



#### Reducing the Effects of RF Obstructions with Artificial Impedance Surface (AIS) technology

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#### Agenda

# A.R.A.

- ARA / HRL Collaboration
- AIS Technology
- AIS Fundamental Theory
- AIS Platform Integration and Results
- Current Development
  - Circular Polarization
  - Conformal AIS Appliques
  - Lower Dielectric Material
- Future Development
- Conclusions
- Questions



## ARA / HRL AIS Collaboration



- In 2010, ARA and HRL collaborated to integrated a curved AISA surface onto UAV fuselage.
  - ARA learned theoretical concepts of AISA technology
  - ARA designed and fabricated a test platform to characterize the AIS
  - ARA developed manufacturing plans to fabricate AIS PCBs.
- In 2011, ARA and HRL are collaborating to develop a circularly polarized conformal AIS.
- In 2012, ARA will begin environmentally qualifying the conformal AIS.



## **AIS Technology**

- AIS Technology is a synthesized impedance surface that redirects RF radiation past obstruction
- AIS's optical analog of the diffraction grating
  - Surface waves on AIS produce interference pattern.
  - Primary radiation lobe is developed by interference pattern.
  - Lobe angle is frequency dependent.

#### AIS Competing Technologies



- Electromagnetic Bandgap (EBG)
  - Manufacturing very complex
  - Band-limited
- Dielectric Coatings
  - Not applicable for complex systems
  - Scattering occurs between non-homogenous layers

#### **AIS IS MORE COST-EFFECTIVE AND VERSATILE**



#### AIS Technology: Use the surface of the platform as the aperture





#### Approach:

- Use fine (<<λ) metal patterns to create large scale (~λ) index variations</li>
   Artificial Impedance Surface
- Large scale (~λ) index variations can produce controlled radiation Microwave holograph



# **AIS Approaches to Reduce**

#### Apply AIS on an obstruction to capture free space wave and wrap energy around

- Previously demonstrated
- · Less dependent on the excitation source
- Applicable to larger, fixed obstructions

#### Use AIS to route excitation surface wave energy around obstruction and then radiate it

Dependent on the source excitation

· Nothing to attach to the obstruction

#### Use AIS to route surface wave energy

#### around surface curvature

- · Previously demonstrated
- · Dependent on the source excitation
- · Can be used to reduce finite ground plane size affects





All three approaches can be applied to reduce real world structural obstructions/scattering pattern degradations







AVA



AIS Technology Benchmark Metrics

- Beam squint- angle / frequency ratio
- Peak angle
- 3 dB beamwidth
- Peak intensity











## **AIS Fundamental Theory**



#### AIS Fundamental Theory

· Compute integral of the fields due to the surface wave currents

$$\vec{\mathbf{E}}_{\textit{rad}}\left(\vec{\mathbf{k}}\right) \sim \int_{\mathcal{AB}} \left[ \left( \hat{\mathbf{k}} \times \vec{\mathbf{J}}_{\textit{sw}}\left(\vec{\mathbf{r}}\right) \right) \times \hat{\mathbf{k}} \right] - e^{-i\vec{\mathbf{k}} \cdot \vec{\mathbf{r}}} \ d^2r$$

- For flat AISA can simplify to  $\vec{\mathbf{E}}_{rad}\left(\vec{\mathbf{k}}\right) \sim \int_{\mathbf{i}\mathbf{l}\mathbf{r}} \left[ \left(\hat{\mathbf{k}} \times \vec{\mathbf{j}}_{sw}\left(\vec{\mathbf{r}}\right)\right) \times \hat{\mathbf{k}} \right] e^{i \left[k \int_{0}^{\mathbf{r}} n_{sw}\left(\vec{\mathbf{r}}\right) d\mathbf{r}' \vec{\mathbf{k}} \cdot \vec{\mathbf{r}}\right]} d^{2}r$
- The field term can be written as a product of the surface current's magnitude,  $j_{sw}(\vec{r})$ , and the field's angular distribution,  $\vec{\mathbf{P}} = \left[ (\hat{\mathbf{k}} \times \hat{\mathbf{j}}_{sw}(\vec{r})) \times \hat{\mathbf{k}} \right]$
- The radiation angular range limitation is

$$\vec{\mathbf{P}} = \begin{cases} \cos(\phi - \phi_r) \cos(\theta) \hat{\theta} & -\sin(\phi - \phi_r) \hat{\phi}; & TM \\ -\cos(\phi - \phi_r) \hat{\theta} & -\sin(\phi - \phi_r) \cos(\theta) \hat{\phi}; & TE \end{cases}$$

- Vertical polarization is practically limited to 75° from normal by cosine term
- No limitation on horizontal polarization
- Making some approximations of surface wave decay, the far field pattern good approximation for engineering studies
  - Implemented approximation integral in Matlab
  - Good correlation with FastScat simulation for main beam angle and firs few sidelobes





# AIS Design Algorithm



Match the surface wave index to the desired plane wave with the AIS grid momentum

$$k_{sw} = k_o \sin \theta_o - k_p$$
  $k_p = \frac{2\pi}{\lambda_s} = k_o \left( n_o - \sin \theta_o \right)$ 

- k<sub>o</sub> is the radiation's free-space wavenumber at the design frequency
- $\theta_o$  is the angle of the desired radiation with respect to the AIS normal,
- $k_p = 2\pi \lambda_p$  is the AIS grid momentum where  $\lambda_p$  is the AIS modulation period,
- k<sub>sw</sub>=n<sub>o</sub>k<sub>o</sub> is the surface wave's wavenumber, where n<sub>o</sub> is the surface wave's refractive index averaged over the AIS modulation



• Replace  $k_p$  by integral multiple of the first equations

$$\sin(\theta_m) = n_o - mk_p / k, \quad m = 1, 2, 3, \dots \operatorname{int}\left(\frac{k}{k_m}(n_0 + 1)\right)$$

- -the beam peaks of all modes can be determined, m = 1 is the main lobe
- -This equation can be used to quantify the AISA beam squint which limits bandwidth
- The wavenumber  $k_o$  can be expressed as periodic variation in the surface-wave propagation index

 $n_{sw}\left(\vec{\mathbf{r}}\right) = n_o + dn\cos(k_o n_o r - \vec{\mathbf{k}}_o \Box \vec{\mathbf{r}})$ 





- Control surface wave index with a grid of metal patches
  - Values can be computed with analytic expressions in many cases
    - > Patch size large relative to substrate thickness
    - > Surface wave phase shift per unit cell not close to 180 deg.
  - Can be computed with unit cell simulation
- Index has strong dependence on frequency, especially for higher indexes; this dominates beam squint





 Experience has shown need for scaling factors to match theory with measurements, but once determined (for substrate and freq.) can be used for design

- Exact reasons not clear, but think it is related to
  - > Finite surface affects
  - Varying index
- This is topic area for future research





• AIS beam squint can be expressed as

- AIS modulation's Floquet term
- To eliminate beam squint would need negative dispersion
  - Possible with active circuits?
  - Topic area for further research
- From our experience the AIS's dispersion is significant
- Most straight forward way to increase bandwidth is to reduce the average AIS index



 $\frac{dn_o}{dk} = -\frac{k_p}{k^2}$ 

 $\frac{d\theta}{dk} = \frac{1}{\cos\left(\theta\right)} \left(\frac{dn_o}{dk} + \frac{k_p}{k^2}\right)$ 

AKA





#### **AISA Platform Integration**



# Obstruction ARA Characterization





## **Obstruction** Characterization

ARA



Frequency (GHz)

# HRI AISA ARA Characterization Setup





#### ACIN Elevation Characterization







IO.6 GHz







## AIS Design Approach



Empirically derive surface wave and modulation indices

Characterize Flat Panel Designs
Optimize AIS bandwidth / decrease beam squint

Curve AISA to achieve near horizon coverage

Compensate for finite ground plane
Extend coverage beyond AIS angle limitations

Optimize pattern on AIS to mitigate the obstacles





![](_page_21_Figure_0.jpeg)

![](_page_21_Figure_1.jpeg)

![](_page_22_Picture_0.jpeg)

# **Strut Effect**

ARA.

![](_page_22_Figure_2.jpeg)

# Surface Waveguide MARA.

- Index is tailored by selectively removing metal to produce a region of comparatively low surface-wave index.
  - Low-index region guides surface-wave energy away from it
  - Physically analogous to a dielectric waveguide

# HE Curved AIS with ARA Optimized Waveguide

![](_page_24_Figure_1.jpeg)

#### AIS Comparison to Aluminum Sheet

ARA

HRL

![](_page_25_Figure_1.jpeg)

![](_page_26_Figure_0.jpeg)

#### AIS Comparison to Aluminum Sheet

![](_page_26_Picture_2.jpeg)

![](_page_26_Figure_3.jpeg)

![](_page_26_Figure_4.jpeg)

12.2 GHz

12.4 GHz

— Aluminum Sheet — Waveguide Curved AISA

![](_page_27_Picture_0.jpeg)

![](_page_27_Picture_1.jpeg)

## **CURRENT AIS EFFORT**

# HRI Circularly MARA Polarized AIS Design

![](_page_28_Picture_1.jpeg)

![](_page_29_Figure_0.jpeg)

#### Conformal Applique

![](_page_30_Picture_1.jpeg)

Forming high dielectric material.

 Existing substrates teflon impregnated
 Vacuum-formable?

 Three dimensional transformation from

 Three dimensional transformation from flat panel to applique.

### Lower Dielectric Materials

- Low dielectric materials cheaper, but require thicker material.
- Dielectric material thickness ratio changes by square-root of initial dielectric / final dielectric ratio.
- Thermo-plastic material in this range.
  - Vacuum-forming process forms applique

![](_page_32_Picture_0.jpeg)

![](_page_32_Picture_1.jpeg)

![](_page_33_Picture_0.jpeg)

Proposed Future Development

![](_page_33_Picture_2.jpeg)

- Investigate other frequency bands (Cellular, ISM, FRS)
- Integrate AIS onto other platforms
- Explore other commercial applications for technology
- Develop baseline AIS synthesis tools
- Environmentally qualify the AIS

![](_page_34_Picture_0.jpeg)

### Conclusions

![](_page_34_Picture_2.jpeg)

- AIS is a cheap and versatile technology that minimizes RF obstructions
- Further research needed to expand bandwidth, theoretically predict indices, and optimize design techniques
- Lower dielectric material not explored

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