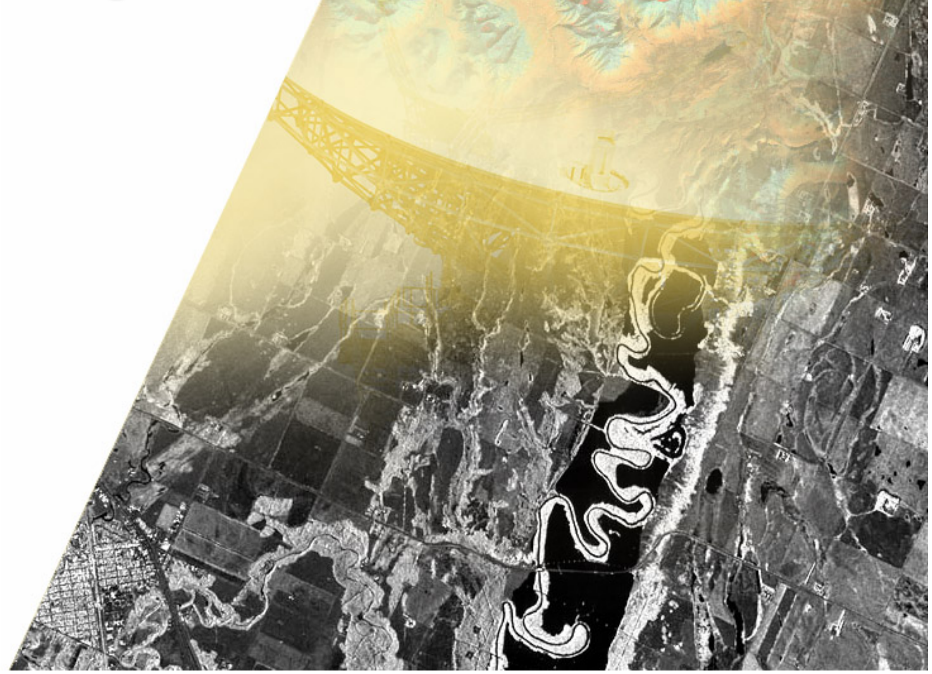
RADARSAT-1 Transponders Revisited

Hawkins, Srivastava, Ikkers, Hoang, Côté, Murnaghan, Nicholls



Some Context

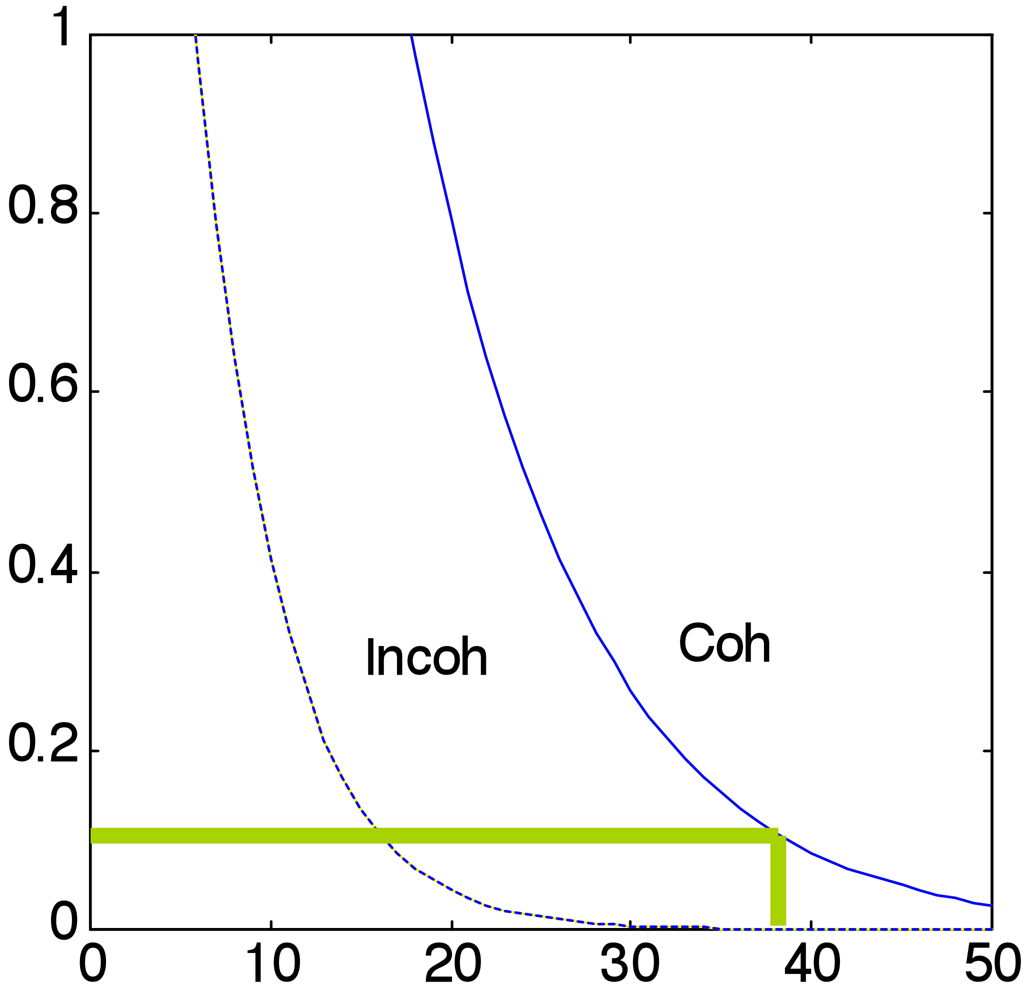
- **Four Transponders (ARCs) build by MPB Technologies, Montreal, 1995**
- **Design principles and system based on ESA/ ESTEC system built for ERS-1**
- **Some extensions for Canada and RS-1**
  - Temperatures
  - Snow
  - Polarization
  - Centre Frequency and BW
- **In continuous operations for 14 years**

Specifications

Characteristic	***RADARSAT-1 Requirement***	***Units***
RCS at Maximum Gain	64.00	dBm^2
RCS gain adjustment	58-64	dBm^2
Calibration Accuracy (absolute)[1]	0.25	dBm^2
Cross-Calibration Accuracy[2]	0.15	dBm^2
Overall Stability	0.10	dB

[1] Defined as the range of residual uncertainties in the value of RCS after a calibration routine on the transponder has been carried out.
[2] Defined as the residual uncertainty in the relative value of RCS when cross-comparing any two transponders.

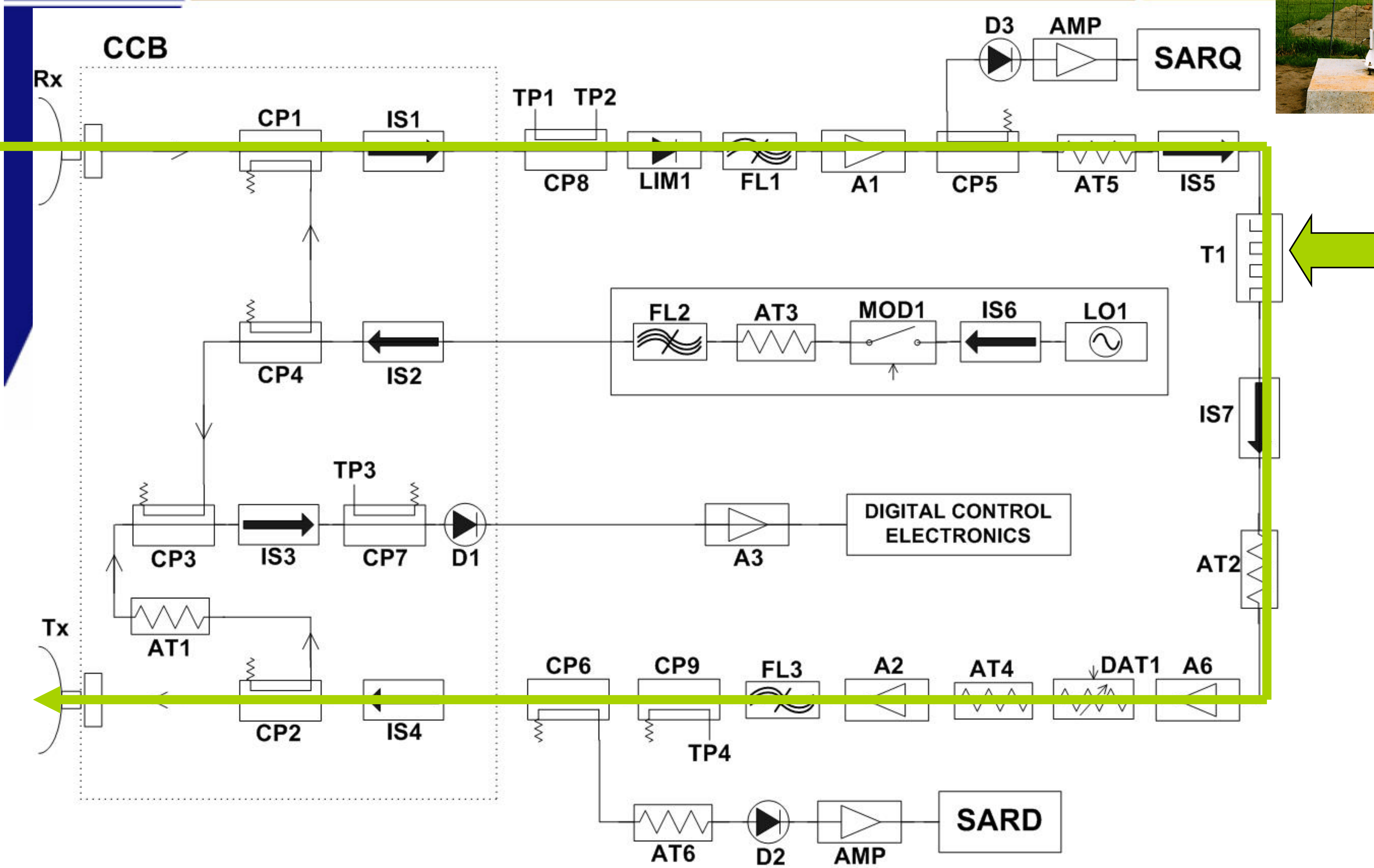
Fading Error with Clutter



$$\sigma > \sigma^o A + 40$$

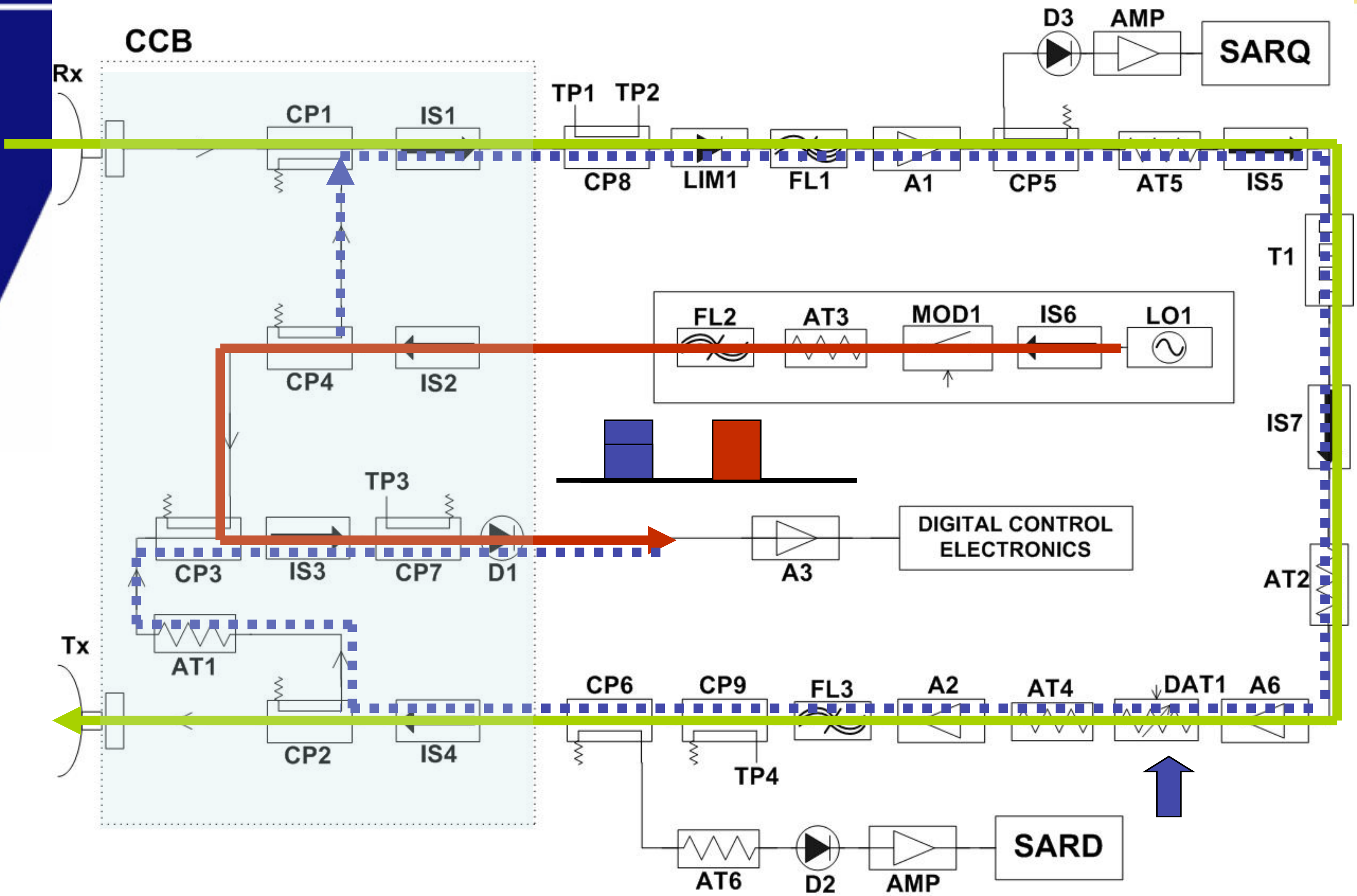
$$> 54 \text{ dBm}^2$$

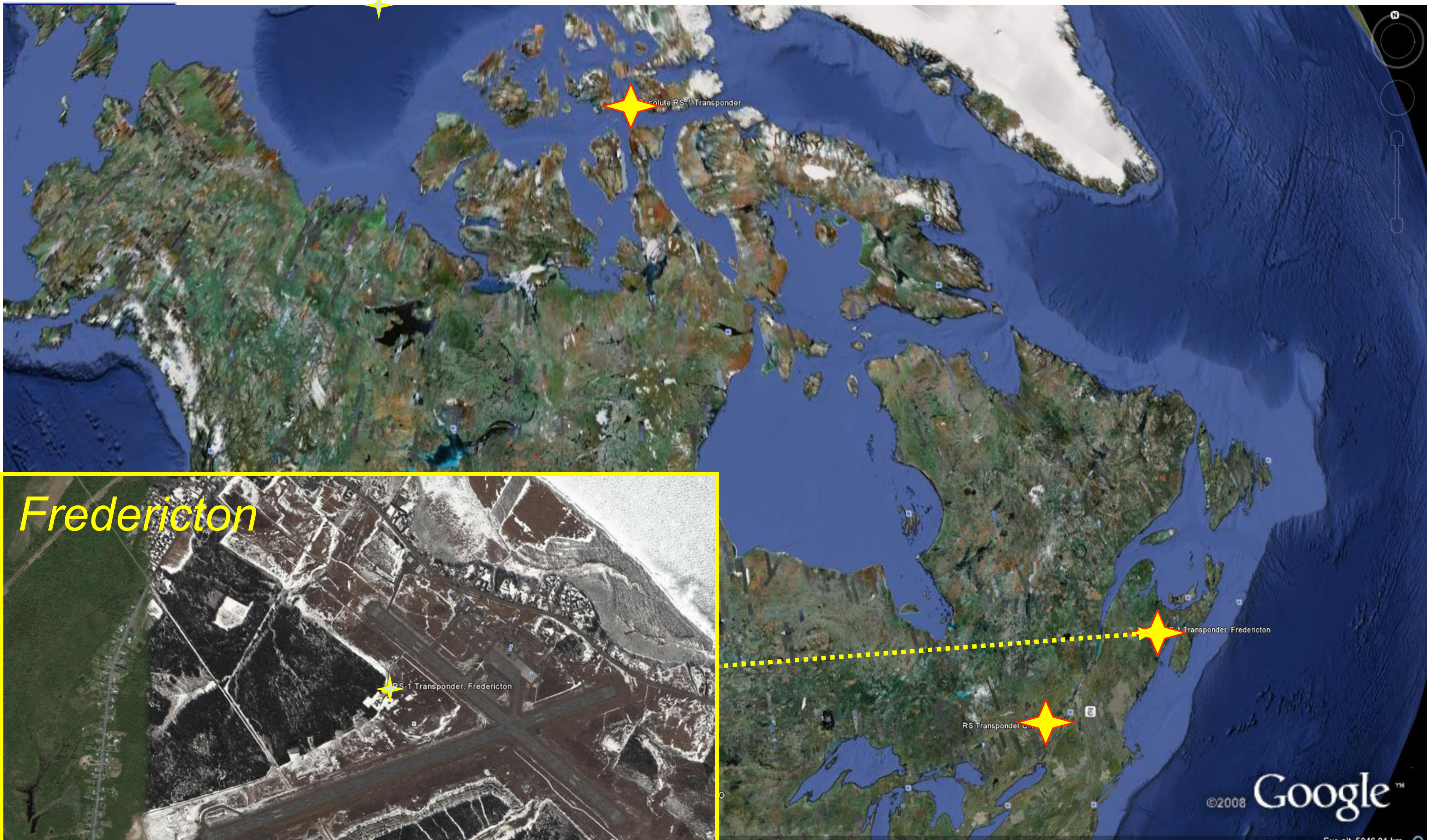
RF Design

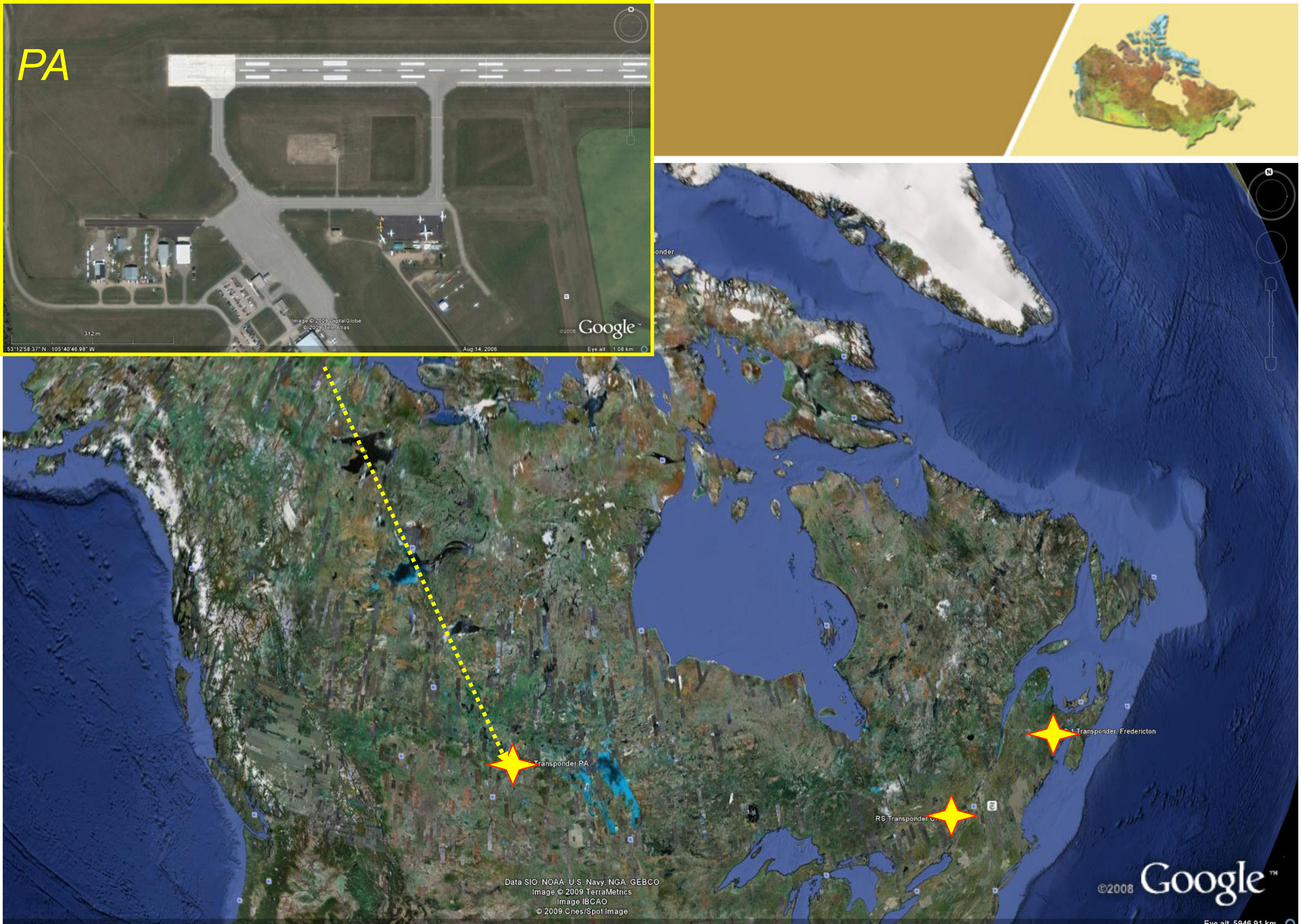


CCB
Rx
Tx
CP1
IS1
TP1
TP2
CP8
LIM1
FL1
A1
D3
AMP
SARQ
CP5
AT5
IS5
T1
FL2
AT3
MOD1
IS6
LO1
CP4
IS2
IS7
TP3
CP3
IS3
CP7
D1
A3
DIGITAL CONTROL ELECTRONICS
AT2
AT1
CP6
CP9
FL3
A2
AT4
DAT1
A6
CP2
IS4
TP4
AT6
D2
AMP
SARD

RF Design- Internal Calibration




Fredericton
RS-1 Transponder, Fredericton
Transponder, Fredericton
RS Transponder
©2008 Google
Eye alt 5946.91 km


PA
Transponder PA
Transponder, Fredericton
RS Transponder
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2009 TerraMetrics
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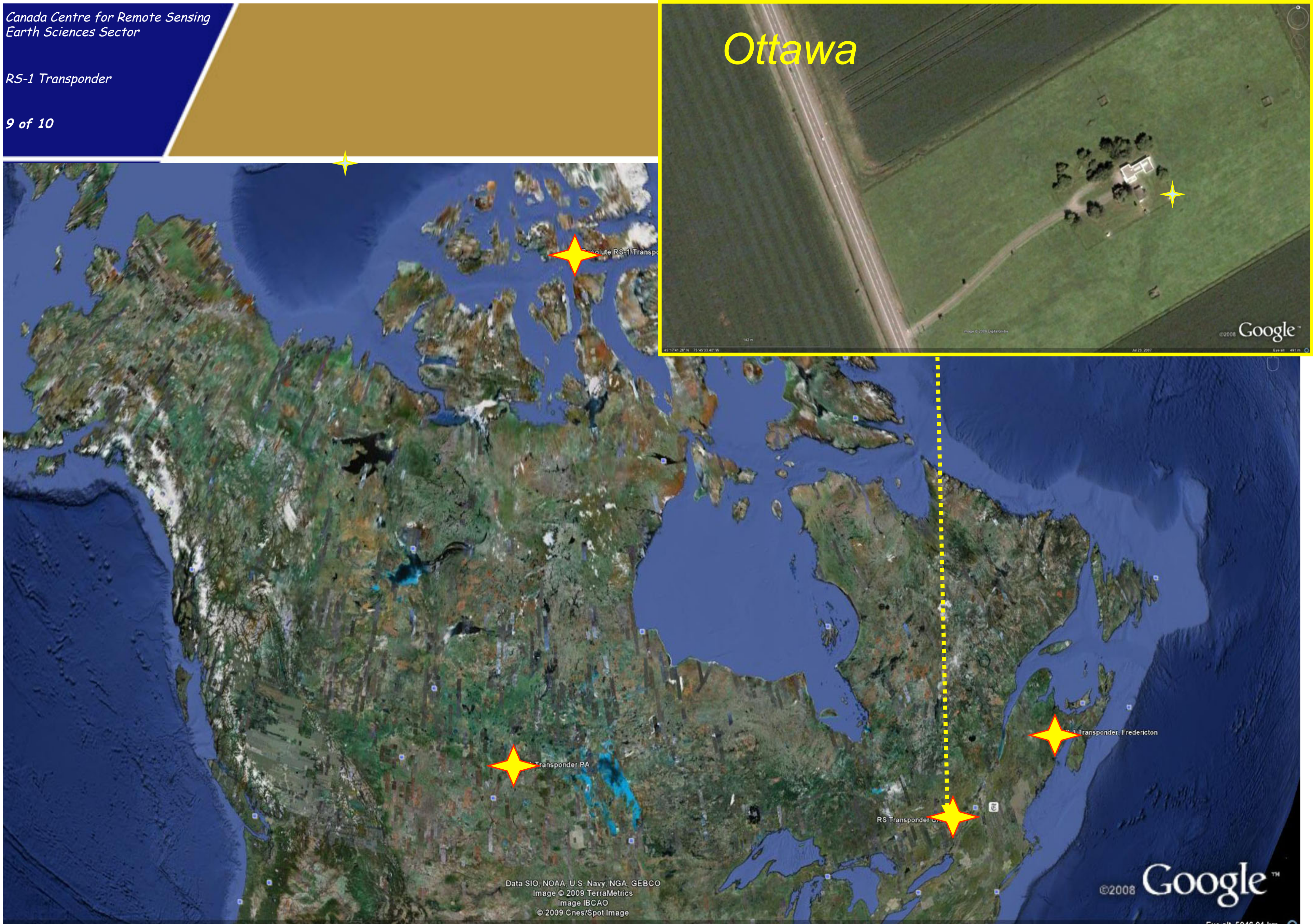
Eye alt 5946.91 km


Ottawa
Google
Transponder PA
Transponder, Fredericton
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2009 TerraMetrics
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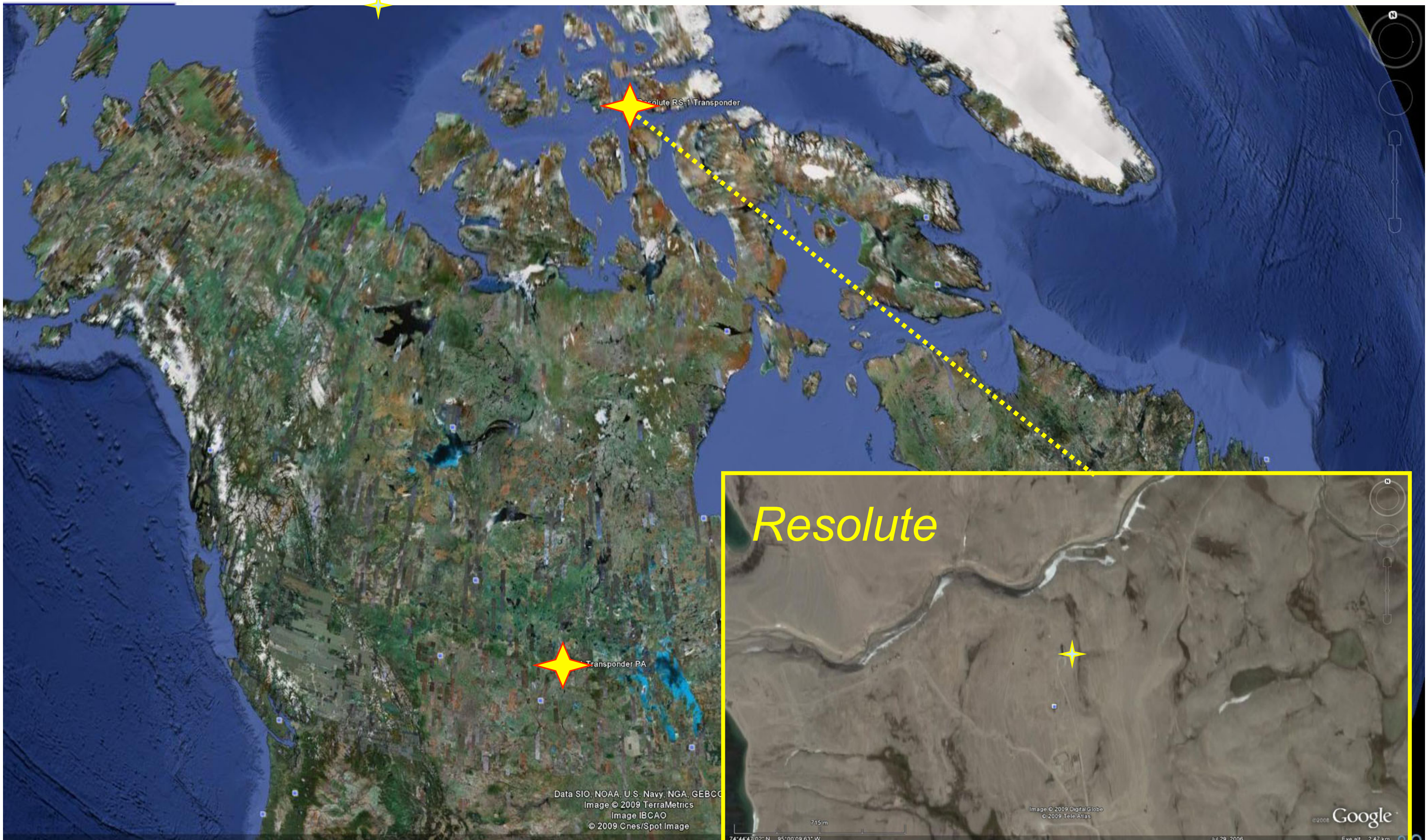
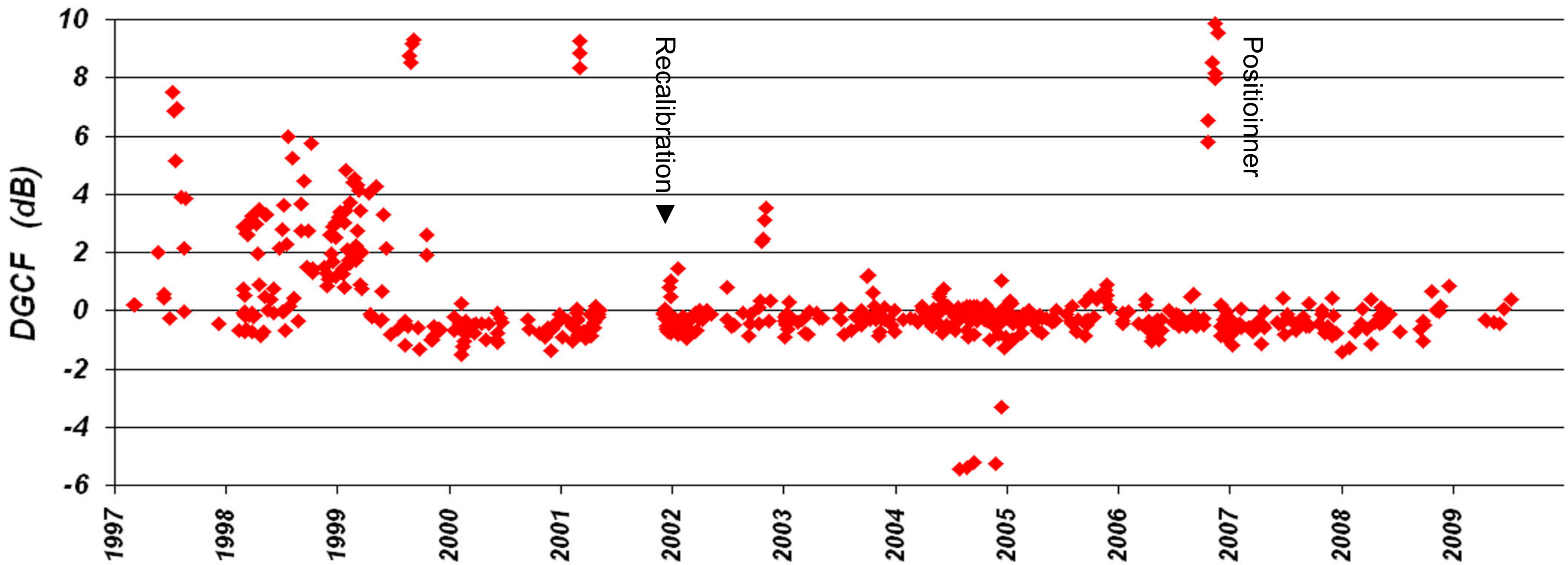
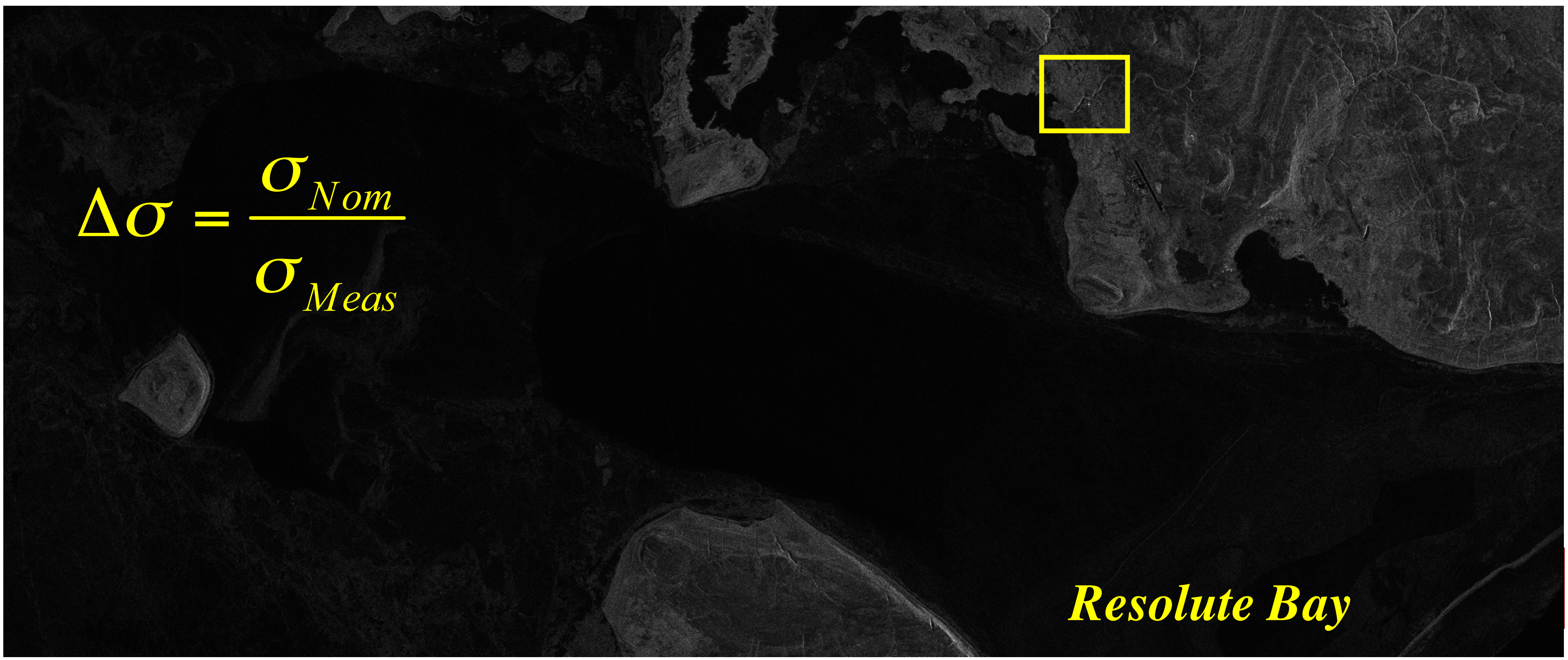
Eye alt 5946.91 km


solute RS-1 Transponder
Transponder PA
Resolute
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2009 TerraMetrics
Image IBCAO
© 2009 Cnes/Spot Image
Google

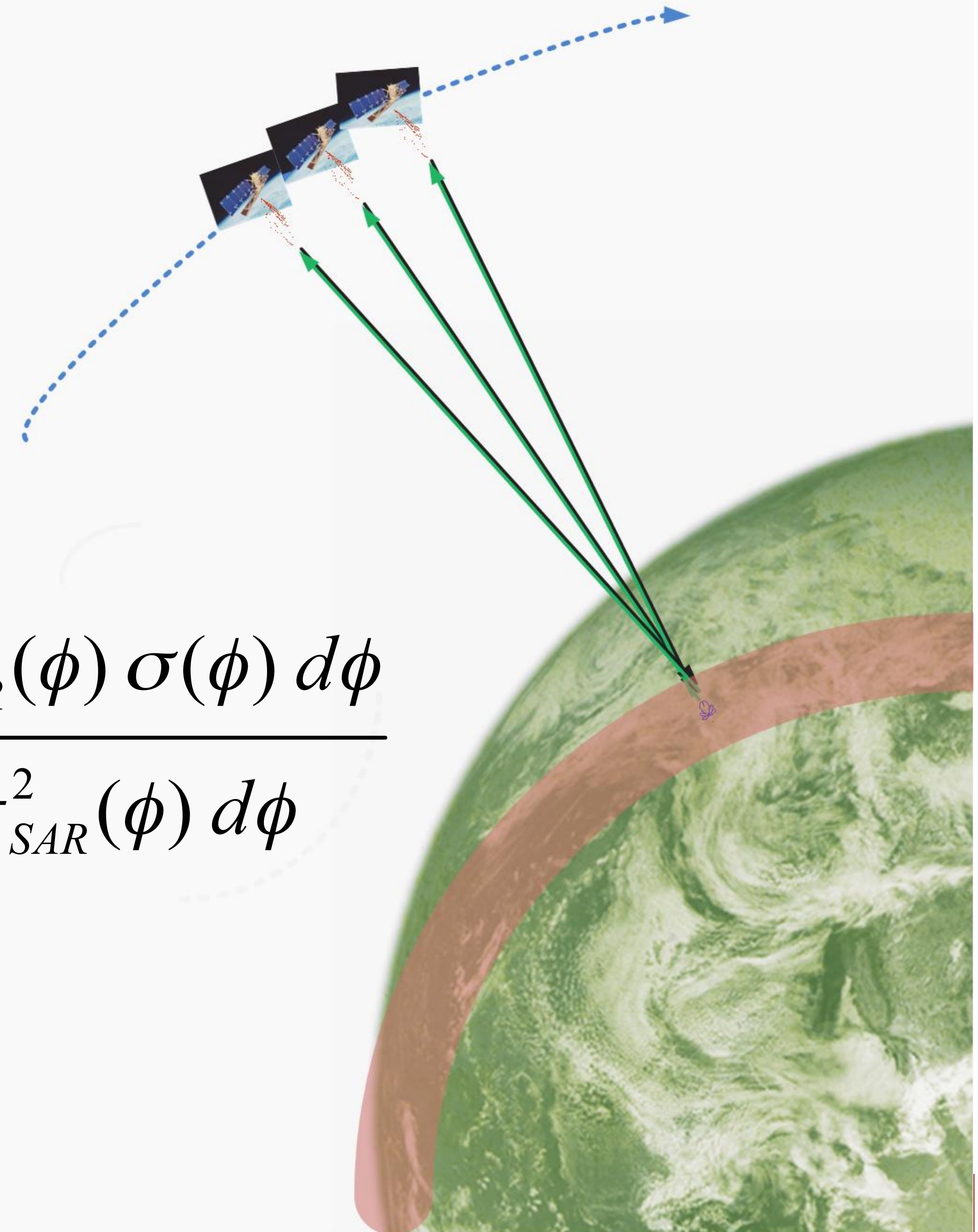

PA
Ottawa
Fredericton
Resolute
RS-1 Transponder, Fredericton
Google


Prince Albert
Ottawa
Fredericton
Resolute


DGCF (dB)
10
8
6
4
2
0
-2
-4
-6
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Recalibration
Positioinner


$\Delta\sigma = \frac{\sigma_{Nom}}{\sigma_{Meas}}$
Resolute Bay

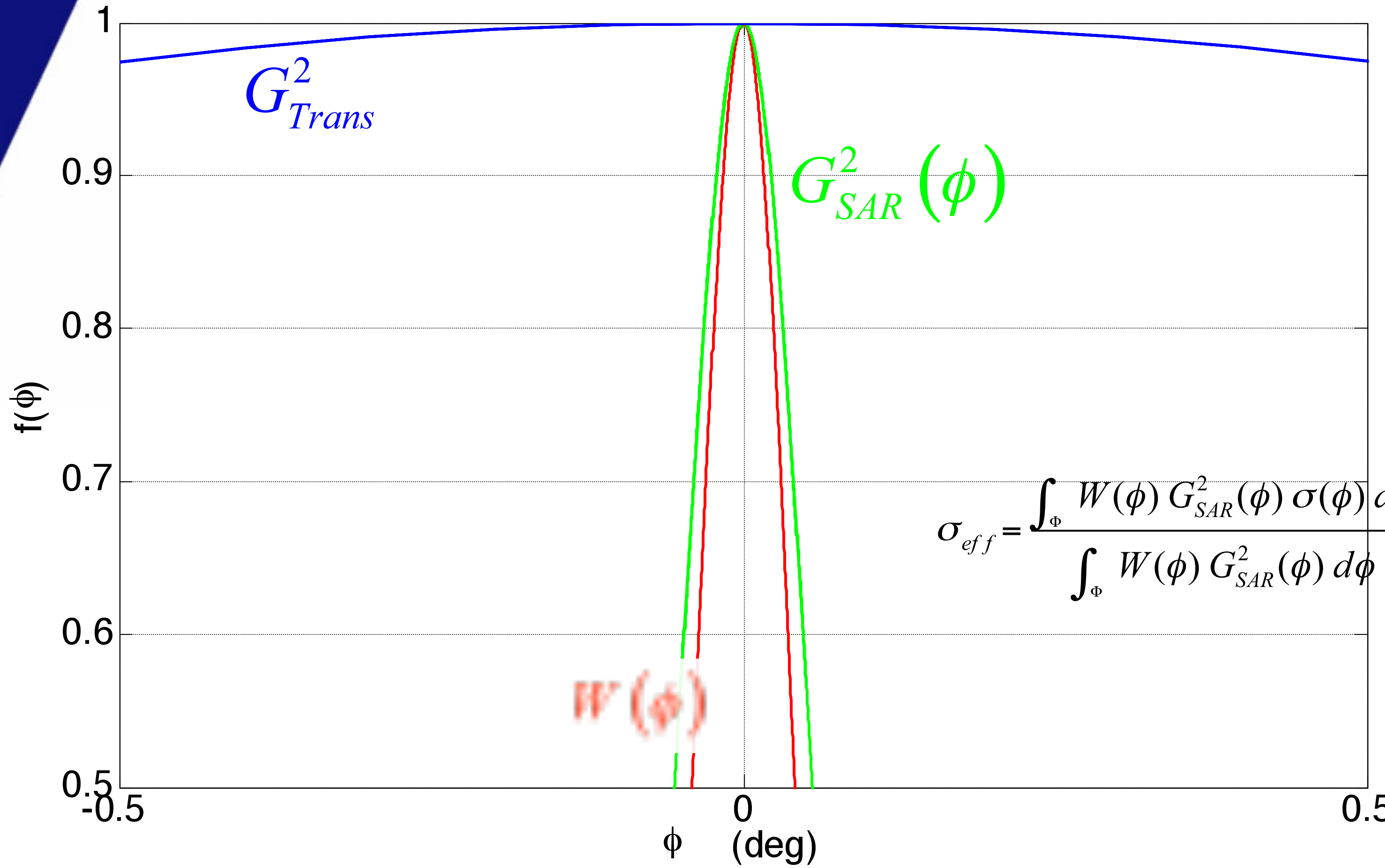
RCS over Synthetic Aperture



$$\sigma_{eff} = \frac{\int_{\Phi} W(\phi)\, g_{SAR}^{2}(\phi)\, \sigma(\phi)\, d\phi}{\int_{\Phi} W(\phi)\, g_{SAR}^{2}(\phi)\, d\phi}$$

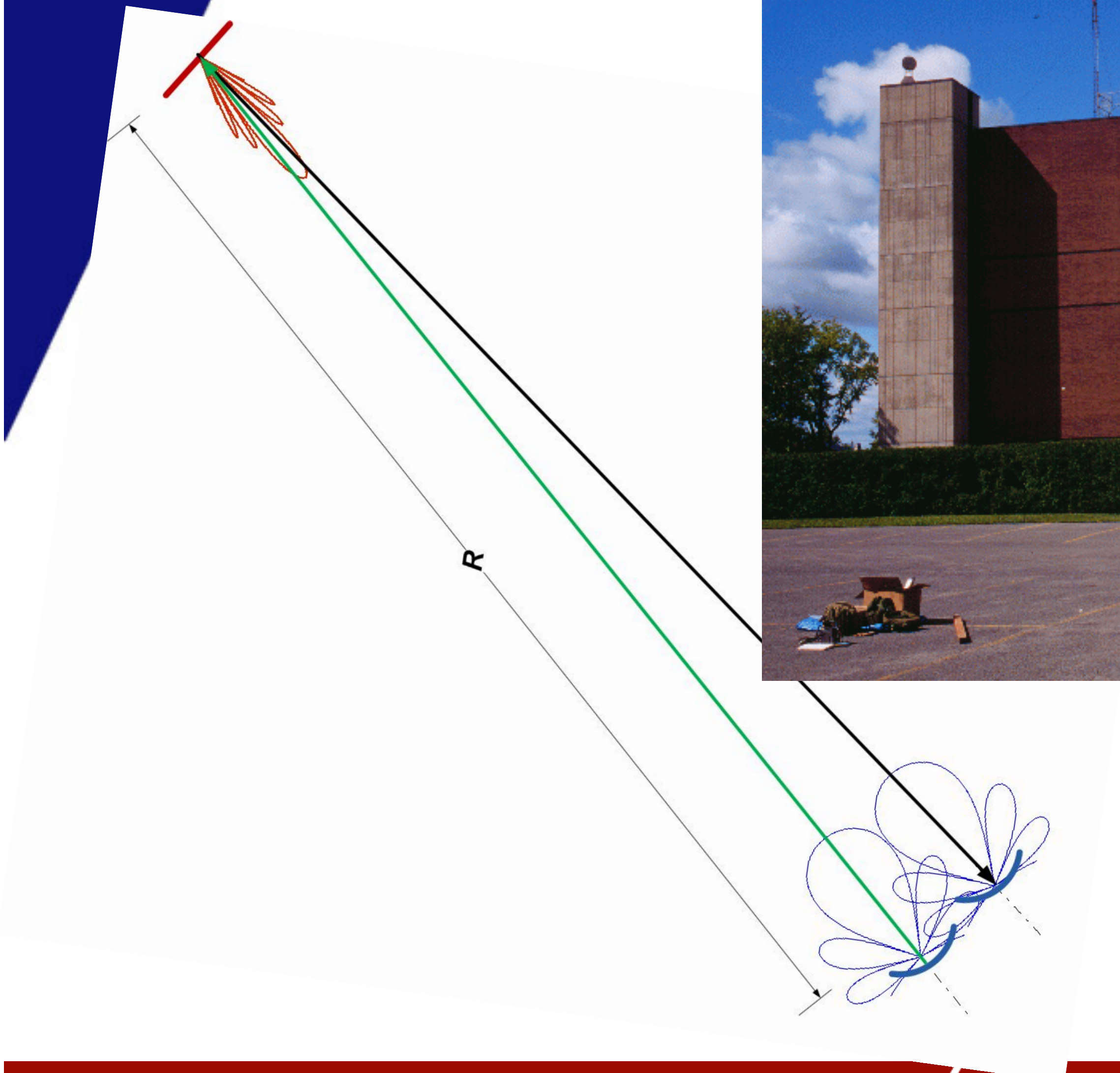
Pattern Over Synthetic Aperture

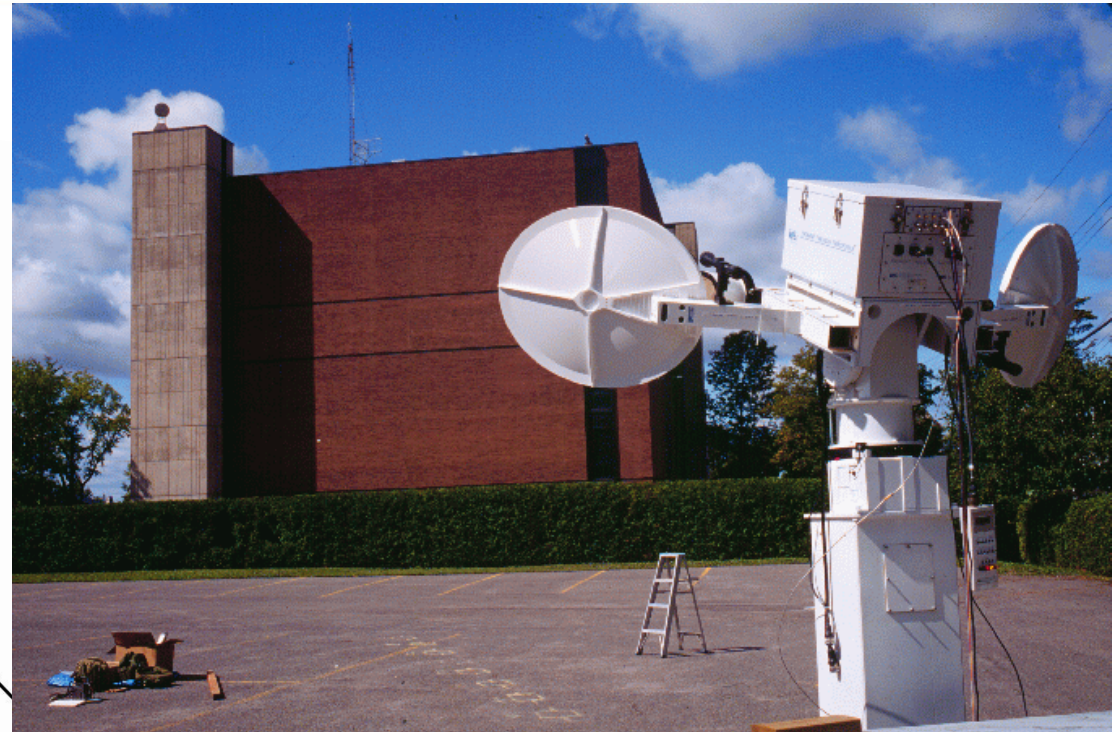
$$\Delta\sigma \sim 3\times10^{-4}\ \text{dB}$$



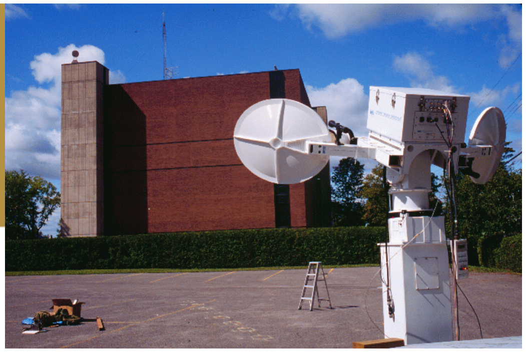
$$\sigma_{eff} = \frac{\int_{\Phi} W(\phi)\, G^2_{SAR}(\phi)\, \sigma(\phi)\, d\phi}{\int_{\Phi} W(\phi)\, G^2_{SAR}(\phi)\, d\phi}$$

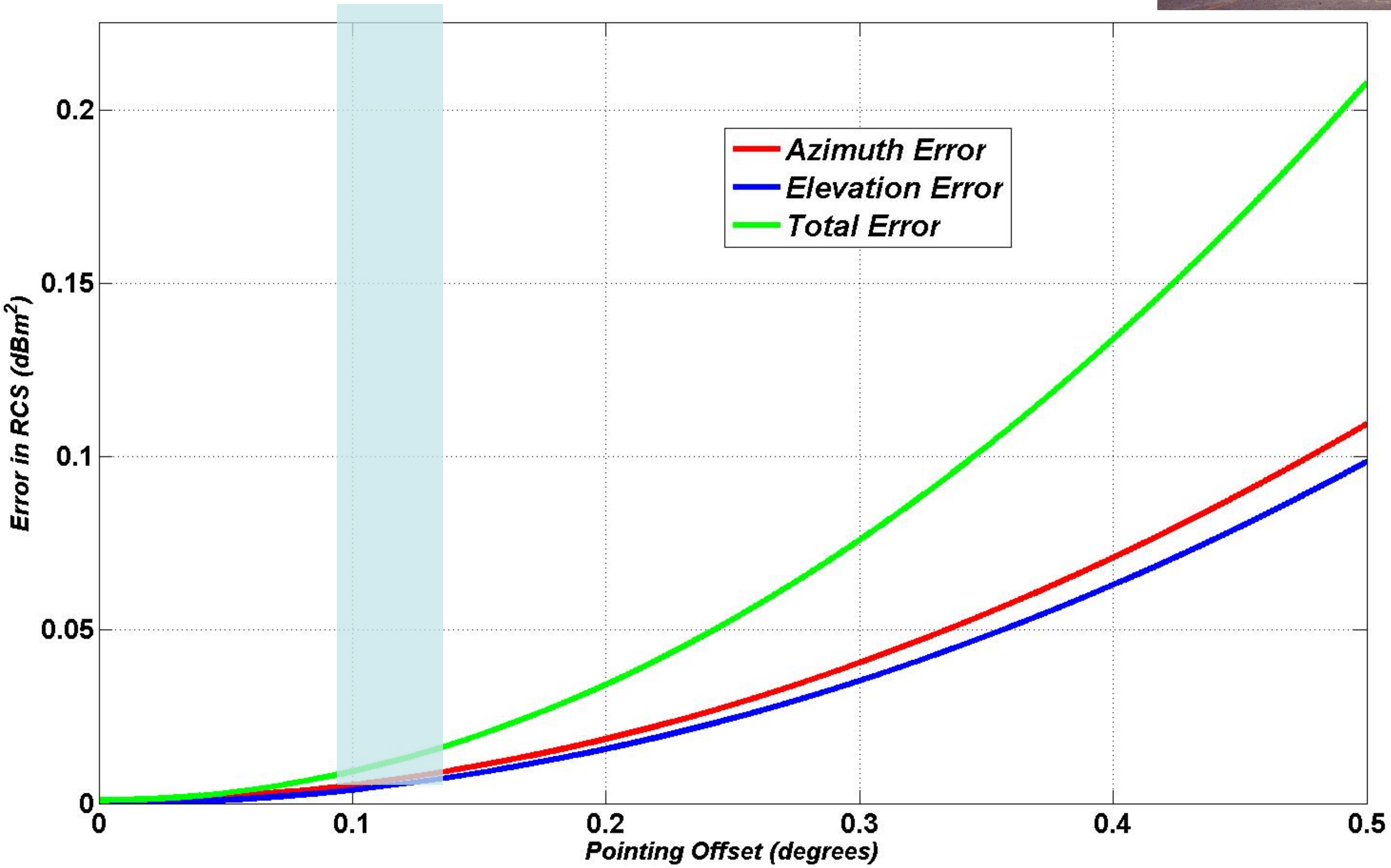
Calibration with Flat Plate



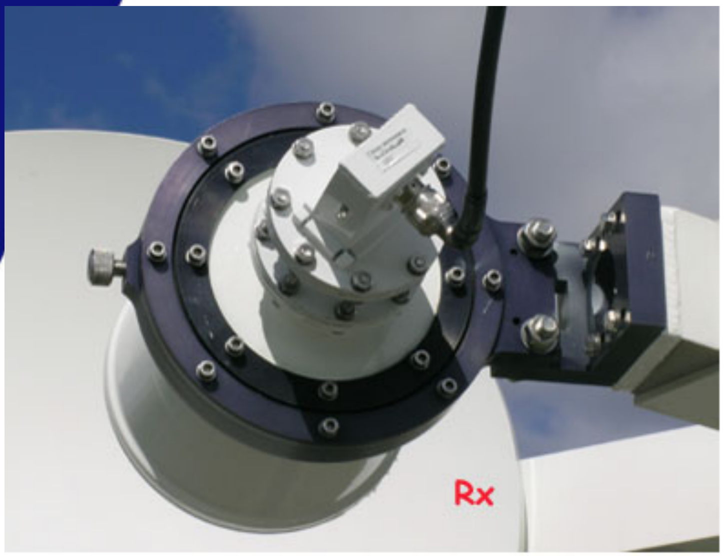


Illumination Integral over Flat Plate



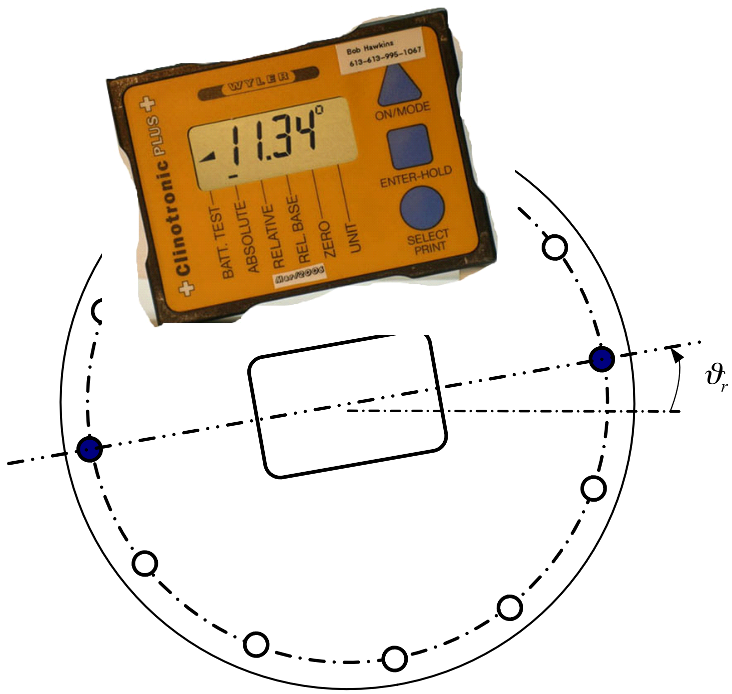


Polarization Measurements



- Tapered pin sets polarization
- H, V, 45°

Measurement wrt WG

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ABSOLUTE
RELATIVE
REL. BASE
ZERO
UNIT
WYLER
F 318

TEST MEASUREMENTS

TEST MEASUREMENTS

Test Measurement Results

Location	**Ottawa, ON0**			
Date	**March 30, 2006**		ϕ_{az} **0**	θ_{el} **0**
Temp/Time	**15.0/11:00**	**16.5/11:30**	**16.5/12:00**	**16.8/13:00**
Nom Pol	**Jig Normal**		**Jig Reverse**	
	Level Normal	**Level Reverse**	**Level Normal**	**Level Reverse**
(90) Rx V	◄0.24	►0.17	◄0.22	►0.17
(0) Rx…H	◄0.21	◄0.26	◄0.20	►0.25
(45) Rx. 45	◄45.20	►45.14	◄45.19	►45.14
(90) Tx V	►0.53	◄0.54	◄0.53	►0.50
(0) Tx…H	►0.55	►0.49	►0.55	►0.50
(45) Tx. 45	◄44.46	►44.40	◄44.43	►44.46

How polarization change?

$$\vec{P}_{Rx}^{Trans} = \vec{\vec{M}}\left(\theta_{Rx}^{Trans}\right)\vec{P}_{Rx_{nom}}^{Trans}$$

$$\theta_{Rx}^{Trans} = \begin{cases} \vartheta_r & \text{Clinotronic Normal} \\ \vartheta_r + 90^o & \text{Clinotronic Perpendicular} \end{cases}$$

$$\theta_{Tx}^{Trans} = -\begin{cases} \vartheta_r & \text{Clinotronic Normal} \\ \vartheta_r + 90^o & \text{Clinotronic Perpendicular} \end{cases}$$

$$\vec{P}_{Rx_{nom}}^{Trans} = \vec{P}_{Tx_{nom}}^{Trans} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$$\vec{\vec{M}}\left(\theta\right) = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

$$\vec{P}_{Tx}^{Trans} = \vec{\vec{M}}\left(\theta_{Tx}^{Trans}\right)\vec{P}_{Tx_{nom}}^{Trans}$$

How polarization change?

$$\vec{P}_{Rx}^{Trans} = \vec{\vec{M}}\left(\theta_{Rx}^{Trans}\right)\vec{P}_{Rx_{nom}}^{Trans}$$

$$\theta_{Rx}^{Trans} = \begin{cases} \vartheta_r & \text{Clinotronic Normal} \\ \vartheta_r + 90^o & \text{Clinotronic Perpendicular} \end{cases}$$

$$\theta_{Tx}^{Trans} = -\begin{cases} \vartheta_r & \text{Clinotronic Normal} \\ \vartheta_r + 90^o & \text{Clinotronic Perpendicular} \end{cases}$$

$$\vec{P}_{Rx_{nom}}^{Trans} = \vec{P}_{Tx_{nom}}^{Trans} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$$\vec{\vec{M}}(\theta) = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

$$\vec{P}_{Tx}^{Trans} = \vec{\vec{M}}\left(\theta_{Tx}^{Trans}\right)\vec{P}_{Tx_{nom}}^{Trans}$$

Impact on Effective RCS?

$$\begin{pmatrix} \sigma_{HH} & \sigma_{HV} \\ \sigma_{VH} & \sigma_{VV} \end{pmatrix} = \sigma \begin{pmatrix} \cos^2\theta_r^m \cos^2\theta_t^m & \cos^2\theta_r^m \sin^2\theta_t^m \\ \sin^2\theta_r^m \cos^2\theta_t^m & \sin^2\theta_r^m \sin^2\theta_t^m \end{pmatrix}$$

$$= \frac{\sigma}{4} \begin{pmatrix} \left[\cos\left(\theta_r^m - \theta_t^m\right) + \cos\left(\theta_r^m + \theta_t^m\right)\right]^2 & \left[\sin\left(\theta_r^m + \theta_t^m\right) - \sin\left(\theta_r^m - \theta_t^m\right)\right]^2 \\ \left[\sin\left(\theta_r^m + \theta_t^m\right) + \sin\left(\theta_r^m - \theta_t^m\right)\right]^2 & \left[\cos\left(\theta_r^m - \theta_t^m\right) - \cos\left(\theta_r^m + \theta_t^m\right)\right]^2 \end{pmatrix}$$

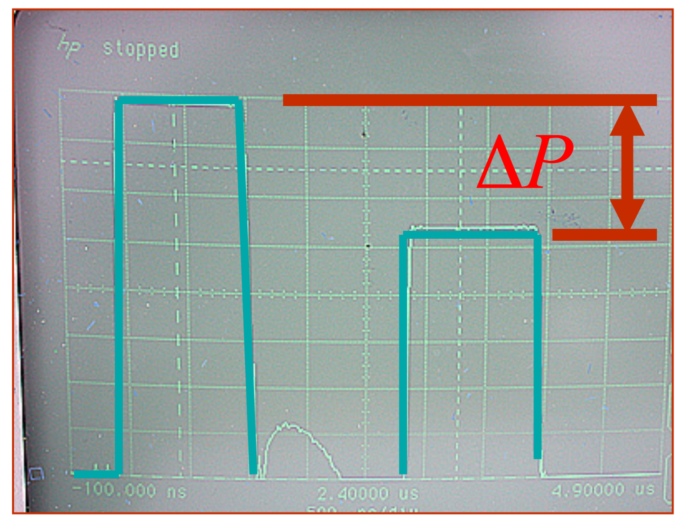
What happens during Calibration?

$$\sigma = \frac{64\lambda^2}{\pi}\left(\frac{R}{D}\right)^2 \Delta P_o$$

$$\Delta P = \Delta P_o \cos^2(\theta_t^{'} - \theta_r^{'})$$

$$\sigma_m = \sigma \cos^2(\theta_t^{'} - \theta_r^{'})$$
$$= \sigma \cos^2(\theta_t^{m} - \theta_r^{m})$$

$$\begin{pmatrix} \sigma_{HH} & \sigma_{HV} \\ \sigma_{VH} & \sigma_{VV} \end{pmatrix} = \sigma_m \left(\frac{\sigma}{\sigma_m}\right)$$
$$= \sigma_m \frac{\begin{pmatrix} \cos^2\theta_r^m \cos^2\theta_t^m & \cos^2\theta_r^m \sin^2\theta_t^m \\ \sin^2\theta_r^m \cos^2\theta_t^m & \sin^2\theta_r^m \sin^2\theta_t^m \end{pmatrix}}{\cos^2\left(\theta_t^m - \theta_r^m\right)}$$



Impact on Effective RCS?

$$\begin{bmatrix} \Delta\sigma_{HH} & \Delta\sigma_{HV} \\ \Delta\sigma_{VH} & \Delta\sigma_{VV} \end{bmatrix} = \begin{bmatrix} -0.04 & 0.13 \\ -0.09 & 0.08 \end{bmatrix} dBm^2$$

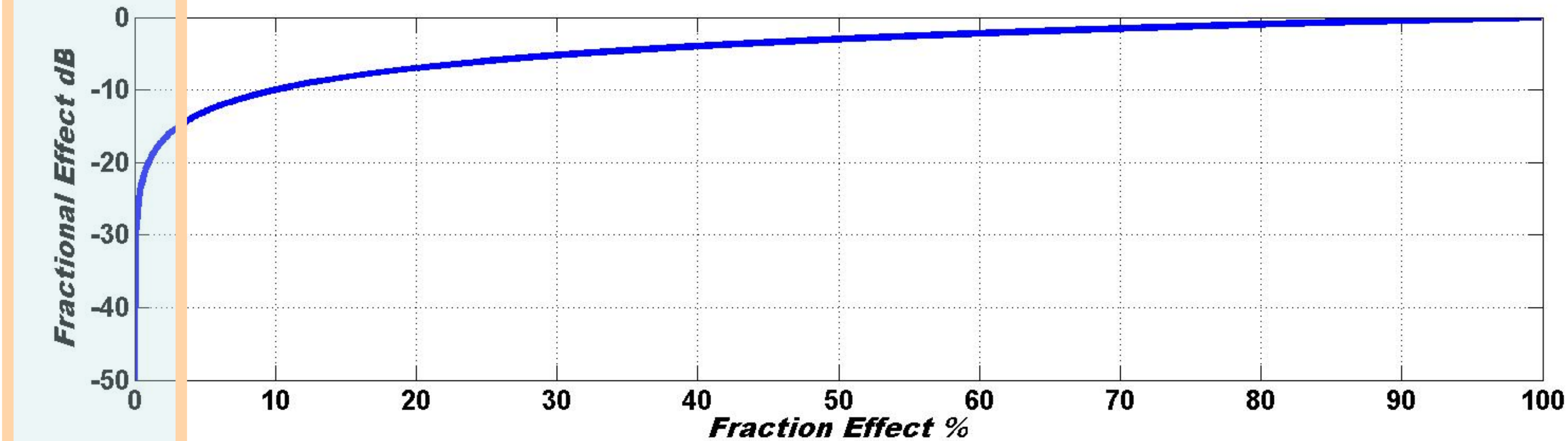
$$\begin{pmatrix} \theta_{Rx} \\ \theta_{Tx} \end{pmatrix} = \begin{pmatrix} 45.17^o \\ 44.44^o \end{pmatrix}$$

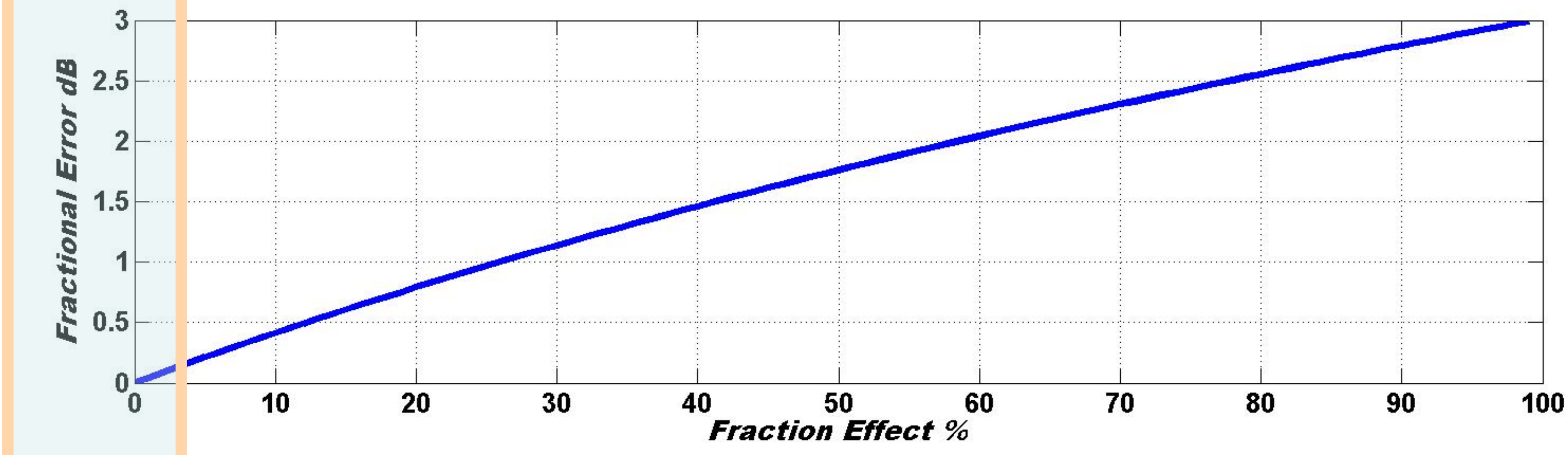
Transponder Generations

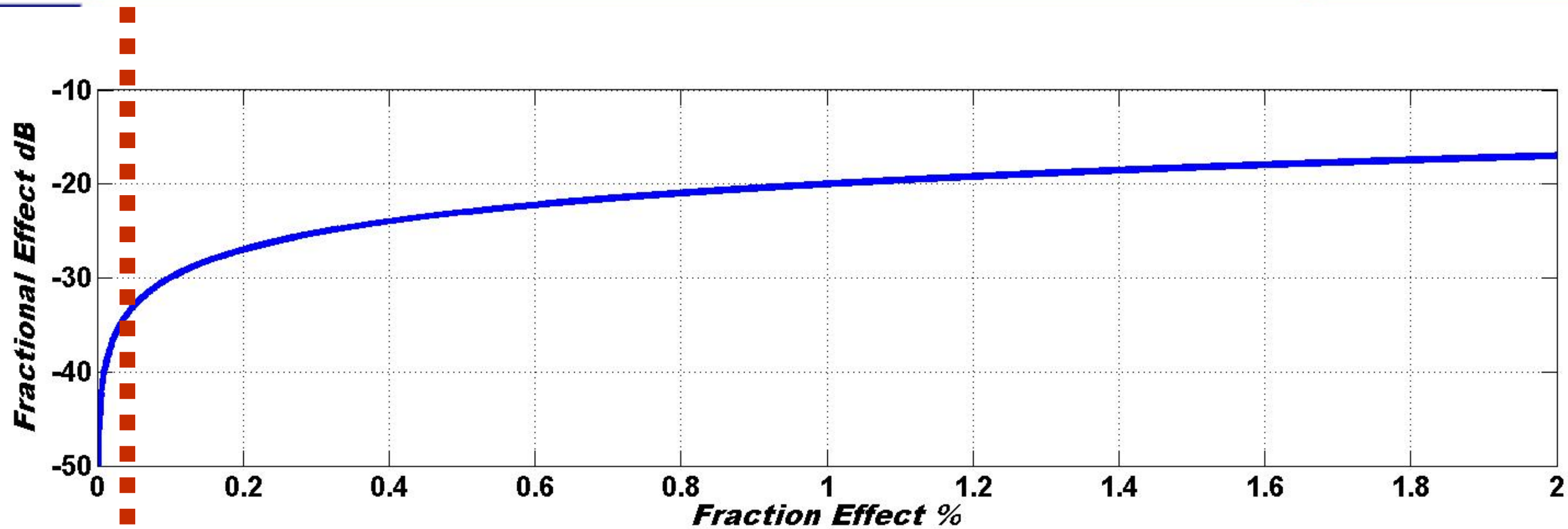
Polarizations	f_o (GHz)	MHz
$S_{ERS-1} = \begin{pmatrix} 0 & 0 \\ 0 & VV \end{pmatrix}$	5.300	15
$S_{RADARSAT-1} = \begin{pmatrix} HH & HV \\ VH & VV \end{pmatrix}$	5.300	30
$S_{Envisat} = \begin{pmatrix} 0 & 0 \\ 0 & VV \end{pmatrix}$ or $\begin{pmatrix} HH & 0 \\ 0 & 0 \end{pmatrix}$ or $\begin{pmatrix} 0 & HV \\ 0 & 0 \end{pmatrix}$ or $\begin{pmatrix} 0 & 0 \\ VH & 0 \end{pmatrix}$	5.331	16
$S_{RADARSAT-2} = \begin{pmatrix} 0 & 0 \\ 0 & VV \end{pmatrix}$ or $\begin{pmatrix} HH & 0 \\ 0 & 0 \end{pmatrix}$ or $\begin{pmatrix} 0 & HV \\ 0 & 0 \end{pmatrix}$ or $\begin{pmatrix} 0 & 0 \\ VH & 0 \end{pmatrix}$ or $\begin{pmatrix} HH & HV \\ VH & VV \end{pmatrix}$ or $\begin{pmatrix} HH & HV \\ VH & VV \end{pmatrix}$ $\begin{pmatrix} HH & 0 \\ VH & 0 \end{pmatrix}$ or $\begin{pmatrix} 0 & HV \\ 0 & VV \end{pmatrix}$ or $\begin{pmatrix} HH & HV \\ 0 & 0 \end{pmatrix}$ or $\begin{pmatrix} 0 & 0 \\ VH & VV \end{pmatrix}$	5.405	100

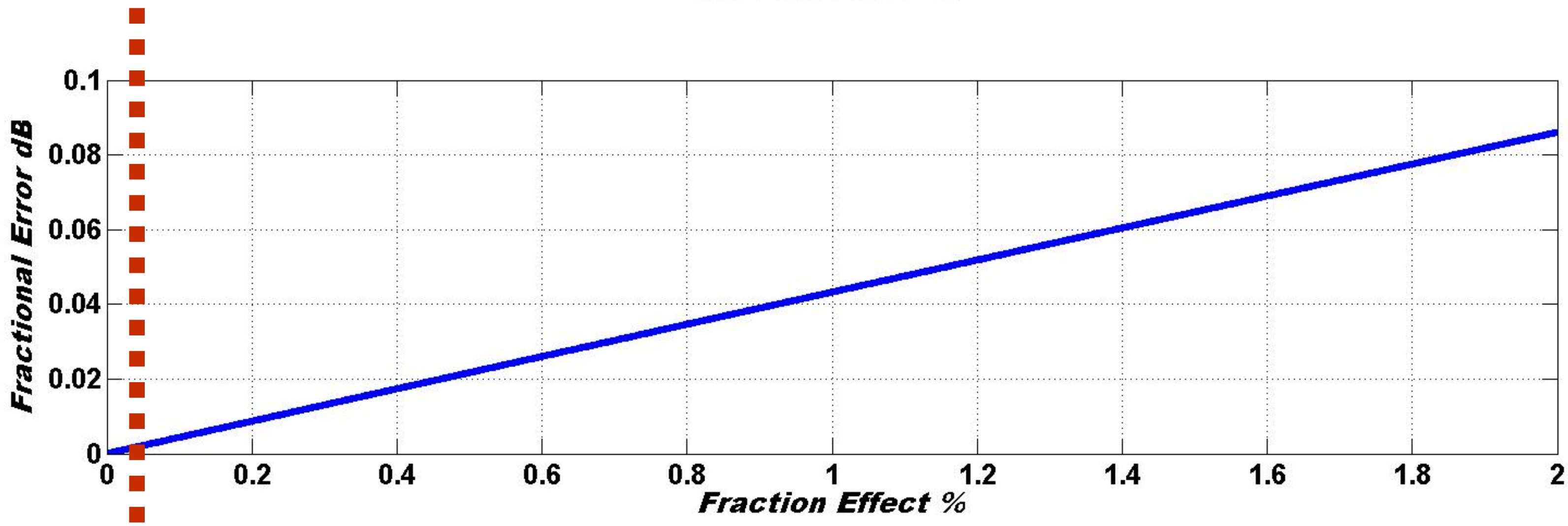
Conclusions

- Does the precise polarization of the satellite needs to be considered in the error budget?
- The ESA/ESTEC design was comprehensive.
- Newer satellites present more challenges for calibration targets.


Fractional Effect dB
0
-10
-20
-30
-40
-50
0
10
20
30
40
50
60
70
80
90
100
Fraction Effect %


Fractional Error dB
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
60
70
80
90
100
Fraction Effect %


-10
-20
-30
-40
-50
Fractional Effect dB
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Fraction Effect %


0.1
0.08
0.06
0.04
0.02
0
Fractional Error dB
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Fraction Effect %