

Headquarters U.S. Air Force

Integrity - Service - Excellence

Integrating Performance & Schedule Analysis with Acquisition Costing for Ground-Based Radars February 18, 2010



**Mr. John Horak
Mr. Jim Harbour
Mr. Chris Holcomb**

U.S. AIR FORCE

**Technomics, Inc.
|P| 805.964.9894 ext. 1016**



Project Description

U.S. AIR FORCE

- Purpose of the Project was to develop capability to support Space Fence cost estimating for the Air Force Cost Analysis Agency (AFCAA)
- Project involved the development of a Radar Database and Radar Cost, Schedule, and Performance Models
 - Technomics, Inc. developed the Radar Database, Radar Cost and Schedule Models, and Integrated Tool
 - Georgia Tech Research Institute (GTRI) developed general and unique Radar Performance Models
- The Performance, Cost, and Schedule Models were integrated to support cost estimates at Milestone A, B, and C
- Period of Performance for this task was 12 months (FY09)



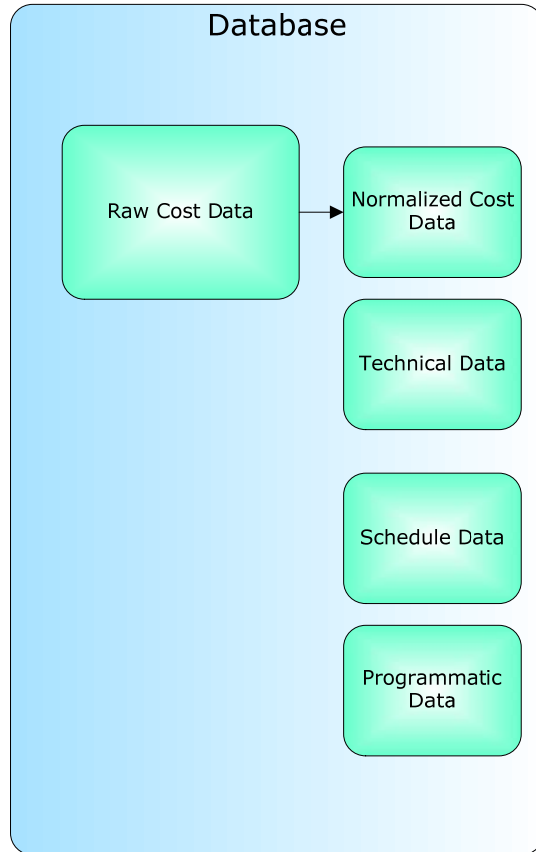
U.S. AIR FORCE

Integrity - Service - Excellence



Database

U.S. AIR FORCE



- **A database was developed for Ground Based Radars**
- **Contains data on Active Phased Arrays, End-Fed Arrays, and Frequency Scanned and Gimbaled Arrays**
- **Four main types of data in the database**
 - **Cost**
 - **Technical**
 - **Program**
 - **Schedule**



Radar Technology Types

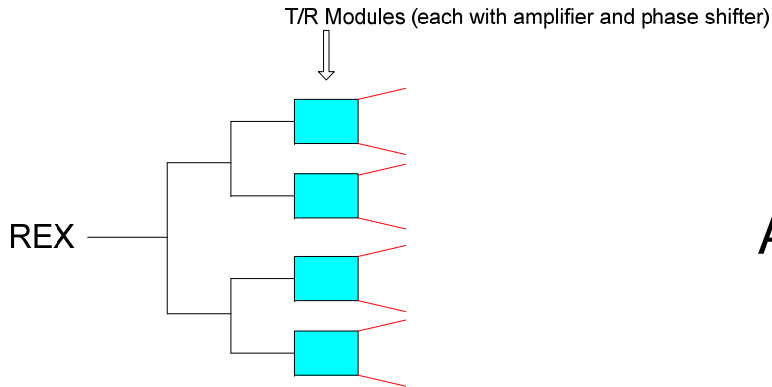
U.S. AIR FORCE

- **Active Phased Array - TR Modules**
 - **RF Power Amplifier and Phase Shifter at every element**
 - **Time delay units may be needed for large, wide-bandwidth arrays**
- **Active Phased Array – Subapertures**
 - **Fewer, More Powerful RF Power Amplifiers driving multiple elements**
 - **Phase shifters at every element**
- **Active Phased Array – Subapertures**
 - **Fewer, More Powerful RF Power Amplifier driving multiple elements**
 - **Could be frequency scanned in one plane – end fed waveguide**
 - **Phase shifters to scan other plane – fewer – only for each row (or column)**
- **Passive Phased Array**
 - **Space fed array with passive phase shifters – not feasible for SF application**
- **Gimbaled – not feasible for this SF application**
 - **Corporate Fed Planar Array**
 - **Reflector**

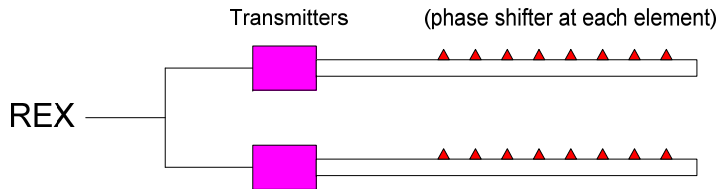


Radar Technology Types in the Database

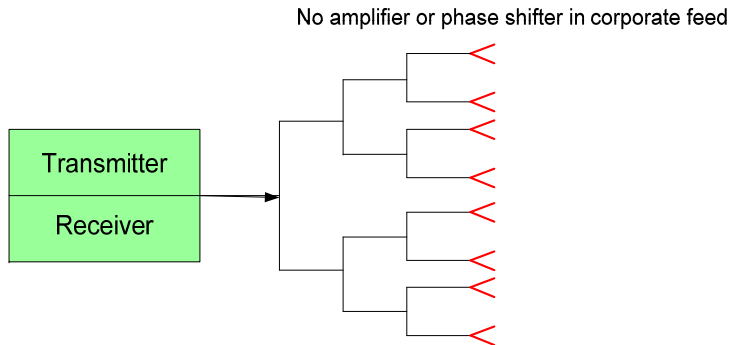
U.S. AIR FORCE



Active Phased Array



End-Fed Arrays



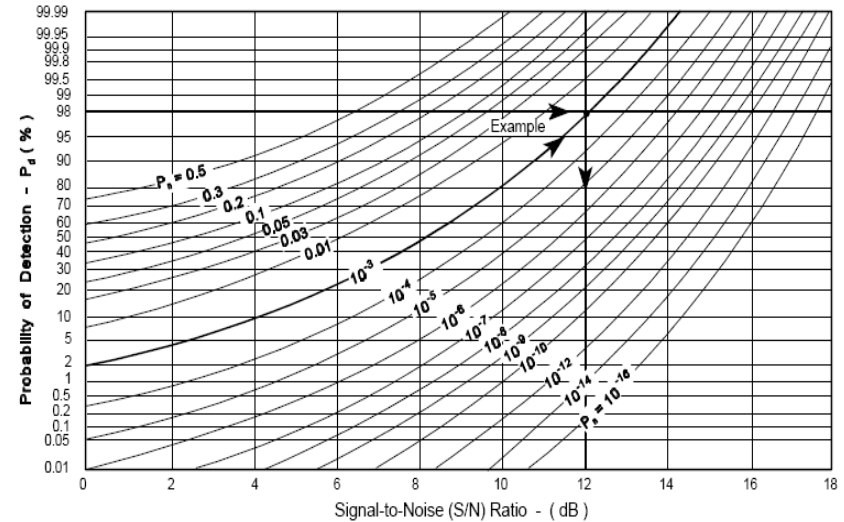
Frequency Scanned and Gimbaled



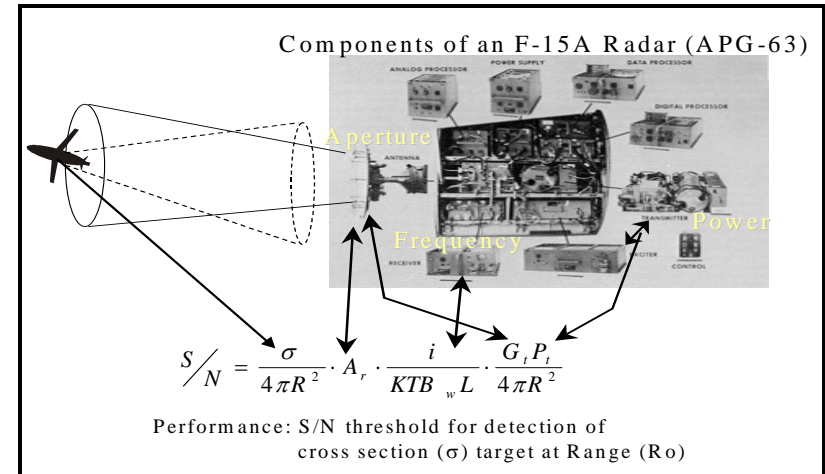
Radar Performance Model

U.S. AIR FORCE

- Radar Performance is determined by power and aperture which drives cost and schedule
- Requirements: P_d , P_{fa} , & Range (R)
- $S/N = f(P_d, P_{fa})$ (see 3 dimensional chart)
- Power x Aperture = $R^4 (4\pi)^2 kTN_f L (S/N) / \sigma T_G$
- Cost = $f(\text{Aperture, Power, Frequency})$
- Schedule Duration = $f(\text{Power, Radar Type})$
- Schedule Expenditures = $f(\text{Aperture, Frequency, Radar Type})$
- Performance Model POC: Sam.Piper@gtri.gatech.edu



0	Description	Value	Units	Value	(dB)
P_t	= Average Transmit Power	= 1,000 kW	=	90.0 dBm	
G_t	= Transmit Antenna Gain	= 4,042,748	=	66.1 dBi	
G_r	= Receive Antenna Gain	= 4,042,748	=	66.1 dBi	
λ^2	= Wavelength ²	= (0.090 m) ²	=	-21.0 dBsm	
σ	= RCS	= 0.00001 m ²	=	-50.0 dBsm	
$(4\pi)^3$	= 1984	= 1,984	=	33.0 dB	
R^4	= (Slant Range) ⁴	= (4,389 km) ⁴	=	265.7 dBm ⁴	
k	= Boltzmann's constant	= 1.38E-20 mW/(Hz K)	=	-198.6 dBm/(Hz K)	
T_0	= Reference Temperature	= 290 K	=	24.6 dBK	
B	= Bandwidth	= 1.0 Hz	=	0.0 dBHz	
F	= Noise Figure	= 2.0	=	3.0 dB	
L	= Losses	= 6.30	=	8.0 dB	
S/NR	= Signal-to-Noise Ratio	= 35	=	15.5 dB	





Radar Cost Model

U.S. AIR FORCE

WBS	Milestone A	Milestone B/C
TOTAL		
<u>RADAR</u>	X	
<u>ANTENNA</u>		
<u>ARRAY</u>		X
T/R MODULES		X
POWER SUPPLIES		X
BEAM STEERING UNIT		X
OTHER ARRAY		X
PEDESTAL/GIMBAL		X
COOLING UNIT/PDU		X
RECEIVER/EXCITER GROUP		X
TRANSMITTER (ON or OFF ARRAY)		X
<u>BACK END GROUP</u>		
SIGNAL AND DATA PROCESSORS		X
CONTROLS & DISPLAYS		X
IAT&C		X
<u>RADAR TOTAL NRE</u>	X	
RADAR HARDWARE NRE		X
SOFTWARE DEVELOPMENT		X
<u>DEV/PROD SUPPORT</u>	X	
<u>SE/PM</u>		
SYSTEM ENGINEERING		X
PROGRAM MANAGEMENT		X
SYSTEM TEST AND EVALUATION		X
TRAINING		X
DATA		X
SUPPORT EQUIPMENT		X
OPERATIONAL/SITE ACTIVATION		X
INITIAL SPARES AND REPAIR PARTS		X

- **Cost Model estimates development and production costs of Active Phased Array, Active End-Fed Array , and Frequency and Gimbaled Scanned Array Radars based on performance, design and physical parameters of the radar and assemblies**
- **Consists of twenty-seven (27) CERs developed from database of Radar development, production, and T/R module programs**
- **Top-Level CERs used for estimating at Milestone A and Lower-Level CERs used at Milestone B/C**
- **The cost model inputs were linked to Radar performance model outputs to support cost versus performance trade studies**



Radar CER Examples

U.S. AIR FORCE

Radar Hdw CER: Cost = A (Power)^B (Aperture)^C (Frequency)^D (Pgm Type)

Statistics: $R^2 = 94.1\%$
 $s = 0.197, (+21.8\%, -17.9\%)$

T/R Module Hdw CER: Cost = A (Power)^B(Frequency)^C (Qty)

Statistics: $R^2 = 94.6\%$
 $s = 0.201, (+22.3\%, -18.2\%)$

Radar NRE CER: Cost = A (Radar Hdw\$) (Pgm Type)

Statistics: $R^2 = 92.1\%$
 $s = 0.330, (+39.1\%, -28.1\%)$

Radar Support CER: Cost = A (Total PMP \$) (Pgm Type)

Statistics: $R^2 = 97.0\%$
 $s = 0.281, (+32.4\%, -24.5\%)$



Radar Schedule Model

U.S. AIR FORCE

- **Model estimates development and production schedule characteristics of various Radar technology types based on performance and design parameters of the Radar**
 - **Radar Schedule Length (Duration) based on complexity parameters (e.g. RF Power Out)**
 - **Radar Average Expenditures (per Month) based on sizing variables (e.g. Antenna Aperture)**
 - **Radar Major Milestones for the development phase**

- **The schedule model inputs were linked to Radar performance model outputs to support schedule versus performance trade studies**



Radar Schedule Estimating Relationships (SERs)

U.S. AIR FORCE

Schedule Length (Months) = A (Power)^B (Pgm Type) Qty

Statistics: R² = 97.3%
 s = 0.120, (+12.7%, -11.3%)

Avg Expenditure Per Month = A (Aperture)^B (Frequency)^C (Pgm Type) Qty

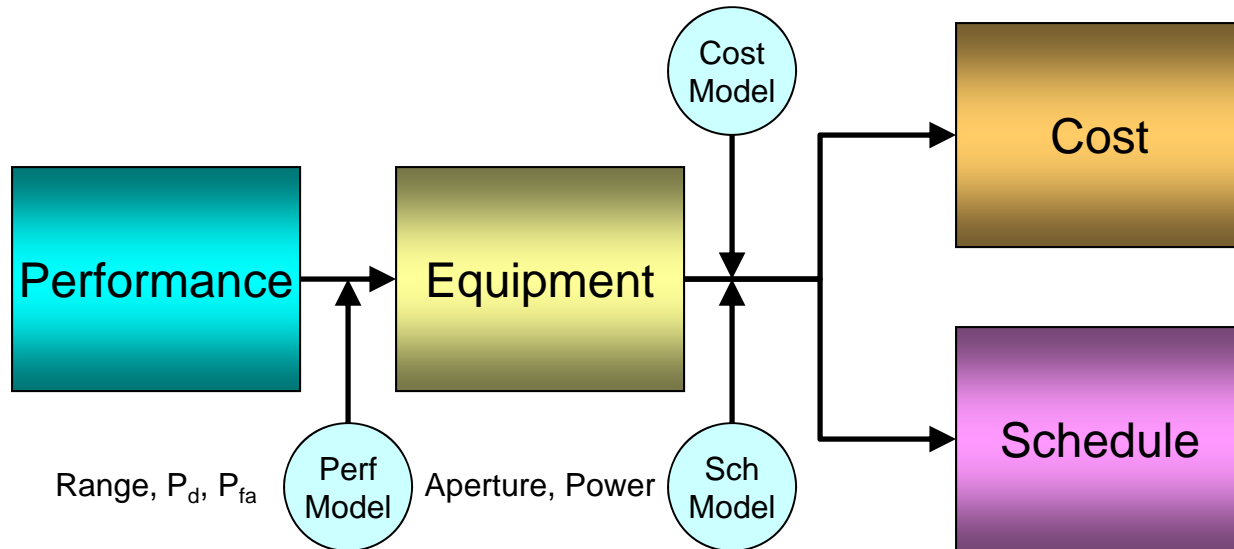
Statistics: R² = 96.2%,
 s = 0.266, (+30.5%, -23.4%)

Program Milestones	Incremental Duration	Cum Duration
Start	0.0%	0.0%
SDR	8.9%	8.9%
PDR	XX%	XX%
CDR	XX%	XX%
Start Sensor I&T	19.5%	44.4%
Deliver to Test Site	XX%	XX%
Start Site I&T	XX%	XX%
Complete	32.4%	100.0%



Milestone A Cost Estimating Process

U.S. AIR FORCE



- **Step 1**: Determine Power and Aperture that meets Requirements (Range, Radar cross-section, Probability of Detection, Probability of False Alarm, etc.)
- **Step 2**: Estimate cost for each Radar Technology Type (Active Phased Arrays, End-Fed Arrays, Frequency Scanned Arrays)
- **Step 3**: Estimate Schedule (Duration, Expenditure level, Major Milestones) for each Radar Technology Type



Milestone A Cost Estimating Example (Hypothetical Designs)

U.S. AIR FORCE

Requirements	Value	Power x Aperture Output
Range	2500 km	301,000 kW*m ²
Cross-Section	0.015 m ²	
P _D	0.90	
P _{FA}	10 ⁻⁶	

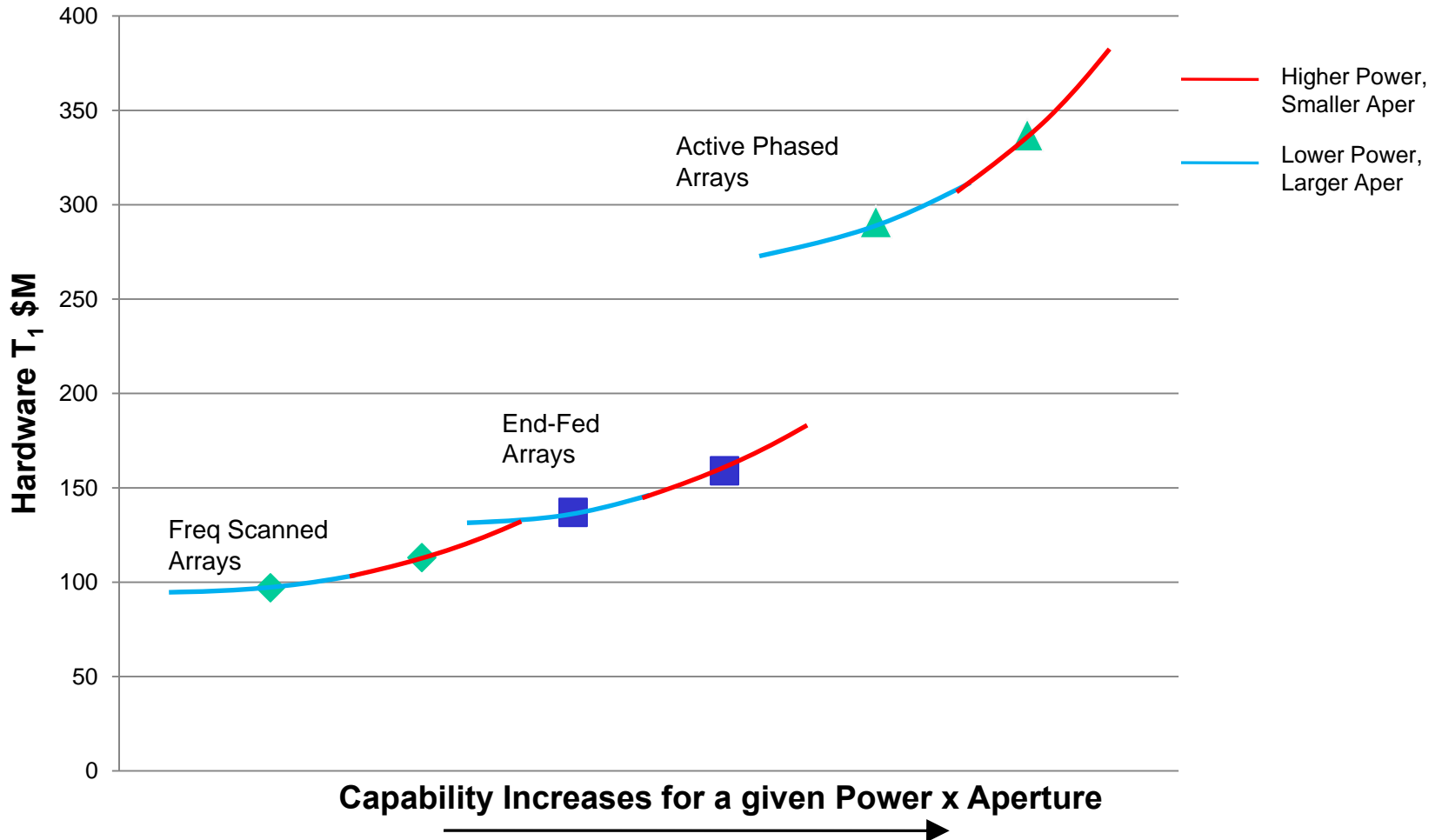
	Active Phased Array		End-Fed Array		Frequency-Scanned Array	
	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6
Performance Outputs/ Model Drivers:						
Power (kW)	500	250	500	250	500	250
Aperture (m ²)	602	1204	602	1204	602	1204
Frequency	S-Band	S-Band	S-Band	S-Band	S-Band	S-Band
Cost Estimates:						
Hardware (T ₁)	\$336.8M	\$290.9M	\$158.5M	\$136.9M	\$113.0M	\$97.6M
Non-Recurring	\$446.9M	\$386.1M	\$210.3M	\$181.7M	\$150.0M	\$129.6M
Support	\$302.5M	\$261.4M	\$142.3M	\$123.0M	\$101.5M	\$87.7M
Schedule Estimates:						
Schedule Length (Months)	104	96	104	96	59	55
Months to CDR	26	24	26	24	15	14
Months to Start Factory I&T	46	43	46	43	26	24
Months to Start Site I&T	70	65	70	65	40	37



Integrated Analysis Results

U.S. AIR FORCE

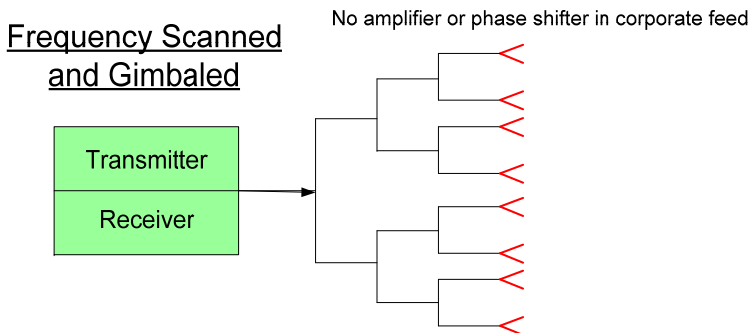
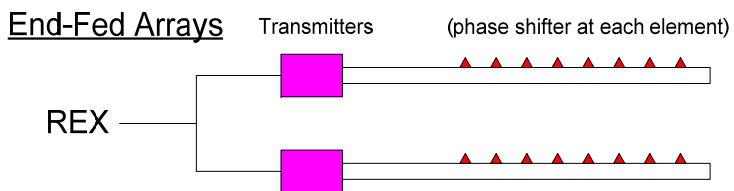
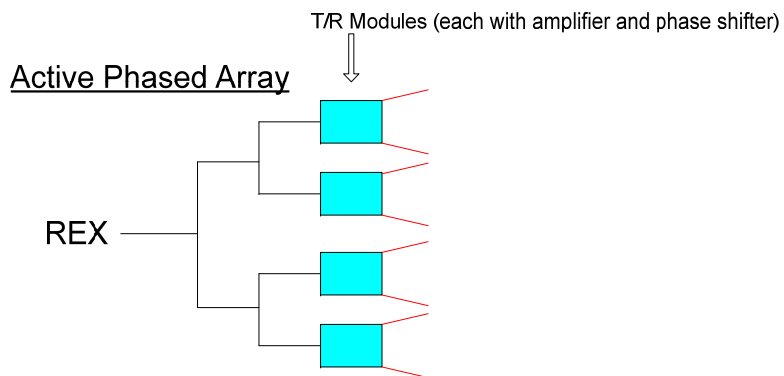
Cost vs. Capability Trade-off for Radar Technology Types





Radar Technology Comparison

U.S. AIR FORCE



Performance				Cost/Maturity	
Beam Agility	Target Tracking	Beam Degredation	Aperture Utilization	Cost	Maturity
Higher	Higher	Lower	Higher	Higher	Lower
Medium	Medium	Medium	Medium	Medium	Medium
Lower	Lower	Higher	Lower	Lower	Higher



Summary

U.S. AIR FORCE

■ Accomplishments to-date

- Initial Database and Performance, Cost and Schedule models have been developed to support radar cost estimating
- Integration of the models has been demonstrated in an Integrated Tool

■ Path Forward

- Expand the database and models with recent S-band technology developments
- Major Technology Focus (S-band):
 - T/R modules
 - Antenna Array Implementation
- Improve linkages between Performance, Cost and Schedule Models for added fidelity (i.e. add additional performance parameters to the cost and schedule models)
- Integrate costs into Schedule Database (i.e. add dollars spent per unit time into schedule database by function or labor type)
- Develop Expenditure Profile Model
- Add the new and improved methodologies to the Integrated Tool