The Role of Electrical Engineers in Ship Design

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Key to the 21st Century is innovative, cross-discipline engineering!

EM Integrated Topside Design is a long term technology challenge of critical importance.

Performance Analysis
General System Link Equation (dB)

$$(G_{te} + P_{te}) + \left(G_{re} - T_{rsys} - T_{ext}\right) - k - L_{prop} \geq \left(\frac{S}{N_o}\right)_{required}$$

S/N_o – signal power to noise density

G_{te} – effective transmit antenna gain

P_{te} – effective transmit power radiated

T_{ext} – external noise (1/°K)

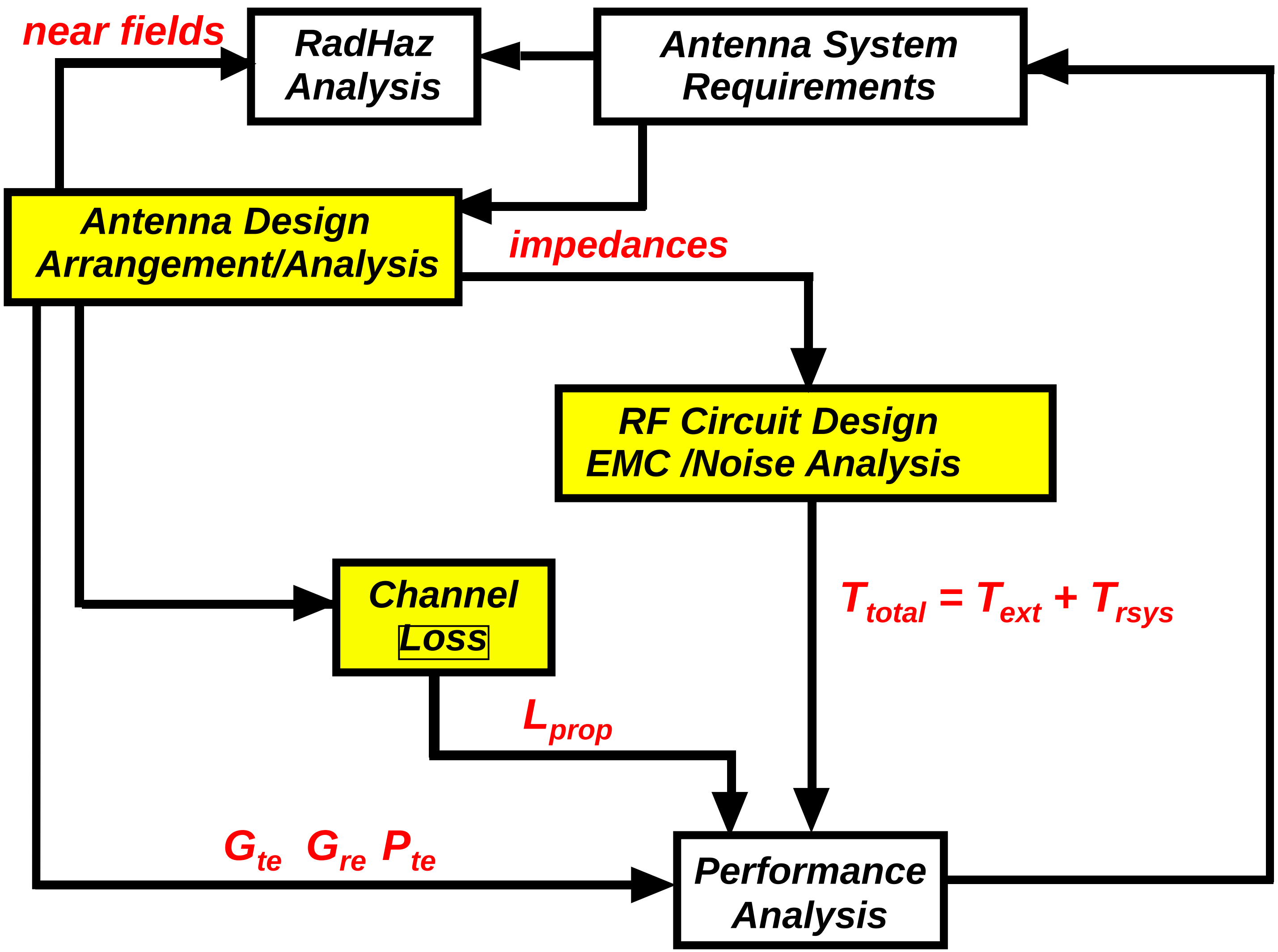
G_{re} – effective receive antenna gain

T_{rsys} – receiver performance (1/°K)

k – Boltzmann's constant ($1.381\ e^{-23}$)

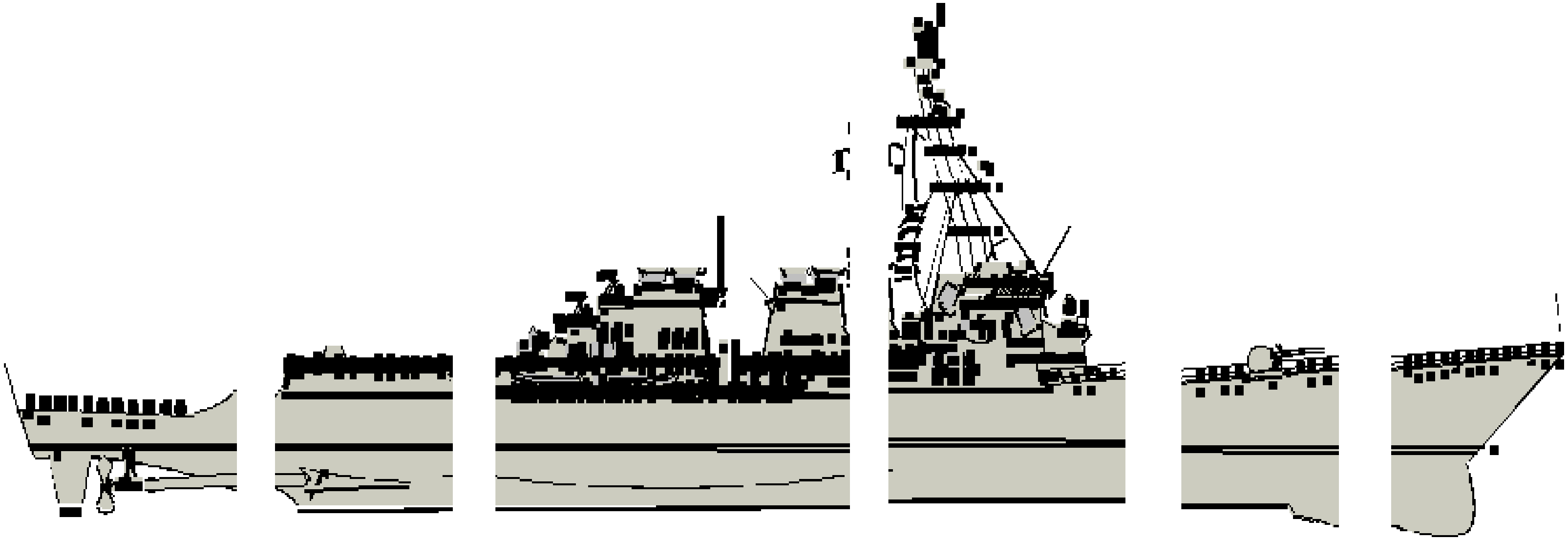
L_{prop} – total channel loss

EM Topside Integration Process
Iterative Analysis

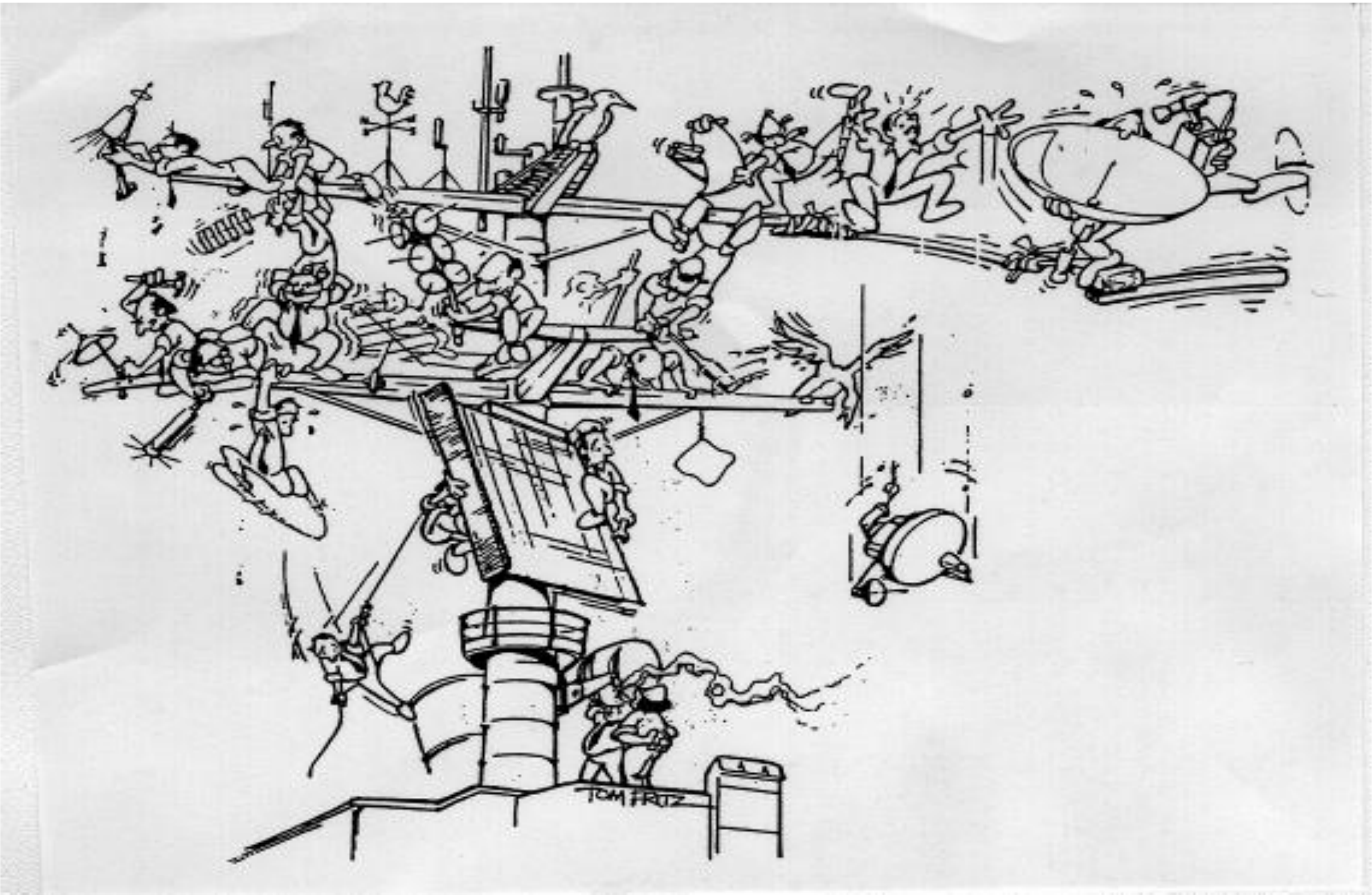


Antenna Design, Arrangement/Analysis

Although a ship may be large, only limited areas are available for antennas.

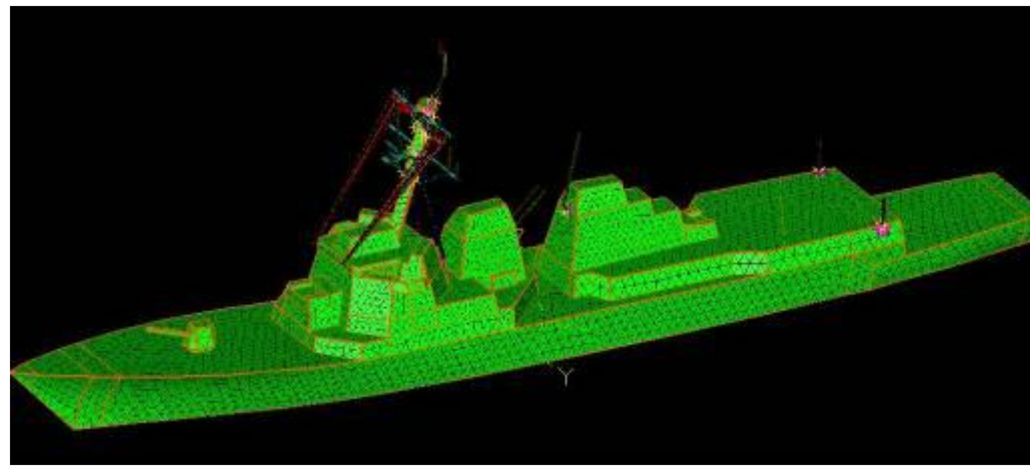


Antenna locations on mast are very contentious!



Antenna Analysis
EM modeling is wavelength dependent!

Physical Modeling | **Computational Modeling**



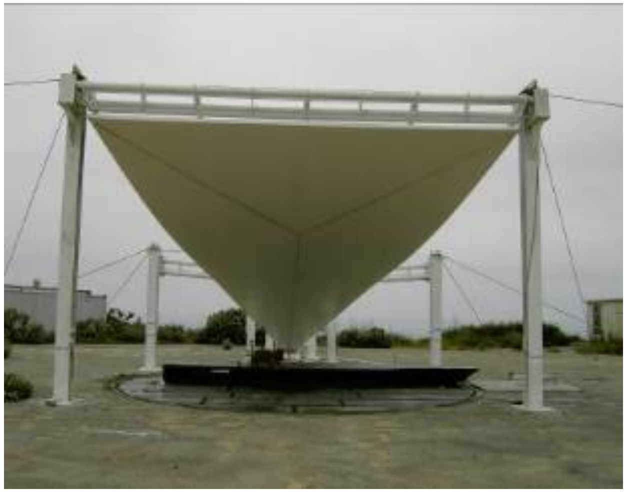
frequency *3* *30* *300* *3000* ***MHz***

resonant region ***transient region*** ***ray optic region***

Physical Modeling

1/48th Scale Brass Models
impedance
coupling

Scale Model Pattern Range
360º Azimuth, 3º - 90º elevation cuts
1 - 30 MHz amplitude and phase



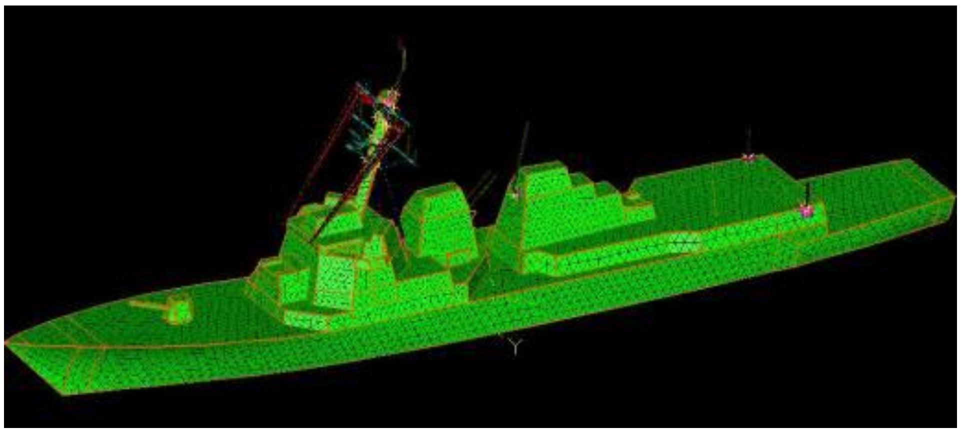
Scale Model Time Domain Range
Bounded Wave Simulator

- HF RCS (Ship Resonances)
- Lightning Protection
- EMP Protection

Computational Modeling

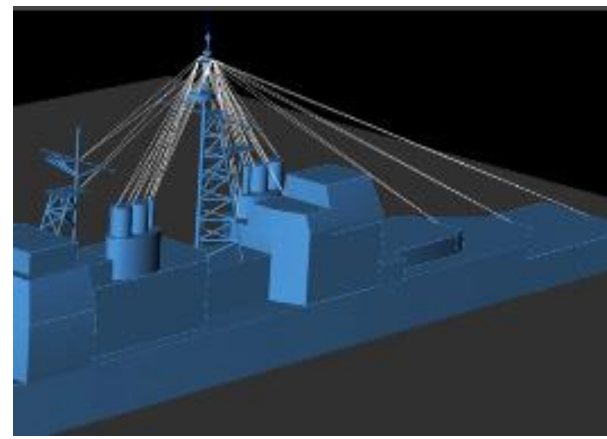
resonant region

NEC-MoM, EIGER



ray optic region

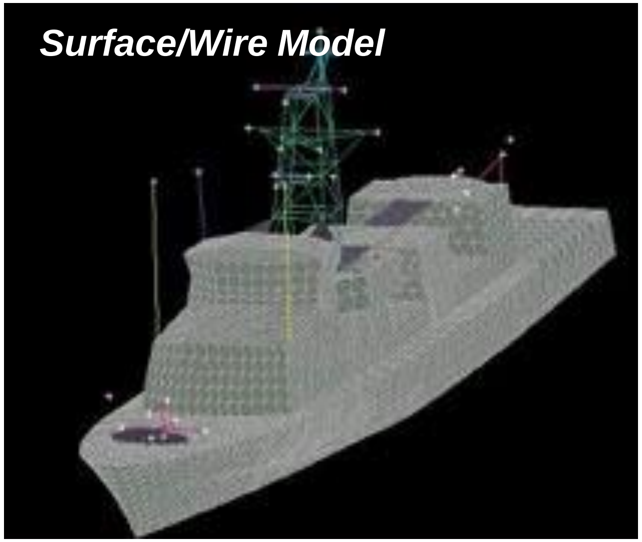
NEC-BSC

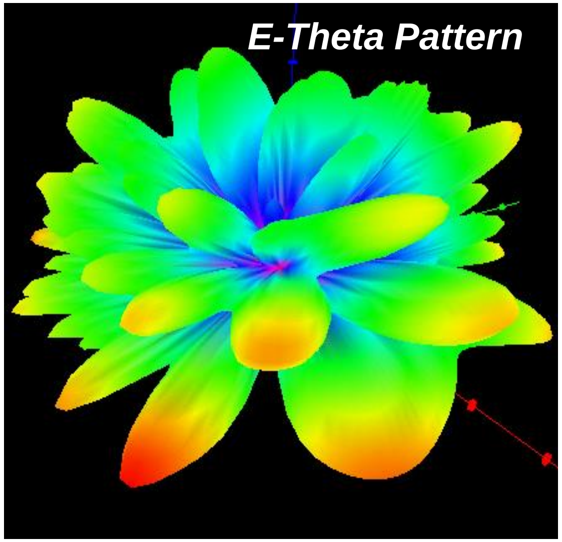


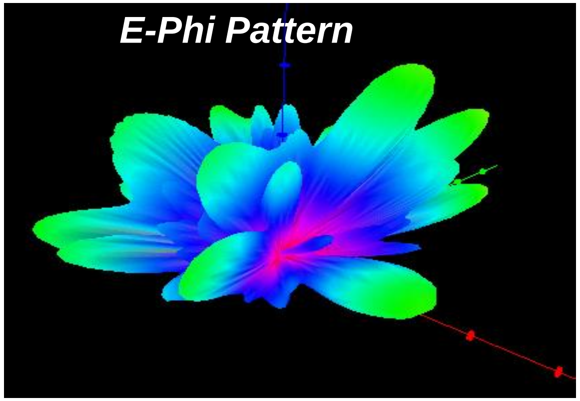
LLNL

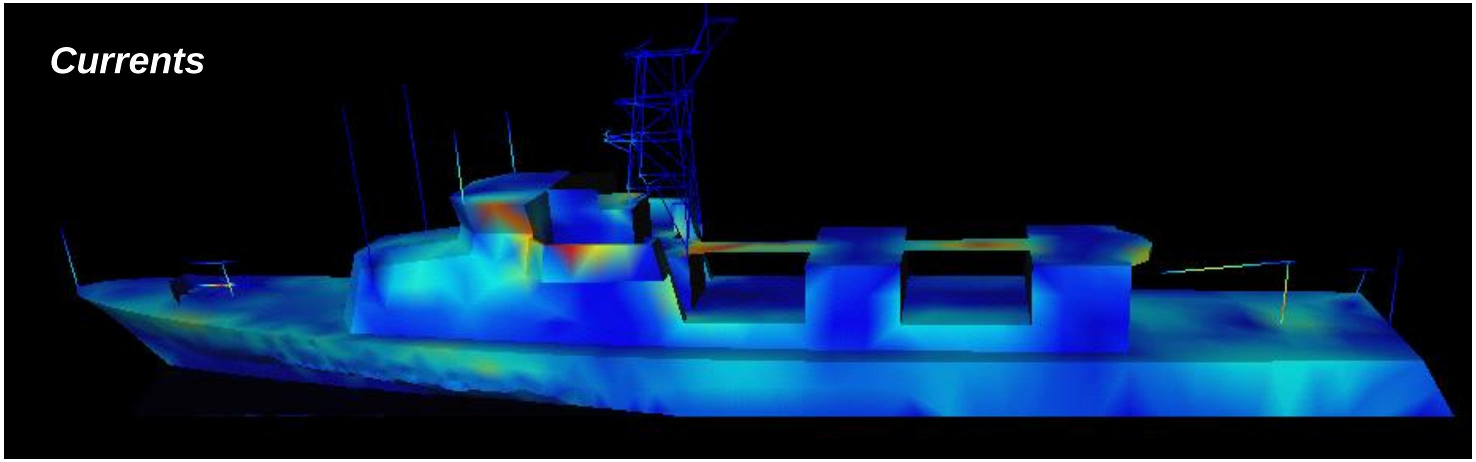
Sandia

Cyclone Class Patrol Craft, PC-1
EIGER Modeling - VHF Antennas



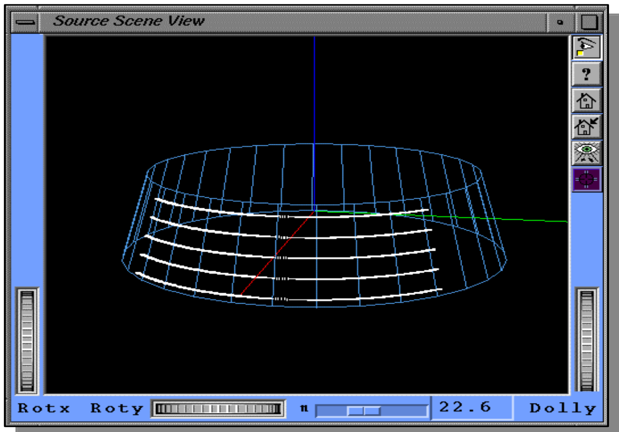


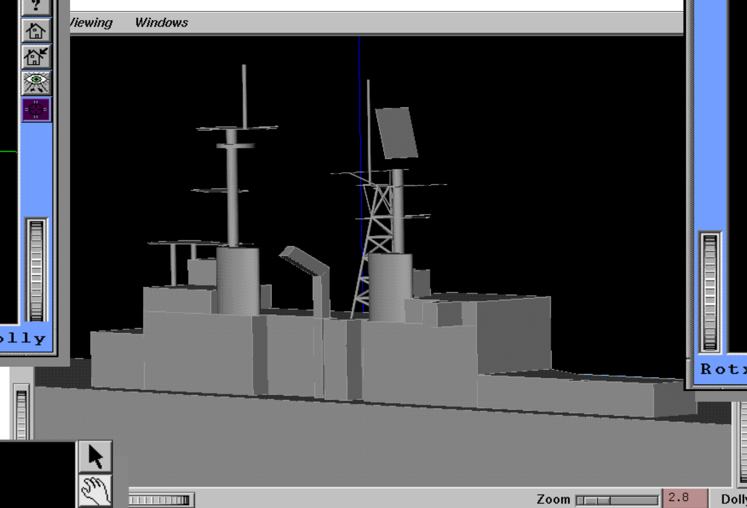




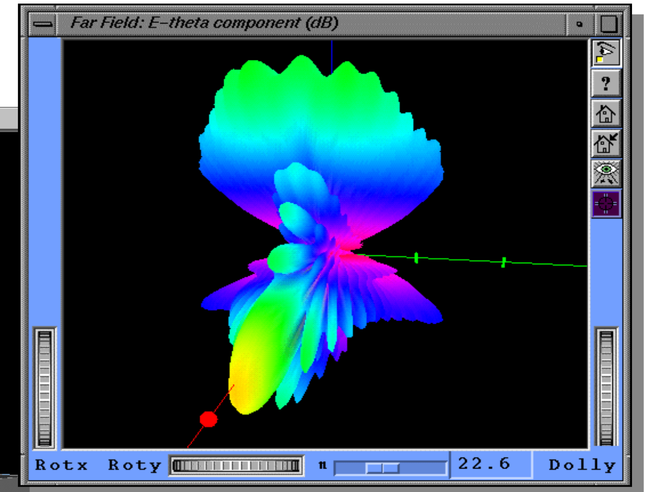
NEC - Basic Scattering Code
Active Phase Array Antenna

Antenna Model

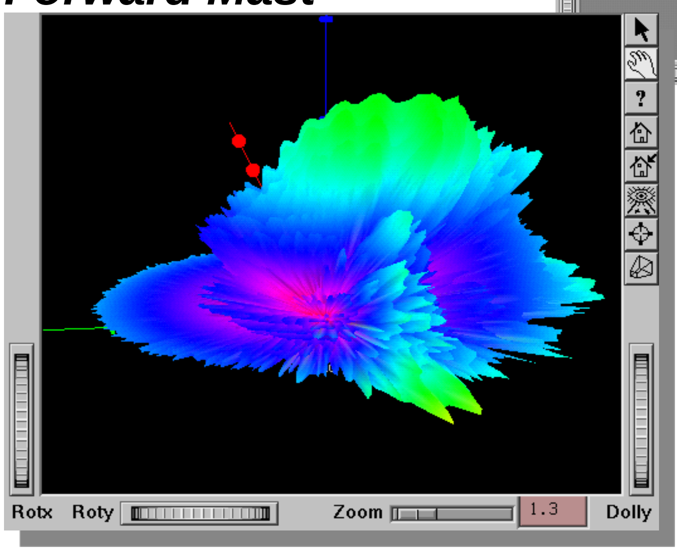




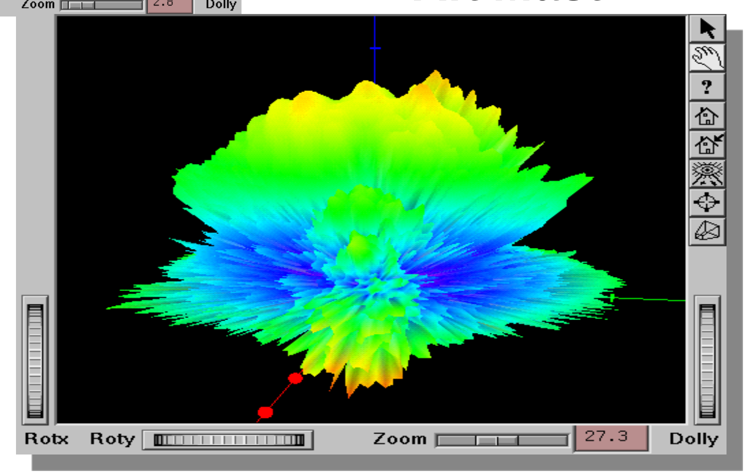
Free Space Pattern



Forward Mast



Aft Mast



L_{prop} – Channel Loss

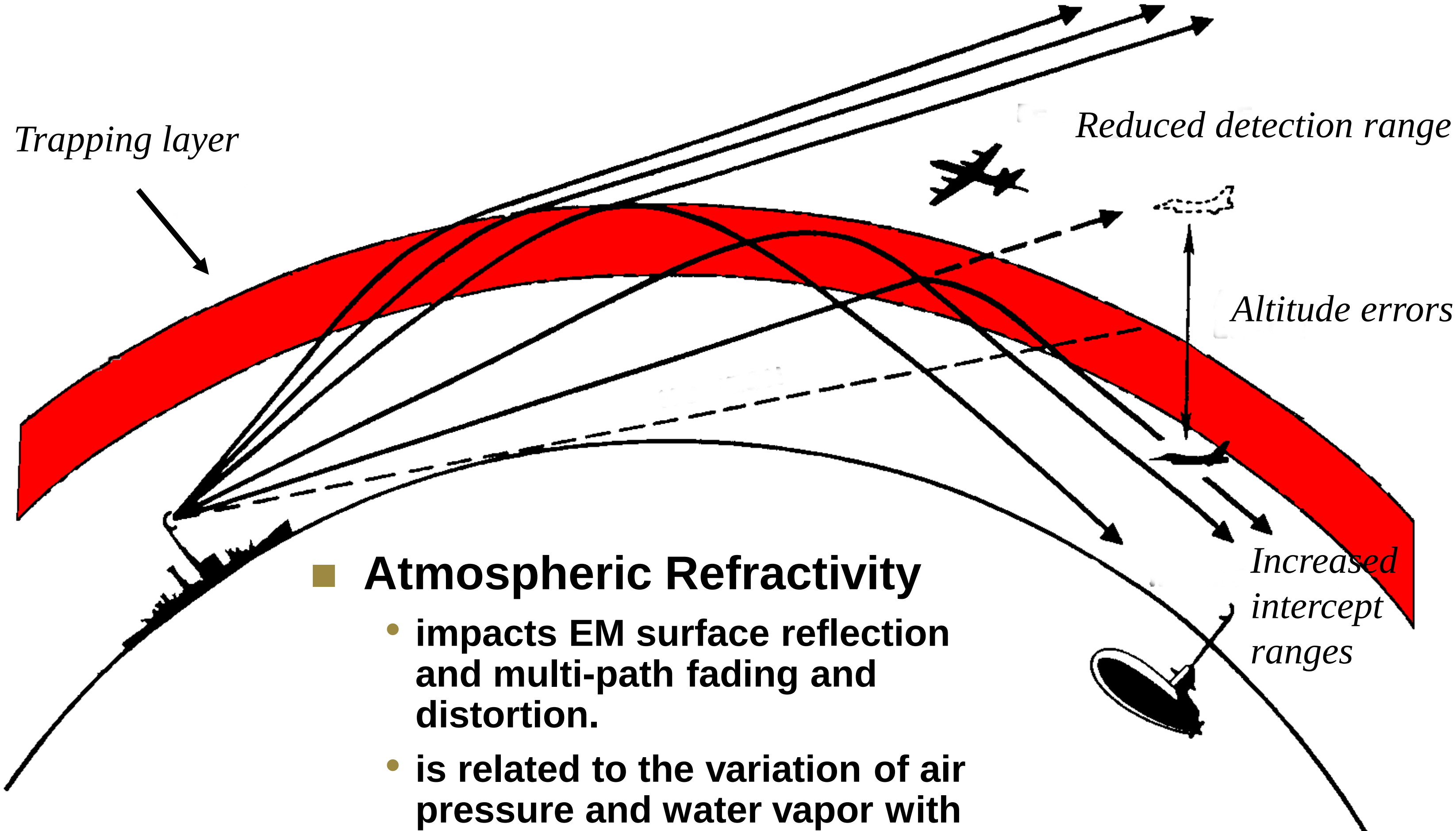
$$L_{prop} = L_{fs} \, L_{abs} \, L_r \, L_{pf}$$

- L_{fs} – free space

$$L_{fs} = \frac{1}{(4\pi r f / c)^2}$$

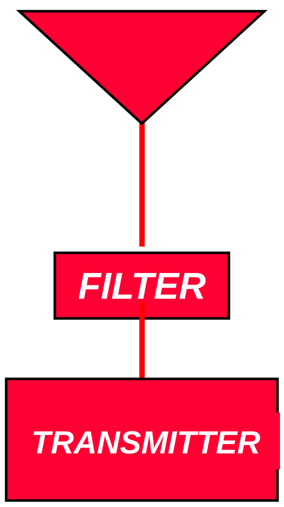
  - *r* – propagation path (meters)
  - *f* – frequency (Hz)
  - *c* – speed of light (meters/sec)
- L_{abs} – absorption
- L_r – rain
- L_{pf} – propagation factor
  - surface reflection, atmospheric refraction, scattering from atmospheric inhomogeneities and earth surface diffraction

Marine Environment Ducting

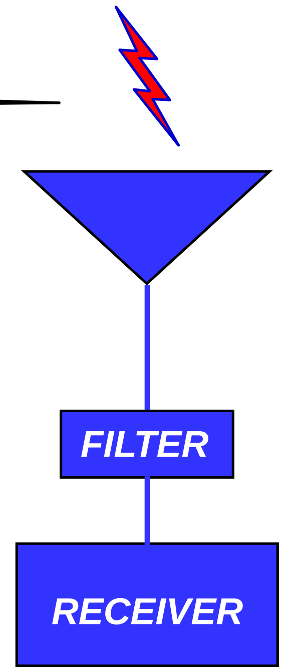


- **Atmospheric Refractivity**
  - **impacts EM surface reflection and multi-path fading and distortion.**
  - **is related to the variation of air pressure and water vapor with altitude.**

In the topside there "will be" insufficient isolation between Tx and Rx systems.



Interference	Mitigation
<u>Transmitter</u>	
broadband noise	filters
spurious emissions	linear amplification
intermodulation	
<u>Receiver</u>	
adjacent signal	filters
spurious response	linear amplification
intermodulation	
<u>Topside Nonlinearities</u>	
intermodulation	locate, mitigate



COSAM - Cosite Analysis Model

- **Interference interaction between Tx and Rx pairs is analyzed.**
- **The equivalent input on-tune interference power (P_{ino}) is calculated.**
  - **Non-linear circuit analysis is the basis for many COSAM formulas.**
- **Emphasis is primarily on Broadband Tx Noise & Rx Adjacent Signal.**
- **Determines additional antenna isolation required to make interference less than the ambient noise plus Rx system noise, $T_{interrference} < T_{ambient} + T_{RxNF}$.**
- **Equipment database supplies all necessary electrical characteristics.**
  - **The RF equipment data base is critical to the value of COSAM. This is also a challenging aspect of using COSAM.**

SPAWAR Systems Center PACIFIC

Topside Intermodulation (IM) Locate, Mitigate

- **Method**
  - **A two-frequency test procedure that use elementary direction finding techniques.**
  - **Concentration on IM signals of the highest, lowest order.**
  - **Location followed by mitigation.**
- **Lowest order (Q) for a detected IM**
  - **Minimize an L1 norm under a linear Diophantine equation constraint.**

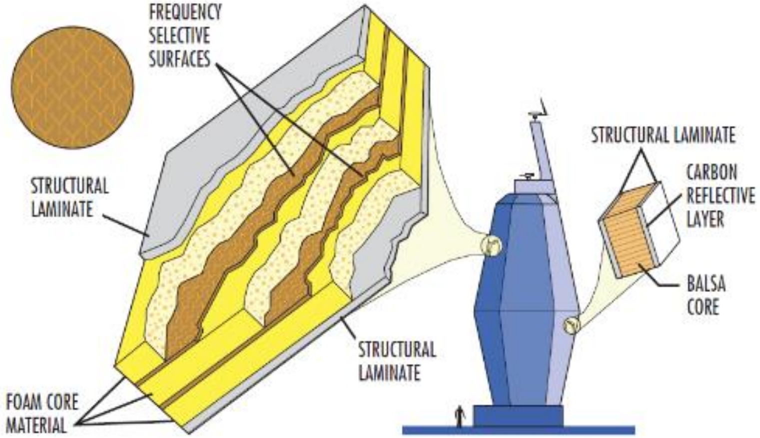
$N_1 F_{T1} + N_2 F_{T2} = F_{IM}$ **(Diophantine equation)**

$Q = |N_1| + |N_2|$ **(L1 norm)**

F_T **– transmit frequencies**
N – integers
Q – intermodulation order

- **Possible basis for IM limited frequency plans?**

Cross Discipline Collaboration
Advanced Enclosed Mast/Sensor (AEM/S) System



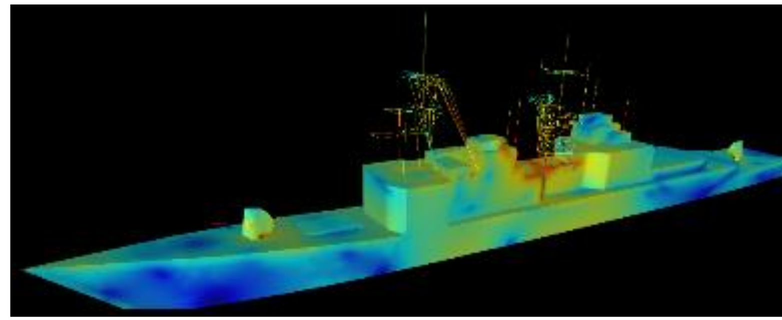
AEM/S Advantages

- **Affordable signature control of legacy antenna systems.**
- **Flat surfaces for mounting “future” phased array antenna.**
- **Less blockage than conventional metallic masts.**
- **Reduced maintenance (antennas are not exposed to the elements).**
- **Less topside weight.**
- **Less wind loading**
- **Other advantages . . .**

Transition to Acquisition Program
LPD-17 Amphibious Dock Landing Ship

EM Topside Integration Design

Modeling



Simulation

TX / RX	ANT P1 Shakespeare 390 2-30 MHz RF-382A-02 RF-5004-PA-100 RF-5045 RF-5020R/T		ANT P1 Shakespeare 390 2-30 MHz RF-382A-02 RF-5004-PA-100 RF-5045 RF-5020R/T		ANT P1 Shakespeare 390 2-30 MHz RF-382A-02 RF-5004-PA-100 RF-5045 RF-5020R/T		ANT P1 Shakespeare 390 2-30 MHz RF-382A-02 RF-5004-PA-[illegible] RF-5045 RF-5020R/T		Transmitter Frequency Separation from Receiver Tuned Frequency
ANT S1	RAS (dB)	TAS (dB)	RAS (dB)	TAS (dB)	RAS (dB)	TAS (dB)	RAS (dB)	TAS (dB)	
Shakespeare 390	55	33	52	30	49	27	46	24	2.50%
2-30 MHz	52	13	48	10	45	7	43	4	5.00%
	50	7	47	4	44	1	41	0	10.00%
RF-382A-02	50	6	47	3	44	0	41	0	15.00%
	50	7	47	4	44	1	41	0	20.00%
	50	8	47	6	44	2	41	0	25.00%
RF-5020R/T	Not Compatible		Not Compatible		Not Compatible		Not Compatible		
ANT S1	RAS (dB)	TAS (dB)	RAS (dB)	TAS (dB)	RAS (dB)	TAS (dB)	RAS (dB)	TAS (dB)	
Shakespeare 390	41	33	38	30	35	27	[illegible]	24	2.50%
2-30 MHz	23	13	20	10	17	7	14	4	5.00%
	0	7	0	4	0	1	0	0	10.00%
RF-382A-02	0	6	0	3	0	0	0	0	15.00%
	0	7	0	4	0	1	0	0	20.00%
RF-5045	0	8	0	5	0	2	0	0	25.00%
RF-5020R/T		10.00%		10.00%		5.00%		7.50%	
ANT S1	RAS (dB)	TAS (dB)	RAS (dB)	TAS (dB)	RAS (dB)	TAS (dB)	RAS (dB)	TAS (dB)	
Shakespeare 390	[illegible]	30	[illegible]	27	19	24	16	21	2.50%
2-30 MHz	0	10	0	7	0	4	0	1	5.00%
	0	5	0	2	0	3	0	0	10.00%
RF-382A-02	0	4	0	1	0	0	0	0	15.00%
RF-5045	0	4	0	1	0	0	0	0	20.00%
RF-5045	0	5	0	2	0	0	0	0	25.00%
RF-5020R/T		5.00%		5.00%		5.00%		5.00%	

Qualified RF Engineers