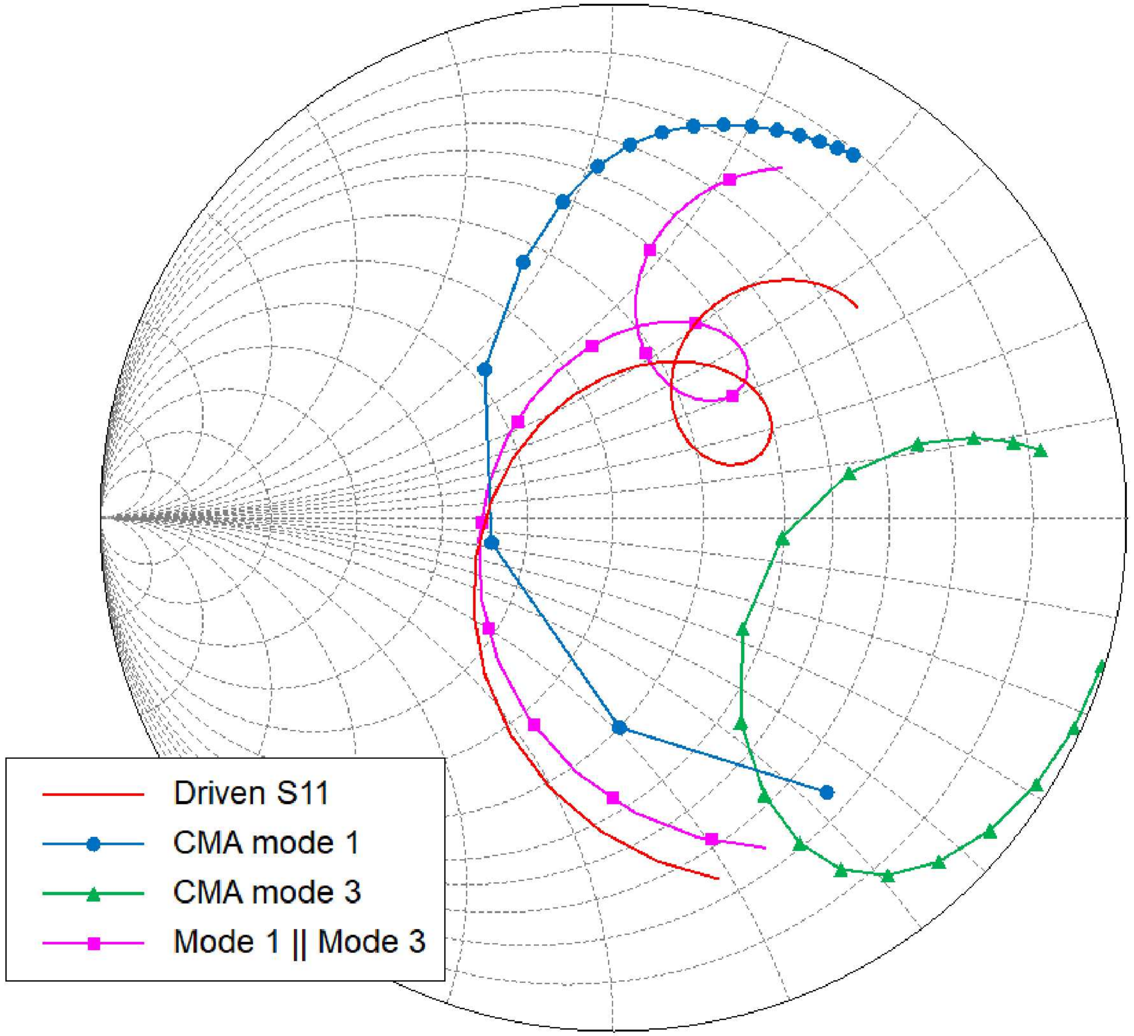


T. Huynh and K. F. Lee, "Single-layer single-patch wideband microstrip antenna," in *Electronics Letters*, vol. 31, no. 16, pp. 1310-1312, 3 Aug. 1995.

Selecting modes

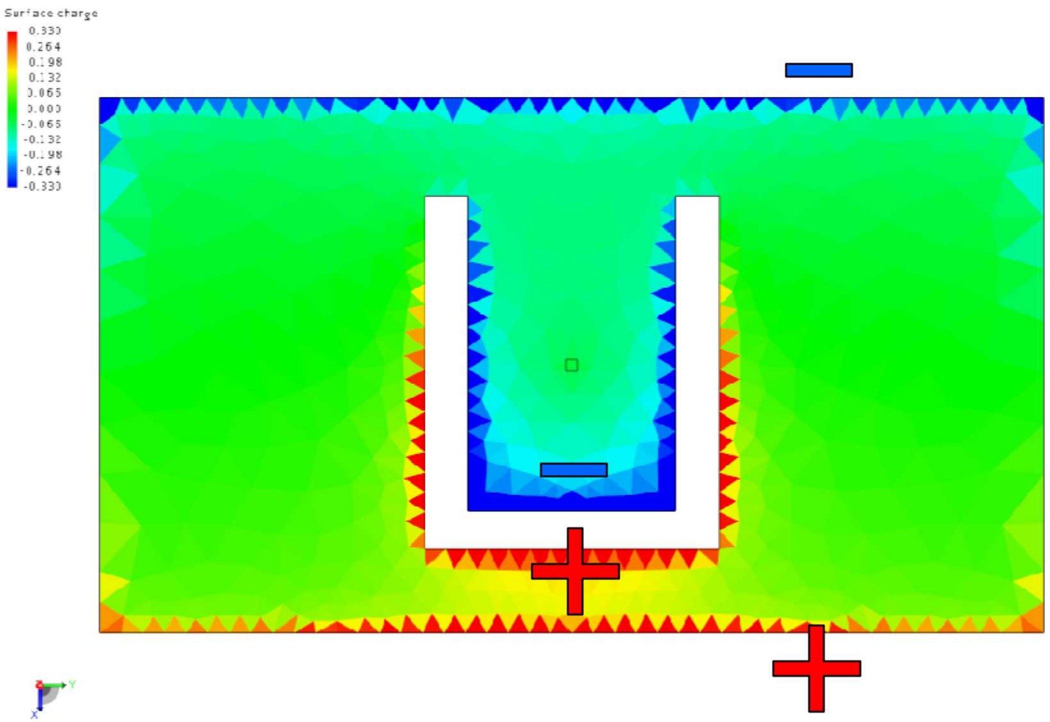






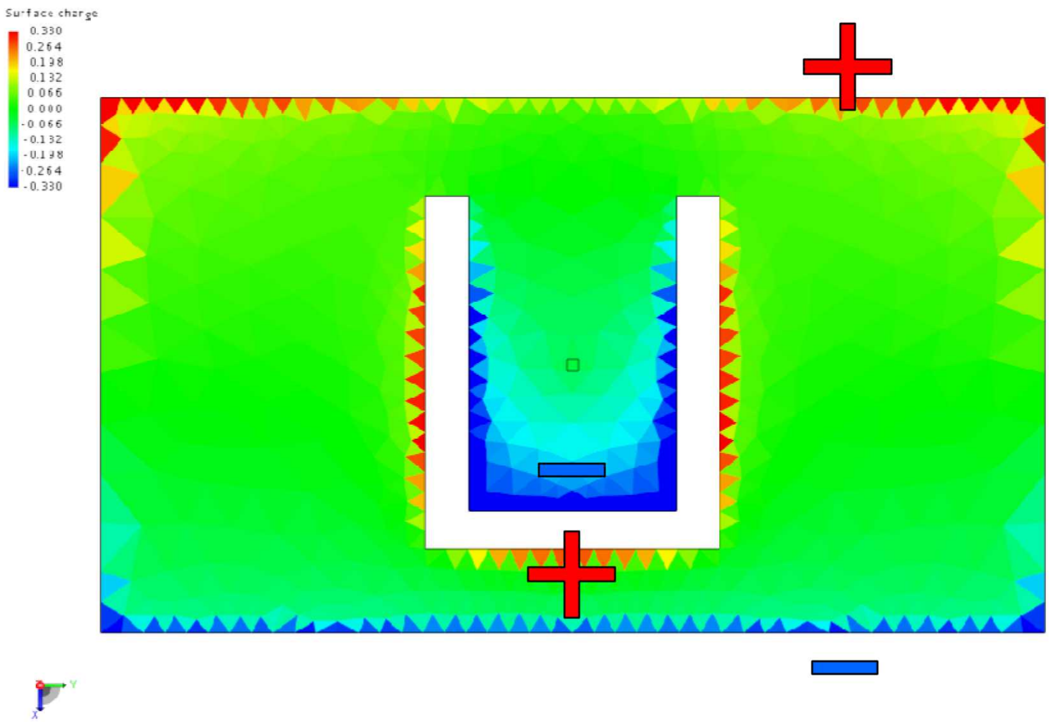
What are these modes?

Mode 1



in-phase

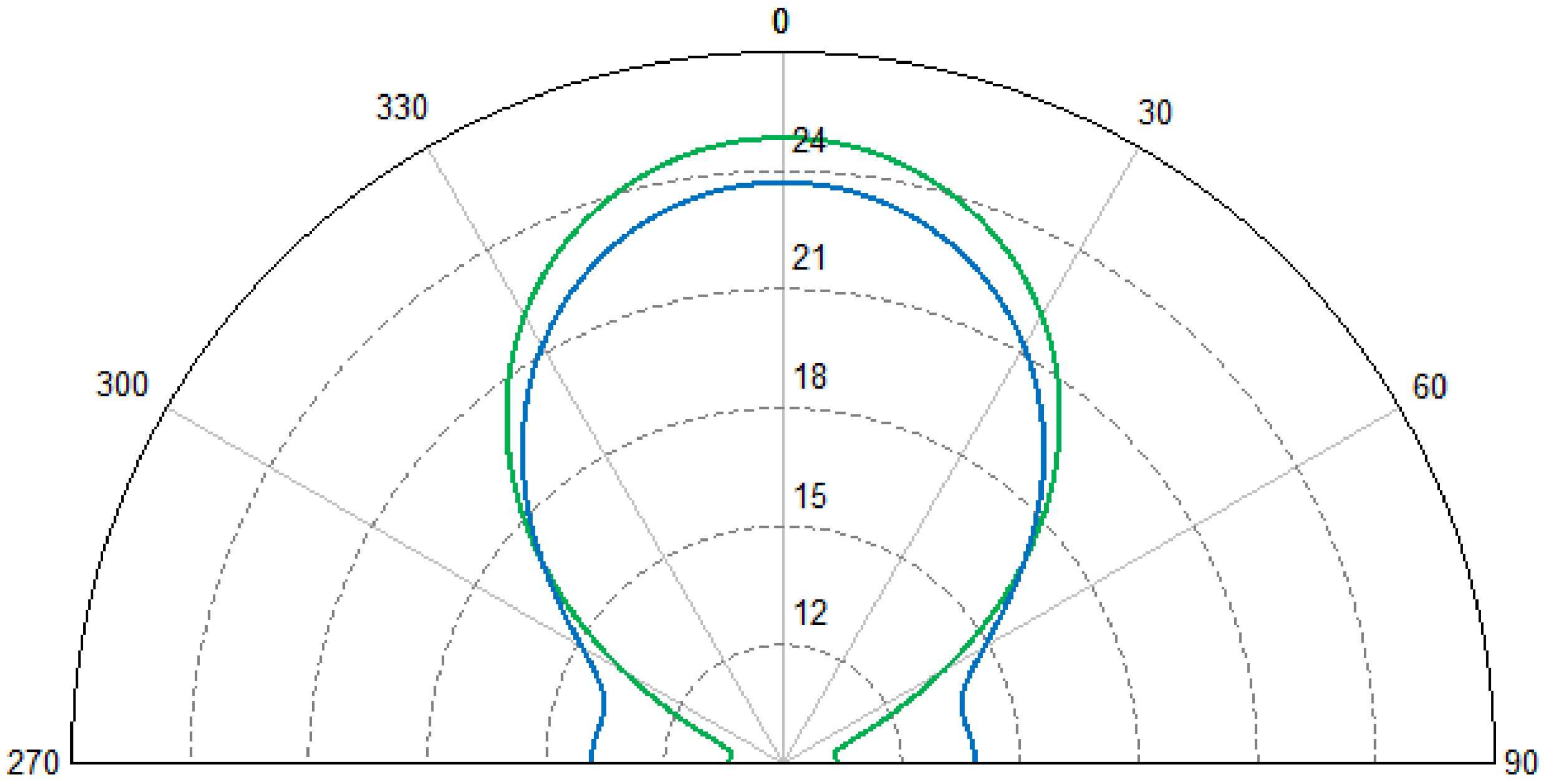
Mode 3



anti-phase

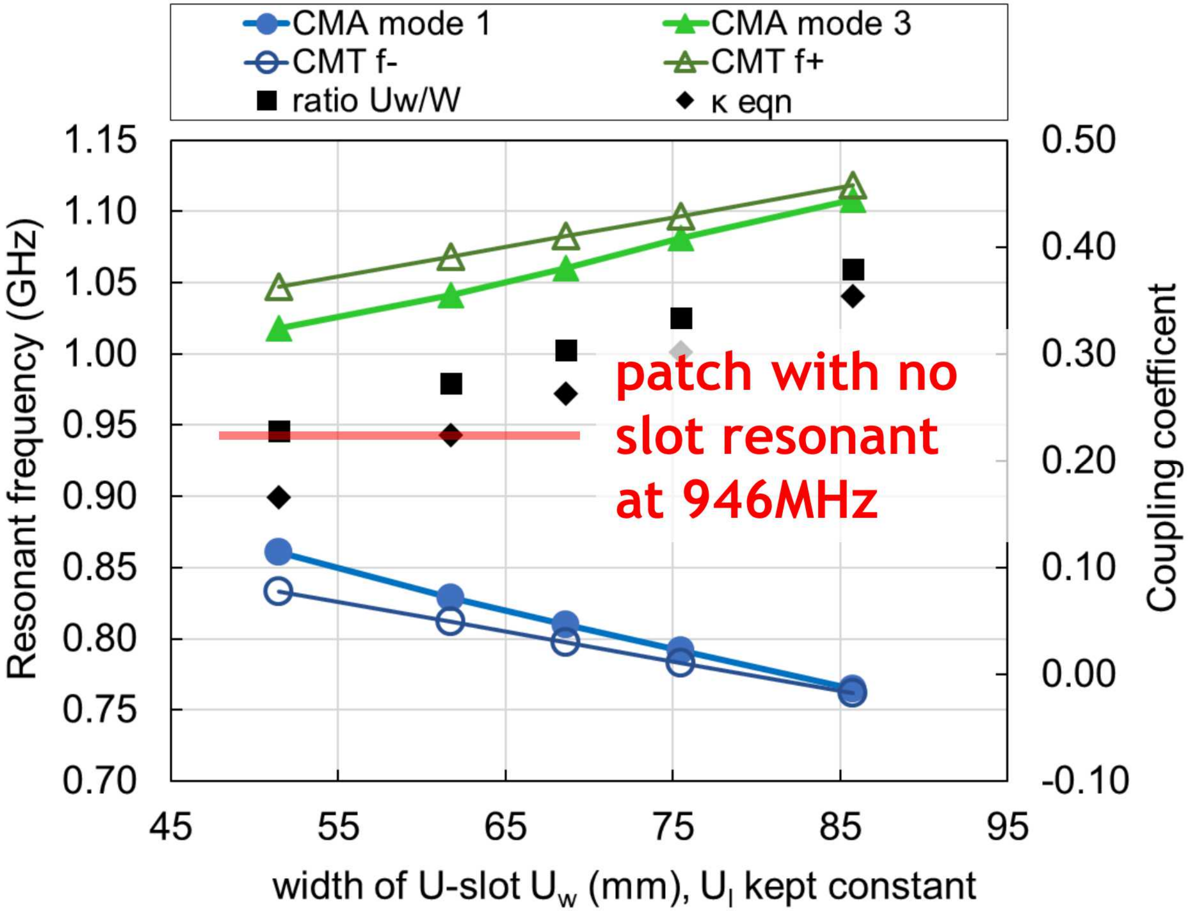
Modal far-fields

Similar broadside radiation patterns, co-polarized



Electric field (dBV/m)

CMT accurately describes CMA resonances



$$U_l = 2U_h + U_w = \text{constant}$$

$$\kappa = \frac{{\omega_+}^2 - {\omega_-}^2}{{\omega_+}^2 + {\omega_-}^2}$$

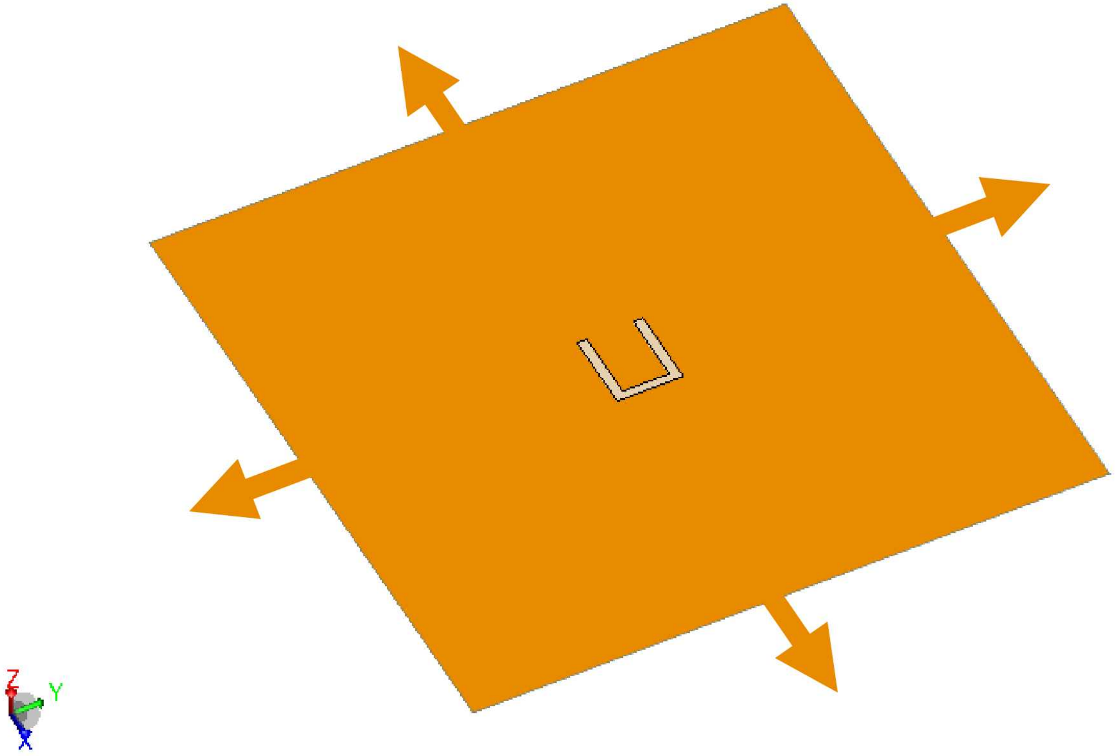
$$\omega_\pm = \omega_0 \pm |K| \qquad K \sim (\omega_0/2)\,\kappa$$

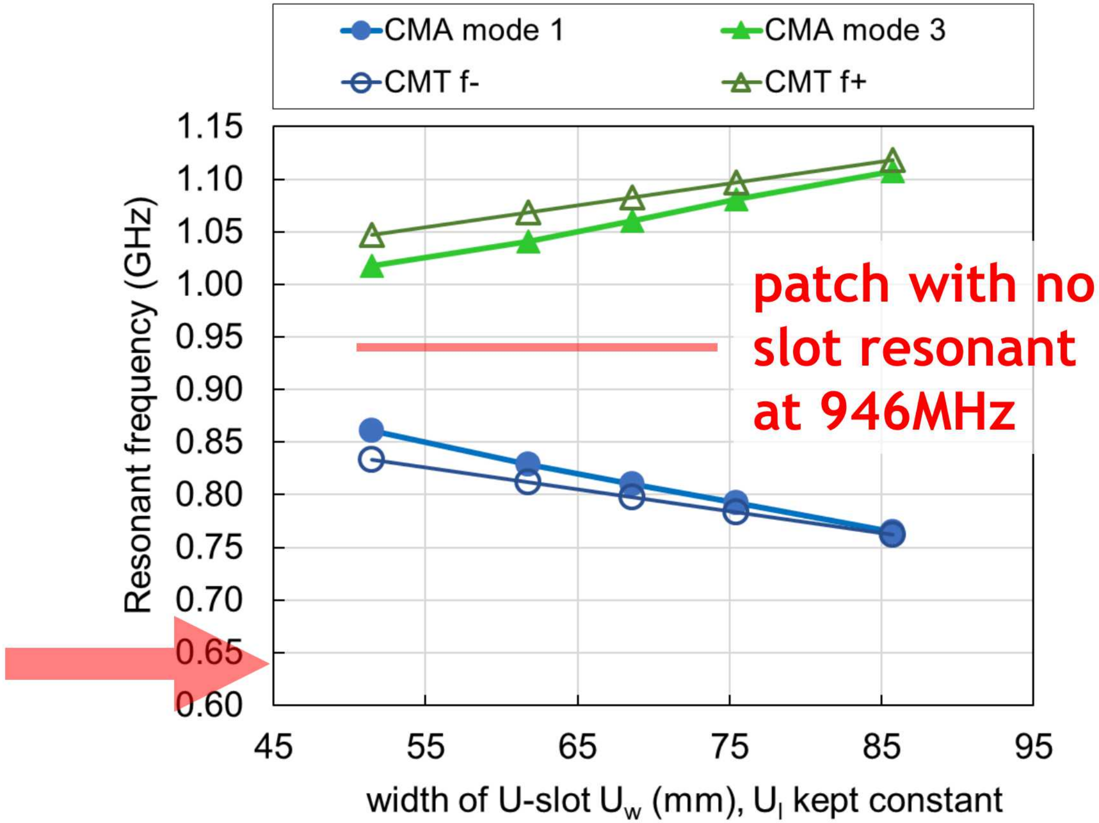
$$\kappa \sim U_w/W$$

$$\omega_\pm = \omega_0 \pm (\omega_0/2)\,(U_w/W)$$

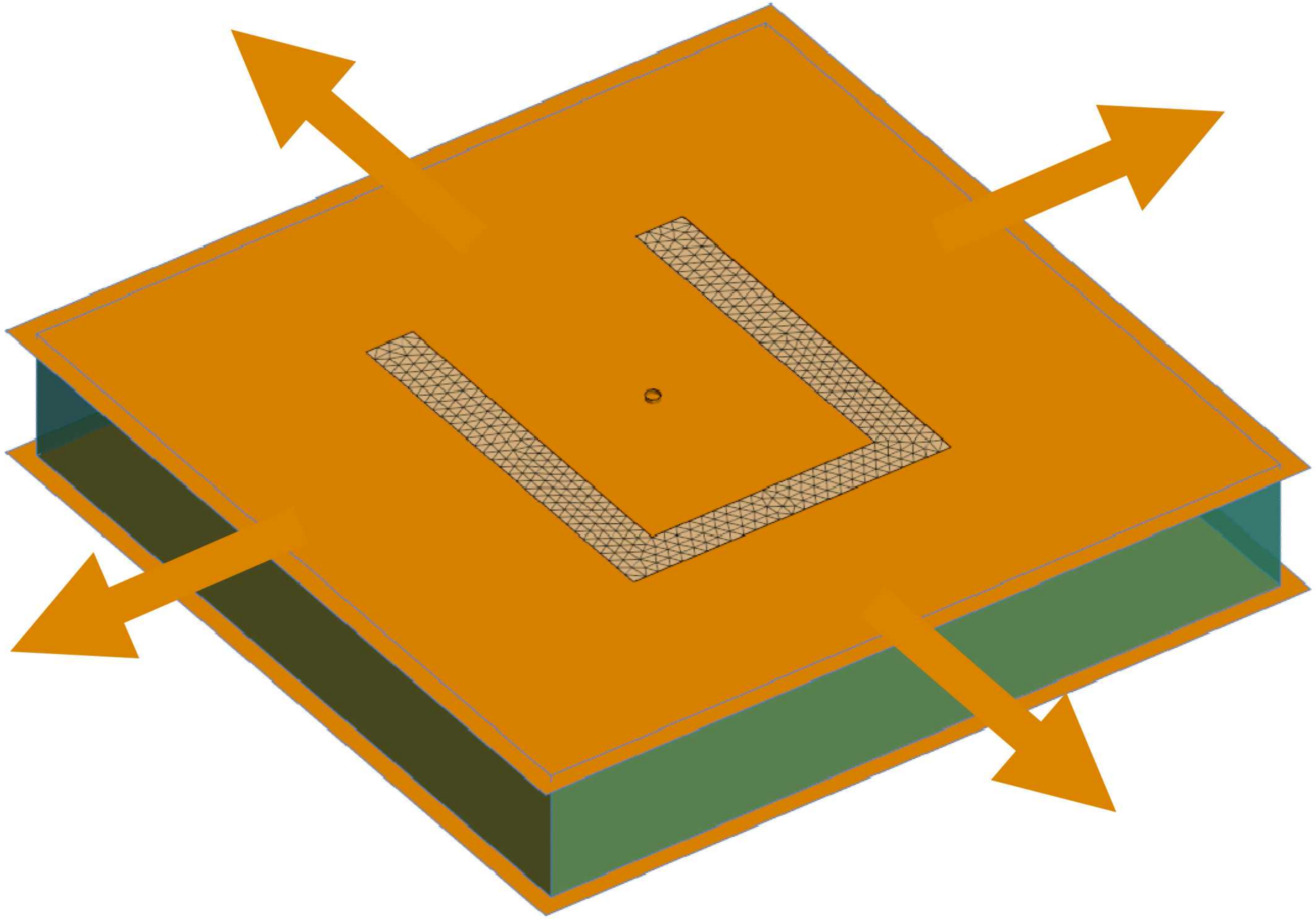
What is the other resonator?

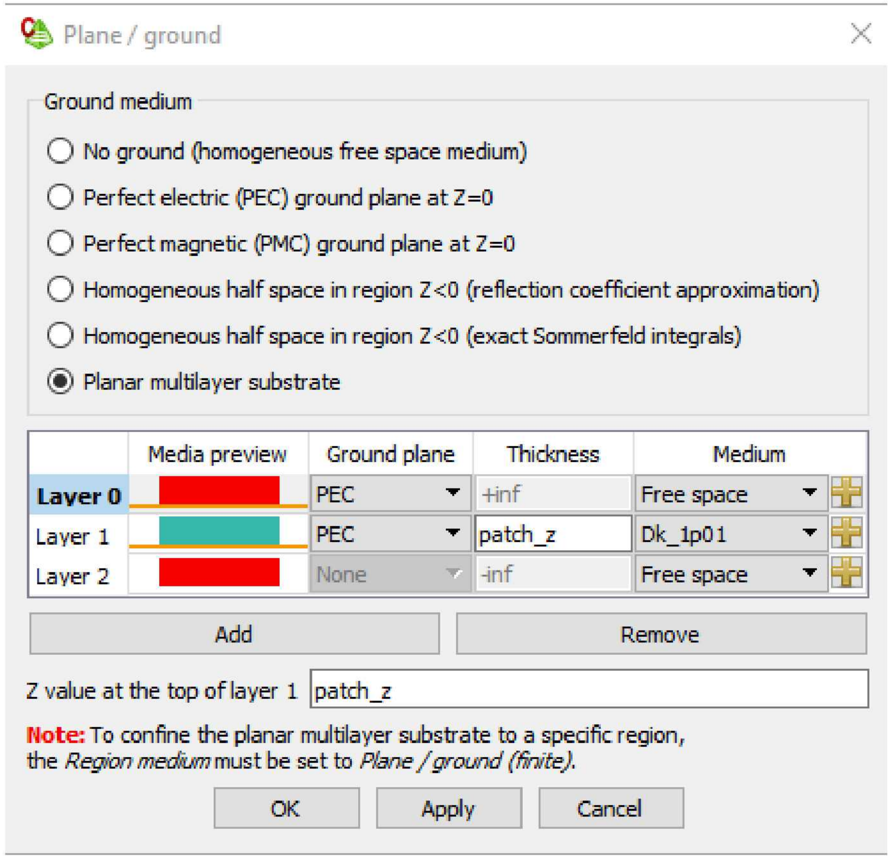
U-slot in single PEC plane gives CM resonance at ~640MHz ($U_l \sim \lambda/2$)…



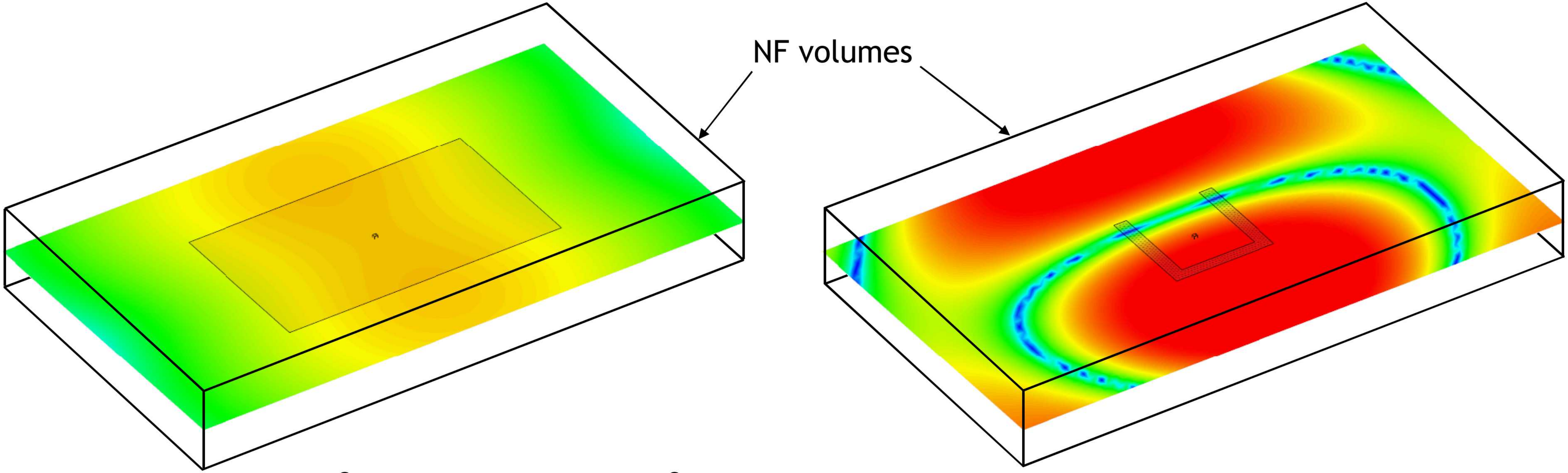


Uncoupled slot resonator, resonant at ~912MHz





Calculating resonator coupling with modal nearfields



$$\kappa = \frac{\int \epsilon E_1 \circ E_2 \, dV}{\sqrt{W_{e1} W_{e2}}} + \frac{\int \mu H_1 \circ H_2 \, dV}{\sqrt{W_{m1} W_{m2}}}$$

$$|\kappa| = 0.19$$

$$W_{e1,2} = \int \epsilon |E_{1,2}|^2 \, dV \qquad W_{m1,2} = \int \mu |H_{1,2}|^2 \, dV$$

J. Hong, IEE Proceedings, vol. 147, no. 5, pp. 354-358, Oct. 2000.

Summary & Take-Homes

- The U-slot patch operates with **coupled** modes; the patch and slot modes are equally important over the entire impedance bandwidth.
- Include the excitation and run driven MoM problem alongside CMA.
- Use Modal Weighting Coefficients & replicate driven admittance.
- Modal **charge** distributions can be very useful.
- For multi-modal antennas, establish uncoupled resonator geometries and use modal near-fields to calculate coupling.

tinyURL.com/UslotCMA