Model of Receiver Design Flaw Crucial for Huygens Space Mission Recovery

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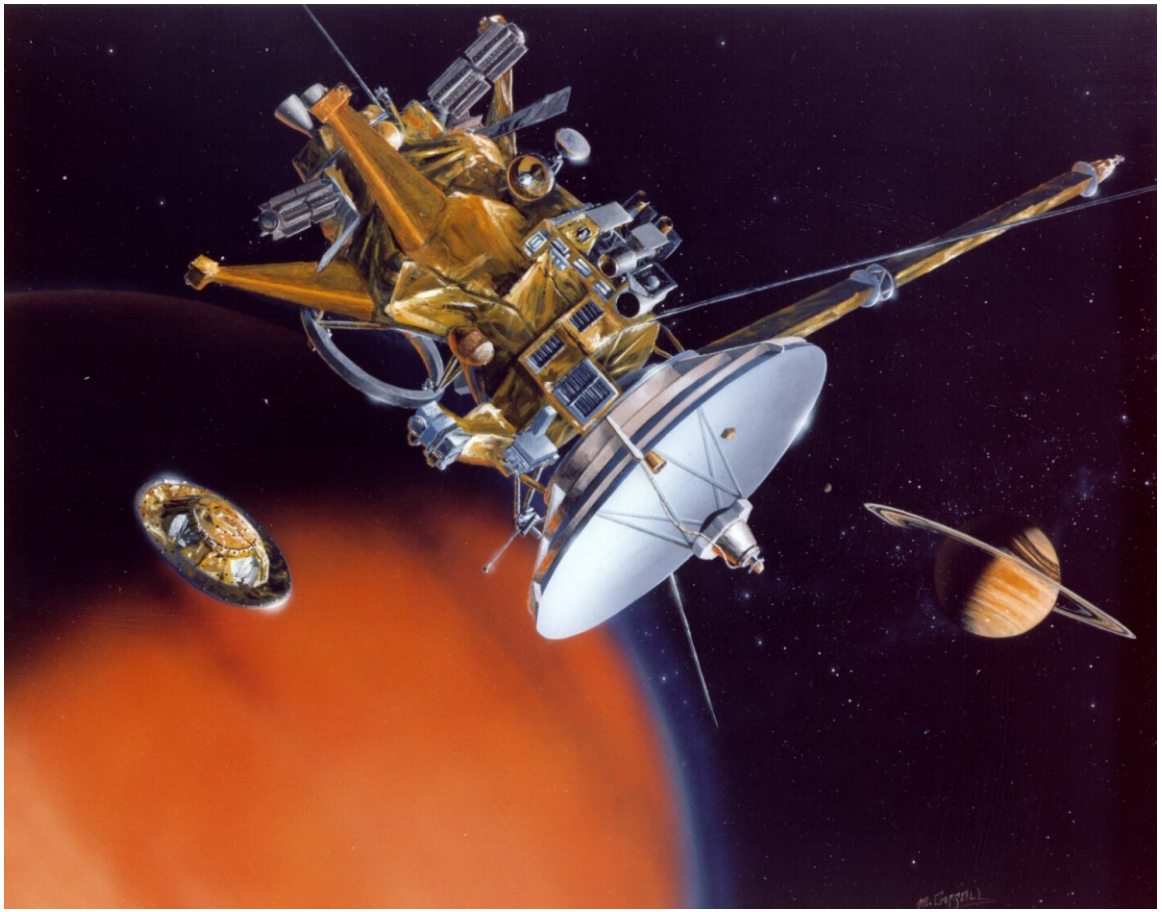
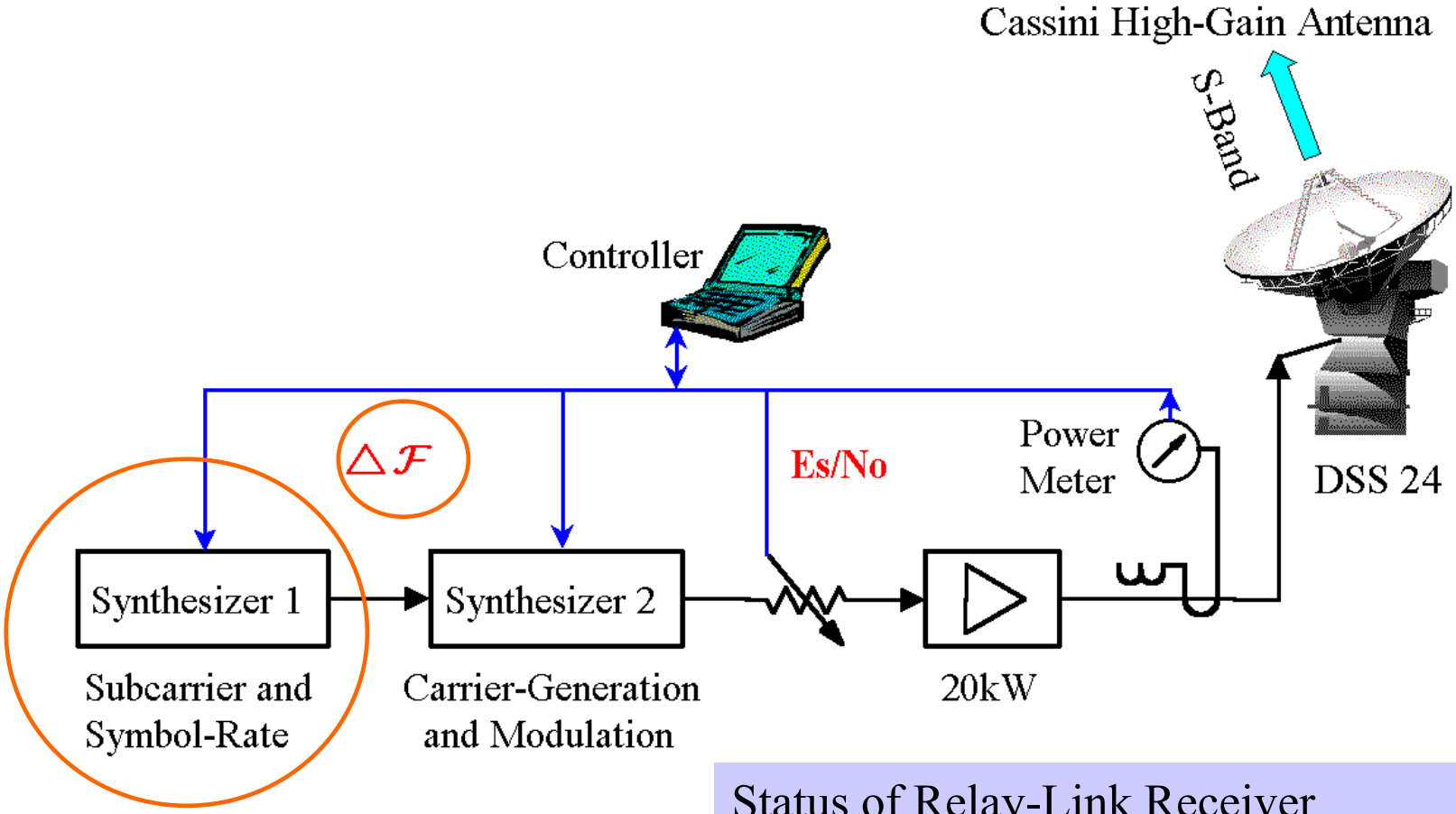
European Space Agency

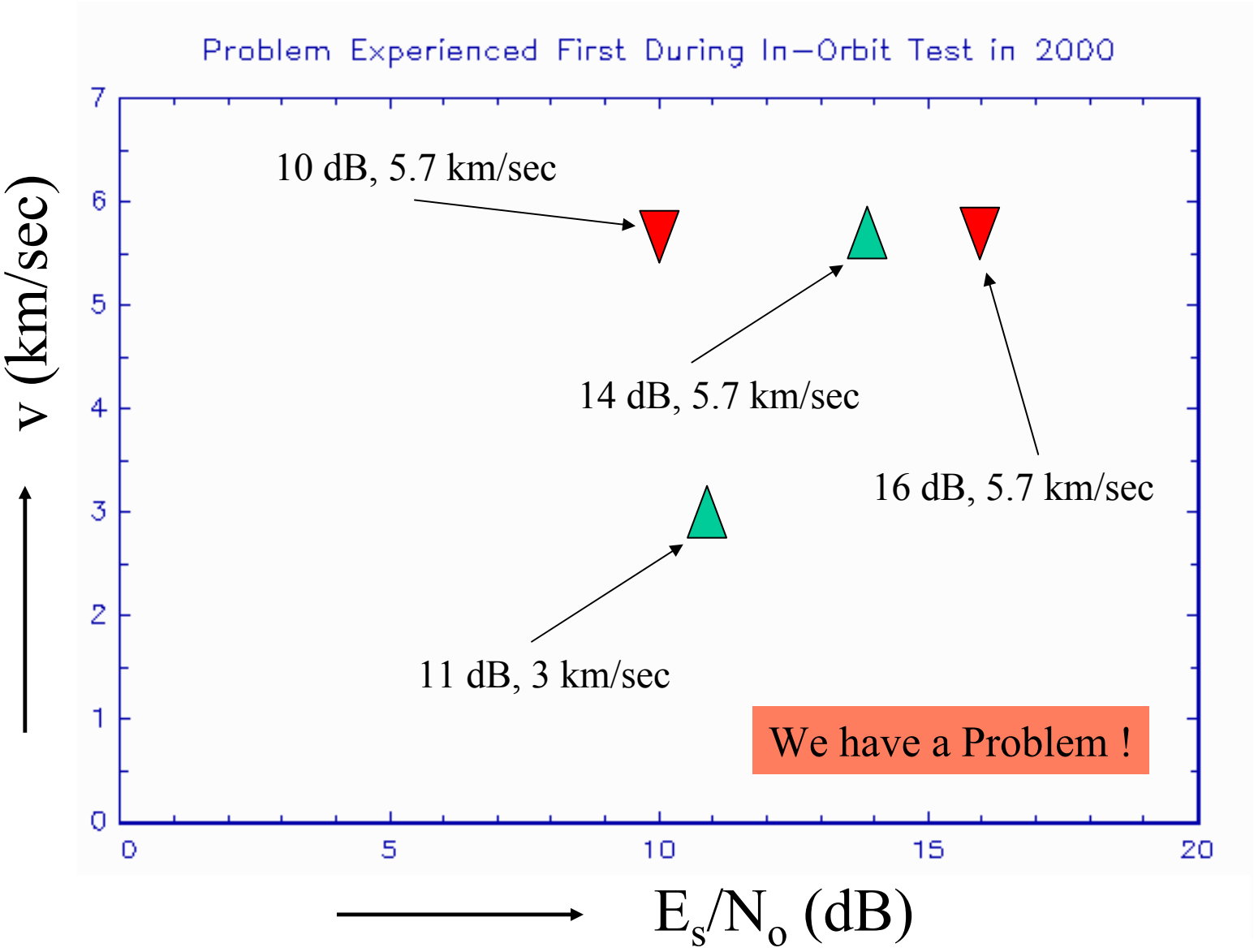
Cassini releases Huygens Probe at Titan



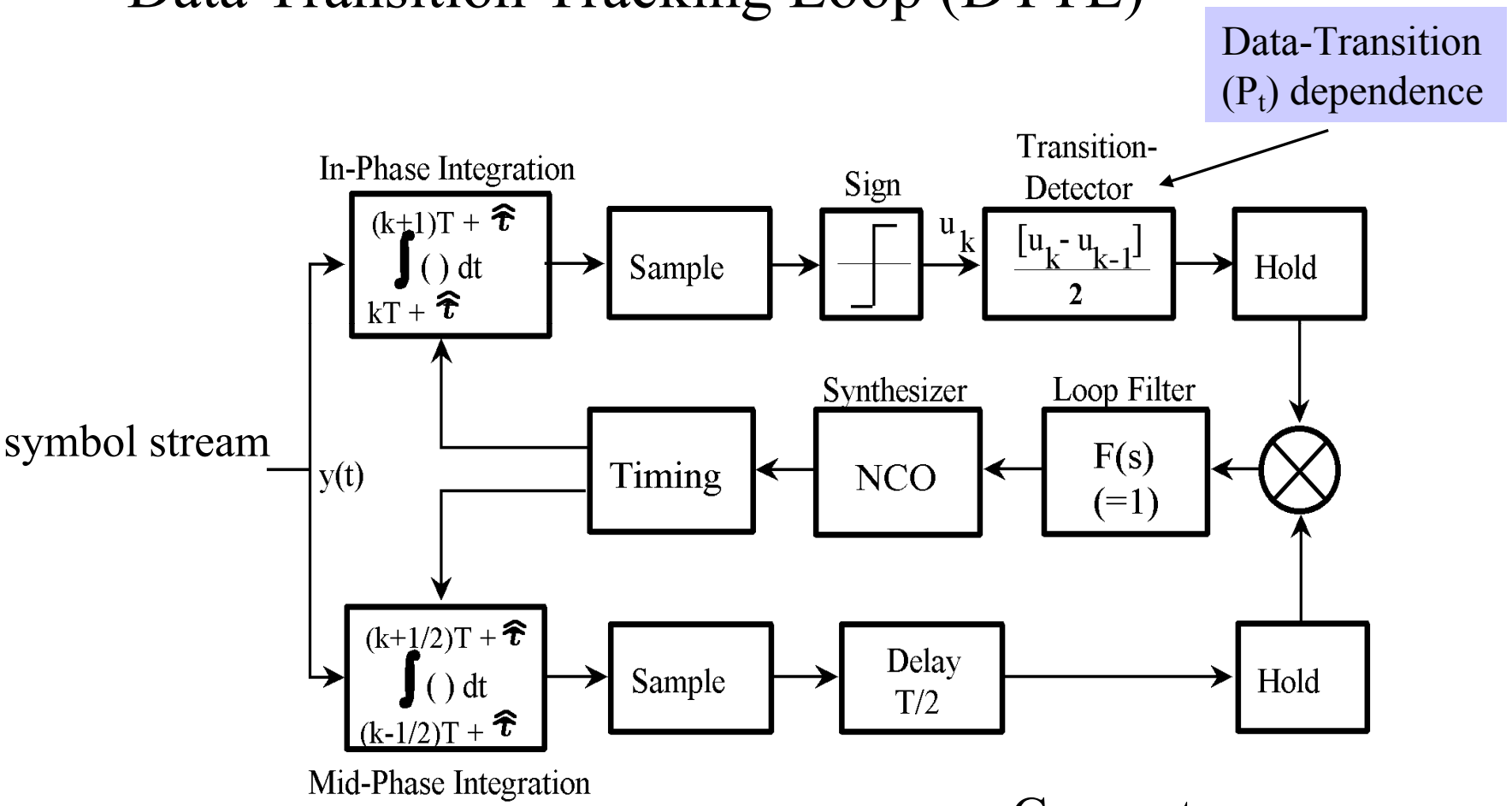
Relay-Link Receiver In-Orbit Test



Status of Relay-Link Receiver monitored via Cassini X-Band Telemetry

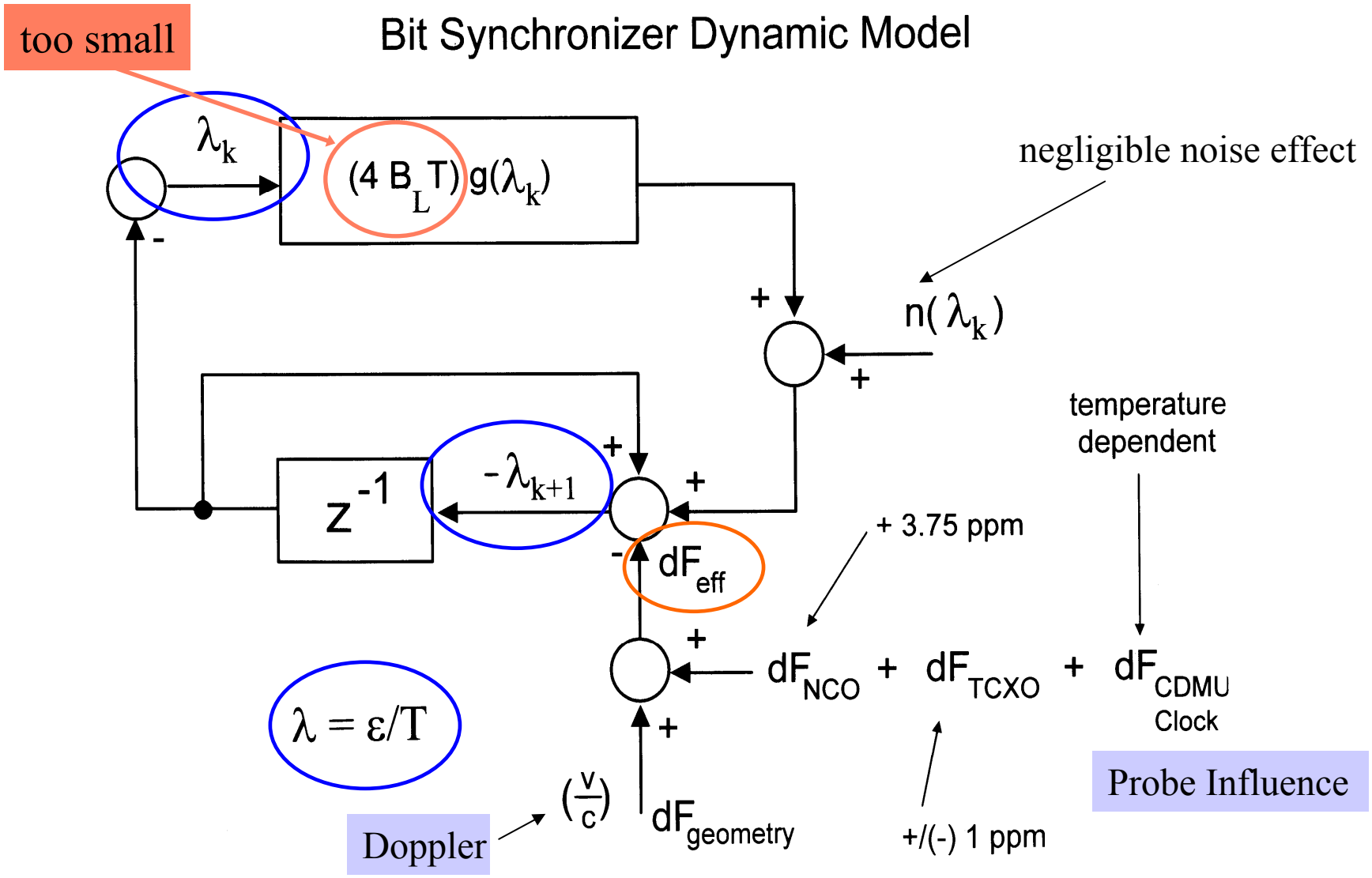

Problem Experienced First During In-Orbit Test in 2000
10 dB, 5.7 km/sec
14 dB, 5.7 km/sec
16 dB, 5.7 km/sec
11 dB, 3 km/sec
We have a Problem !
v (km/sec)
E_s/N_o (dB)
0
1
2
3
4
5
6
7
0
5
10
15
20

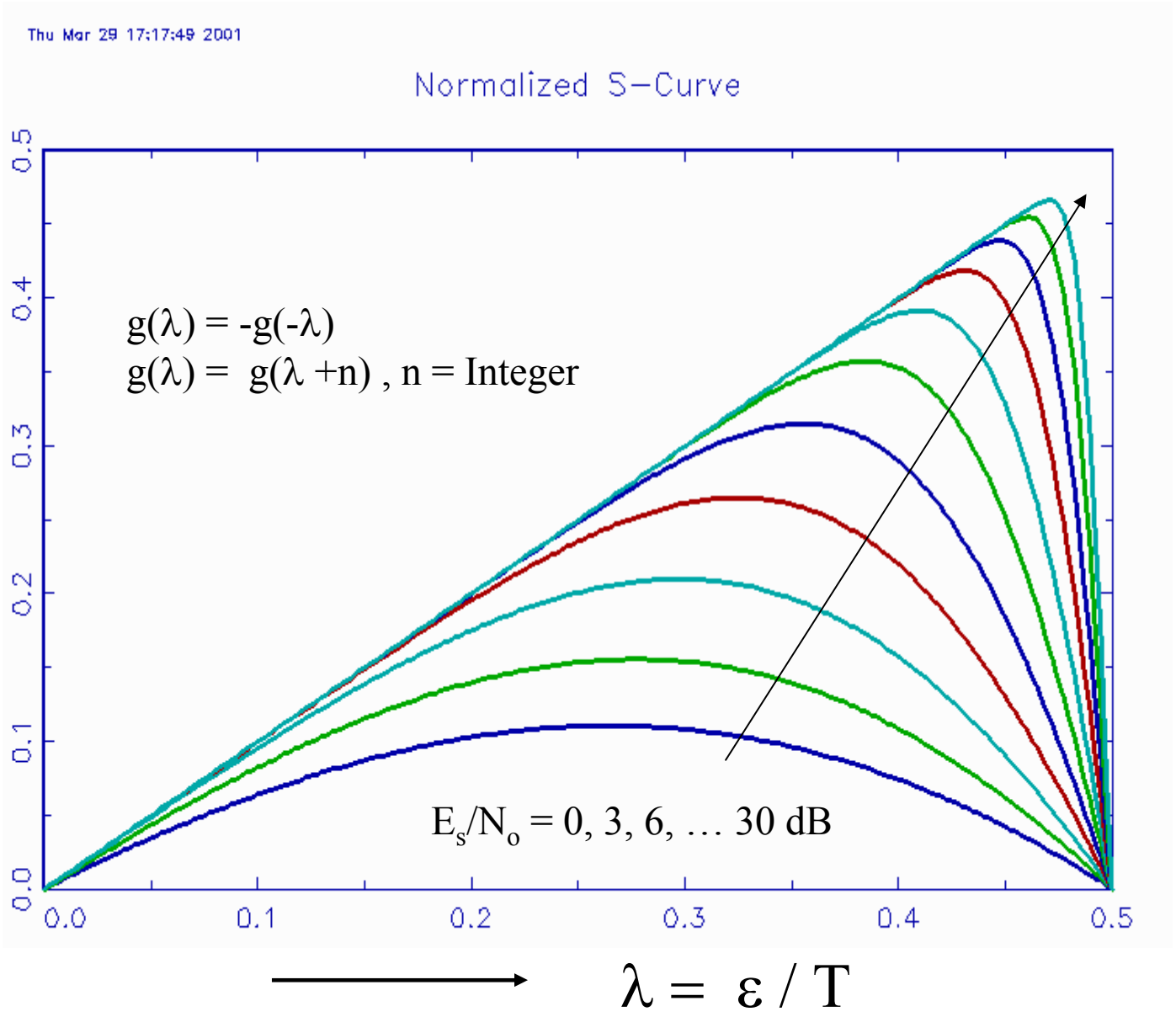
Data Transition Tracking Loop (DTTL)



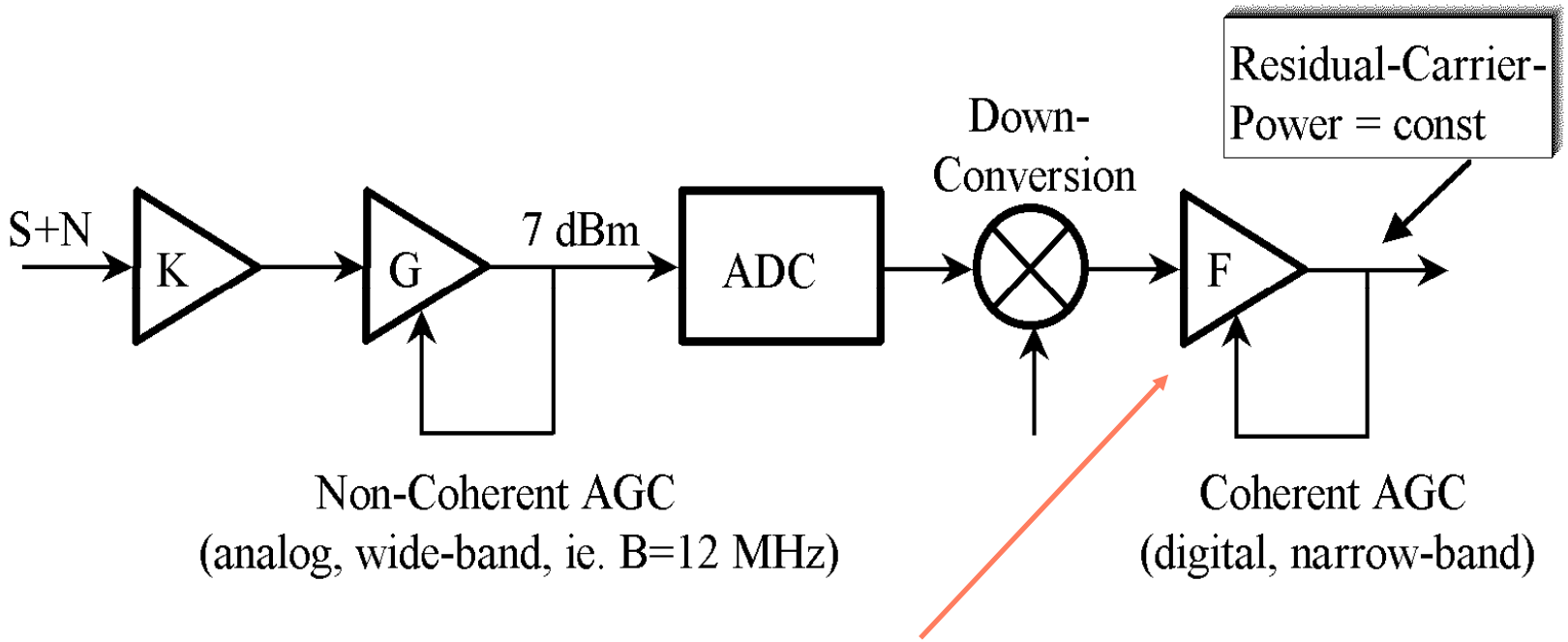
Concept

Bit Synchronizer Dynamic Model

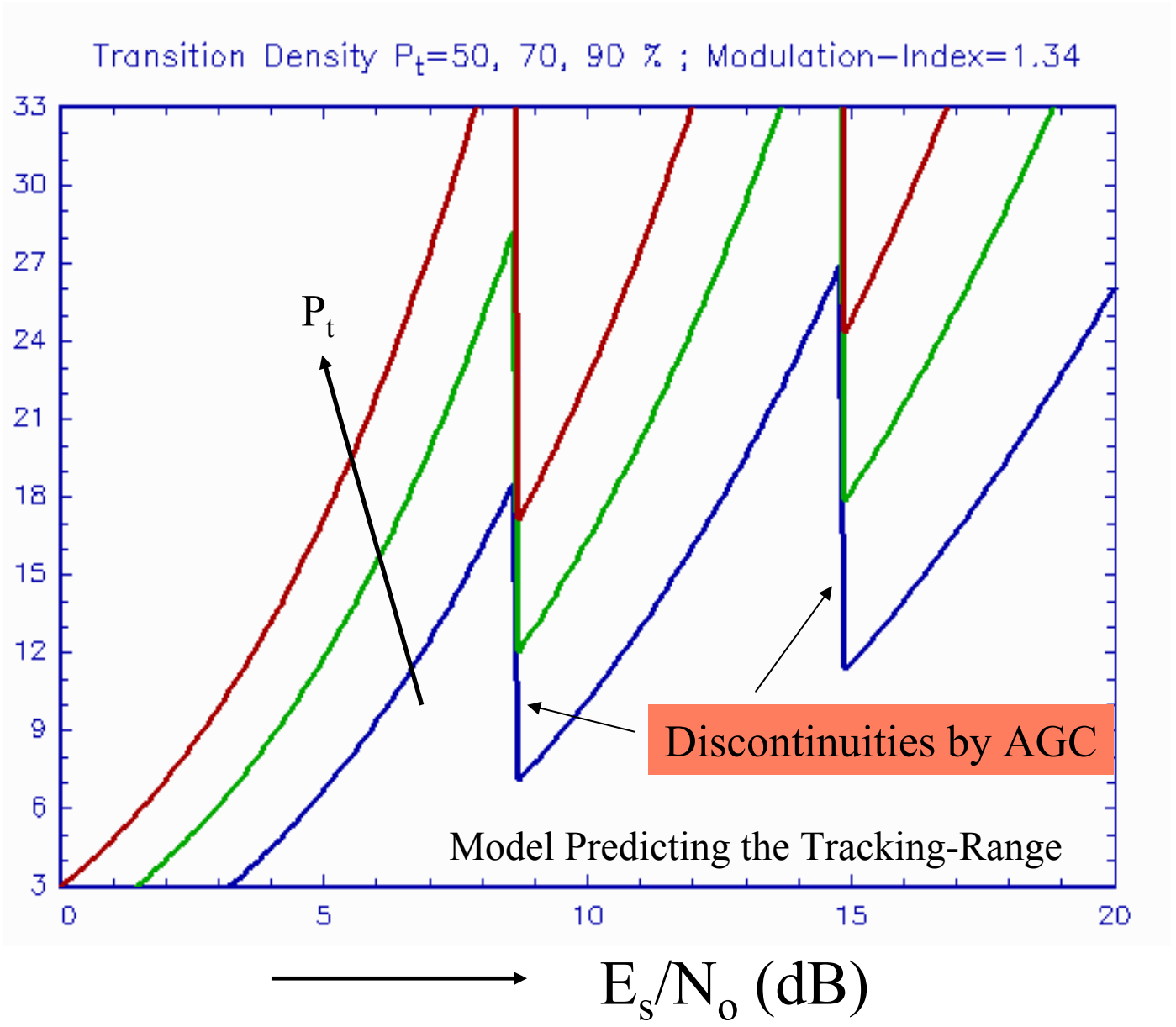


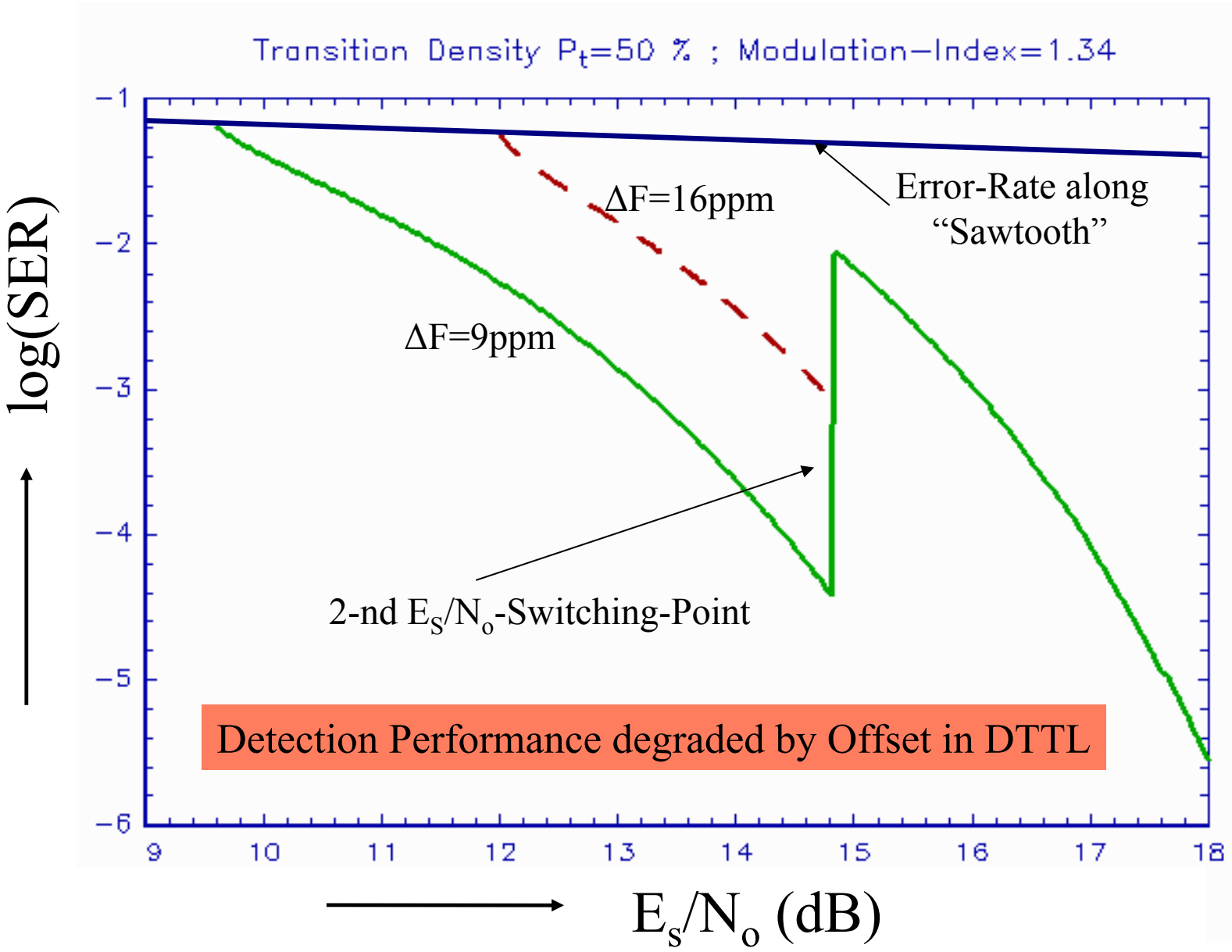

Thu Mar 29 17:17:49 2001
Normalized S-Curve
g(λ) = -g(-λ)
g(λ) = g(λ +n) , n = Integer
E_s/N_o = 0, 3, 6, … 30 dB
g (λ)
λ = ε / T
0.0
0.1
0.2
0.3
0.4
0.5

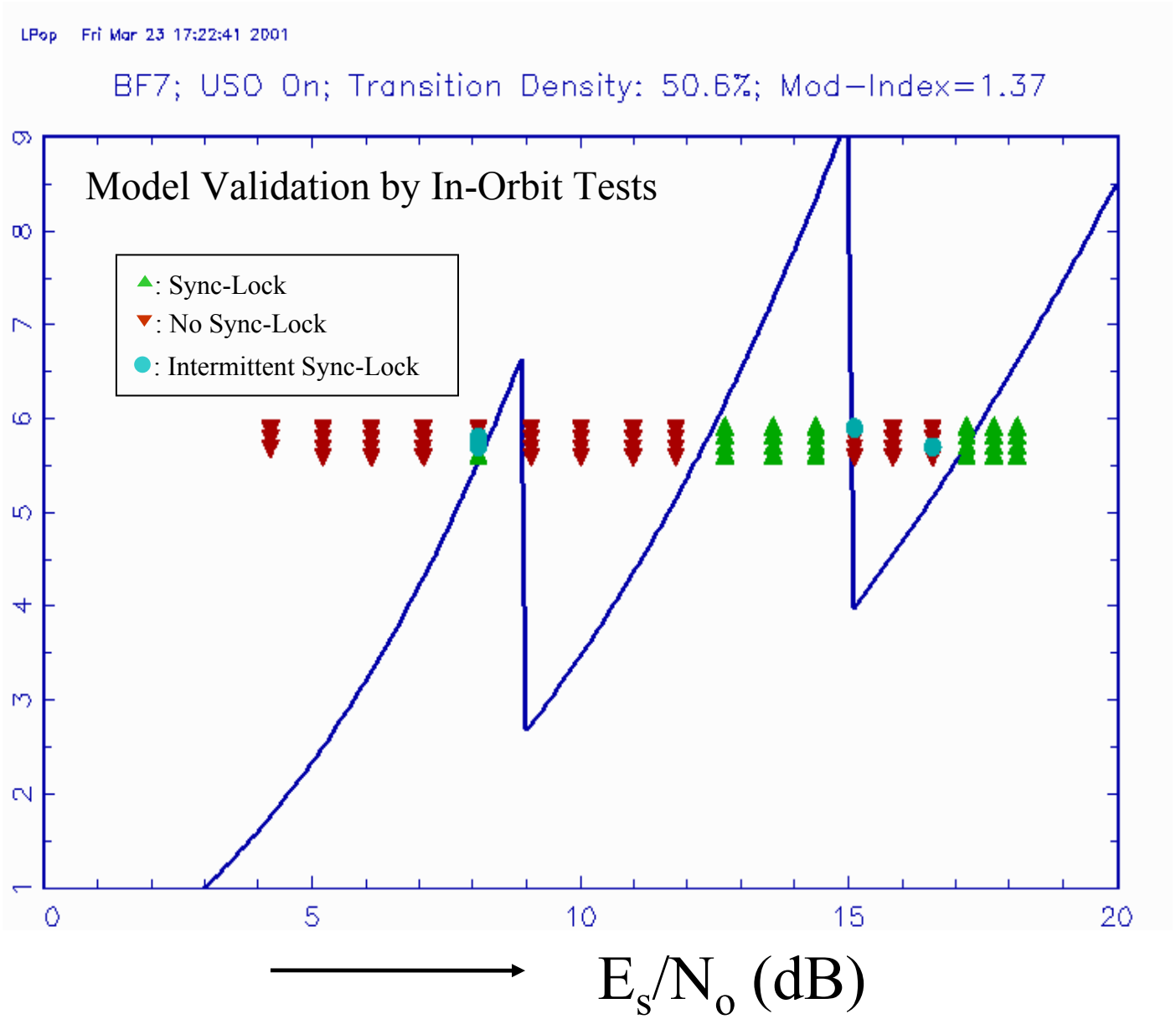
Automatic Gain Controls

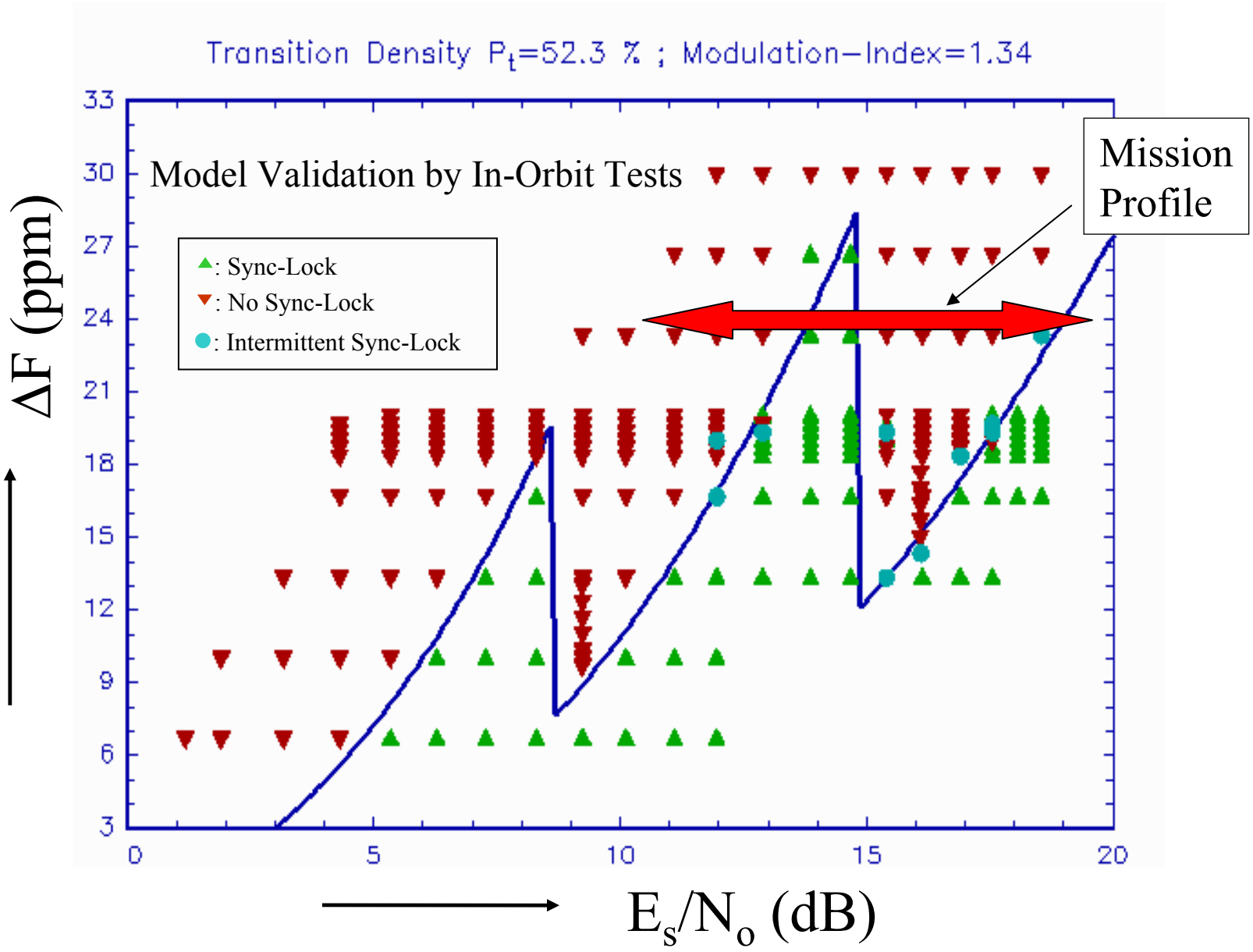


Coherent-AGC Gain affects DTTL Loop-Gain

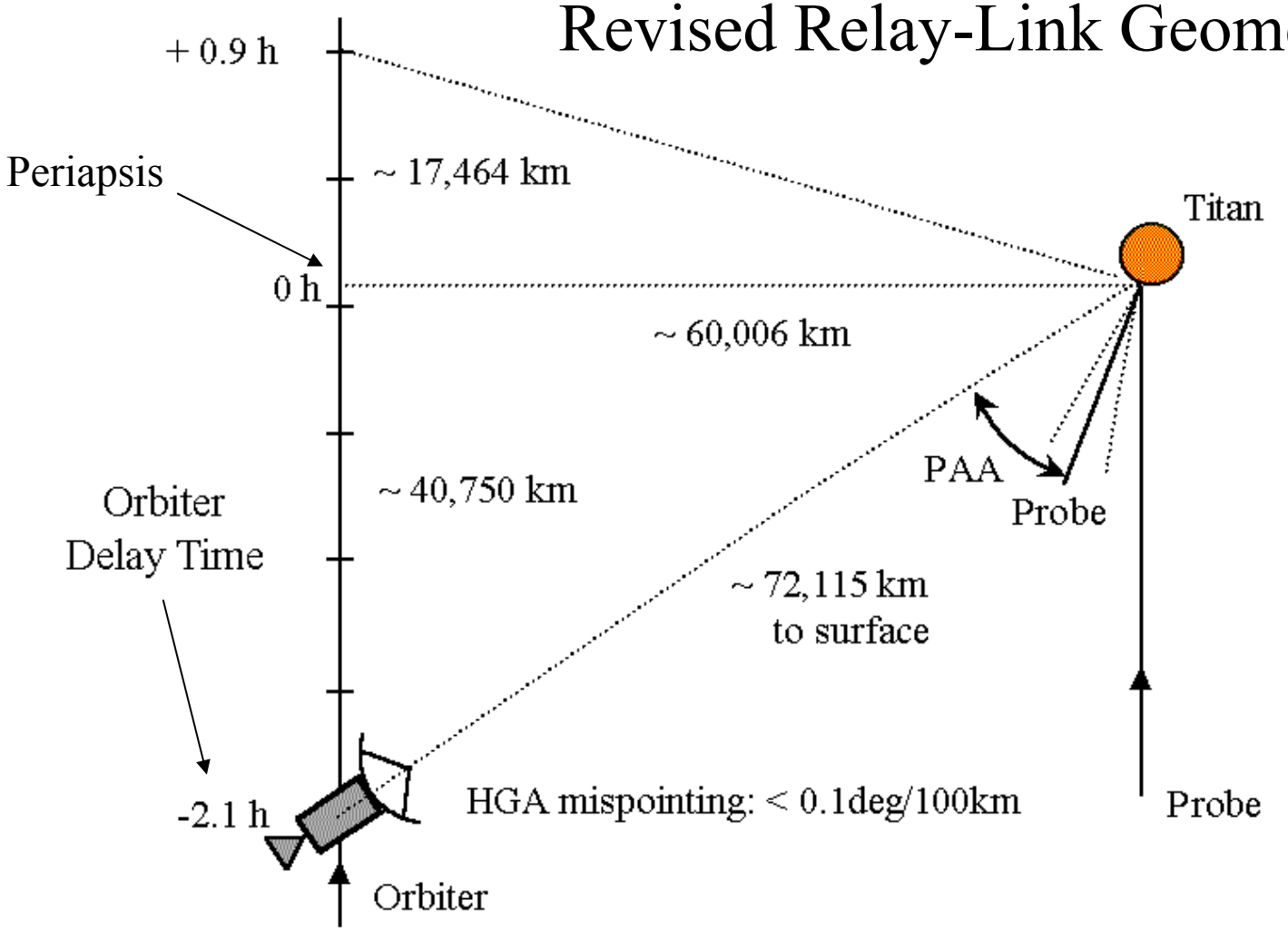

Transition Density P_t=50, 70, 90 % ; Modulation-Index=1.34
ΔF (ppm)
33
30
27
24
21
18
15
12
9
6
3
0
5
10
15
20
P_t
Discontinuities by AGC
Model Predicting the Tracking-Range
E_s/N_o (dB)

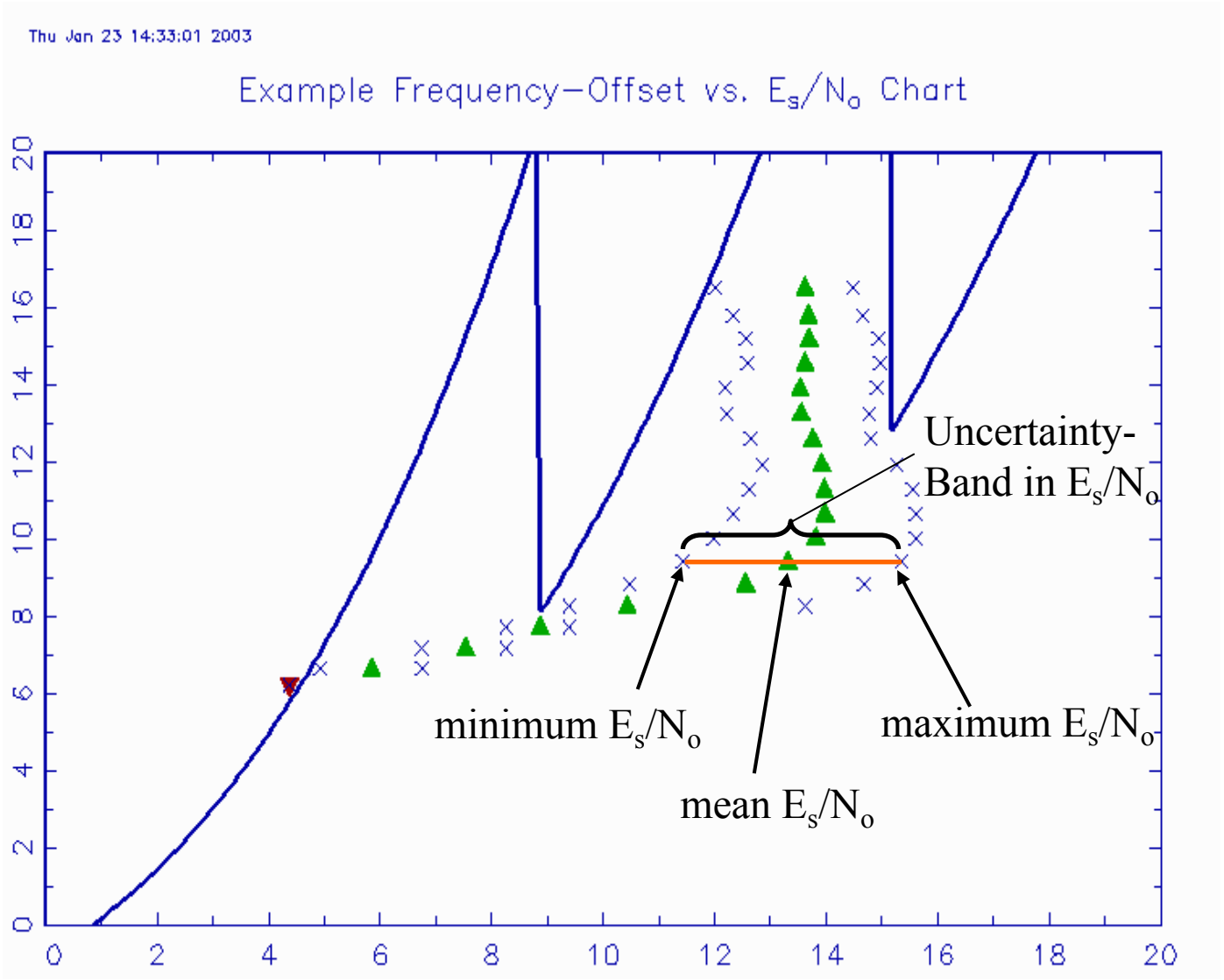

Transition Density P_t=50 % ; Modulation-Index=1.34
log(SER)
−1
−2
−3
−4
−5
−6
9
10
11
12
13
14
15
16
17
18
ΔF=16ppm
ΔF=9ppm
Error-Rate along "Sawtooth"
2-nd E_S/N_o-Switching-Point
Detection Performance degraded by Offset in DTTL
E_s/N_o (dB)


LPop Fri Mar 23 17:22:41 2001
BF7; USO On; Transition Density: 50.6%; Mod-Index=1.37
Model Validation by In-Orbit Tests
: Sync-Lock
: No Sync-Lock
: Intermittent Sync-Lock
v (km/sec)
1
2
3
4
5
6
7
8
9
0
5
10
15
20
E_s/N_o (dB)


Transition Density P_t=52.3 % ; Modulation–Index=1.34
Model Validation by In-Orbit Tests
Mission Profile
▲: Sync-Lock
▼: No Sync-Lock
●: Intermittent Sync-Lock
ΔF (ppm)
33
30
27
24
21
18
15
12
9
6
3
0
5
10
15
20
E_s/N_o (dB)

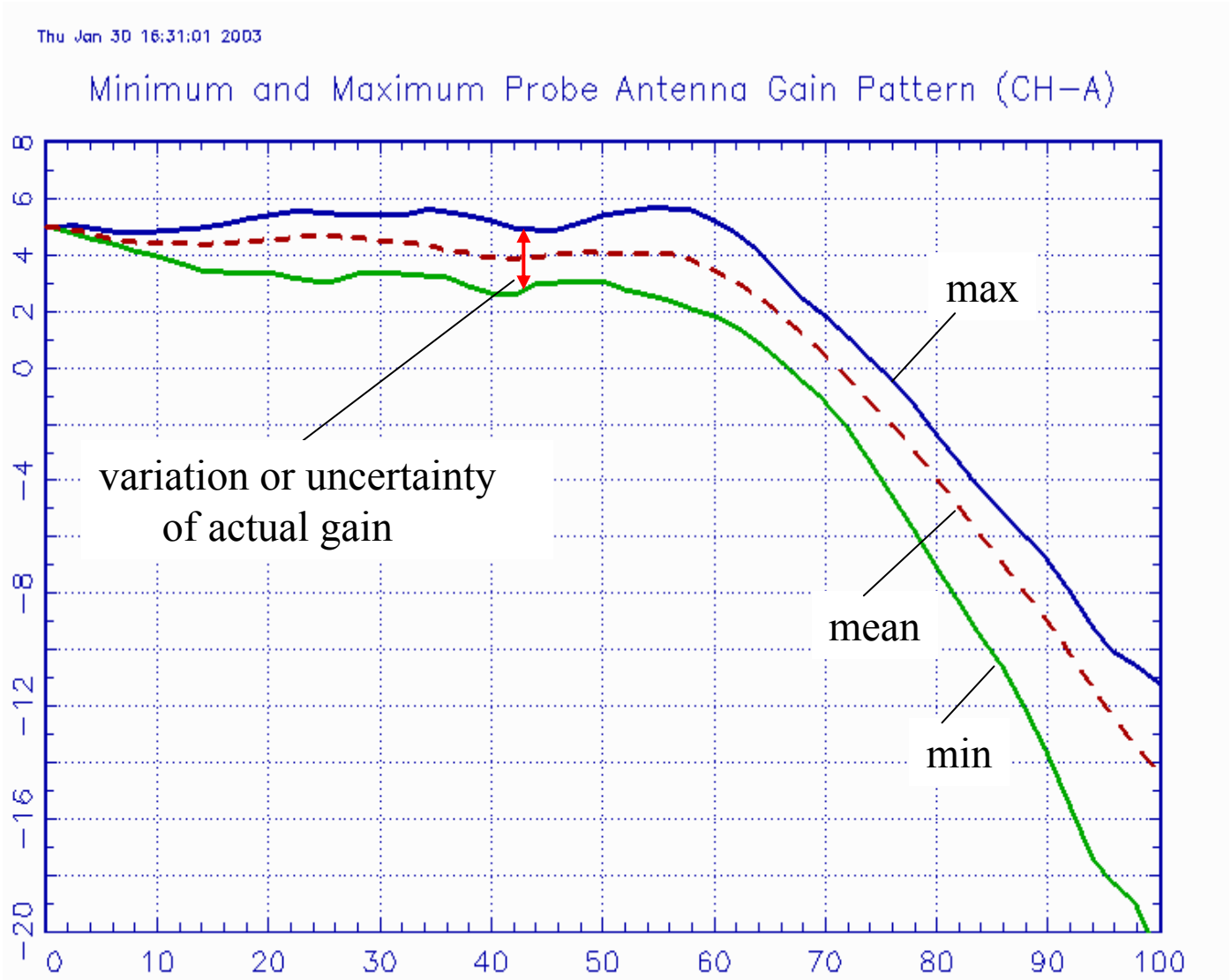
Revised Relay-Link Geometry

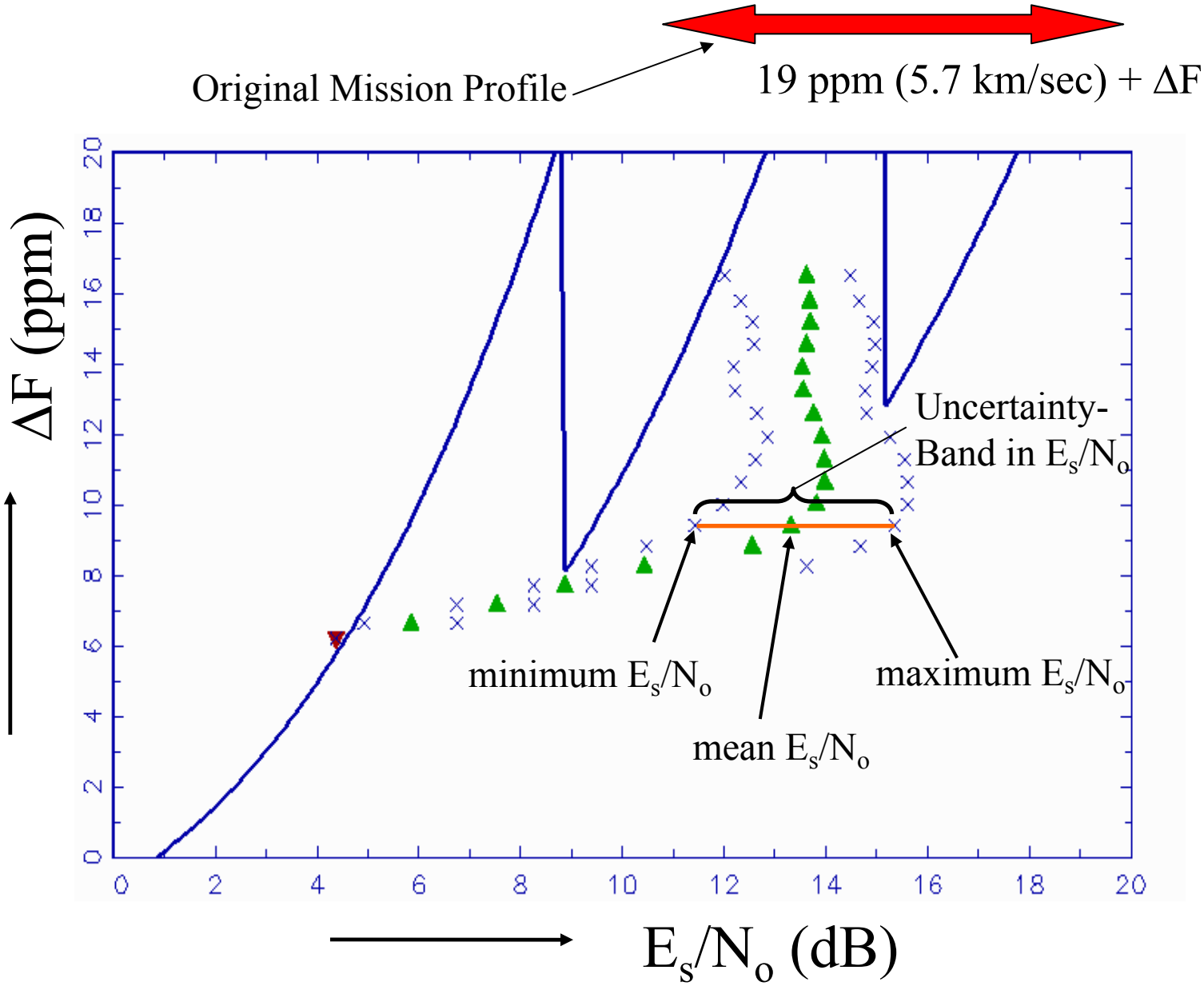



Thu Jan 23 14:33:01 2003
Example Frequency-Offset vs. Es/No Chart
ΔF (ppm)
Es/No (dB)
Uncertainty-Band in Es/No
minimum Es/No
mean Es/No
maximum Es/No
0
2
4
6
8
10
12
14
16
18
20

		A (LHCP)	B (RHCP)	Comment
Probe Tx RF POWER	dBW	*10.66*	*10.83*	
CIRCUIT LOSSES	dB	*0.42*	*0.35*	
Probe ANT GAIN	dBi	*3.46*	*3.63*	***Reference Case***
Probe EIRP	dBW	13.70	14.11	
FREQUENCY	GHz	2.040	2.098	
DISTANCE	1000*km	60.00	60.00	***Reference Distance***
SPACE LOSS	dB	194.20	194.45	
Probe ANT AXIAL RATIO	dB	*1.62*	*1.18*	***Reference Case***
HGA AXIAL RATIO	dB	*4.20*	*3.20*	
POLARIZATION LOSS	dB	0.19	0.11	
Total PROPAGATION LOSS	dB	194.45	194.60	
Cassini RX ANT GAIN, peak	dBi	*35.05*	*35.30*	
HGA POINTING LOSS	dB	*0.00*	*0.00*	***Reference Case***
G/T	dB/K	10.90	10.77	
Es/No REFERENCE	***dB***	**14.11**	**14.33**	

Extract from Reference Link Budget


Thu Jan 30 16:31:01 2003
Minimum and Maximum Probe Antenna Gain Pattern (CH-A)
Gain (dBi)
8
6
4
2
0
-4
-8
-12
-16
-20
0
10
20
30
40
50
60
70
80
90
100
max
mean
min
variation or uncertainty
of actual gain
Probe-Aspect Angle (deg)


Original Mission Profile
19 ppm (5.7 km/sec) + ΔF
ΔF (ppm)
Uncertainty-
Band in Es/No
minimum Es/No
mean Es/No
maximum Es/No
Es/No (dB)
0
2
4
6
8
10
12
14
16
18
20

Lessons Learned

- Implement sufficient onboard Reconfigurability for Recovery from Design-Problems or Hardware-Failures:
  - Design for Parameter-Selection or -Modification by Telecommand:
    - Tracking-Loop and Synchronization Parameters, Thresholds.
  - Allow for Algorithm-Adaptation by Software-Patch.

- Transmission of Telemetry Data should never be blocked intentionally.
  - No conditioning on Data-Integrity or Correct Data-Alignment.
  - Sophisticated Data Recovery can be applied on ground.