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Development Path of a Ka-Band Extended Interaction Klystron for Space-borne Interferometer

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With special Thanks to Igor Botvinnik, Jose Fernandez, David Pukala,
Charles Le, Karthik Srinivasan
and Mike Settember of JPL
And
Agence Spatiale Canadienne / Canadian Space Agency

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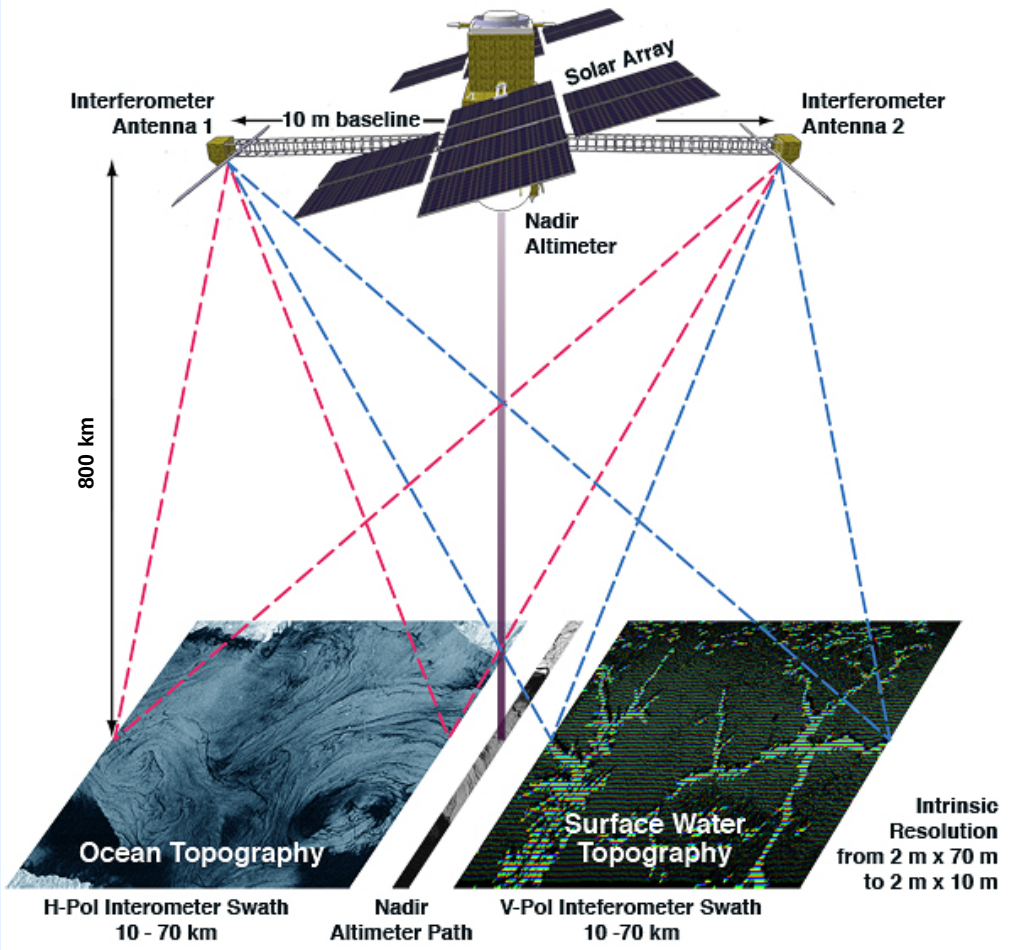
EIK Development for the SWOT Interferometer
SWOT Transmit-Receive Geometry

SWOT* Transits and Receives through **two antennas** with **two feeds each**, **separated by 10 meters** targeting two along-track swaths and attempts to use the geometry of the beams to **resolve cm-scale** height structure of bodies of water to **monitor levels of lakes, flow rates of rivers and ocean currents.**

Measurements are dependent on maintaining small uncertainties in effective path electrical length (wavelengths); therefore **HPA output phase must be quite stable.**

Since **SWOT will "chirp"** (sweep RF frequency across the pulse) **amplitude Vs. frequency** and **Vs. time** should be stable to facilitate separability of these parameters.



SWOT* = Surface Water and Ocean Topography

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Development Path of a Ka-Band EIK for Space-borne Interferometer

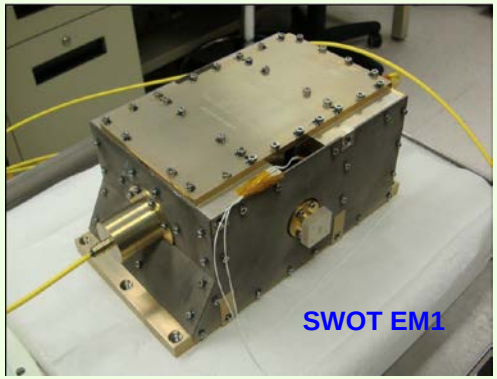
SWOT* will use an Extended Interaction Klystron (EIK) as its high power radar transmitter. This EIK belongs to a Communications and Power Industries, Canada (CPI) family of space-flight EIKs extending back to CloudSat

Program	Ctr Freq	Bandwidth	Peak Power	Duty
CloudSat	94 GHz	1 MHz (1 – dB)	1500 W EOL	1.4%
EarthCare	94 GHz	1 MHz (1 – dB)	1500 W EOL	2.2%
EGPM	35.5 GHz	170 MHz (1 – dB)	1300 W EOL	5% (Tested)
SWOT	35.75 GHz	240 MHz (0.2 – dB)	1500 W EOL	7% (10% Tested)

CloudSat

EarthCare

EGPM


SWOT EM1

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Development Path of a Ka-Band EIK for Space-borne Interferometer – EGPM Heritage

The SWOT EIK's most direct heritage is EGPM

- **Center Frequency (35.5 GHz Vs. 35.75 GHz for SWOT)**
- **Output Power level (1300 W Vs. 1750 W BOL for SWOT)**

SWOT Differences from EGPM

- **Broader passband**
- **Stringent phase and amplitude stability Requirements that were not required of EGPM**
  - **This stability includes unaccustomed amplitude flatness across a wide band – a key EIK design driver**
  - Precisely characterized EIK Phase and Amplitude pushing factors
    - Input for HVPS Voltage Stability Requirements.
    - Reference RF stability characterization for a known set of (bench supply) HVPS voltage stabilities.

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Development Path of a Ka-Band EIK for Space-borne Interferometer – EGPM Heritage

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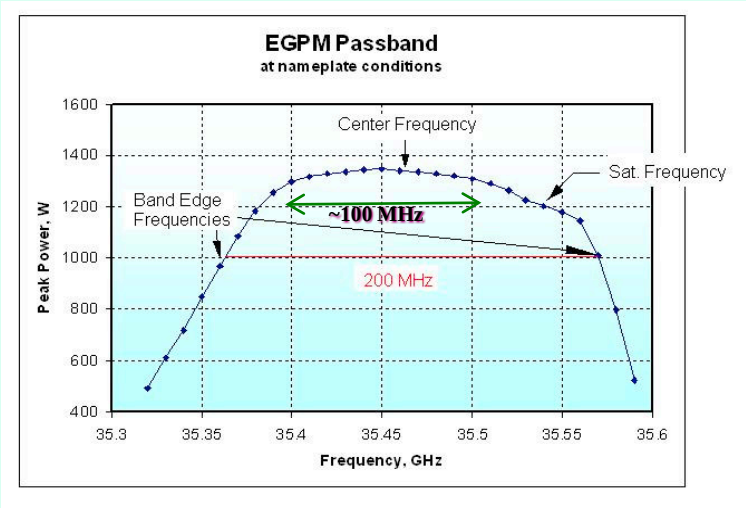
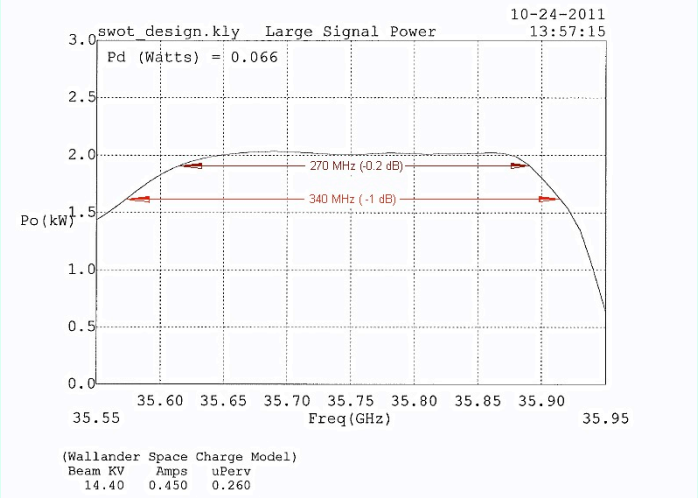
EGPM Heritage Passband issue

- **EGPM Passband was defined as the frequency range over which the RF output power drops by 1 dB**
- **SWOT Radar System Engineering desired a 0.2 dB flatness over the band to avoid phase noise and Group Delay degradation**



Would require adjusted cavity design parameters



Pushing Factors Uncertainty Issue

- **CPI and JPL were unsure of uncertainty in 2009 measurements of EGPM Pulse Amplitude and Phase "Pushing Factors.**
  - **Resolved acceptably with Jan-Feb 2012 Testing at CPI with Sect 334 (Tope, Perkovic, et al) Test Set. degradation**

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Development Stages of a Ka-Band EIK for Space-borne Interferometer

Stages of SWOT EIK Development from EGPM:

- **EGPM** Engineering Model **(EM)** EIK tested by CPI, JPL (Tests Jan-Feb, 2012)
  - Phase and Amplitude Pushing Factors (wrt Grid & Cathode Voltage, temperature)
  - Provided input to refine computer models of the EIK design and informed SWOT-specific EIK design
  - Developed preliminary limits on acceptable HVPS Grid and Cathode voltage noise

- **SWOT** Demonstration Model **(DM)** EIK developed by CPI, tested by CPI, JPL (Tests Feb-Mar, 2014)
  - Phase, Amplitude and Group Delay Pushing Factors (wrt Grid & Cathode Voltage, temperature)
  - Confirmed operability with Breadboard HVPS

- Based on analysis of SWOT DM tests, **SWOT** Engineering Model **(EM1)** EIK developed by CPI, tested by CPI, JPL (Tests Sept-Oct, 2015)
  - Phase, Amplitude and Group Delay Pushing Factors (wrt Grid & Cathode Voltage, temperature)
  - Established PDR-ready HVPS Grid and Cathode voltage noise requirements

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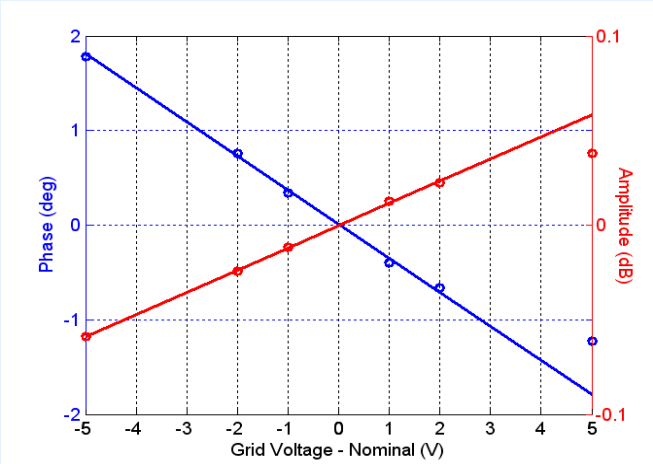
Development Path of a Ka-Band EIK for Space-borne Interferometer

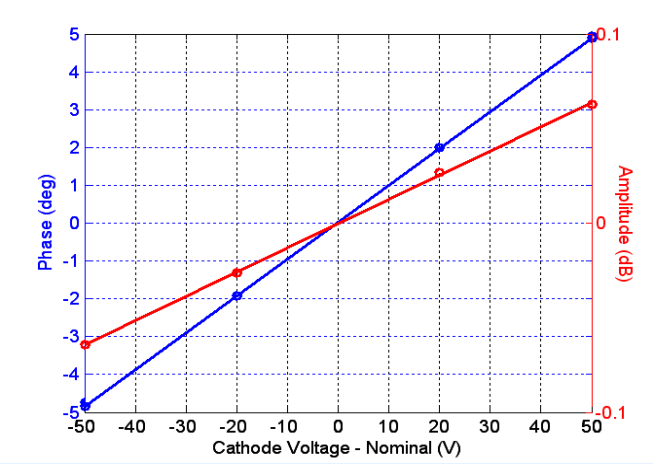
EGPM Characterization Testing

- 2009 – Coarse pushing factor characterizations (instrument feasibility study)
- Jan-Feb, 2012 used a sophisticated performance measurement system to evaluate
  - Grid and Cathode Amplitude and Phase Pushing Factors
  - Amplitude and Phase temperature sensitivities
  - Drift of Phase and Amplitude for 4 hour run time

Grid phase pushing factor: -0.36deg/V
Grid amplitude pushing factor: 0.012dB/V



Cathode phase pushing factor: 0.1deg/V
Cathode amplitude pushing factor: 0.0013dB/V



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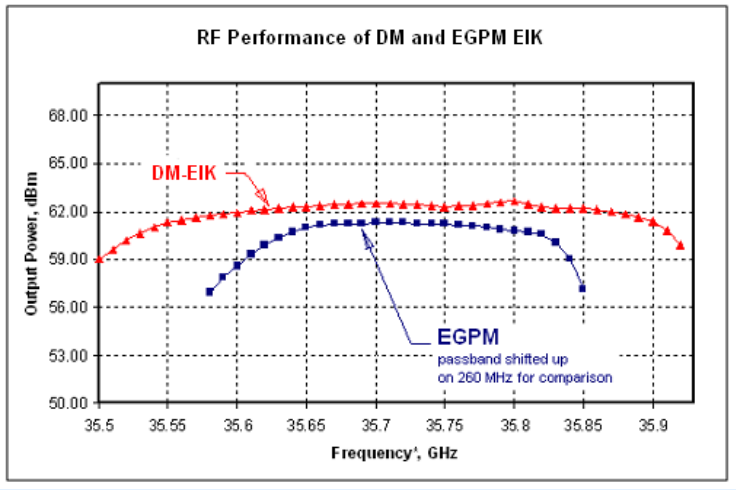
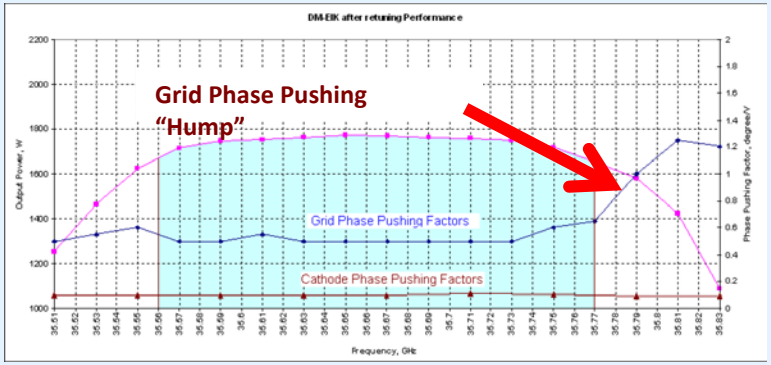
Development Path of a Ka-Band EIK for Space-borne Interferometer DM Results

Demonstration Model (DM) Development at CPI

- **Based on EGPM performance relative to SWOT requirements, CPI successfully adapted the EGPM RF circuit design to achieve broader, flatter passband**



- **DM RF circuit cold testing revealed tuning limit of one cavity before achieving it's proper center frequency. This resulted in a "Hump" in Grid Phase Pushing factor at the upper end of the passband. CSA, CPI and JPL jointly decided to proceed with DM EIK build and test to advance understanding of all SWOT EIK performance parameters**
- **Design adjustment made for the EM1 EIK to move Grid Phase Pushing "Hump" out of band.**



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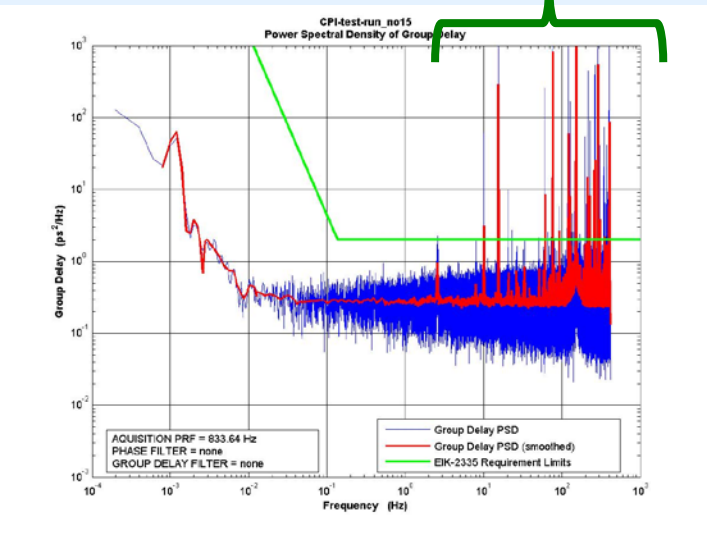
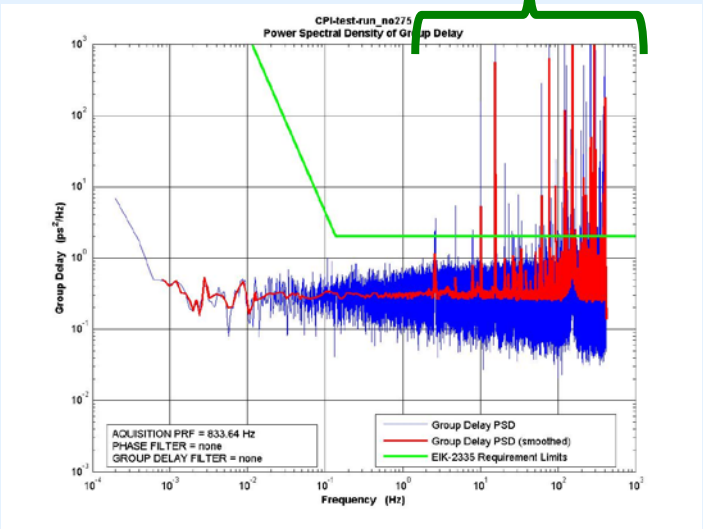
Development Path of a Ka-Band EIK for Space-borne Interferometer DM Stability Results

Even with the Phase Pushing factor “Hump” at the upper band edge, its effects on the DM EIK Group Delay PSD performance was masked by test set noise and spurs.

Artifacts of GSE spurs



DM EIK Group Delay PSD



GSE Only Group Delay PSD

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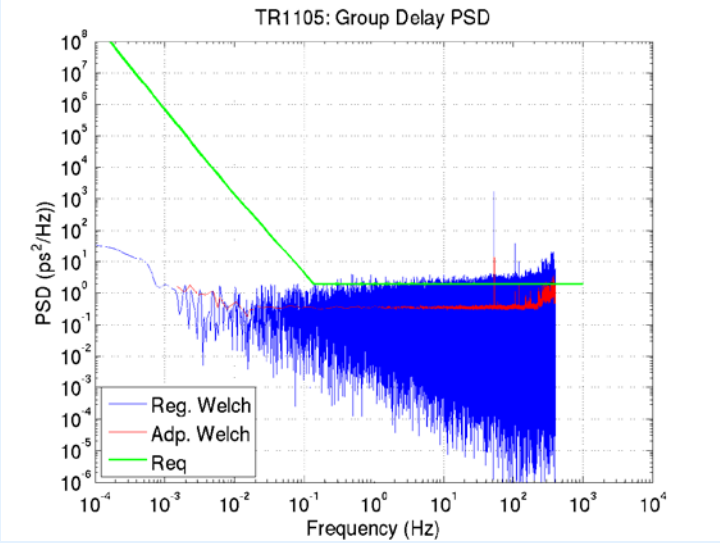
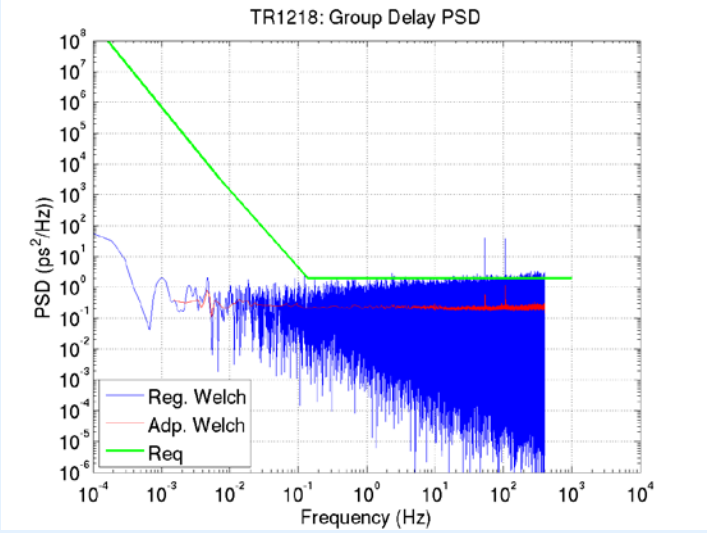
Development Path of a Ka-Band EIK for Space-borne Interferometer EM1 Results

Based on the DM EIK test results, for the EM1 design CPI adjusted the RF circuit design to move the Phase Pushing factor "Hump" above the high end of the SWOT frequency band.



EM1 EIK Group Delay PSD



GSE Only Group Delay PSD

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Development Path of a Ka-Band EIK for Space-borne Interferometer Conclusion

Nutshell View:

- **No one could have been certain that the Phase and Group Delay stability goals could be met when the SWOT EIK development efforts began.**
- **The joint US/Canadian team has retired many risks and uncertainties.**
- **The SWOT EIK Design has been proven to perform well.**
- **The EIK Performance characterization enabled adjustment of the HVPS development to achieve its voltage control requirements. DM EIK – BB HVPS testing at JPL in March 2015 confirmed the combined EIK-HVPS performance.**
- **The EM1 EIK design has been jointed accepted for flight SWOT EIKs by CSA,CPI and JPL.**

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