Cost Equation for the SKA

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1. General form of spreadsheet

2. Performance and cost parameters

3. Results: Cost vs antenna diameter and other parameters

4. Front-end model

5. Signal processing model

SKA Cost Equation Spread Sheet

Rows are for input or computed parameters such as cost coefficients or performance parameters

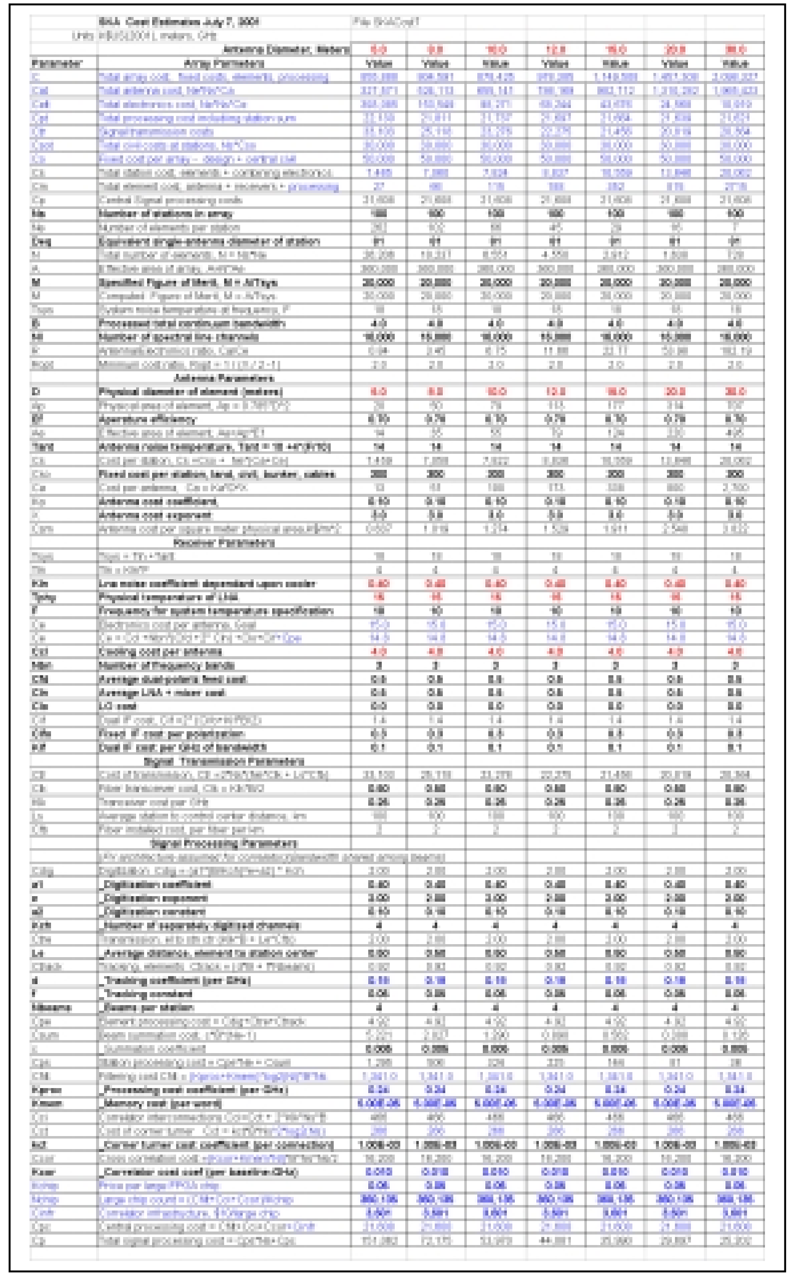
Columns are for varying antenna diameters

Sheets are for varying major parameters such as cryogenic temperature or era of electronics costs.

Output of the program is the total cost and cost of each subsystem. The Aeff/Tsys is constrained at 20,000 by computing the number of antennas needed for each station.

Parameters – There are 14 performance parameters and 19 cost parameters listed on the next page

Models – Details are in the equations in the spreadsheet. Antenna cost is 0.1*D^3 K$.



SKA Cost Equation Input Parameters

Units: K$US(2001), meters, GHz

Param	Array Performance Parameters	Default Value
Ns	Number of stations in array	100
M	Specified Figure of Merit, M = A/Tsys	20,000
B	Processed total continuum bandwidth	4.0
Nl	Number of spectral line channels	16,000
D	Physical diameter of element (meters)	10.0
Ef	Aperature efficiency	0.70
Tant	Antenna noise temperature, Tant = 10	14
Kln	Lna noise coefficient dependant upon	0.40
Tphy	Physical temperature of LNA	15
F	Frequency for system temperature sp	10
Nbn	Number of frequency bands	3
Kch	_Number of separately digitized chan	4
Le	_Average distance, element to station	0.50
Nbean	_Beams per station	4

Param	Array Cost Parameters	Default Value
Cso	Fixed cost per station, land, civil,	300
Ka	Antenna cost coefficient,	0.10
X	Antenna cost exponent	3.0
Ccl	Cooling cost per antenna	20.0
Cfd	Average dual-polariz feed cost	2.0
Cln	Average LNA + mixer cost	0.8
Clo	LO cost	3.0
Cifo	Fixed IF cost per polarization	1.0
Kif	Dual IF cost per GHz of bandwidt	0.2
a1	_Digitization coefficient	2.00
e	_Digitization exponent	2.00
a2	_Digitization constant	0.50
d	_Tracking coefficient (per GHz)	0.72
f	_Tracking constant	0.10
Kproc	_Processing cost coefficient (per	0.48
Kmem	_Memory cost (per word)	2.10E-04
kct	_Corner turner cost coefficient (p	1.00E-03
Kcor	_Correlator cost coef (per baselir	0.024
Kchip	Price per large FPGA chip	0.14

Color code:

Purple: correction of error since previous version.

Blue: change to value or formula since previous version.

Red: variable whose value changes across this sheet

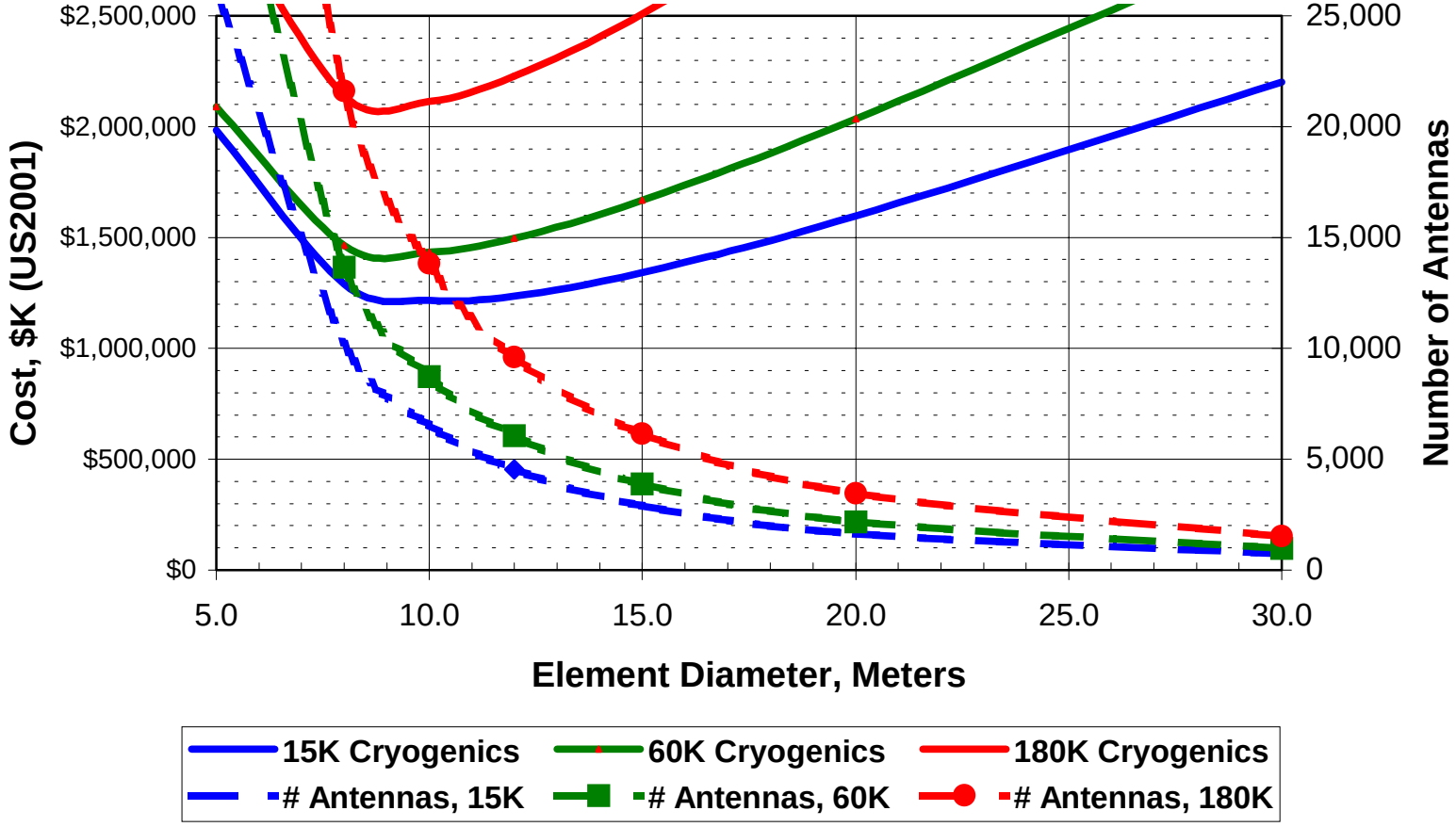
Green: variable whose value is different from previous sheet

Bold type: input parameter; normal type means value is calculated.

SKA Cost vs Antenna Diameter for 3 Cooling Temperatures

Aeff/Tsys = 20,000, Aeff=360,000, Tsys=18K, BW=4GHz,

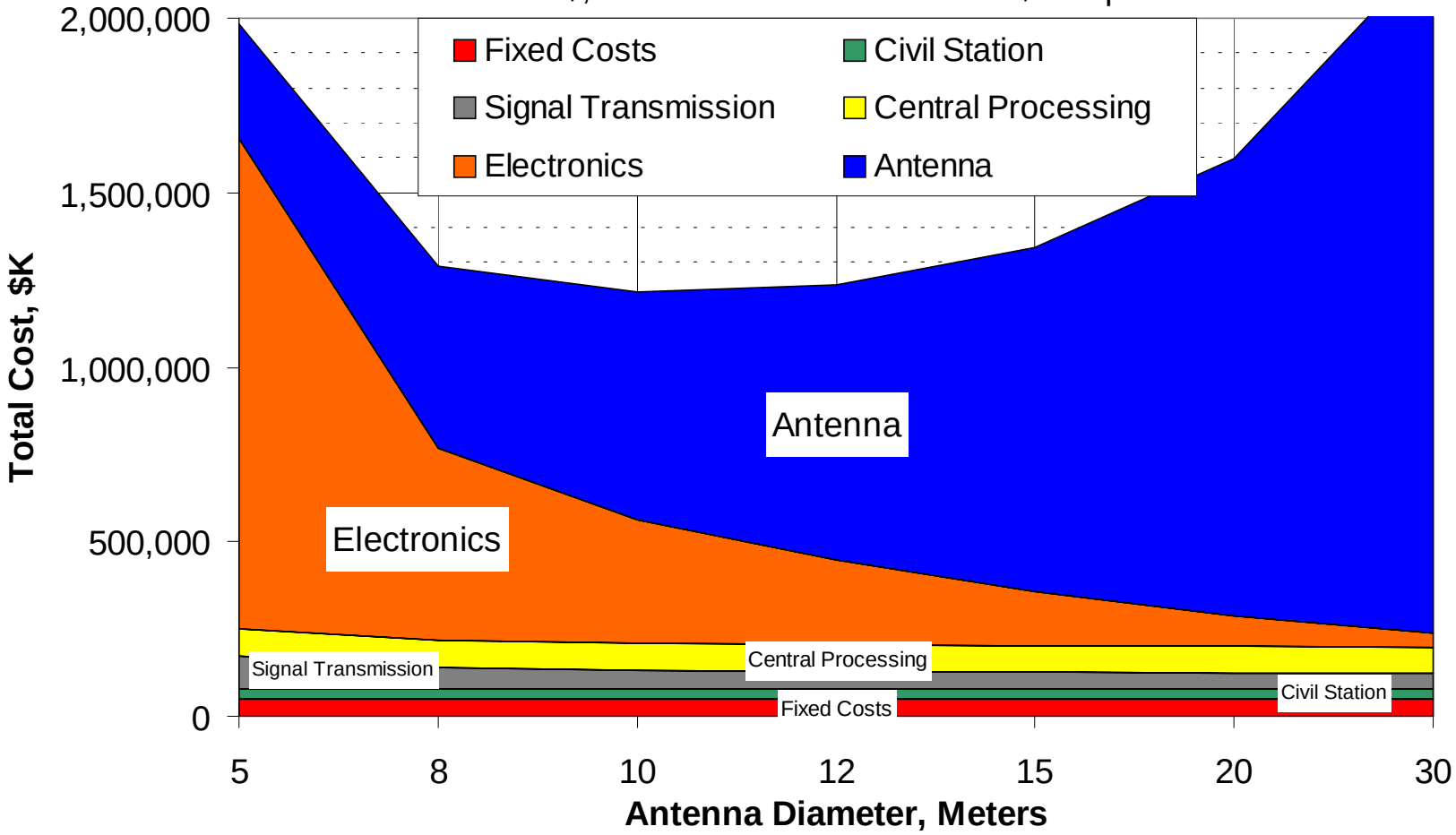
Antenna Cost = 0.1D^3 K$, 2001 Electronics Cost = $54K per Element



SKA Cost Breakdown by Subsystem vs Antenna Diameter

Aeff/Tsys = 20,000, Aeff=360,000, Tsys=18K, BW=4GHz, 15K Cryogenics

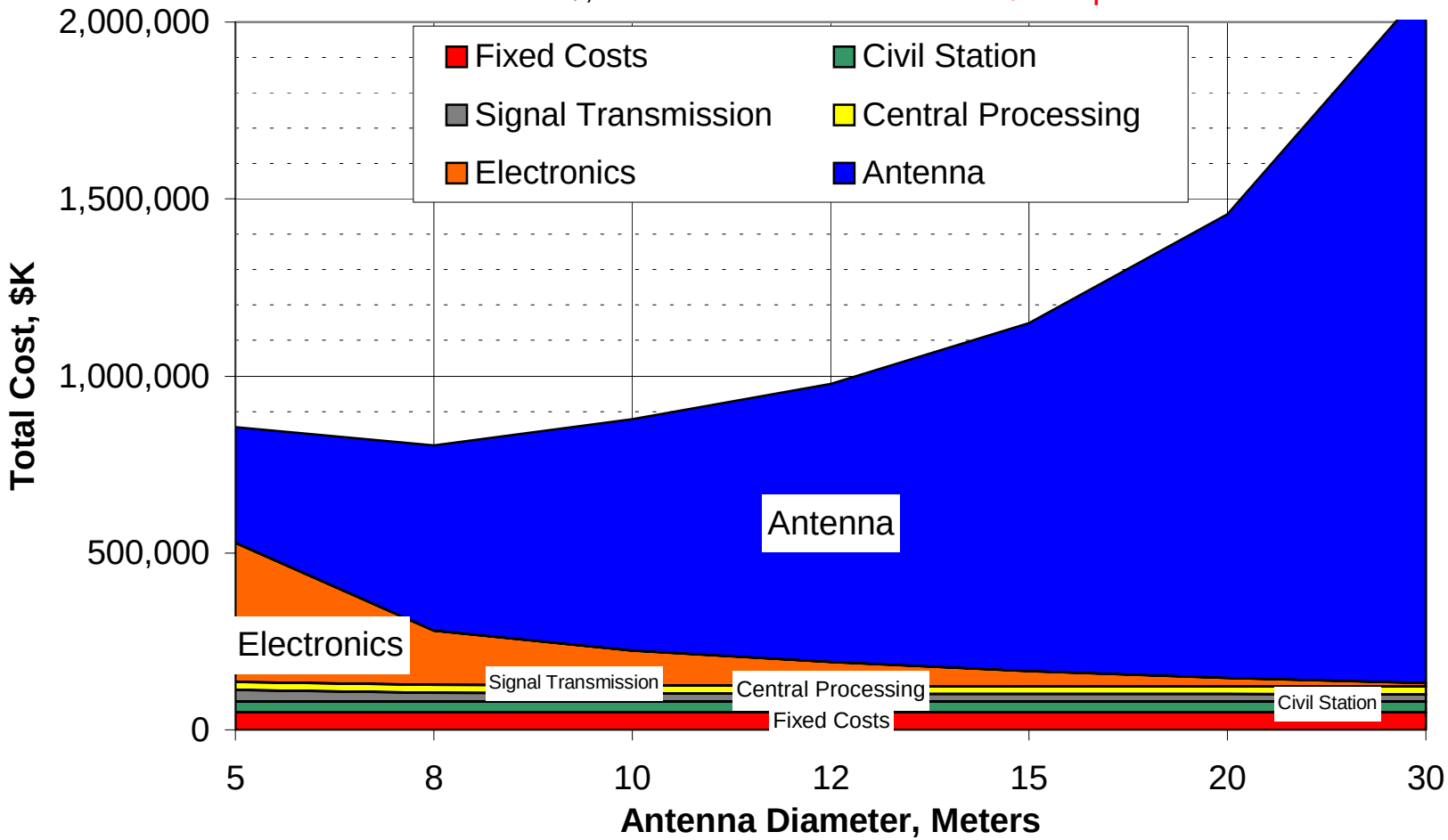
Antenna Cost = 0.1D^3 K$, 2001 Electronics Cost = $54K per Element



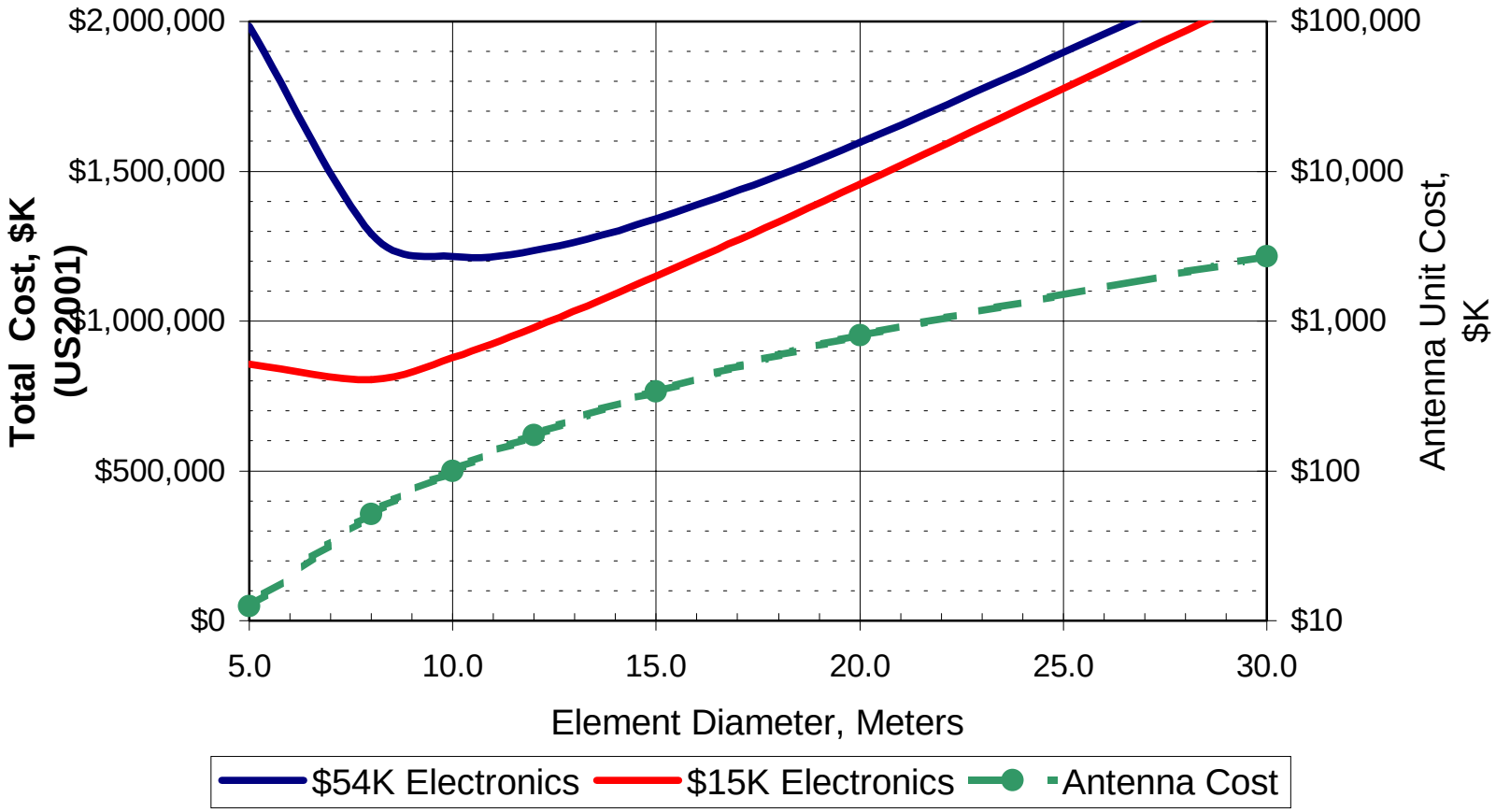
SKA Cost Breakdown by Subsystem vs Antenna Diameter

Aeff/Tsys = 20,000, Aeff=360,000, Tsys=18K, BW=4GHz, 15K Cryogenics

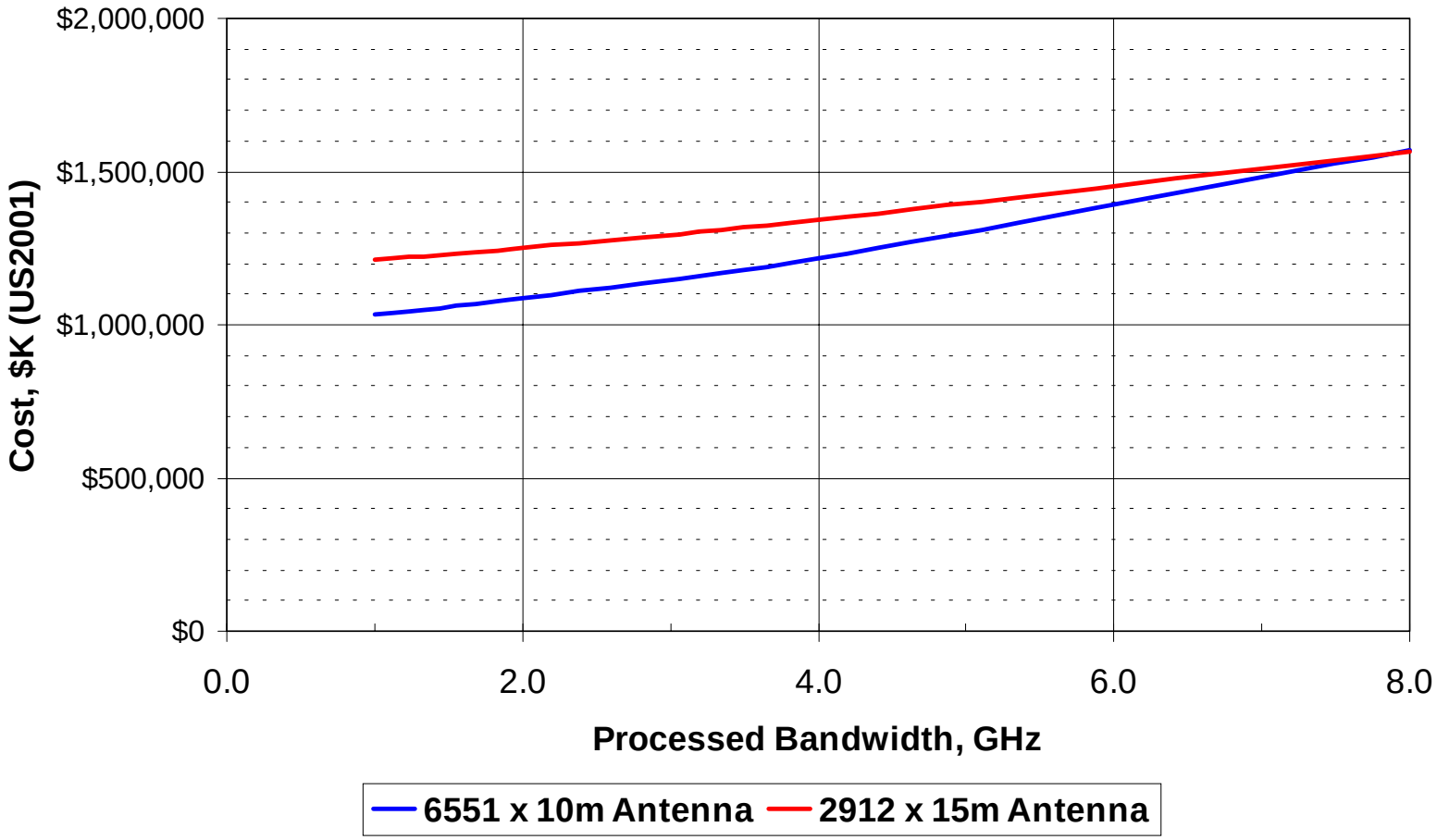
Antenna Cost = 0.1D^3 K$, 2010Electronics Cost = $15K per Element



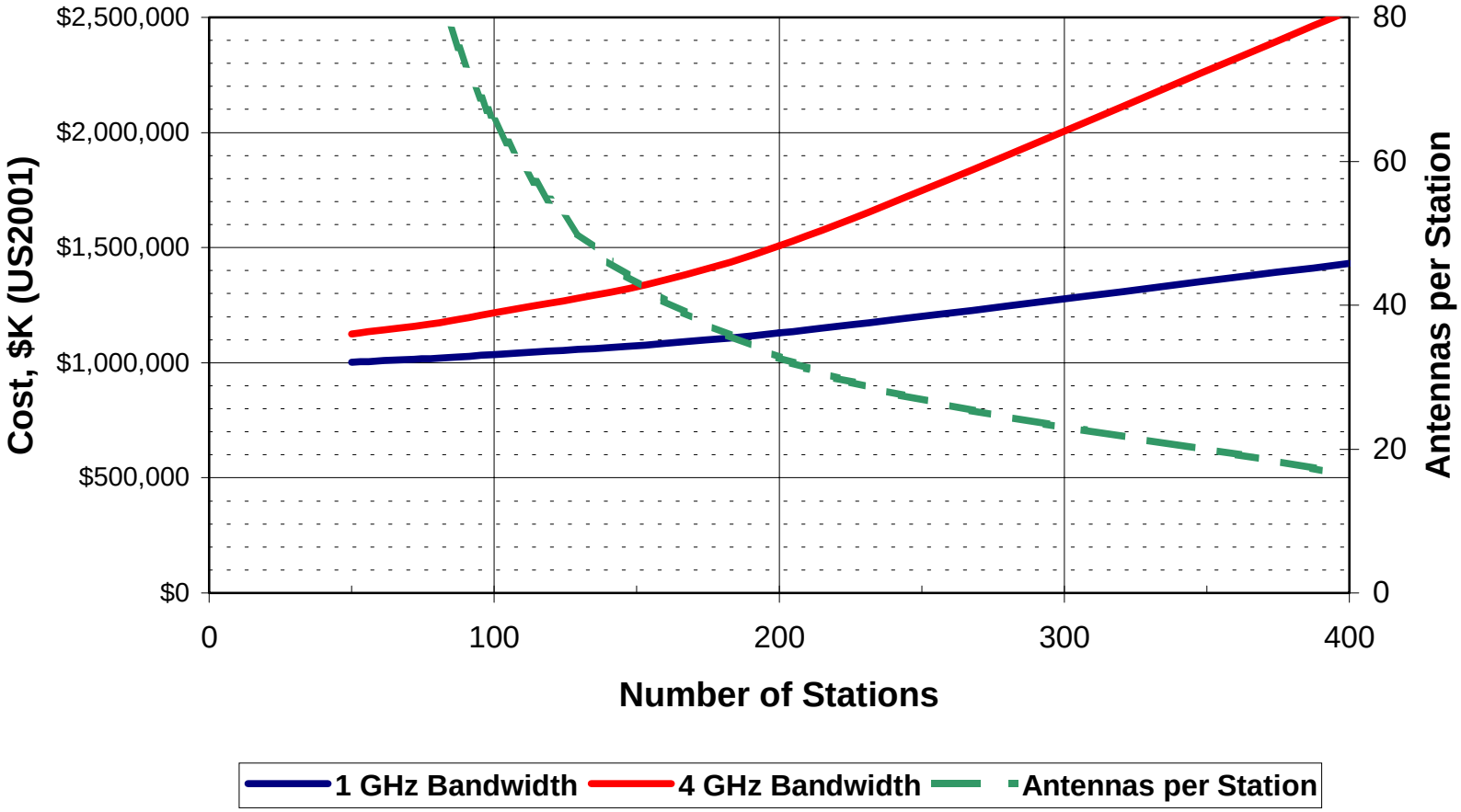
SKA Cost vs Antenna Diameter
Compares Current and Projected (2010) Electronics Costs
All for 15K cryogenics, 4 GHz BW, 100 Stations, A/T = 20,000
Antenna Cost = 0.1D^3 $K



SKA Cost vs Processed Bandwidth for
Two Antenna Diameters
All for 15K Cryogenics



SKA Cost vs Number of Stations for
Two Processed Bandwidths
All for 15K Cryogenics, 10m antennas. A/T = 20,000



Front-End Cost and Performance Model

Cooler Type	Physical Temp	Cooler Cost, K$	Noise @ 10 GHz	Noise @ 50 GHz	Noise @ F GHz
None	300	1	40	200	4*F
Peltier	180	3	24	120	2.4*F
Pulse or Klemenko	60	6	10	50	1.0*F
Gifford-McMann	15	20	4	20	0.4*F

Total Front-End Cost, FE$

FE$ = Cooler$ + 3(Bands)*2(Polarizations)* LNA$
LNA$ = $0.8K*(Fmax/10)^.3
i.e. FE$ = $11.9K for Pulse Cooling with Fmax = 20 GHz

Total Electronics Cost, EL$, per Antenna

EL$ = FE$+ 3*Feed$+LO$+IF$+Fixed$
Feed$ = $1K, LO$ = $5K, IF$ = 2*(0.5 + 2*BW), Fixed$ = $1K
i.e. EL$ = 11.9 + 3*1 + 5 + 2*4.5 +1 = $29.9K

Total System Noise, Tsys

Tsys = Tlna + [10 + 4* (F/10)]

Signal Processing Cost Model

- **EACH ANTENNA**
  1. Digitization
     $C_d = [k_d (B/N_{ch})^e + c_d] N_{ch}$ (exponent e is approximately 2)
     Cost per channel increases *faster* than bandwidth => more channels
     - Presently expensive -- total for array is more than the correlator!
  2. Tracking
     - Primarily delay and phase tracking of sources
     - Per antenna per beam -- multi beaming is probably needed to mitigate small FOV of station beam.
     - All-digital implementation assumed
- **EACH STATION**
  1. Summation to form phased-array, per beam
     - Multi-beaming probably needed due to small station beam
  2. Transmission to central processing facility
     - available bandwidth shared among beams.
- **CENTRAL PROCESSING (CORRELATION)**
  1. Per antenna section
     - filter bank for L spectral channels
     - cost grows as $B \log(L)$ if minimum-memory FFTs are used
  2. Interconnection section
     - can dominate cost for large N
     - natural architecture grows as $B N^3$
     - clever architecture grows as $B N \log(N)$
  3. Cross correlation section
     - grows as $B L N^2$ (note L dependence, even for FX architecture)