Investigation of Nonlinear Modeling for Active Antenna Design

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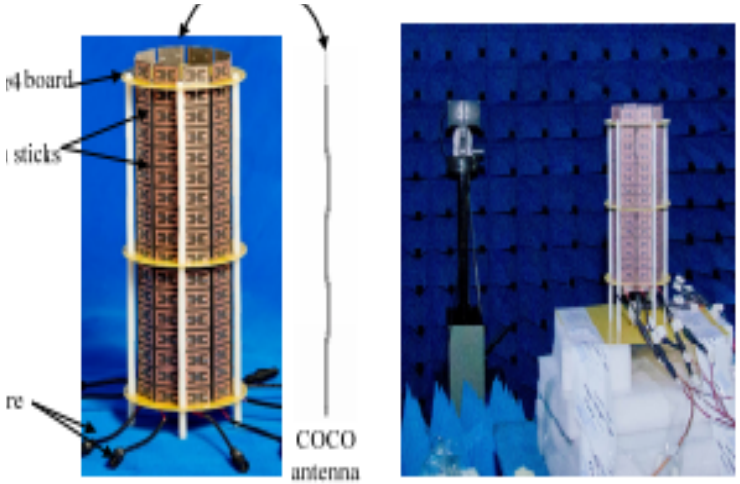
Outline

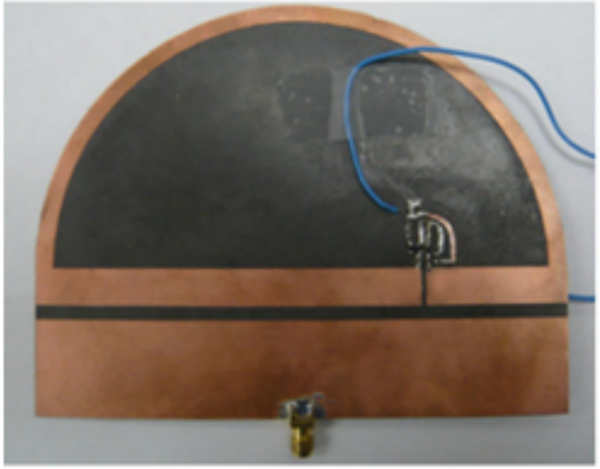
- Backgrounds: active antennas and simulation methods
- Active metamaterial design
- Active metamaterial antenna design
- Large-signal modeling
- Simulation and results
- Summary

The concept of active antennas

- **Antennas** usually regarded as passive, reciprocal, linear, and time-invariable devices.
- **Active antennas** integrated with nonlinear active devices, such as varactors, transistors, and nonfoster circuits.



An example of electronically steerable antennas


An example of non-foster antennas

- (Left figre) L Zhang, G. Yang, and Q. Wu, A novel reconfigurable antenna based on active band reflective frequency selective surface, 2012 IEEE APS/URSI
- (Right figre) Ning Zhu and Richard W. Ziolkowski, Appl. Phys. Lett. **101**, 024107 (2012);

Benefits and problems of active antennas

Benefits:

- compensation of losses
- improvement in sensitivity of receiving antennas
- Broadband matching
- Beam-steering capability

Problems:

- Harmonic radiations
- Intermodulation
- Stability
- Gain compression/expansion

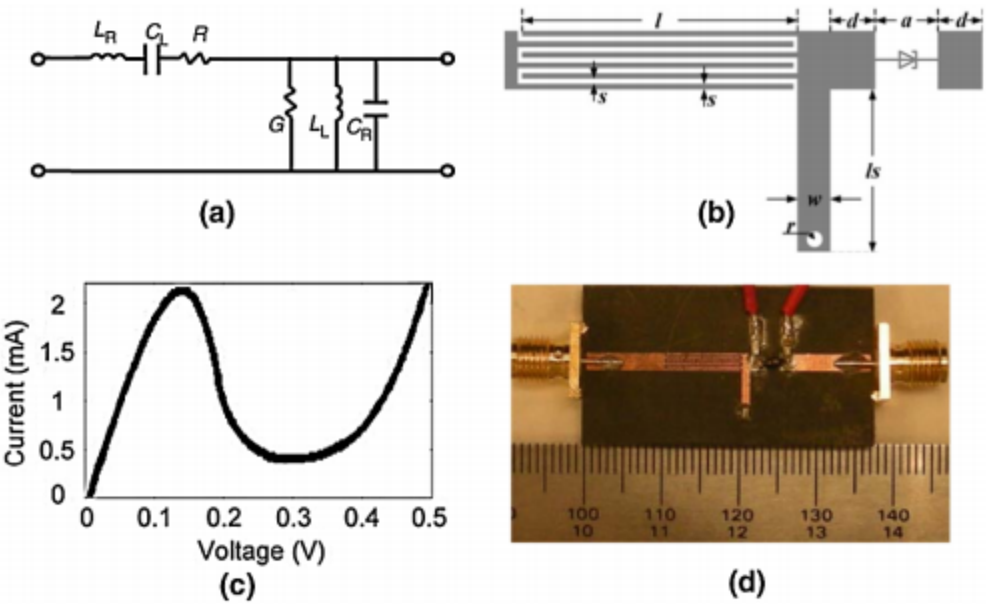
How to model and simulate active antennas accurately and efficiently?

Numerical simulation methods for active antennas

1. Time-domain approach (e.g. FDTD+SPICE)
   – Most rigorous.
   – Not effective for optimization
2. Equivalent circuit model of antenna+ nonlinear circuit simulation
   – (Possible) harmonic radiation (dissipated powers at Resistance)
3. EM (S-matrix) + nonlinear circuit simulation
   – No harmonic radiation provided
4. ANSYS (Ansoft) designer and HFSS Dynamic link
   – Solve the field after HB simulation
   – Harmonic radiation included

Zhengwei Hao, Soheil Saadat, and Hossein Mosallaei, “FDTD-SPICE for Characterizing Metamaterials Integrated with Electronic Circuits,” International Journal of Antennas and Propagation, vol. 2012, Article ID 282159, 7 pages, 2012. doi:10.1155/2012/282159

Active metamaterials

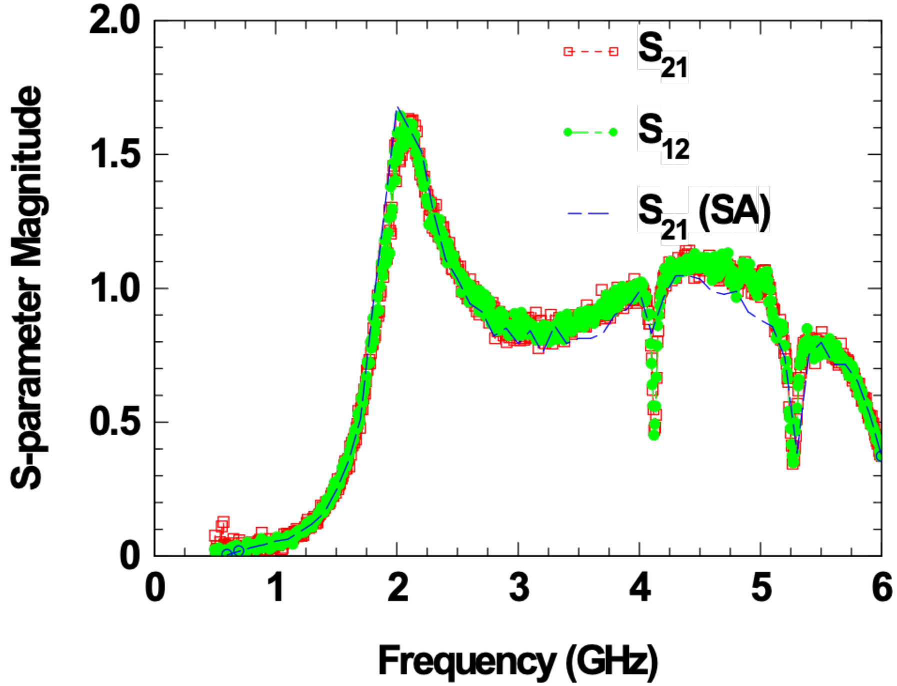


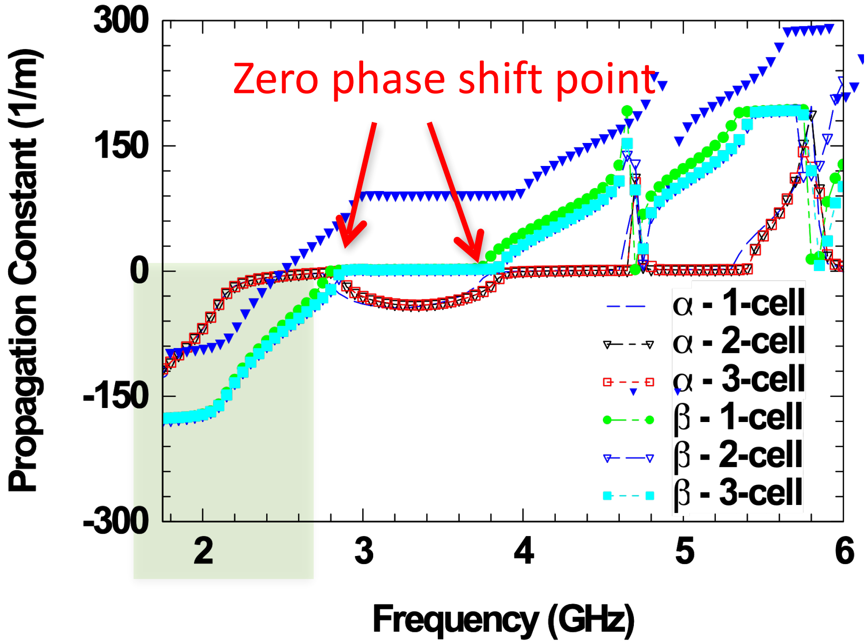
- **Compensate Loss / Provide Gain**
- **Potential application: Electrically Small Antennas**

(a) Equivalent circuit model of a unit cell of CRLH metamaterial
(b) Germanium tunnel diode used in the active CRLH TL unit cell design.
(c) I-V curve of tunnel diode TD260-TD276 (Ge)
(d) Photo of a fabricated single unit cell of the active CRLH TL.

Tao Jiang, Kihun Chang, Li-Ming Si, Lixin Ran, Hao Xin, “Active Microwave Negative-Index Metamaterial Transmission Line with Gain”, Phys. Rev. Lett. 107, 205503 (2011)

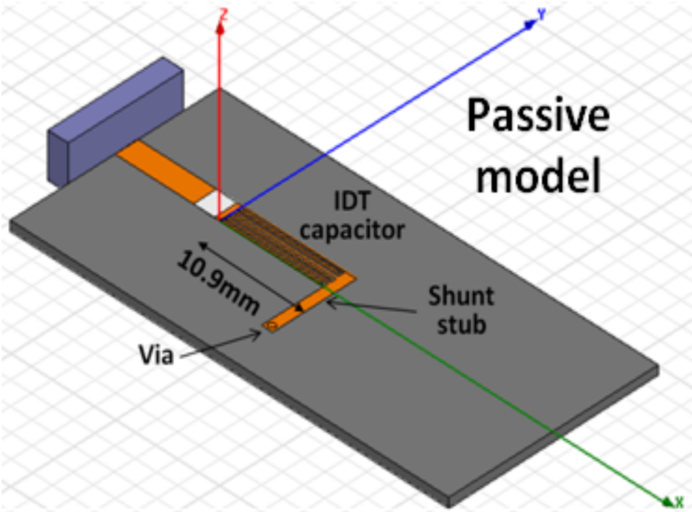
Active metamaterials (cont'd)

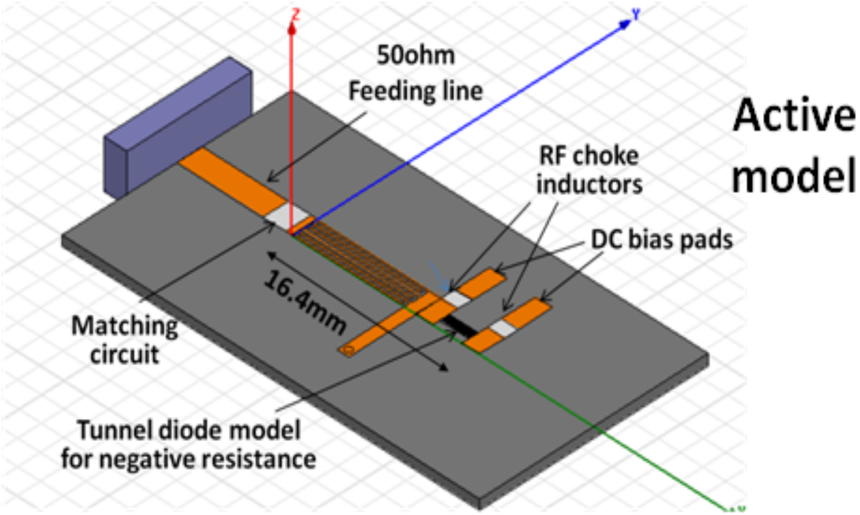


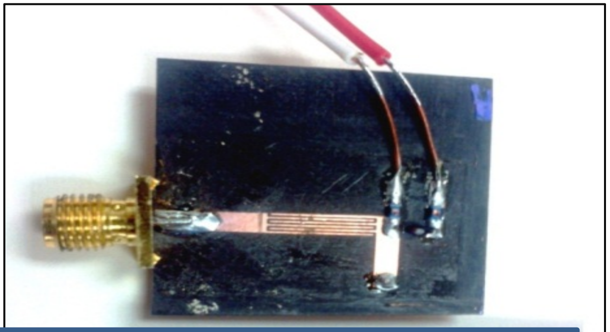


- "Simultaneous" negative β and α in 1.75 GHz to 2.75 GHz.
- Zero phase shift near 2.75 and 3.75 GHz.

Metamaterial antennas

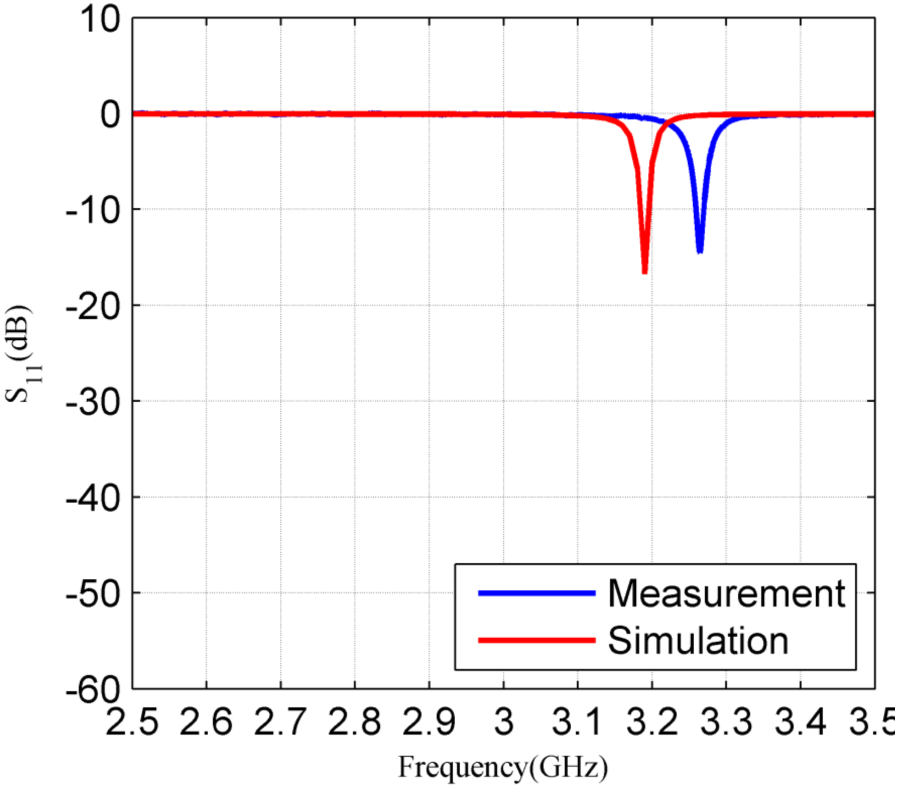


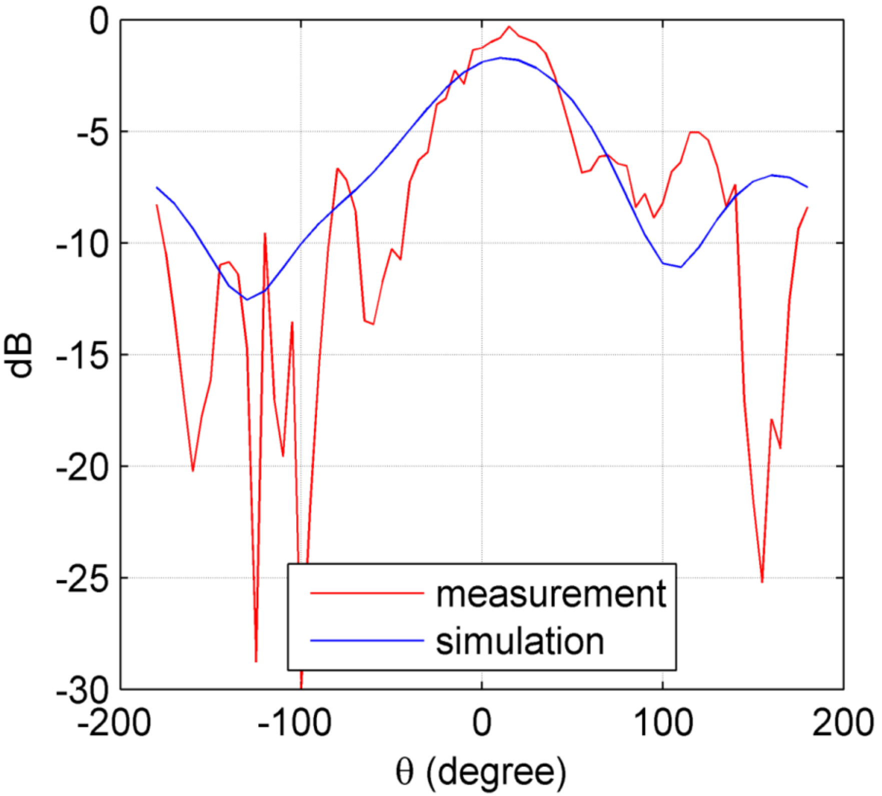




1. Zeroth-order Resonant (ZOR) antennas (λ/6)
2. Design purpose for active MTM: compensation for low radiation efficiency ← Passive ZOR Antenna

Passive MTM antenna

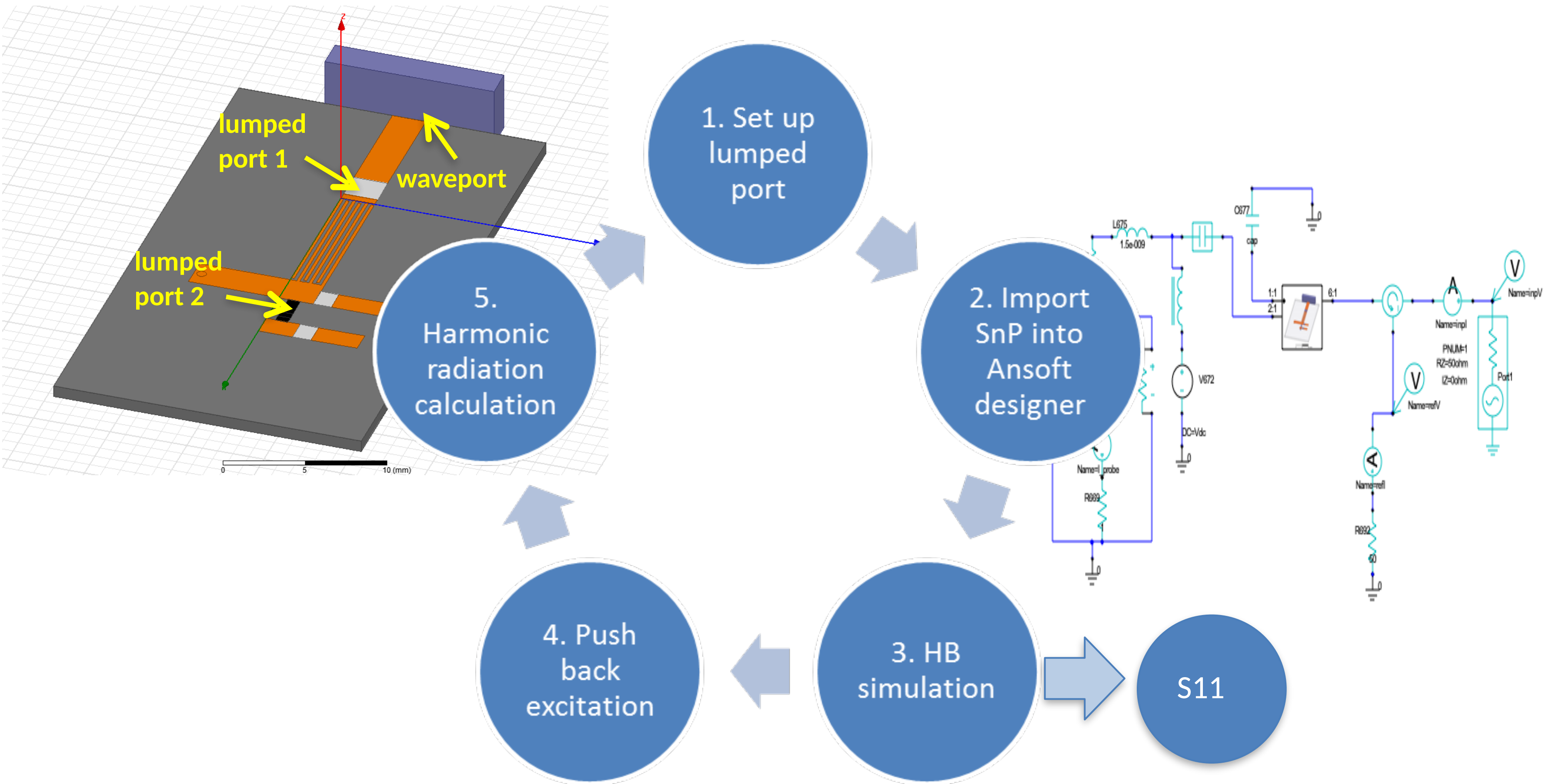




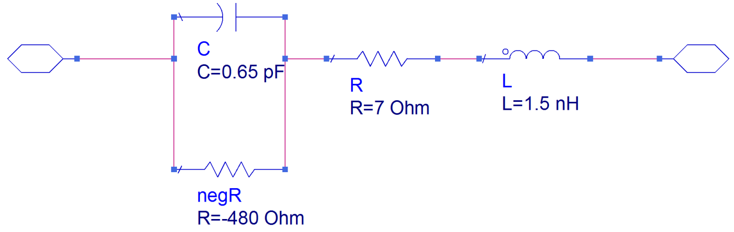
BW_mea is 10MHz, 0.3%

Realized gain is -0.3dBi(Measured) and -1.68dBi(simulated)

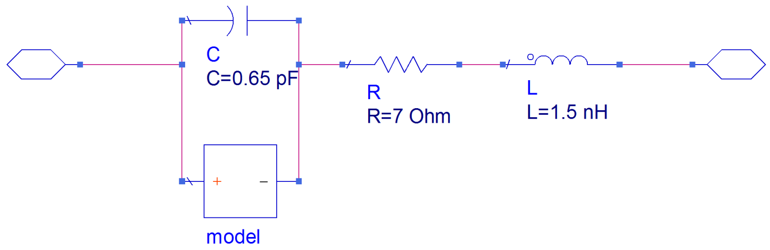
Active MTM antenna: Large-signal simulation



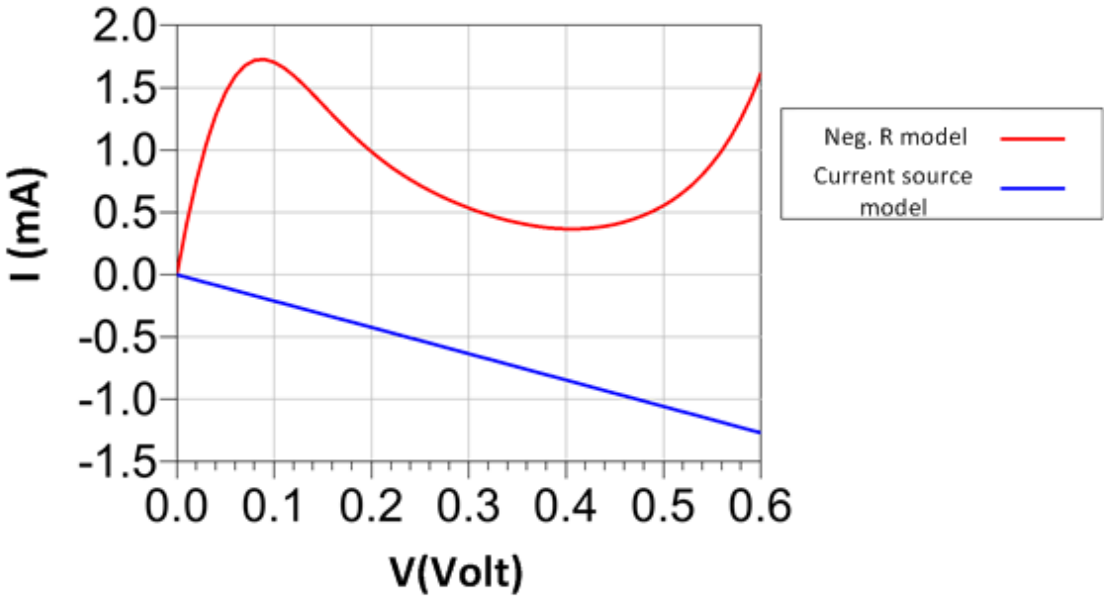
Diode models



Negative Resistance model

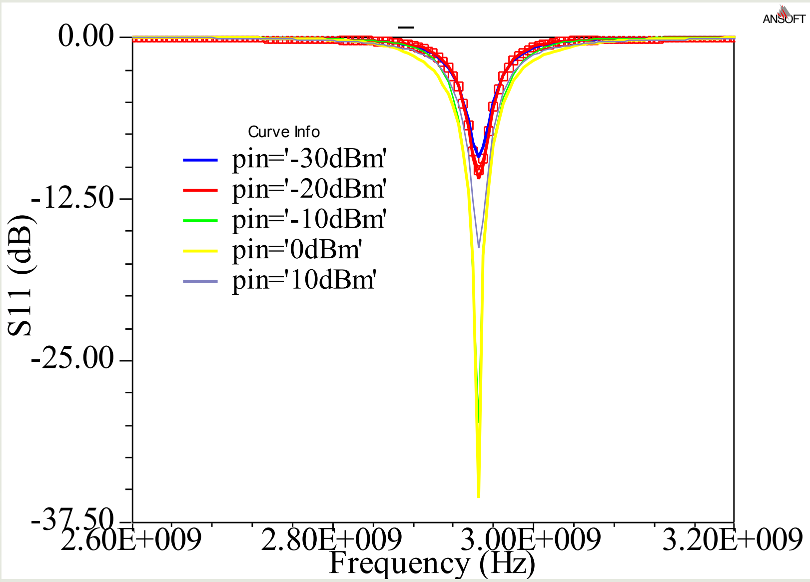


Current source model



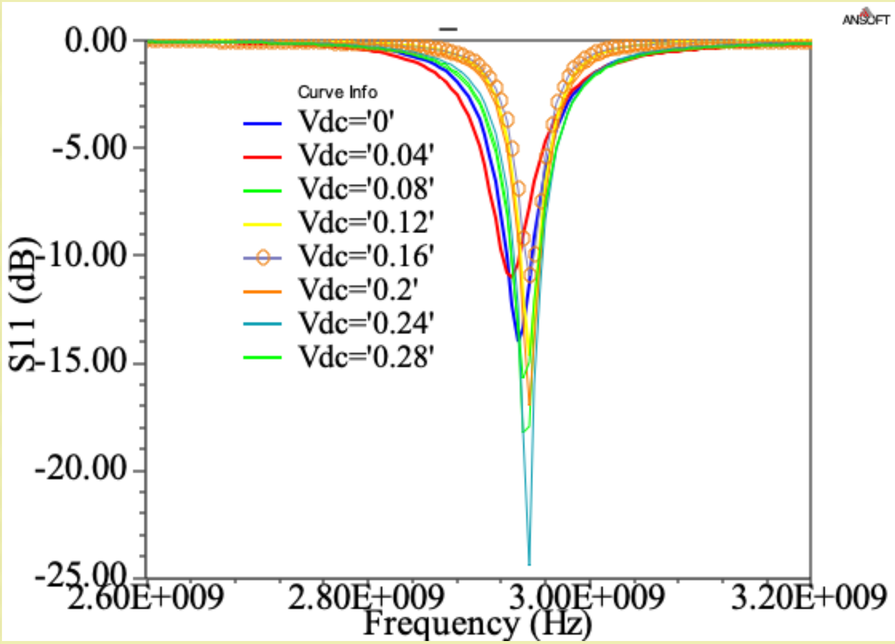
Power-dependent reflection coefficients

- For different input power:

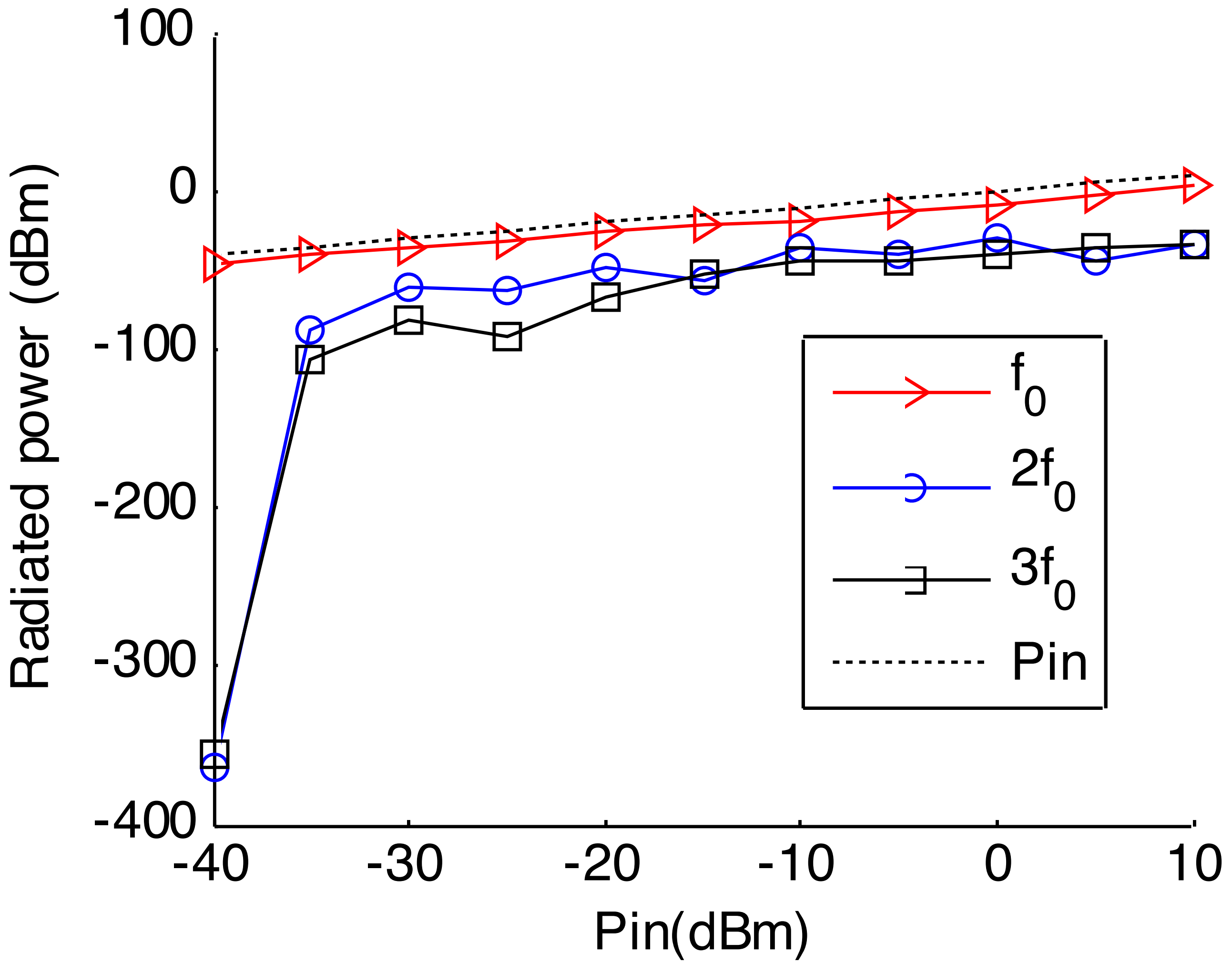


Pin≤-20dBm → S11 doesn't change

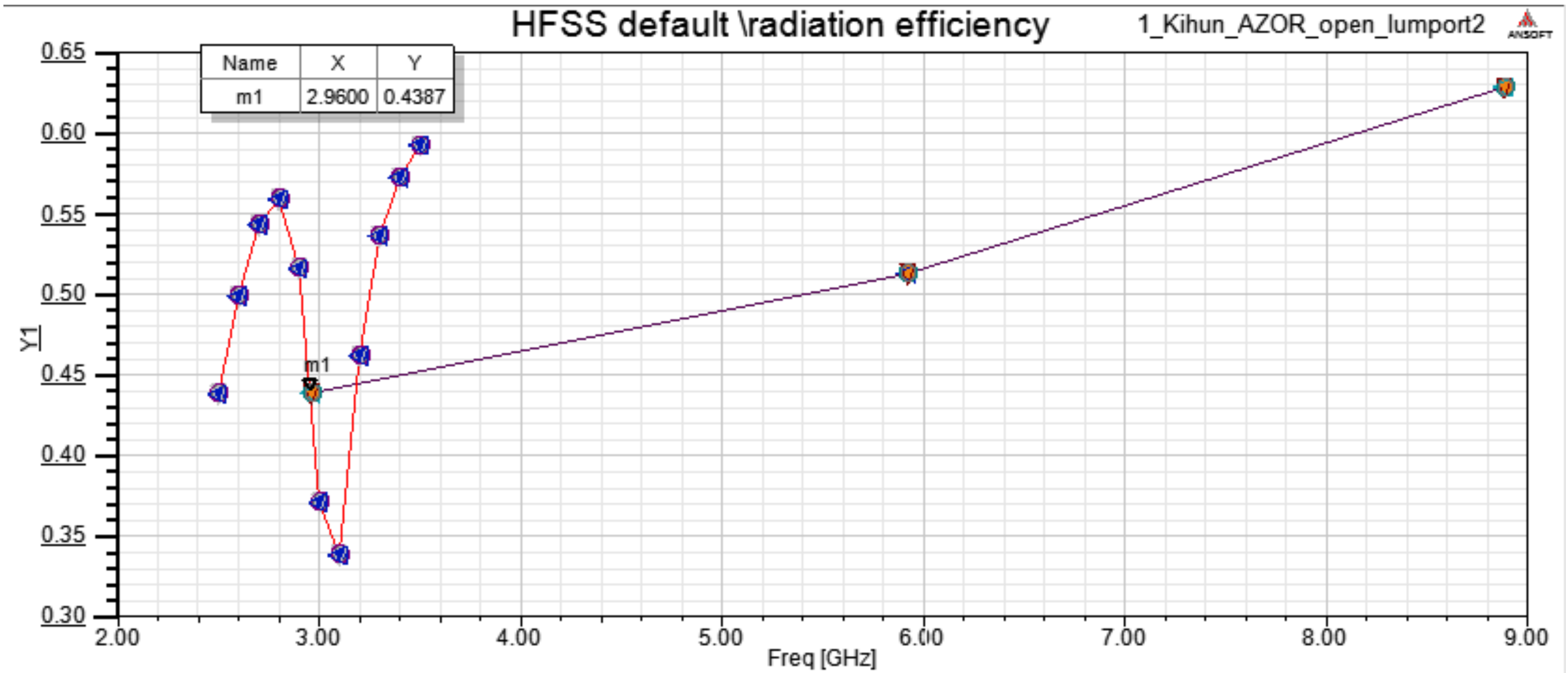
- For different bias voltage



Power level of harmonic radiation



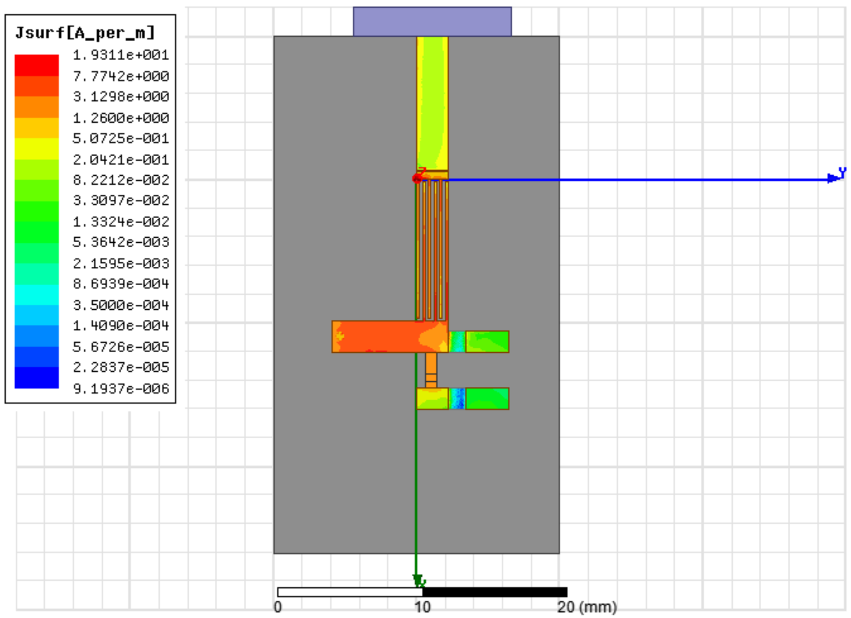
Harmonic radiation efficiency



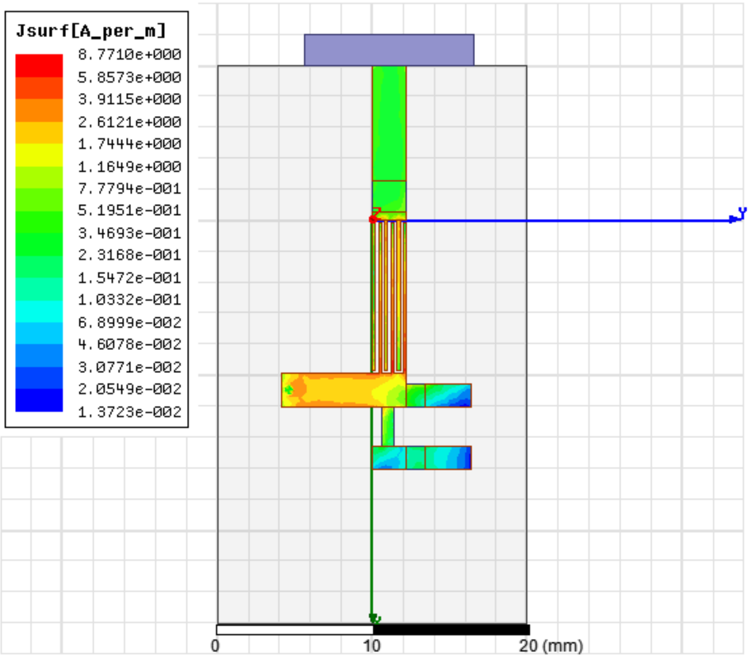
Pin = -30dBm

Current distribution comparison

Use small signal modeling



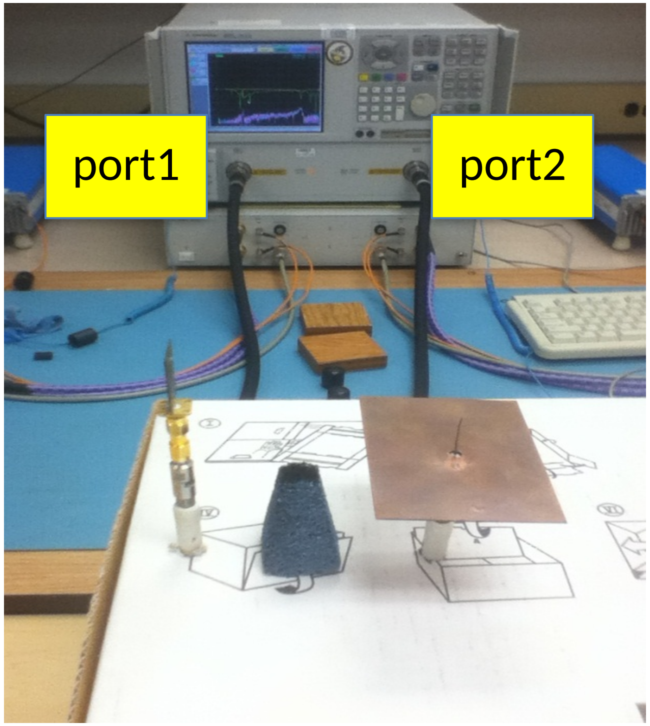
Use large signal modeling



Gain measurement

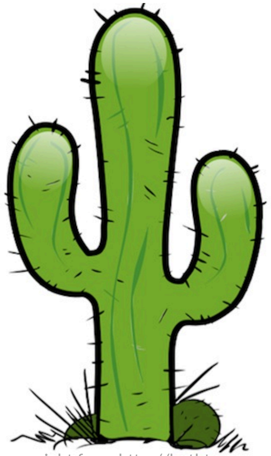
- Port1: DUT (Passive/Active MTM ant.)
- Port2: monopole antenna
- VNA source power: -50dBm

	Simulated Gain	Simulated Efficiency	Measured S12	Measured gain
Passive	-1.89dBi	28.7%	-40dB	-0.3dBi
Active	0.22dBi	**51%**	**-42dB**	**(-2.3dBi)**



Summary

- Different simulation methods for active antennas discussed
- Passive and active MTM antenna designed and measured
- Large-signal modeling of active MTM antennas by using HFSS and the designer dynamic link.
- Power-dependent reflection coefficient, and harmonic radiation efficiency investigated.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THANK YOU.

ARIZONA

Pushing Excitations to a Dynamic Link N-Port Field Solver Model

You can set the excitations in dynamically linked field solver elements from a parent circuit so that true electromagnetic field levels can be calculated by the electromagnetic solver (HFSS, Q3D, SIwave, PlanarEM). This means that the field values calculated by the electromagnetic solver element approximate the true field values when the circuit is active. These calculations are useful for active and passive antenna simulations, EMI/EMC simulations, and signal integrity applications. Ansoft calls this "pushing excitations" from a circuit to a field solver.

The procedure used to push excitations differs slightly depending on whether the electromagnetic simulator is in the Designer desktop, as is the case with the PlanarEM simulator, or external to the Designer desktop, as is the case with HFSS, Q3D, and SIwave.

To begin, insert a PlanarEM, HFSS, Q3D, or SIwave model into a circuit using the techniques described in previous sections. While the circuit/field-solver combination can be simulated immediately and S-parameters can be extracted, some additional setup is required to view field values in the field solver element.

Pushing Excitations to an EM Design

In order to view fields and currents in an EM Design you must force the simulation engine to compute and save currents. To do this, navigate to the EM Design in the Designer project tree and insert a simulation setup and discrete frequency sweep into the model. Be sure to select **Generate surface currents** in the EM Design model.

ACTIVE ANTENNAS

- compensation of increased losses and parasitic coupling at higher frequencies
- increase in antenna bandwidth and improvement in impedance matching
- improvement in sensitivity of receiving antennas
- active transmitting arrays can be used for spatial power combining techniques

- ,active arrays suffer from electromagnetic interference (EMI) and distortions caused by nonlinear behavior of the active elements
- Harmonics generation,
- Intermodulation,
- Cross-modulation,
- Desensitization,
- Gain compression/expansion,
- Local oscillator harmonics and noise conversion,
- Spuriousness in mixers,
- Amplitude-to-amplitude (AM-AM) and amplitude-to-phase (AM-PM) conversion,
- Gain and phase sensitivity of amplifiers and mixers to power supply voltages.
- A number of software analysis and simulation packages are commercially available.