Experimental Results of an AMC Antenna Fabricated with a Magnetically-Loaded Elastomeric Substrate

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A presentation for the 2008 IEEE International Antennas and Propagation Symposium, San Diego, CA

Outline

1. **Motivation**
2. **Artificial Magnetic Conductor (AMC) Design**
3. **Magnetic Material Development**
4. **Antenna Fabrication**
5. **Experimental Results**
6. **Conclusions**

Motivation: The Need for Low Profile Antenna Systems

Commercial:

1. Cell phone flip

2. Laptop Computer Screen

3. Wireless PDA

Military:

1. Aircraft Comm.

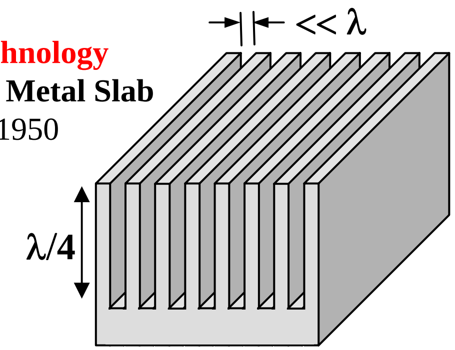
2. Replacement for Whip Ant.

3. Brief-case antenna system

What are Artificial Magnetic Conductors (AMCs)?

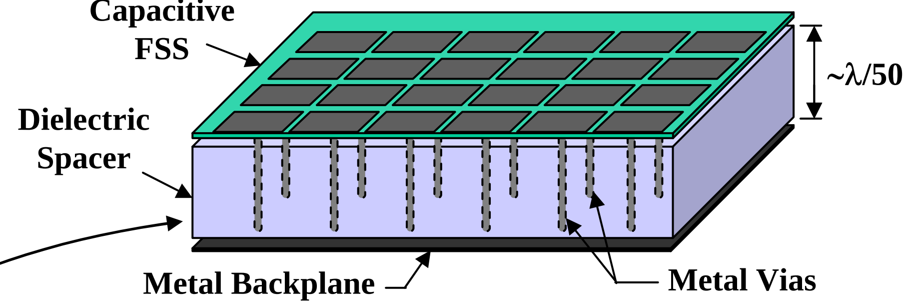
What is an artificial magnetic conductor (AMC)?

It is a) a lossless, reactive surface, whose
b) equivalent surface impedance is an open circuit,
c) which inhibits the flow of equivalent tangential electric surface current,
d) thereby approximating a zero tangential magnetic field.



How can we make a conventional AMC?

One embodiment (Sievenpiper AMC) is
a) a printed periodic structure
b) with vertical and horizontal conductors
c) which can be fabricated using light-weight low-loss dielectric materials.



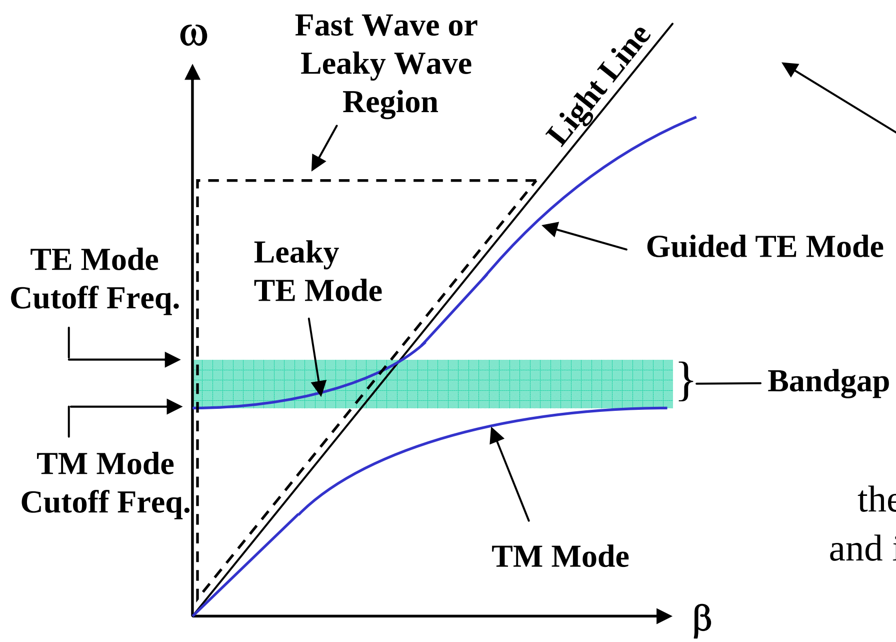
Thinner and Lighter!

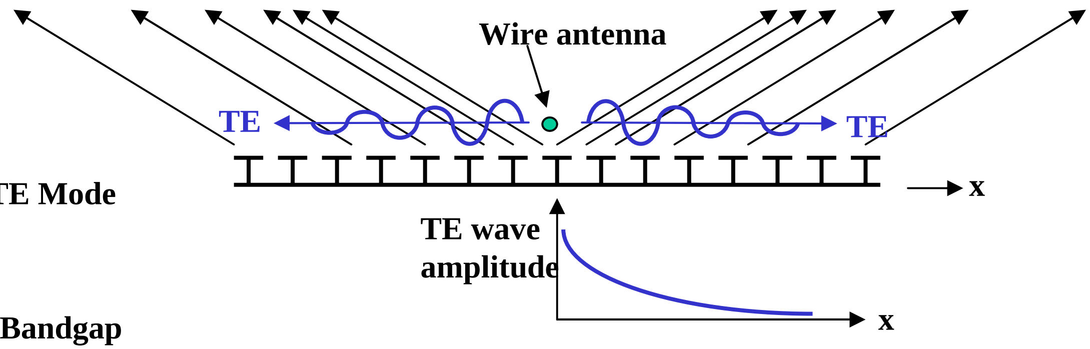
In this work, we replaced the dielectric spacer with a magneto-dielectric material.

An AMC Surface Has Two Fundamental Properties

1. **It is a high impedance surface** ($Z_s = E_{tan}/H_{tan}$) which permits wire antennas to radiate when placed in close proximity to the surface (λ/100 above).

2. **A surface wave bandgap exists where a) the dominant TM mode is cutoff, and b) the dominant TE mode is leaky.** This 2nd property dramatically reduces the diffracted energy from edges of the AMC surface when the wire antenna radiates. So the radiation pattern from this wire antenna can be essentially confined to one hemisphere.

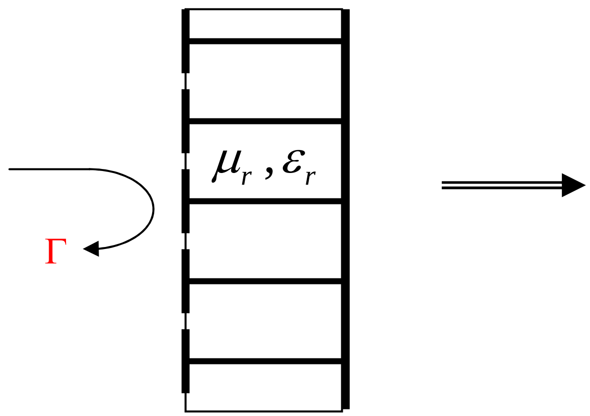


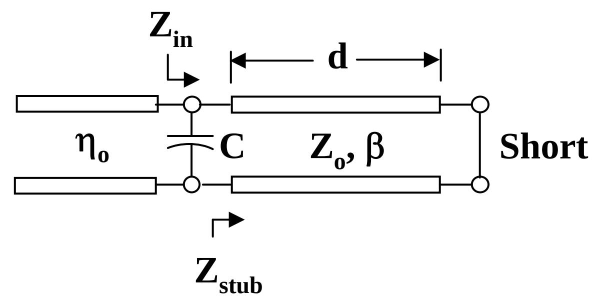


As the TE mode surface wave propagates away from the wire antenna element, it leaks energy into space waves, and it's amplitude decays exponentially with lateral distance x.

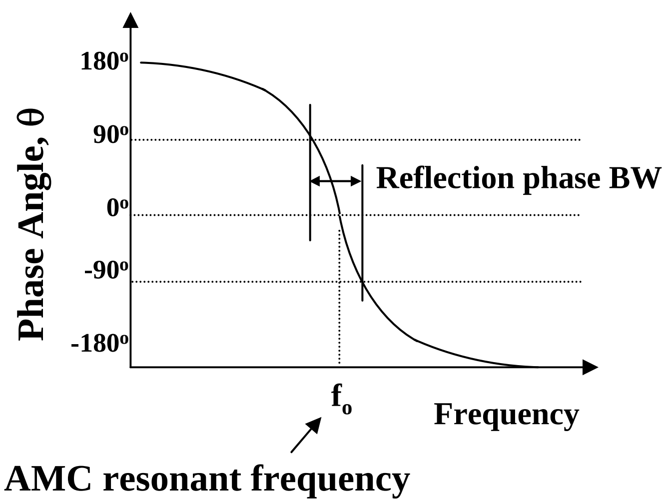
Both of these properties must exist over the same frequency range to make a viable AMC based wire antenna.

Reflection Phase Bandwidth of a Sievenpiper AMC Structure





For plane waves at normal incidence, the substrate may be understood as an electrically short length of shorted transmission line in parallel with a shunt capacitance at the reference plane of the outer surface.

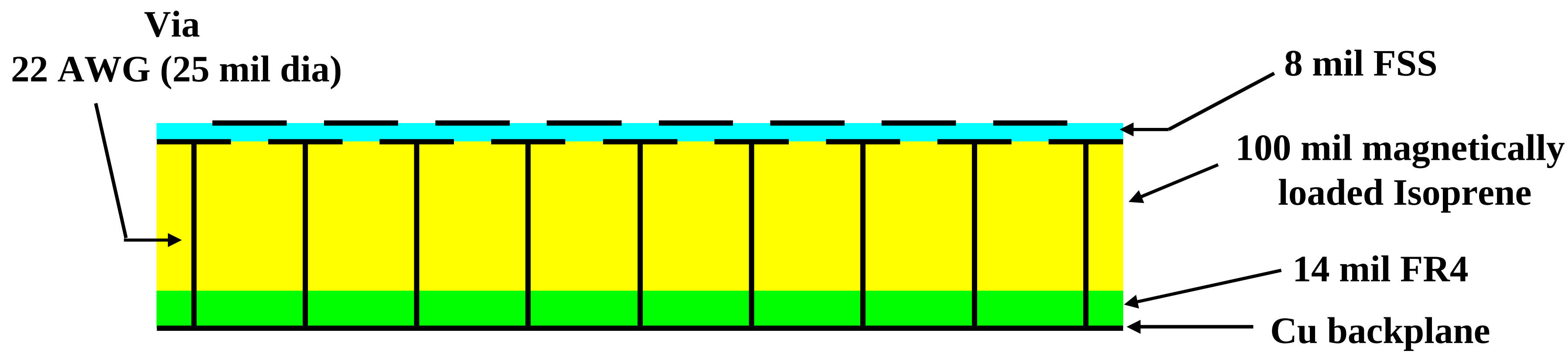


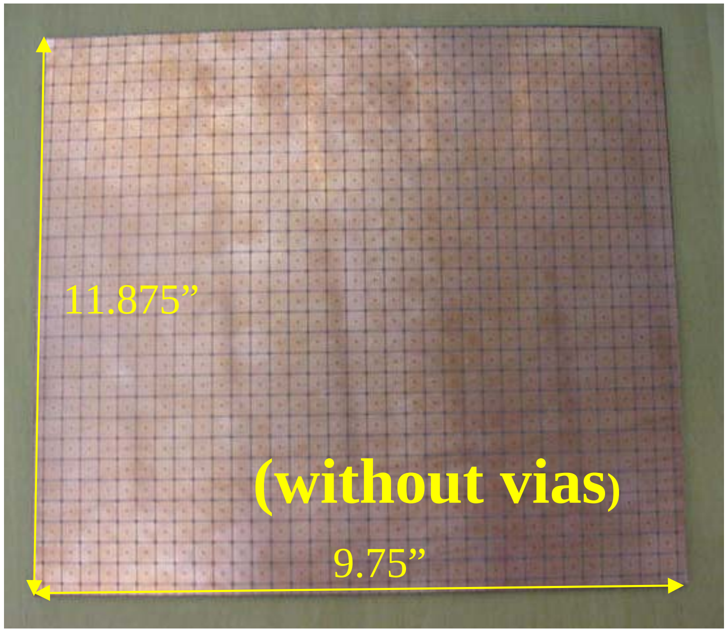
Define ω_1 and ω_2 where Arg(Γ) = +/- 90°.

$$\frac{\omega_2-\omega_1}{\omega_o} = 2\pi\,\mu_r\frac{d}{\lambda_o} = \frac{1}{\eta_o}\sqrt{\frac{L}{C}}$$

Bandwidth increases linearly with μ_r.

Construction of the Magnetically-Loaded AMC



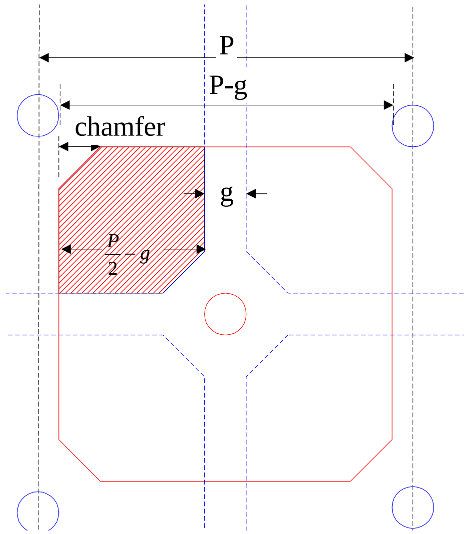


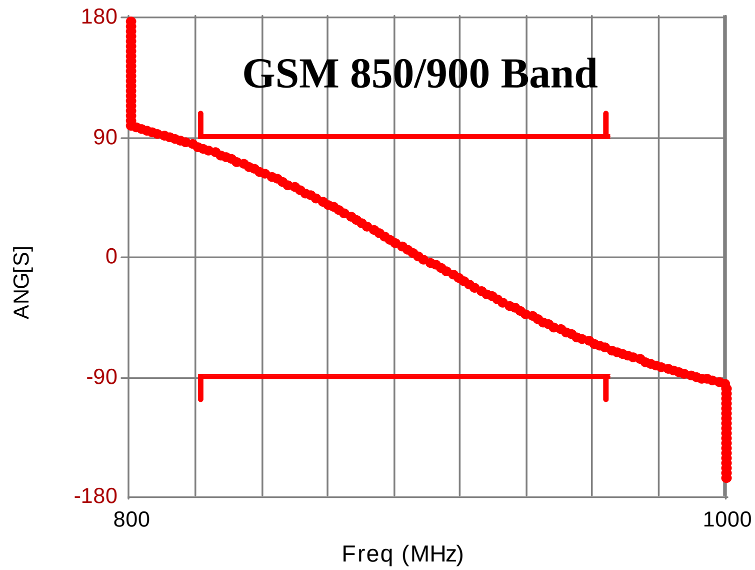
- **Layers were attached with repositionable spray adhesive.**
- **Vias were made by drilling with a 31 mil drill bit, wires inserted, and soldered by hand.**
- **Weight ~ 2.1 lb/ft^2**

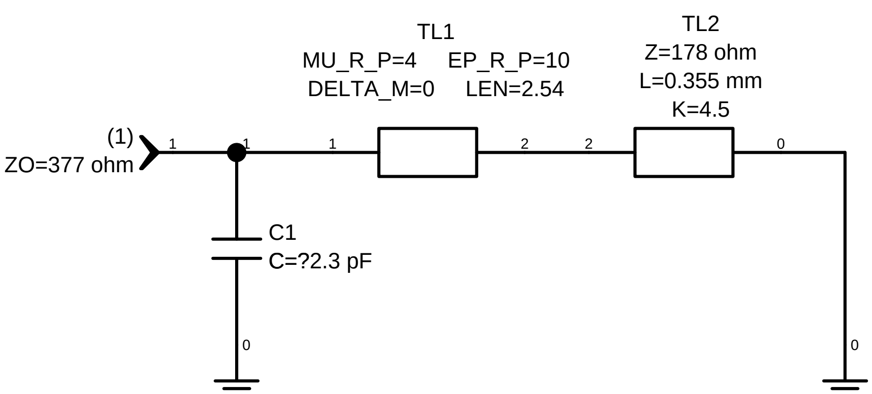
Sievenpiper AMC Designed for GSM 850/900 Band

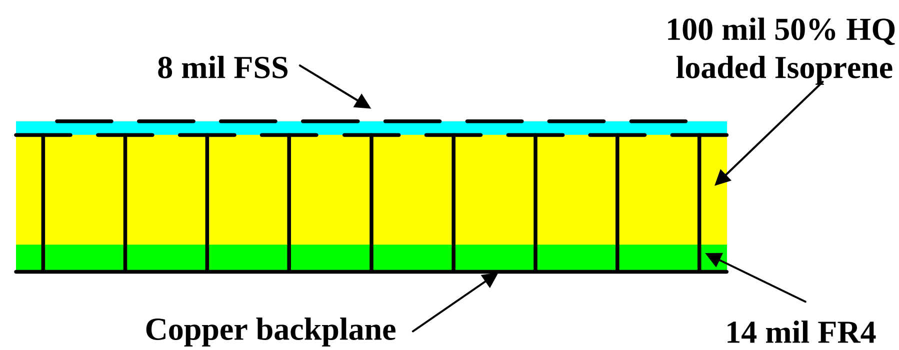
FSS Design:

- 2.3 pF/sq.
- Period: 349 mil
- Gap: 15 mil
- Chamfer: 35 mil
- Thickness: 8 mil
- Dielectric: R4003
- $\varepsilon_r = 3.38$
- 0.5 oz copper
- Through holes: 30 mil dia.







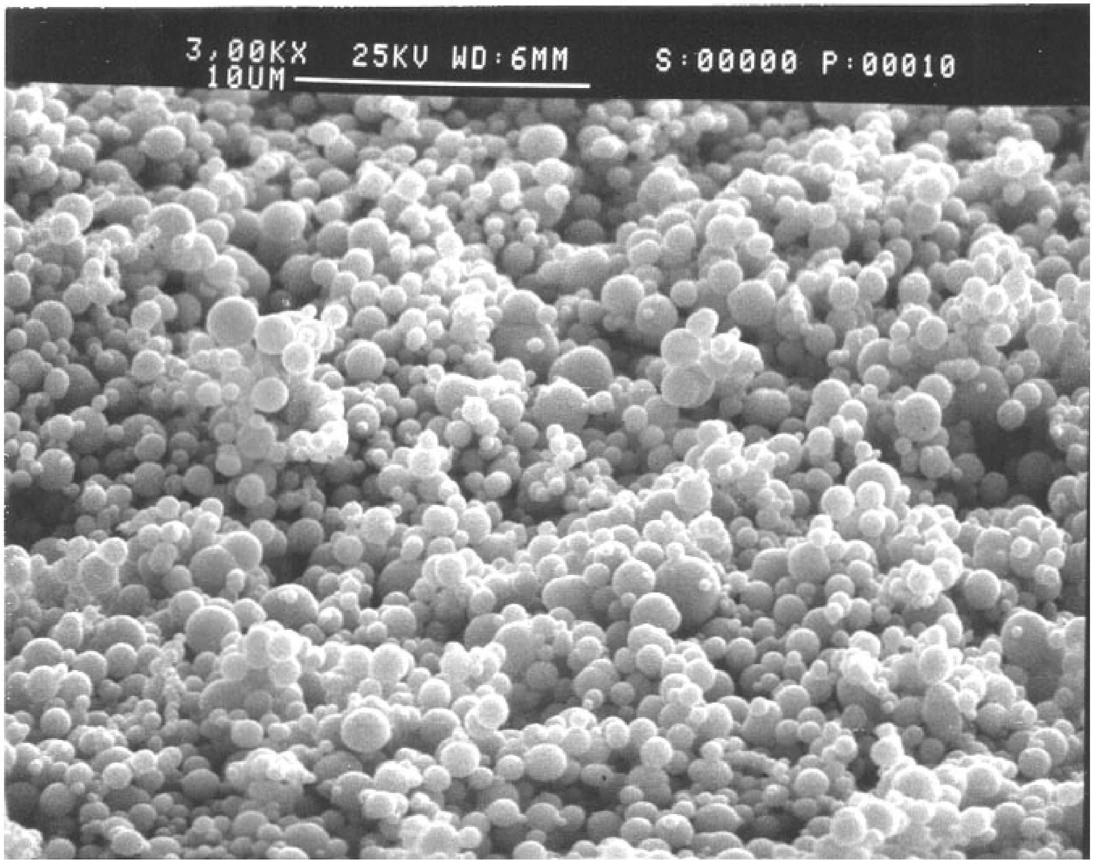


Magnetic Material

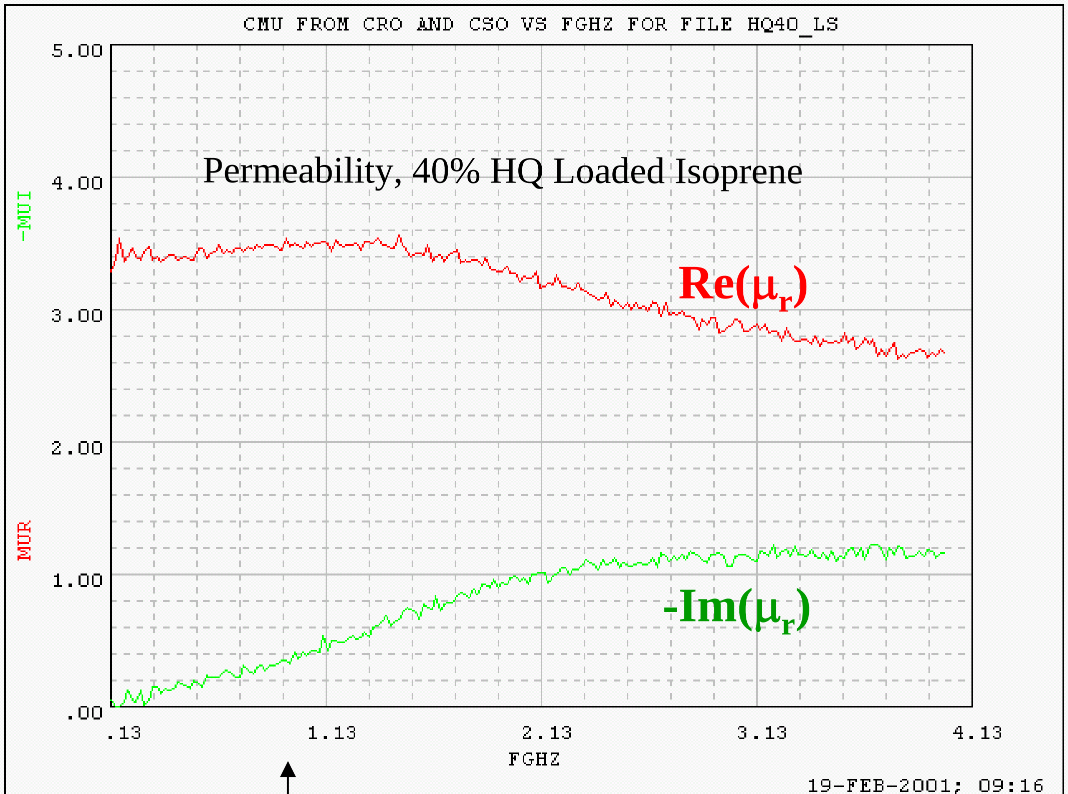
- Iron powder was mixed into gum rubber using a kneading process (rollers).
- Two mixtures were fabricated: 40% loading and 50% loading by weight.
- Iron powder was made by BASF, type HQ:

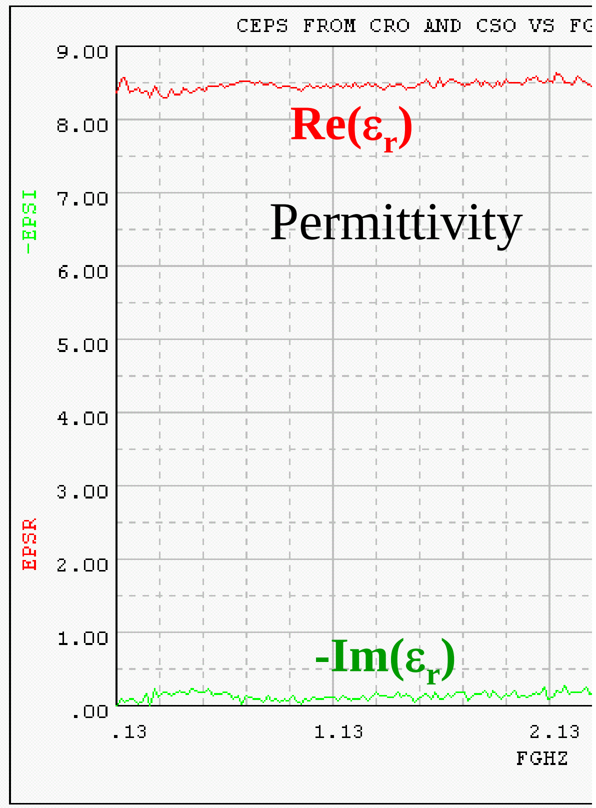
SEM Image

Mean dia. ~ 1 to 2 um



Material Parameters for 40% Loaded HQ Isoprene

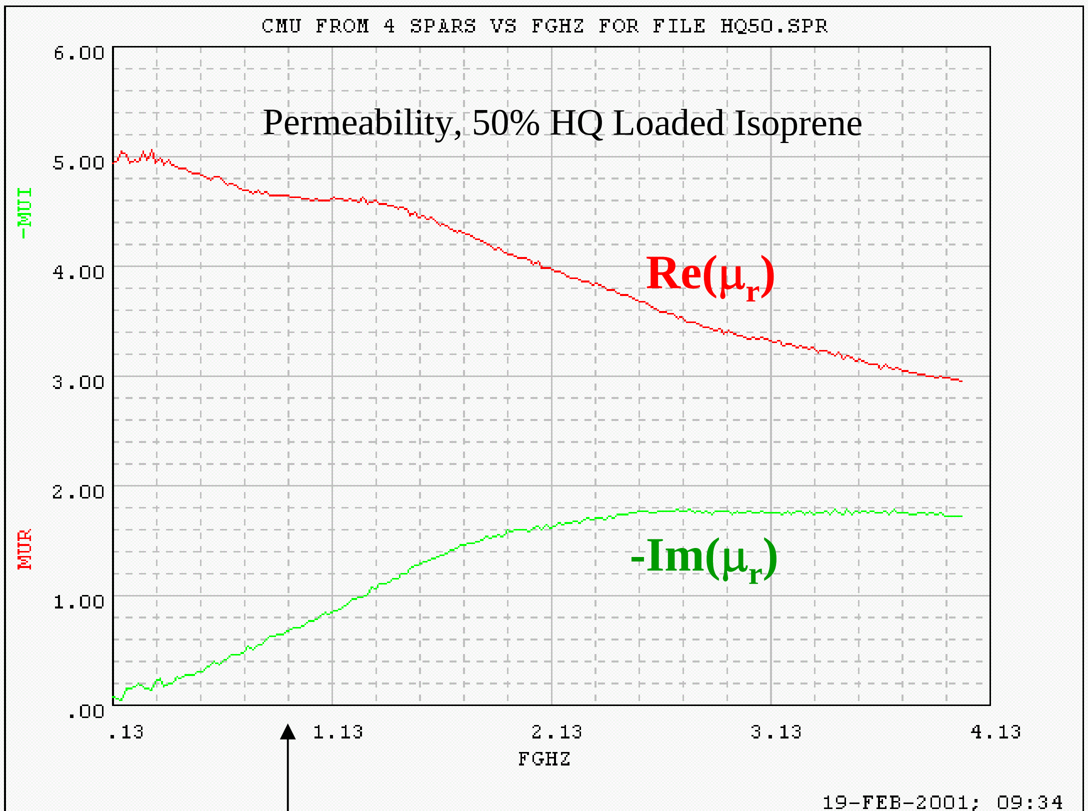


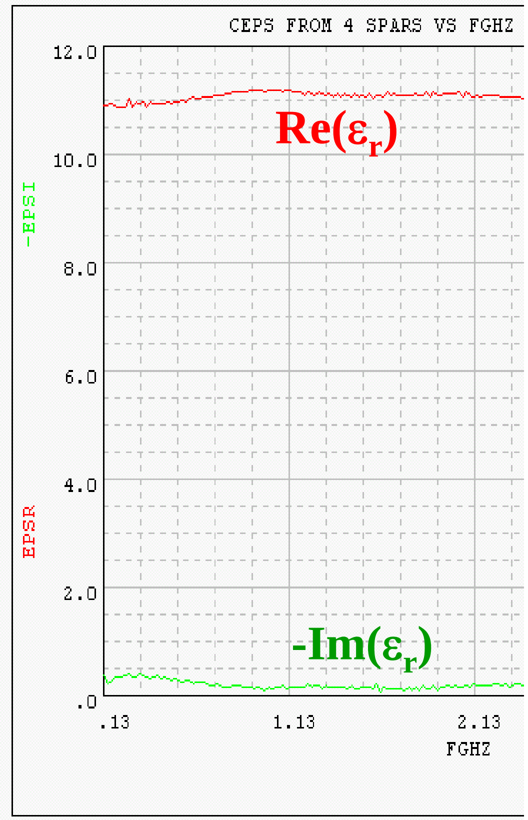


tan δ_m = .11 at 900 MHz
12" x 12" x 0.1" sample weighs 2.125 lb.

Notes: Full 2-Port Measurement
7mm Airline Test
100 mil thick sample
1 micron iron particles

Material Parameters for 50% Loaded HQ Isoprene





tan δ_m = .20 at 900 MHz
12" x 12" x 0.1" weighs 2.5 Ib.

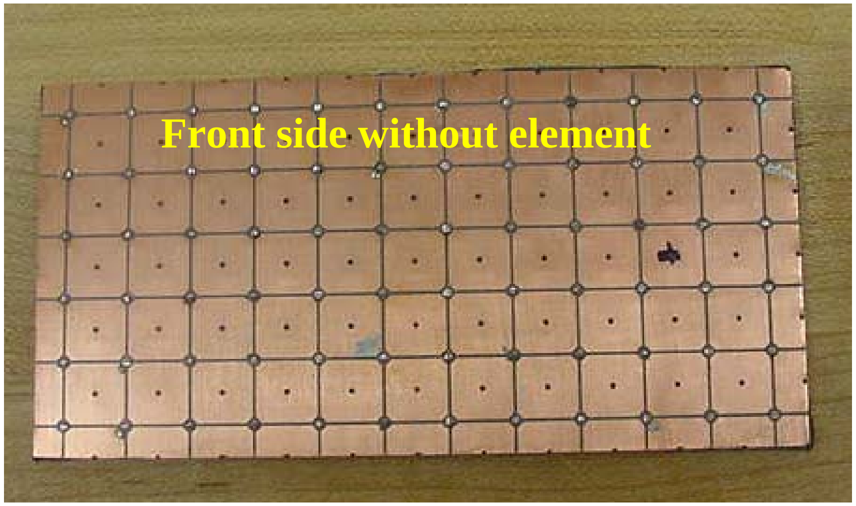
Notes: Full 2-Port Measurement
7mm Airline Test
100 mil thick sample
1 micron iron particles

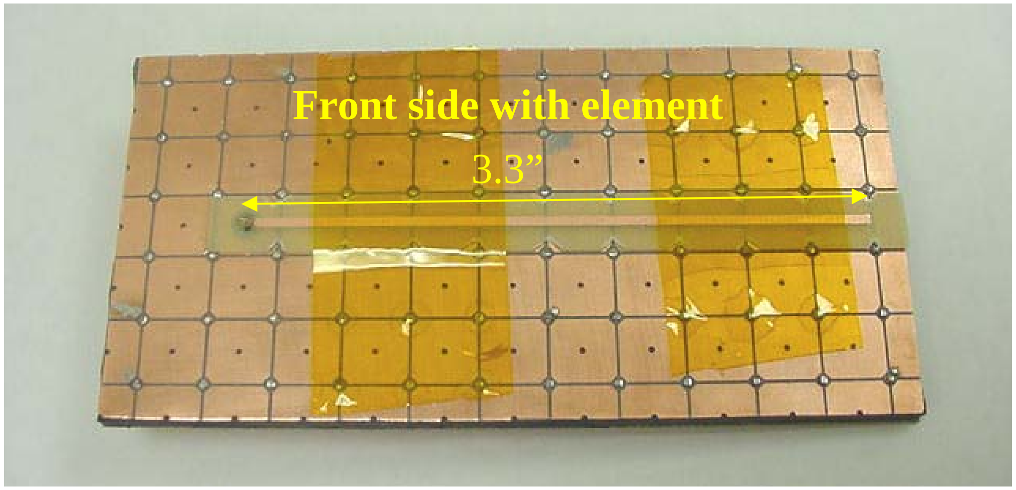
Antenna Experiments

- Three AMCs were fabricated with the same 2.125” x 4.25” FSS (2.3 pF/sq.), but different spacer layers:
  - 40% HQ-loaded isoprene without vias
  - 40% HQ-loaded isoprene with vias
  - 50% HQ-loaded isoprene with vias
- Two lengths of wire antennas: 2” and 3.3” (0.15λ_o and 0.22λ_o at 860 MHz)
- Measurements: return loss, efficiency, gain patterns

3.3” Wire Antennas on Magnetically-Loaded AMCs

72 vias were soldered by hand in order to connect the lower patches to the copper backplane.





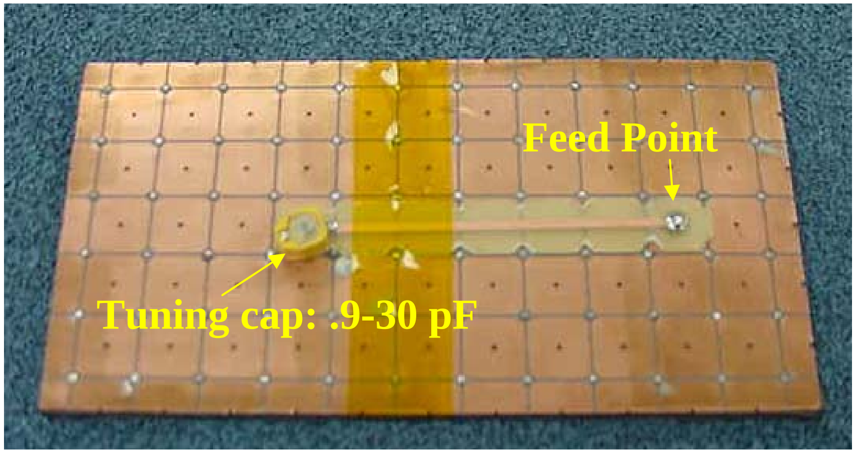
Notes:

1. **Size: 2.125” by 4.25”**
2. **Total thickness: 153 mils including solder (λ_o/90 at 860 MHz)**
3. **This AMC has a 50% HQ loaded isoprene substrate, 100 mils thick**

2” Wire Antenna on Magnetically Loaded AMCs

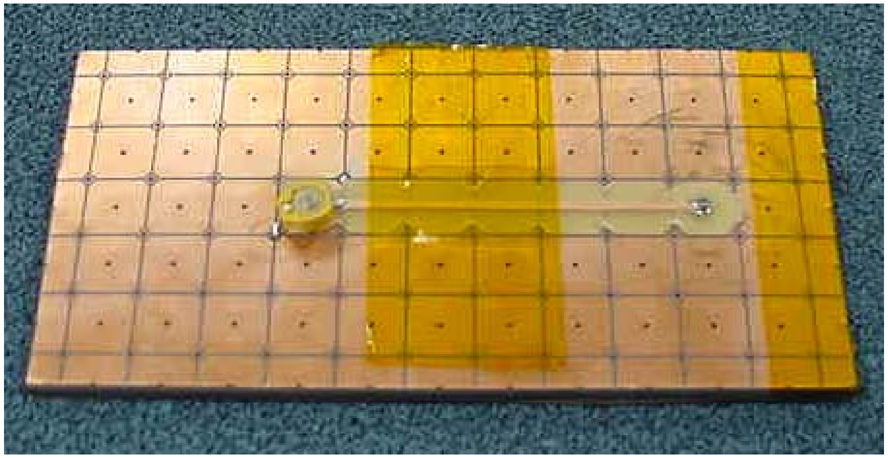
50% HQ Loading:

AMC with vias:



40% HQ Loading:

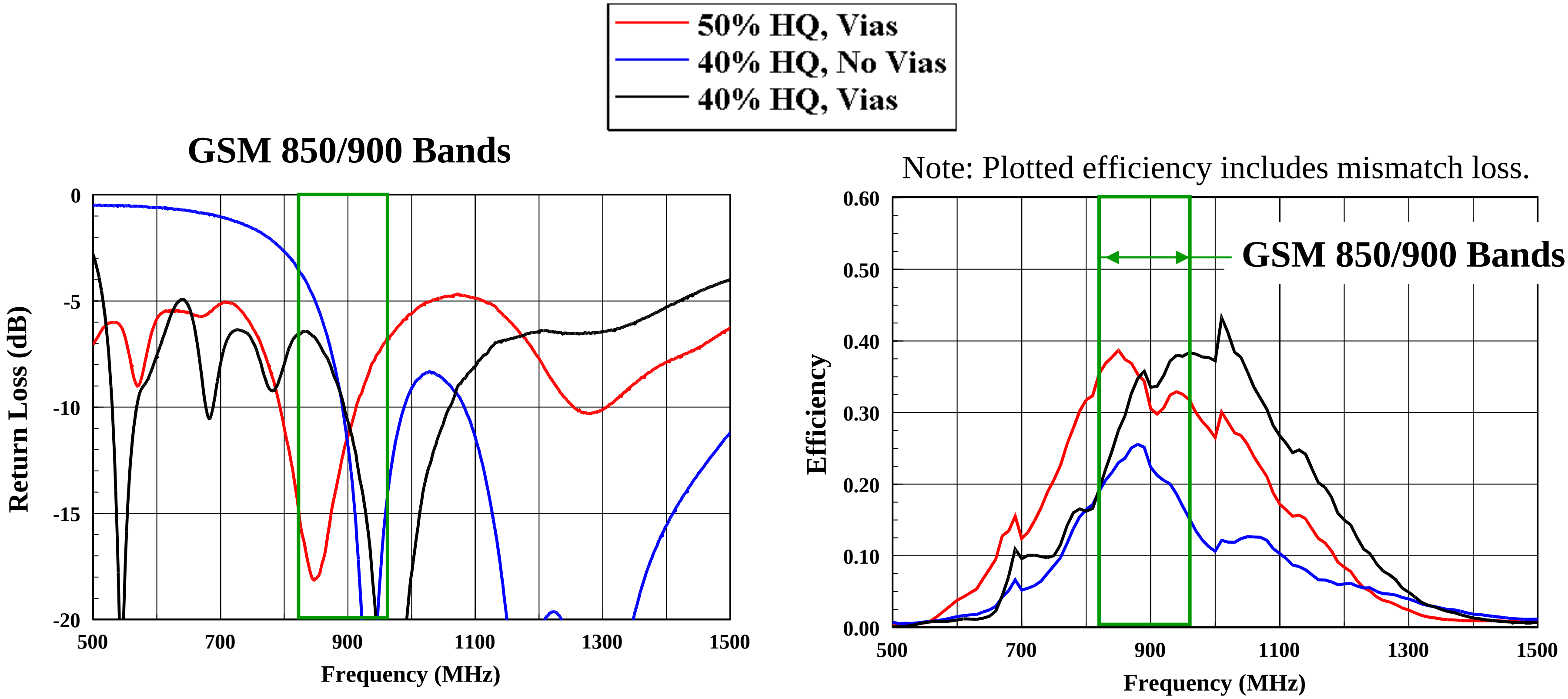
No vias:



Notes:

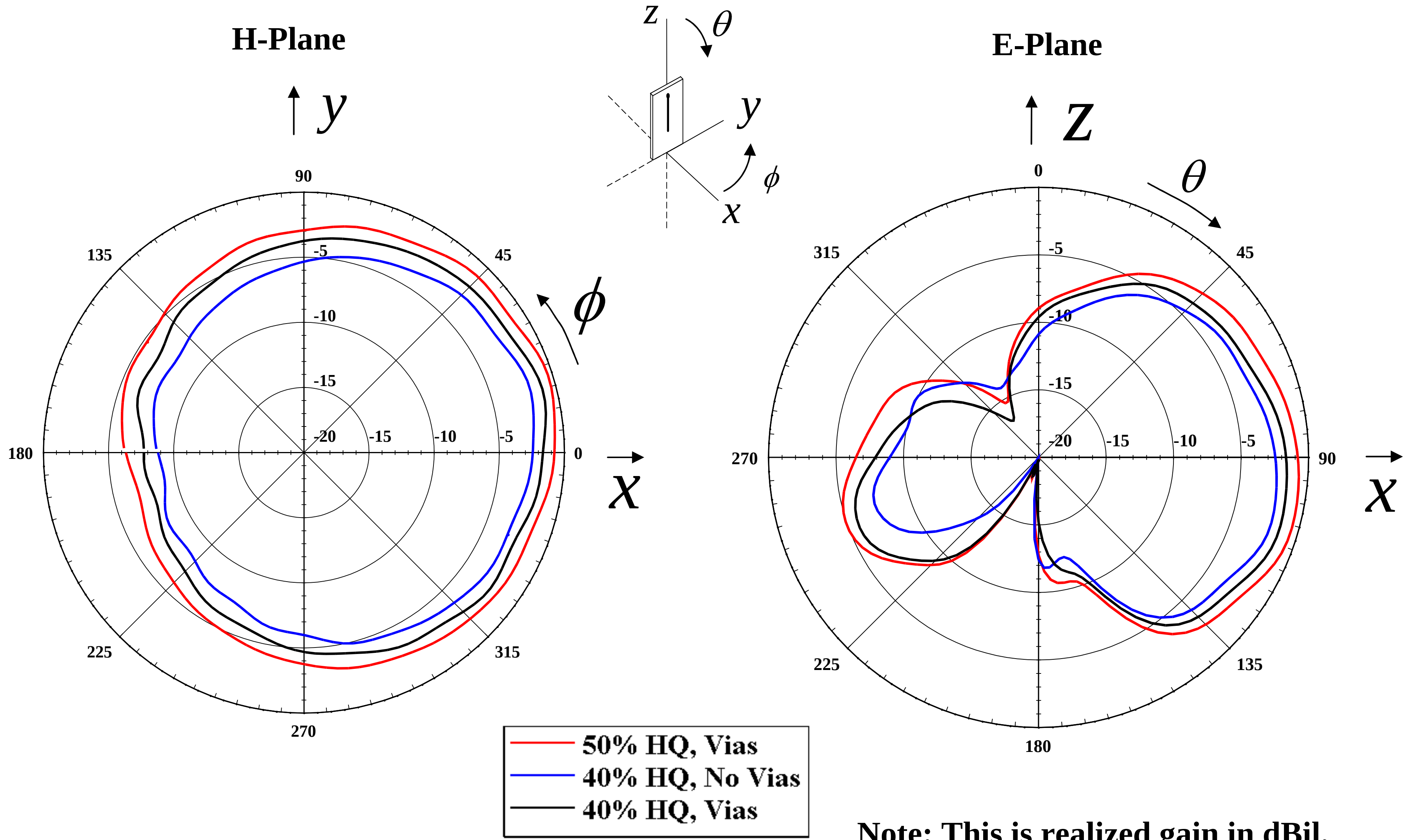
1. **Size: 2.125” by 4.25”**
2. **Total thickness: 153 mils including vias and solder. (λ_o/90 at 860 MHz)**

Return Loss and Efficiency Using 2” Wire Antennas



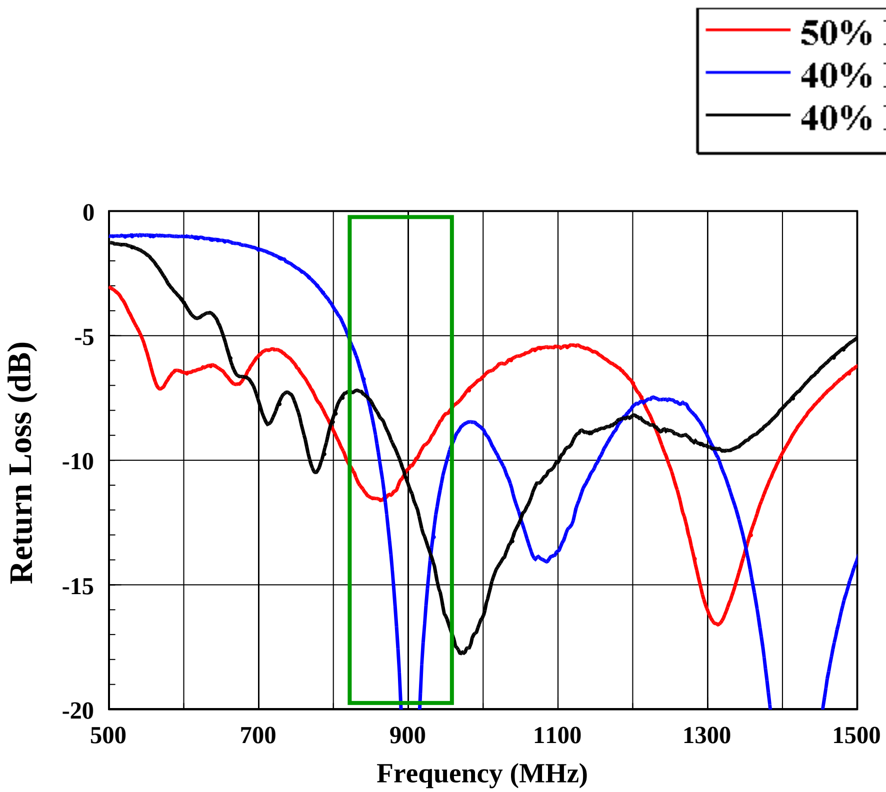
- Peak efficiencies lie between 30% and 40% for substrates with vias.
- The no-via antenna has substantially less efficiency.

860 MHz Principle Plane Cuts
Using 2” Wire Antennas

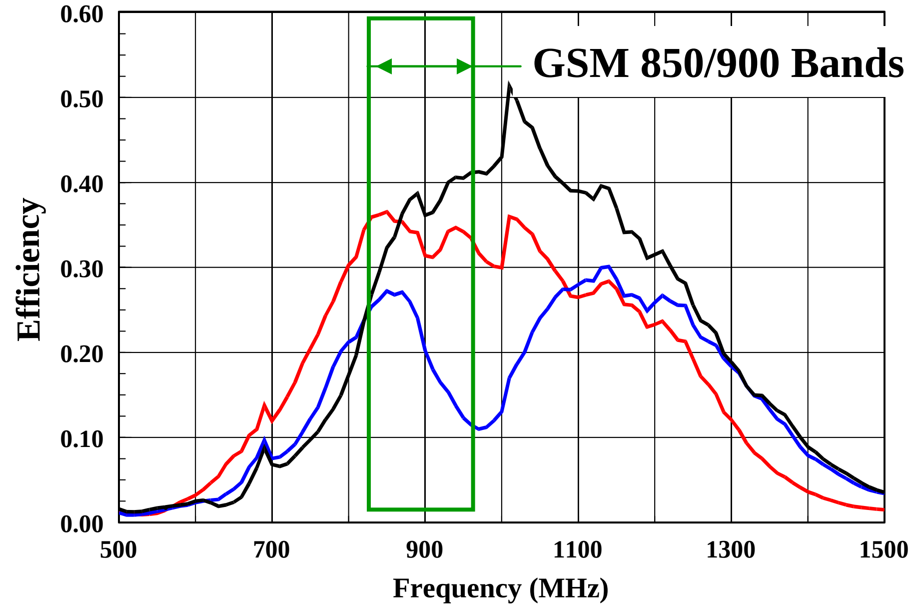


Note: This is realized gain in dBil.

Return Loss and Efficiency Using 3.3" Wire Antennas

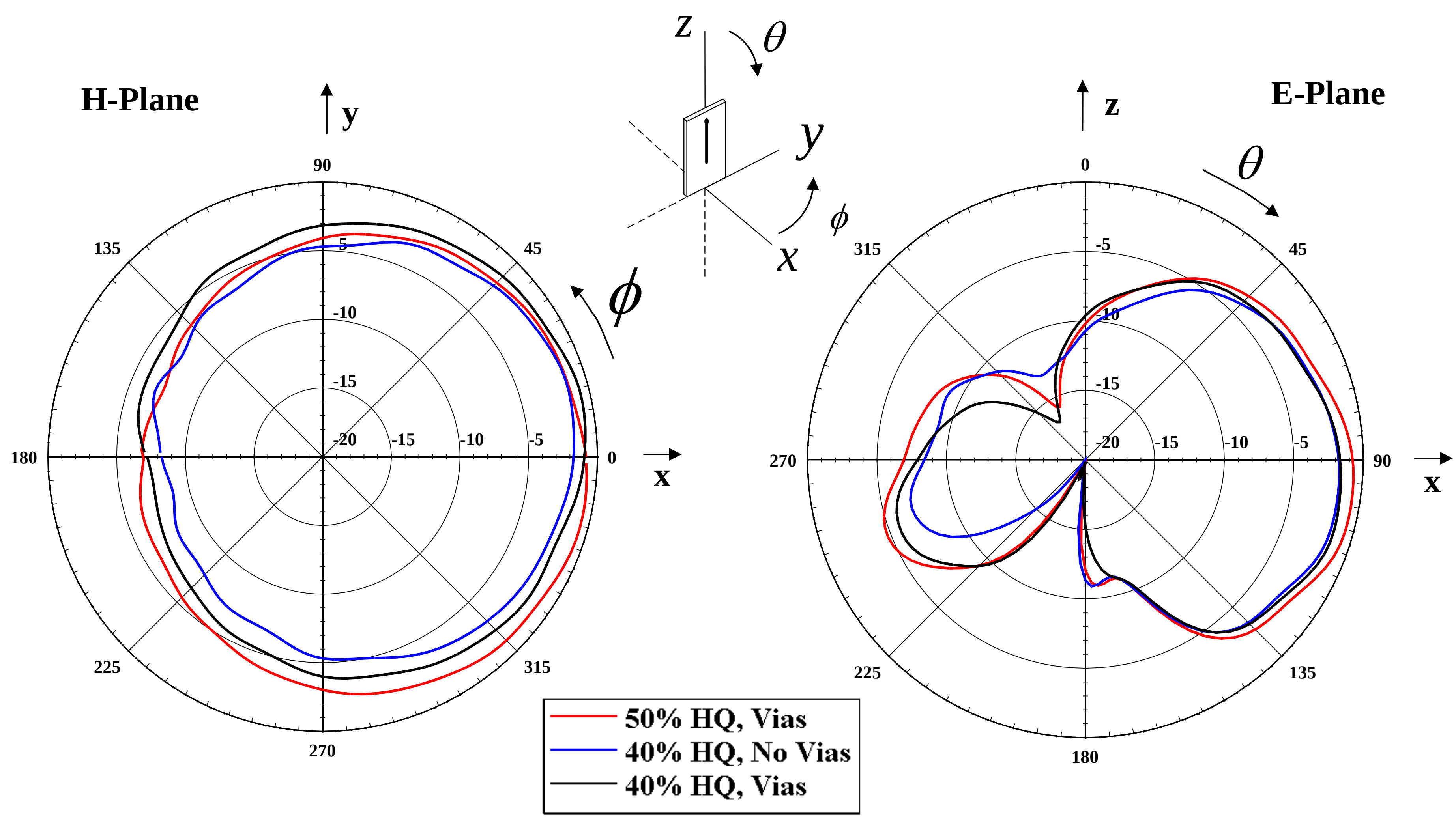


Note: Plotted efficiency includes mismatch loss.



- Peak efficiencies lie between 30% and 50% for substrates with vias.
- The no-vias antenna has substantially less efficiency.

860 MHz Principle Plane Cuts
Using 3.3" Wire Antennas

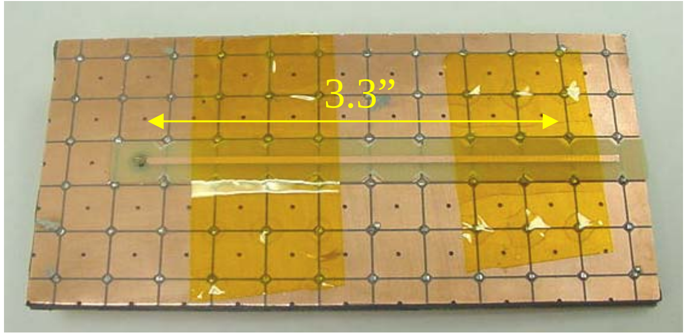


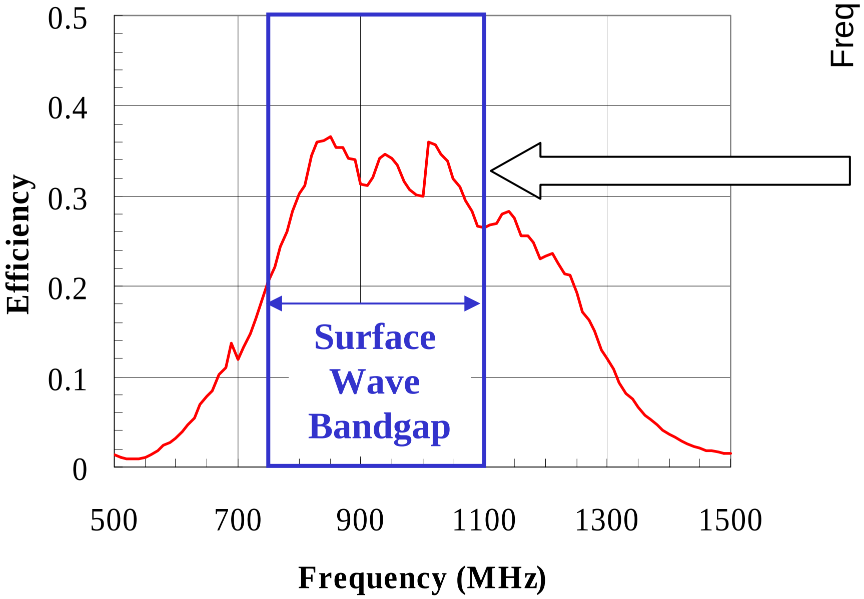
Note: This is realized gain in dBil.

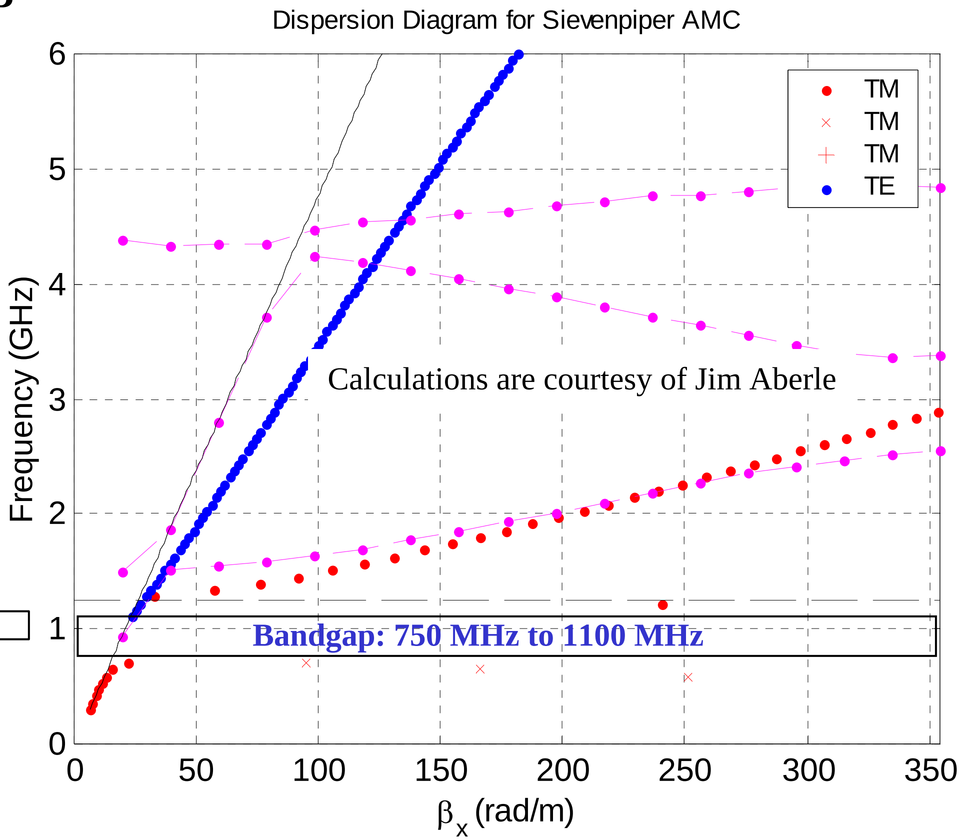
Comparison of Predicted Surface Wave Bandgap to Measured Radiation Efficiency for a Magnetically-Loaded AMC Bent-Wire Monopole.

AMC Antenna Element: 2.1” x 4.25”x.153”

(Substrate has 100 mils of 50% HQ loaded isoprene)



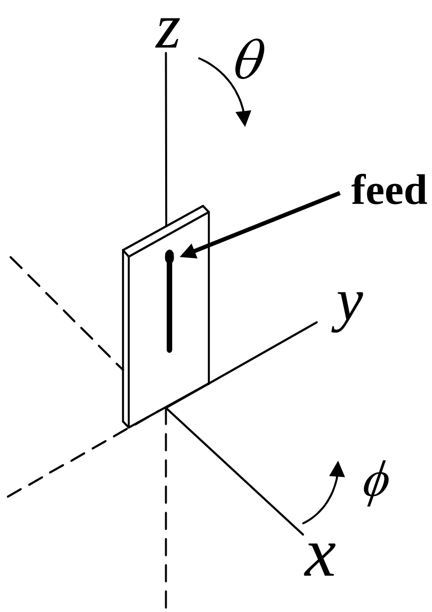


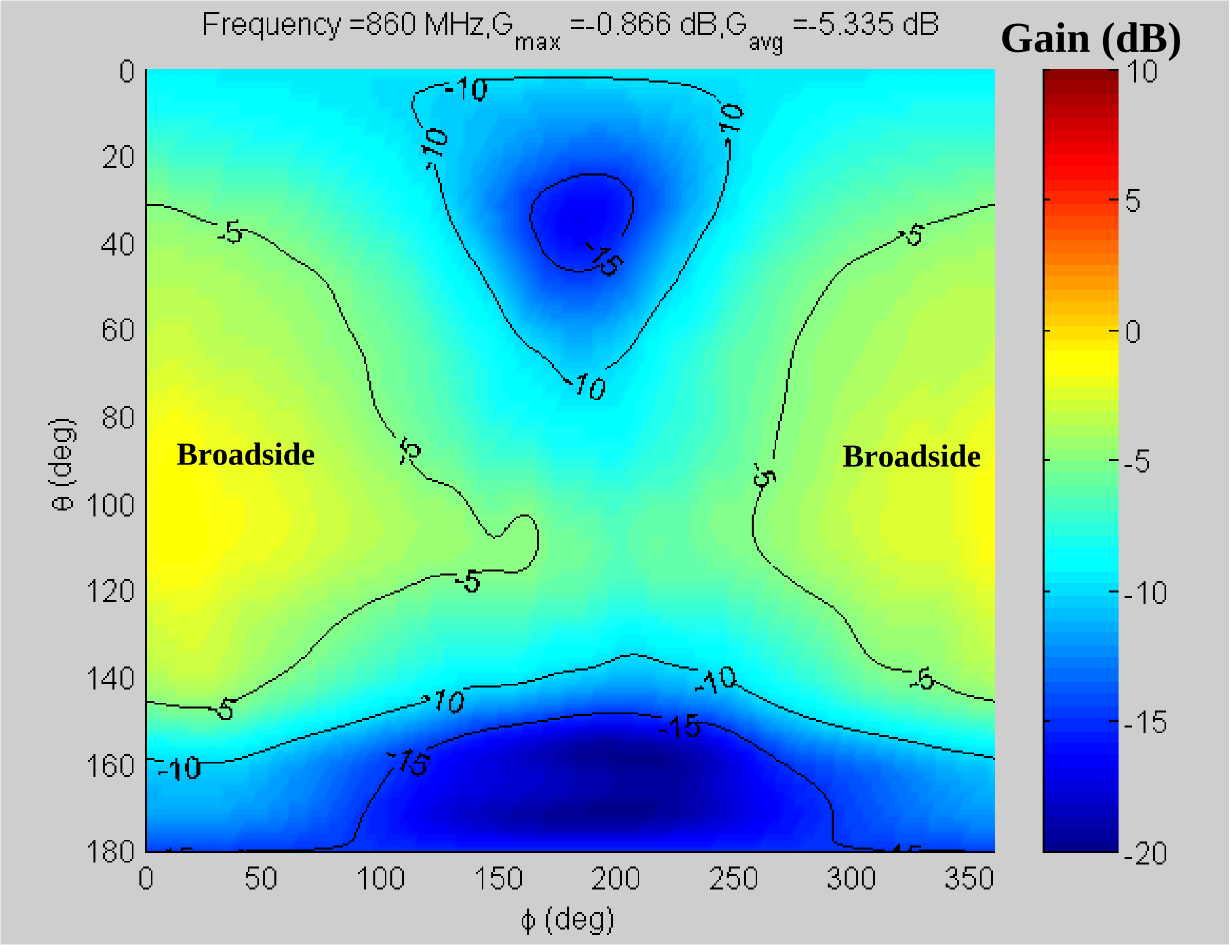


Shown at right is the product of radiation efficiency and mismatch loss. **It is observed that the highest efficiency is found only in the surface wave bandgap of the AMC.**

Antenna Gain Contours at 860 MHz of a 2" Wire Antenna, 40% Loaded HQ Isoprene

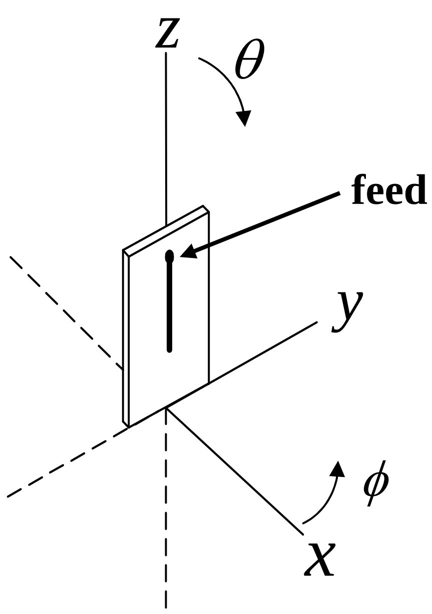
With Vias

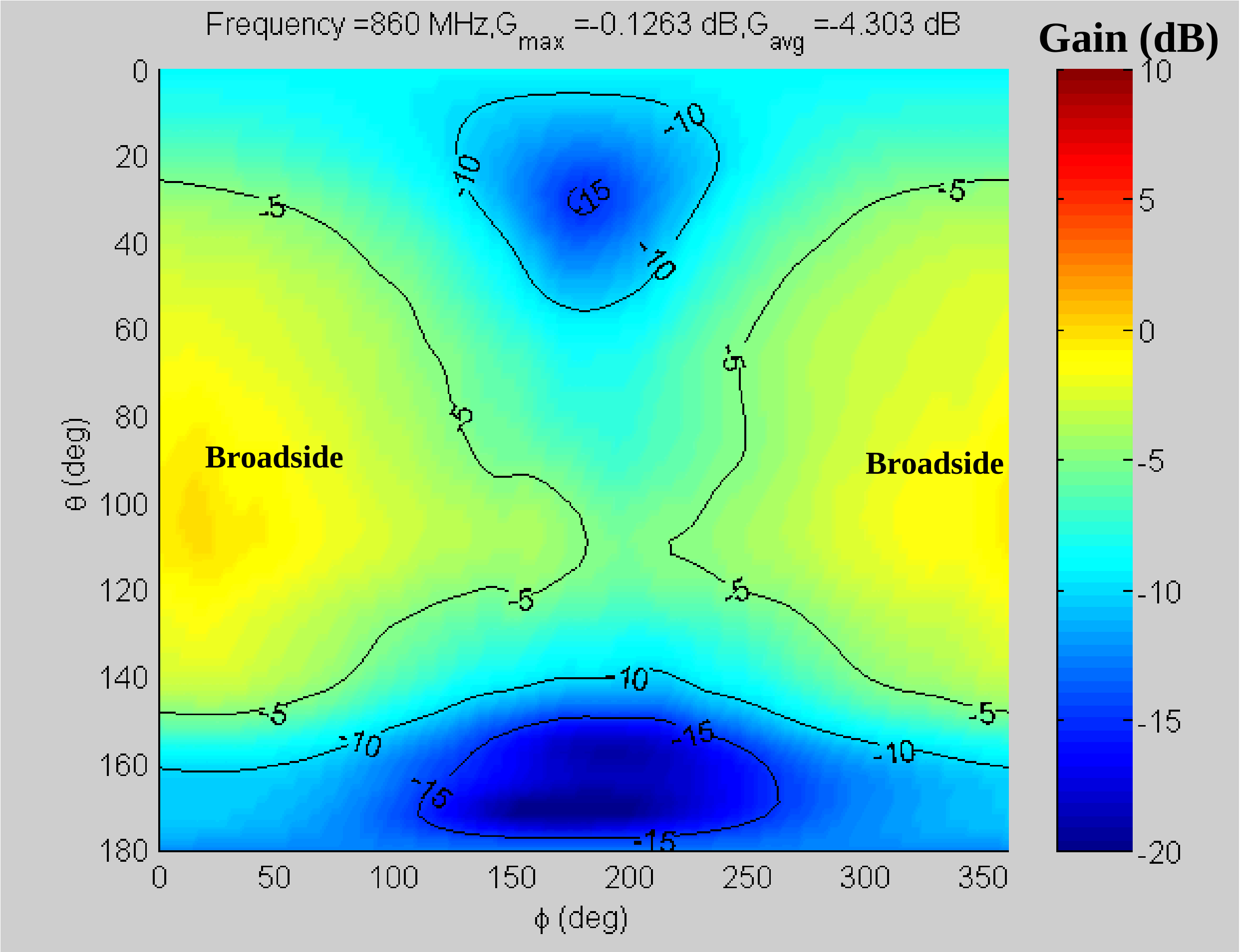




Note: This is realized gain in dBil.

Antenna Gain Contours at 860 MHz
2” Wire Antenna, 50% Loaded HQ Isoprene

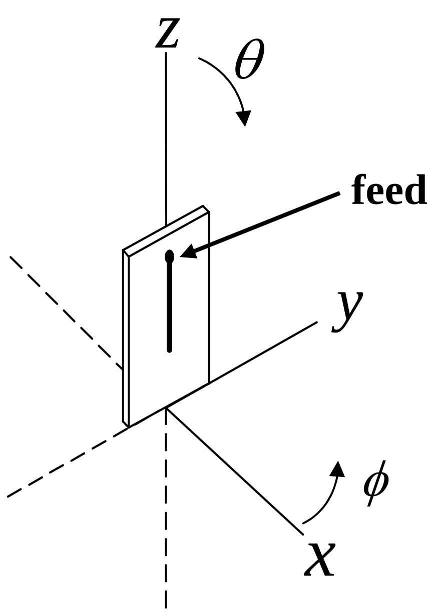


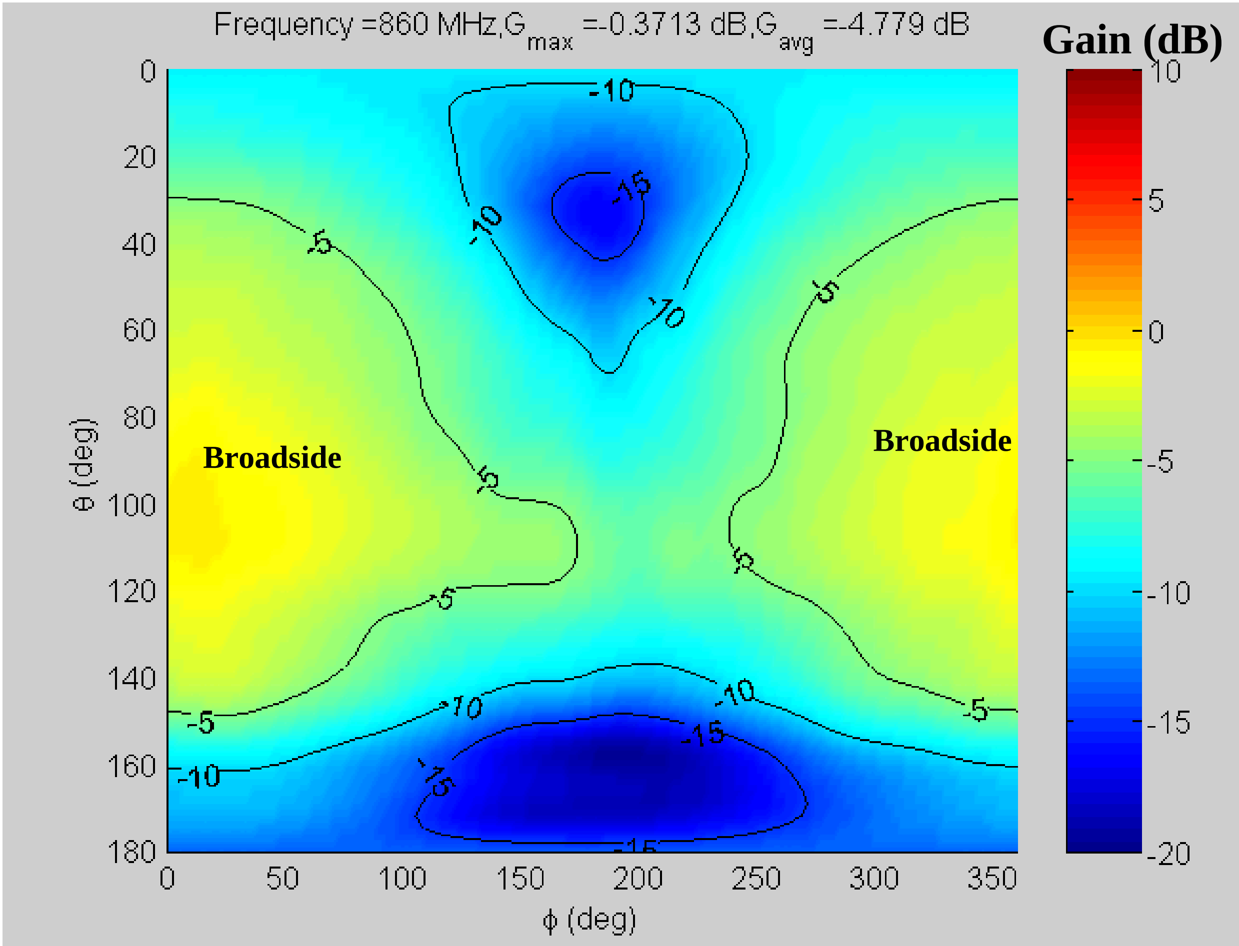


Note: This is realized gain in dBil.

Antenna Gain Contours at 860 MHz
3.3" Wire Antenna, 40% Loaded HQ Isoprene

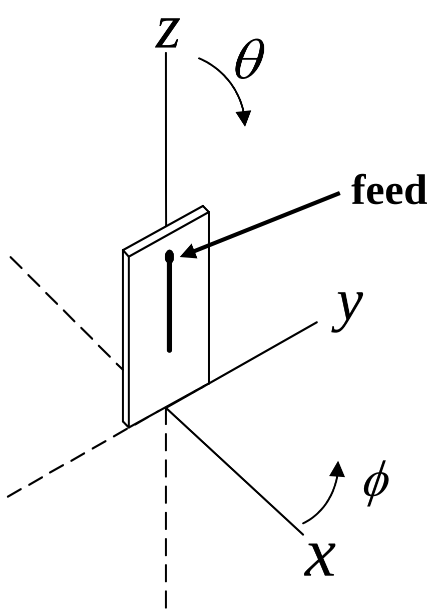
With Vias

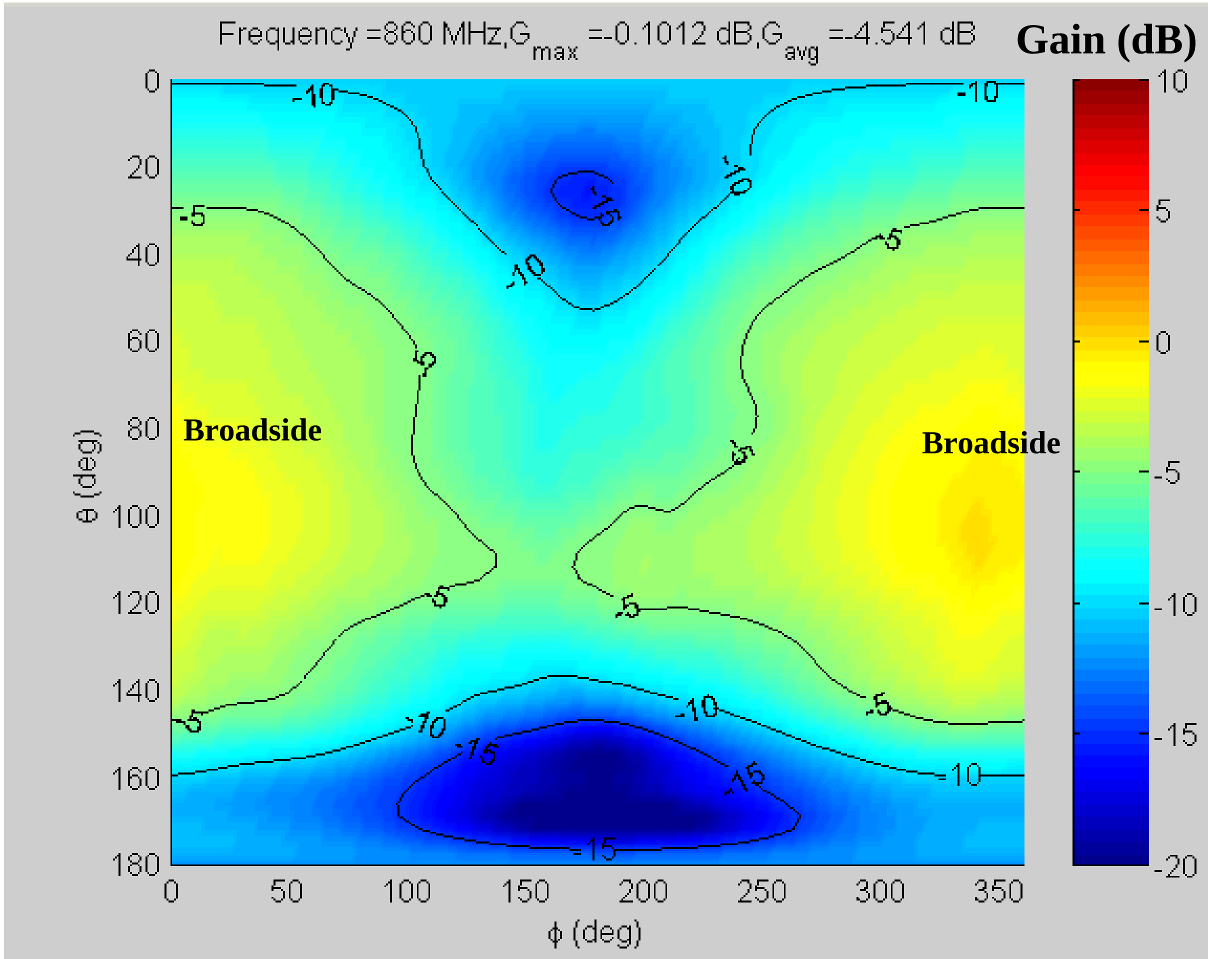




Note: This is realized gain in dBil.

Antenna Gain Contours at 860 MHz
3.3" Wire Antennas, 50% Loaded HQ Isoprene





Note: This is realized gain in dBil.

Conclusions

- The magnetically-loaded AMC antennas of this study have:
  - peak radiation efficiency of 30% to 40%,
  - -10 dB RL bandwidth of ~ 20% (900 MHz to 1100 MHz),
  - stackup thickness is 125 mils (λo/105 at 900 MHz)

- Estimated +/-90^o reflection phase bandwidth is 21% (40% HQ loading).

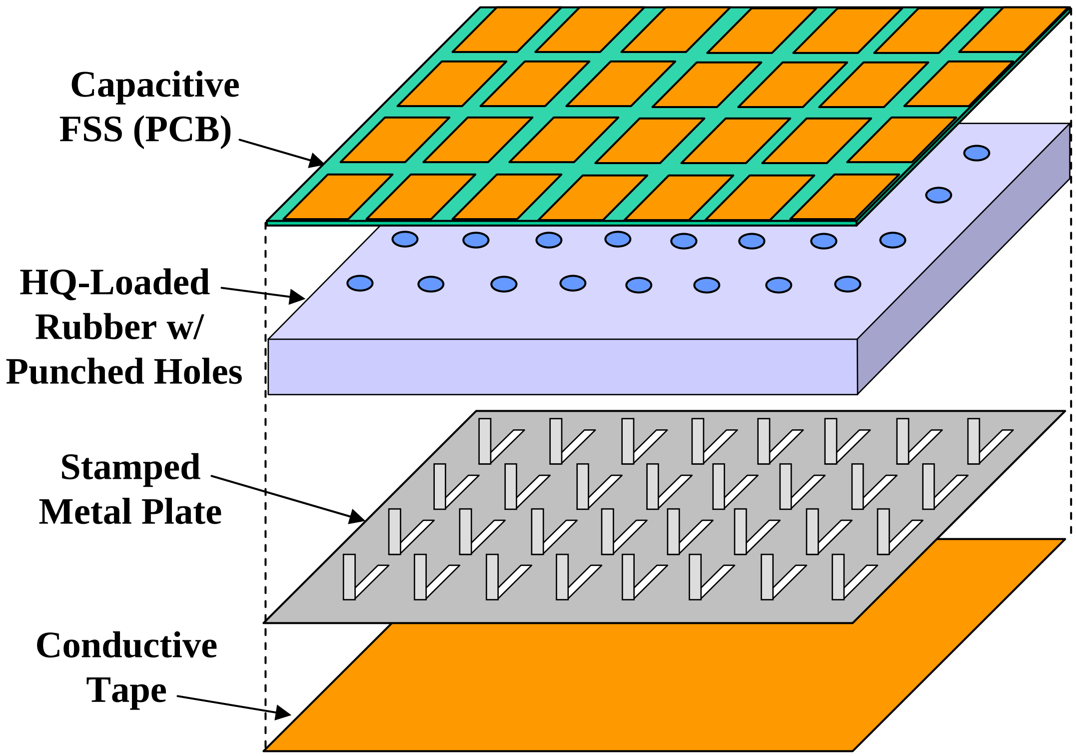
- Higher efficiency is achieved when the AMC structure contains vias.

- An eigenvalue simulation predicted a surface-wave bandgap that corresponds well to the band where the AMC antenna exhibits greatest efficiency.

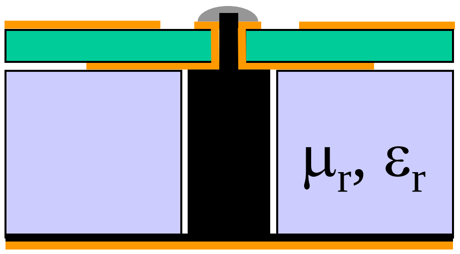
- This work was completed in March of 2001.

- Future improvements – employ smaller iron particles. This should reduced the magnetic loss tangent and increase the antenna efficiency.

Proposed Method to Manufacture a Magnetically-Loaded AMC

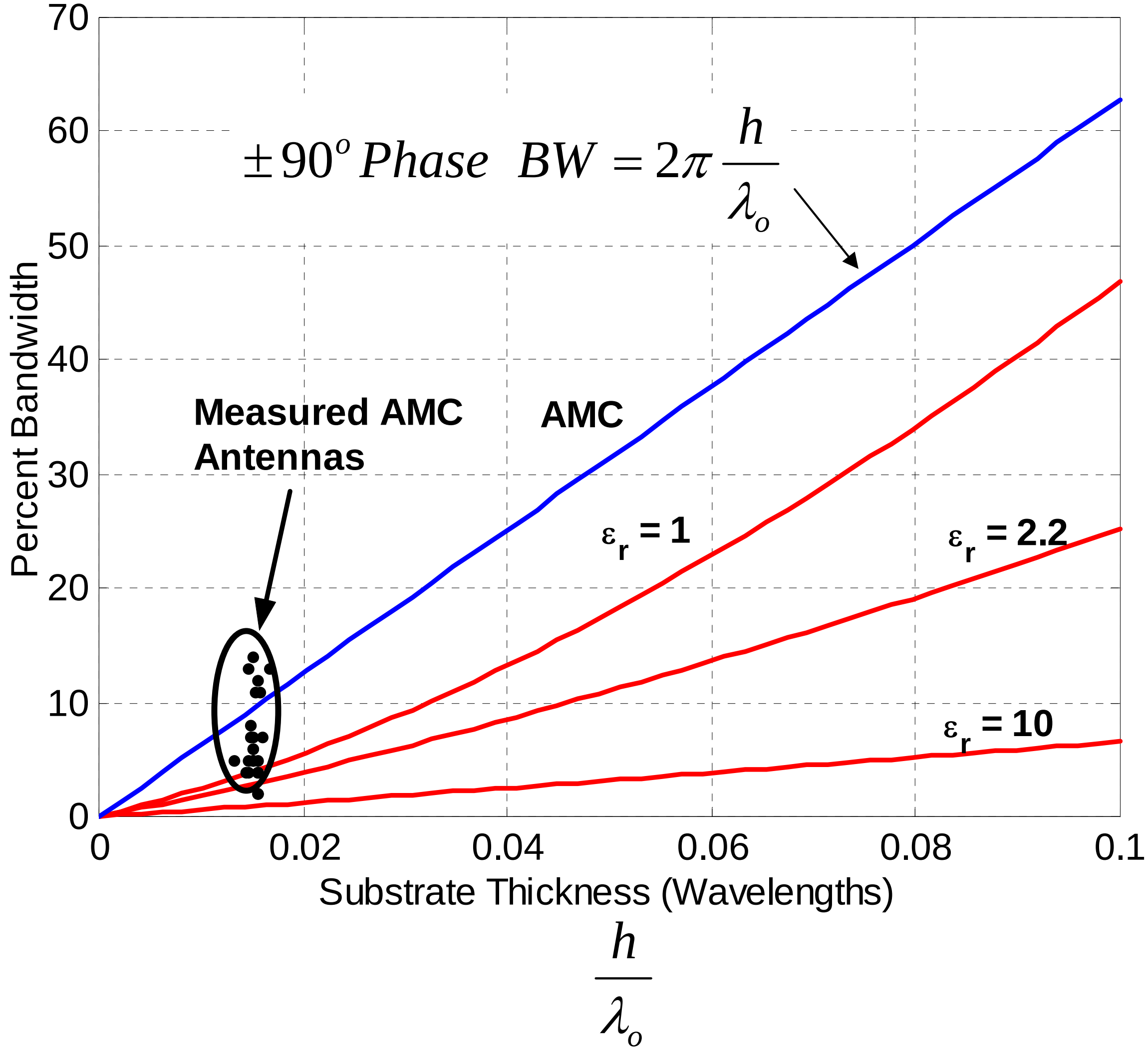


Exploded View



Profile View

AMC Antennas Have a 2X to 10X Bandwidth Advantage Over Microstrip Patch Antennas



- AMC bandwidth corresponds to the +/- 90 degree reflection phase points

- Microstrip patch bandwidth corresponds to a –6 dB return loss for circular patch, computed using simple cavity model.

- Measured AMC antenna bandwidths correspond to a –6 dB return loss.