# Ku-Band Enhanced MetaSurface Radar with CMOS System-on-Chip Radar Using Hardware Machine Learning for Enhanced Remote Snowpack Sensing

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# What you need to Measure SWE

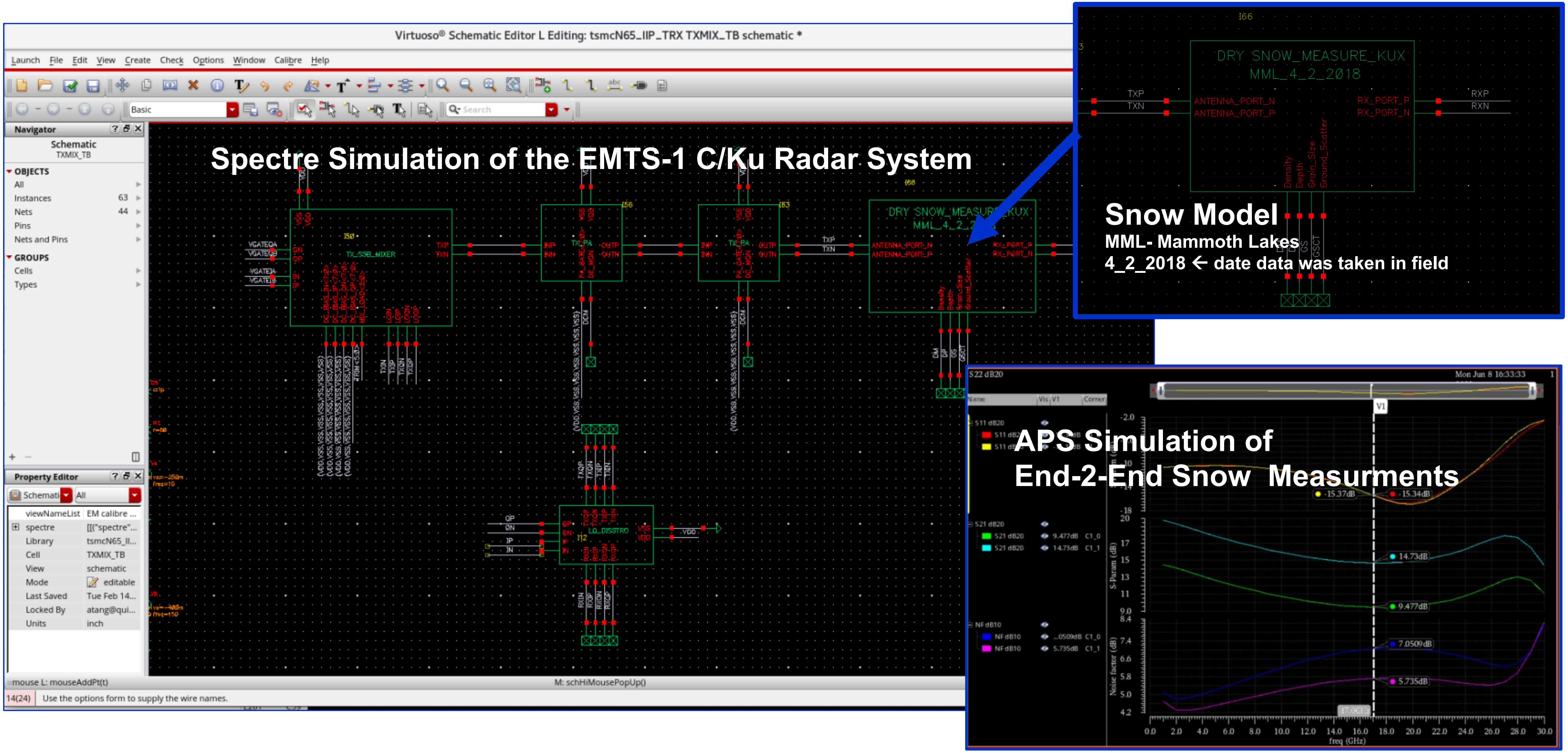
**Snow Cover**: The area covered by snow. This can be either 2D or 3D (mountainous) terrain.

**Snow Depth**: The total depth of the snow at each point within the snow cover.

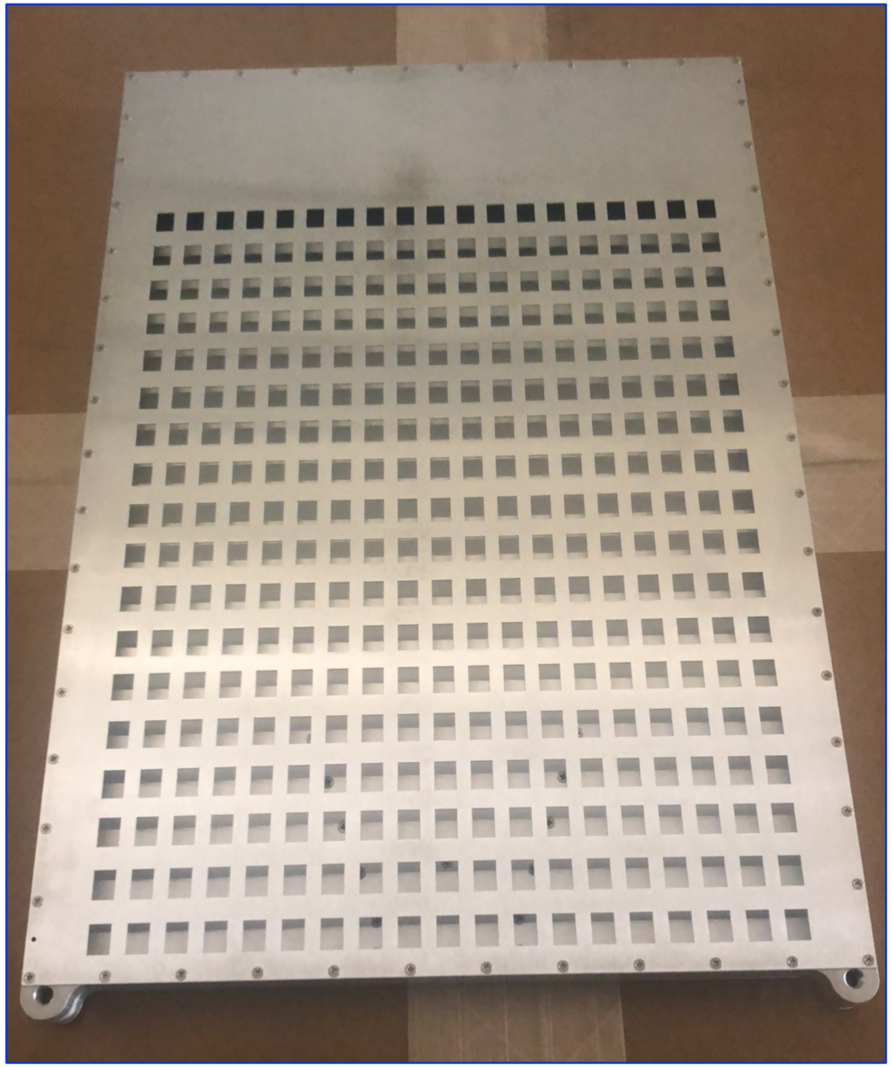
**Snow Density**: The density or how “packed” the snow is at each point within the overall snow cover… up to 40% of the SWE!

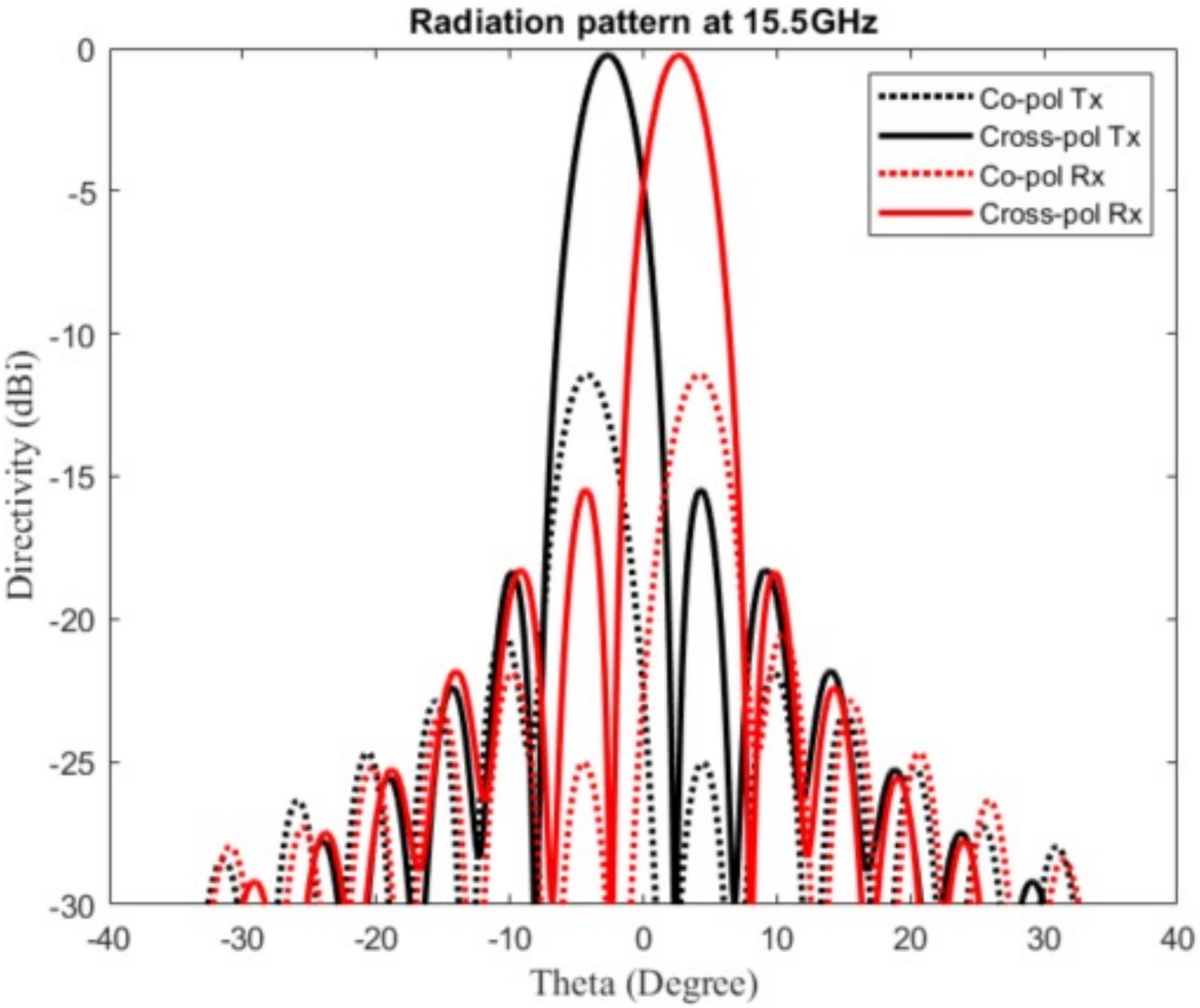
**Snow Liquid Water Content**: Snow has liquid water both throughout the volume and pooled at the bottom that needs to be counted… up to 30% of the SWE!

# Designing Radars Specifically for Snow



# Design of EMTS-1 MetaSurface





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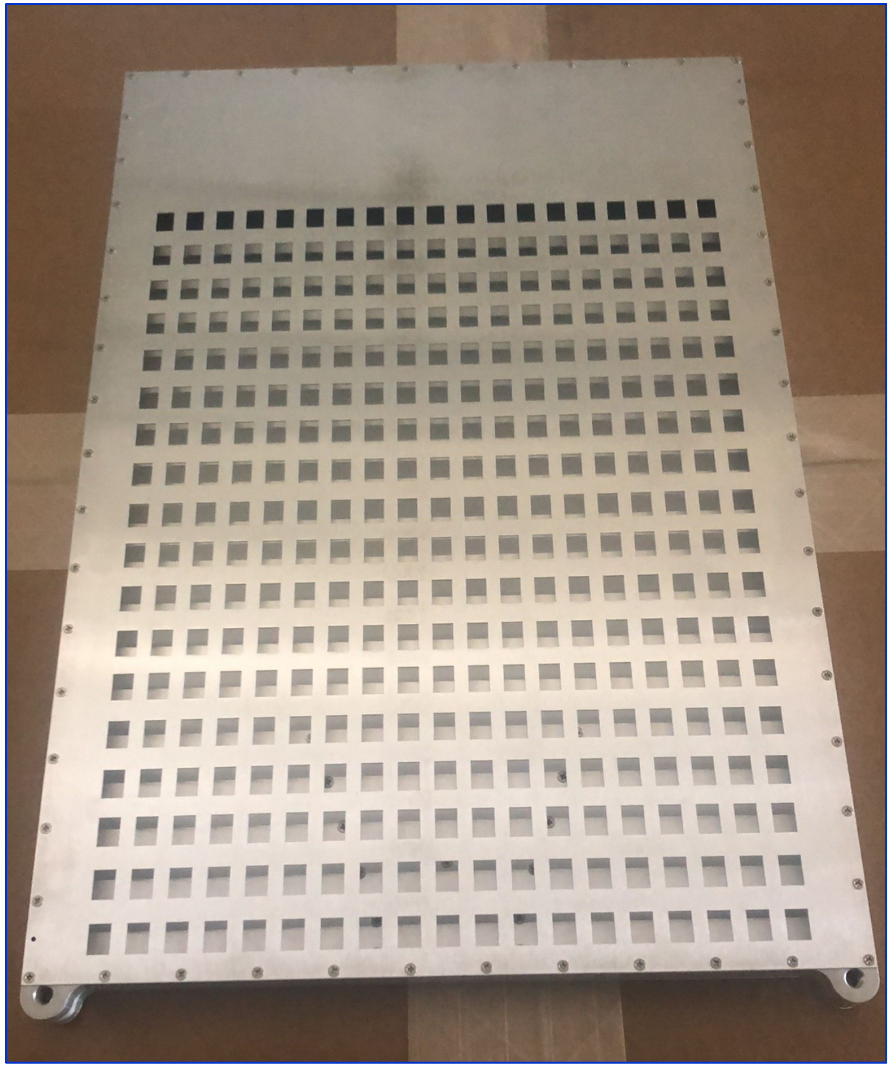
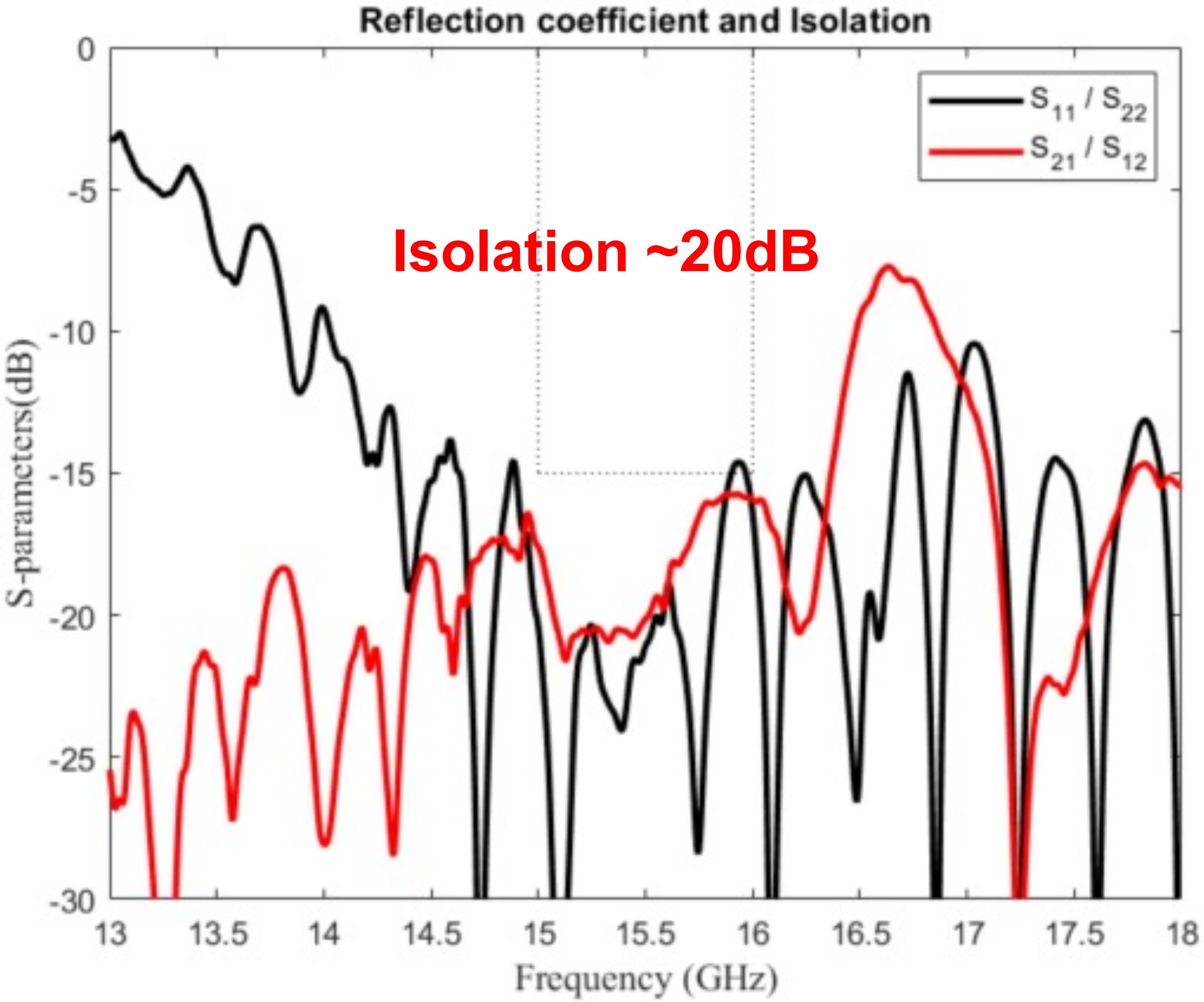
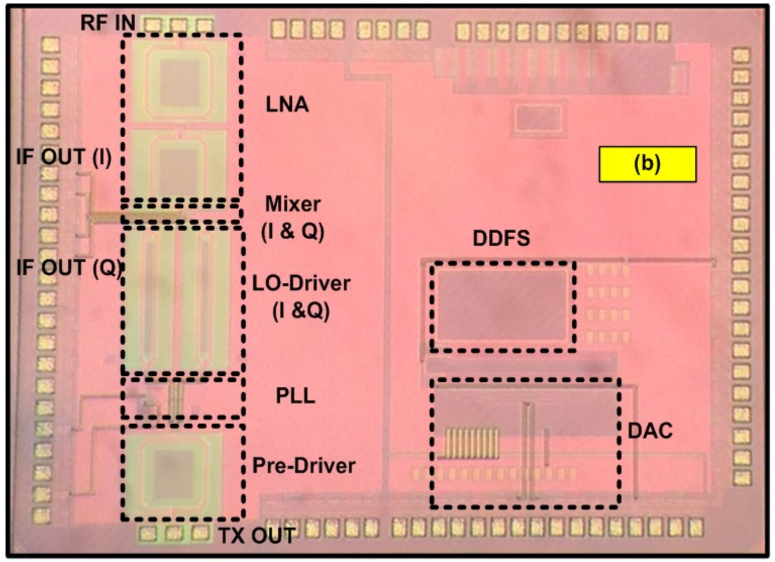
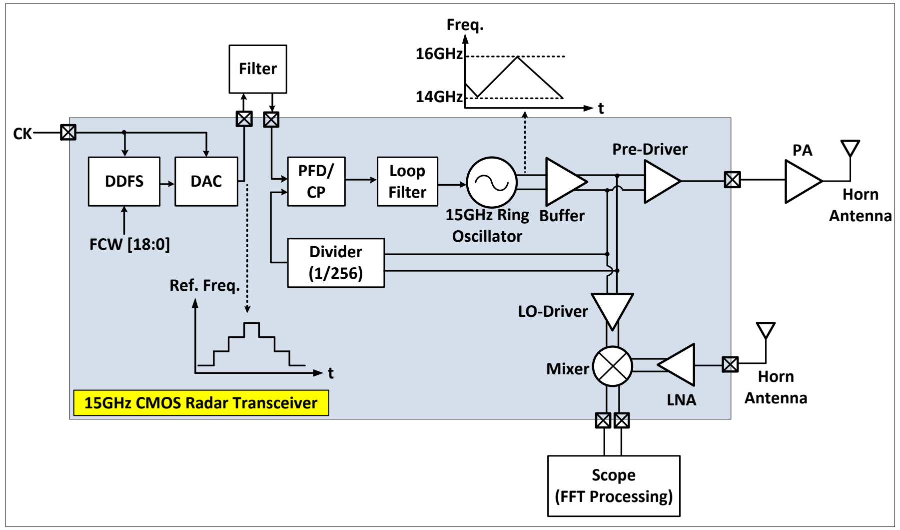




# Design of EMTS-1 (Initial Ku Build)



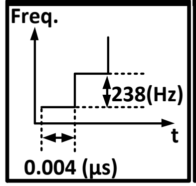

| RF Chirp Parameter | |
|---|---|
| Chirp Bandwidth (GHz) | 2 |
| Range Resolution (cm) | 7.5 |
| Frequency Low (GHz) | 14 |
| Frequency Center (GHz) | 15 |
| Frequency High (GHz) | 16 |
| PLL Division Ratio | 256 |

| DDFS Parameter | |
|---|---|
| Clock Frequency (MHz) | 250 |
| Clock Period (µs) | 0.004 |
| Accumulator Bits | 19 |
| Accumulator Levels | 524288 |
| Nyquist Rate (MHz) | 125 |
| Step Size (Hz) | 238.41858 |
| Start FCW Code | 229376 |
| Stop FCW Code | 262144 |
| Reference BW (MHz) | 7.8125 |
| Reference BW (Codes) | 32768 |
| Chirp Time (µs) | 131.072 |

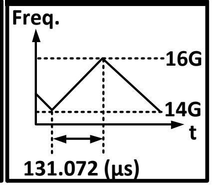
| Reference Chirp Parameter | |
|---|---|
| Reference Low (MHz) | 54.6875 |
| Reference Center (MHz) | 58.59375 |
| Reference High (MHz) | 62.5 |

| Radar Performance | |
|---|---|
| Chirp Rate (Hz/s) | $1.53 \times 10^{13}$ |
| Radar Gain (MHz/m) | 0.1017 |
| Midrange IF (MHz) | 1000 |
| Operation Range (m) | 100 |
| Operation IF (MHz) | 10.1725 |
| Range Bin (KHz) | 7.6 |
| Spatial Resolution (m) | 6 |

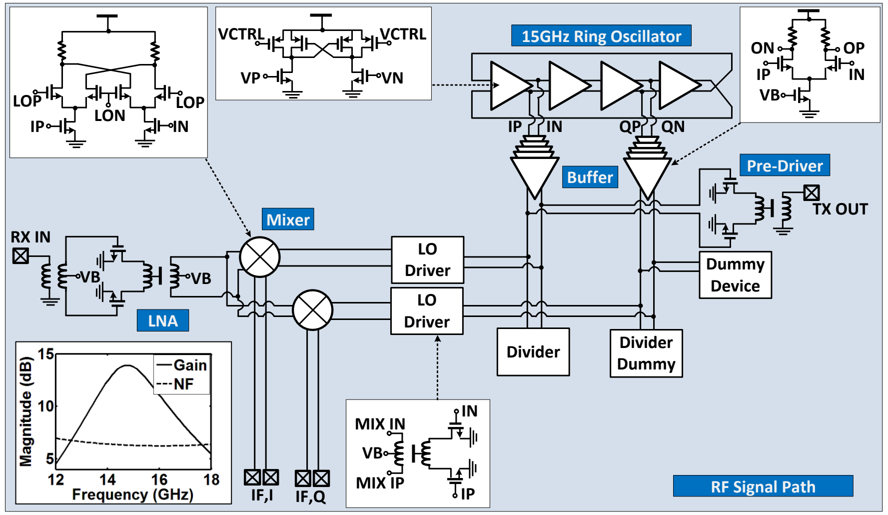
**Reference Chirp**

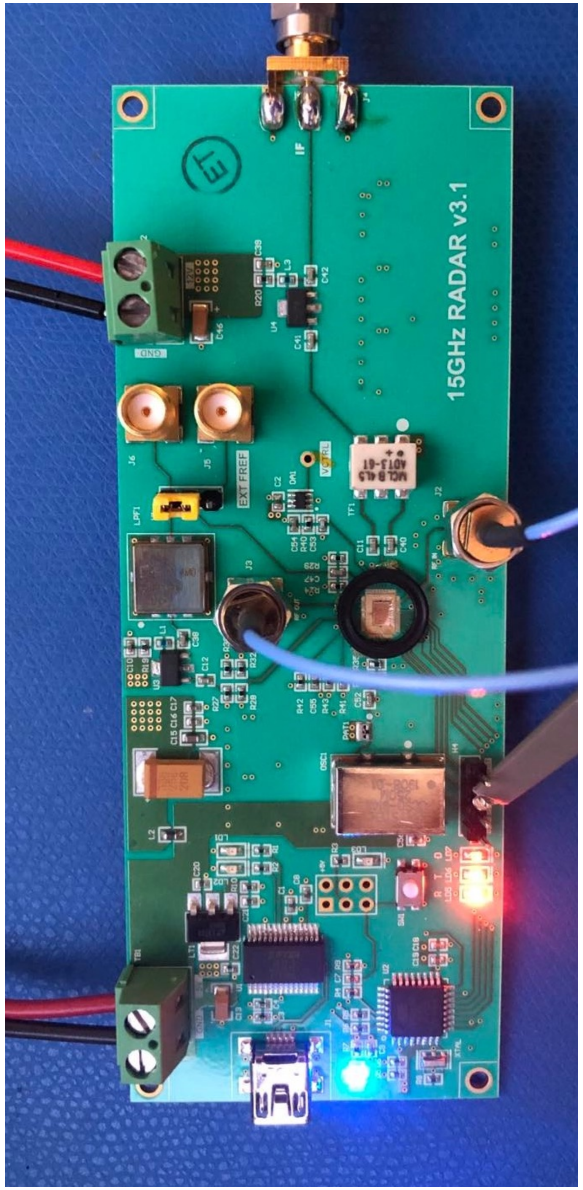



**RF Chirp**

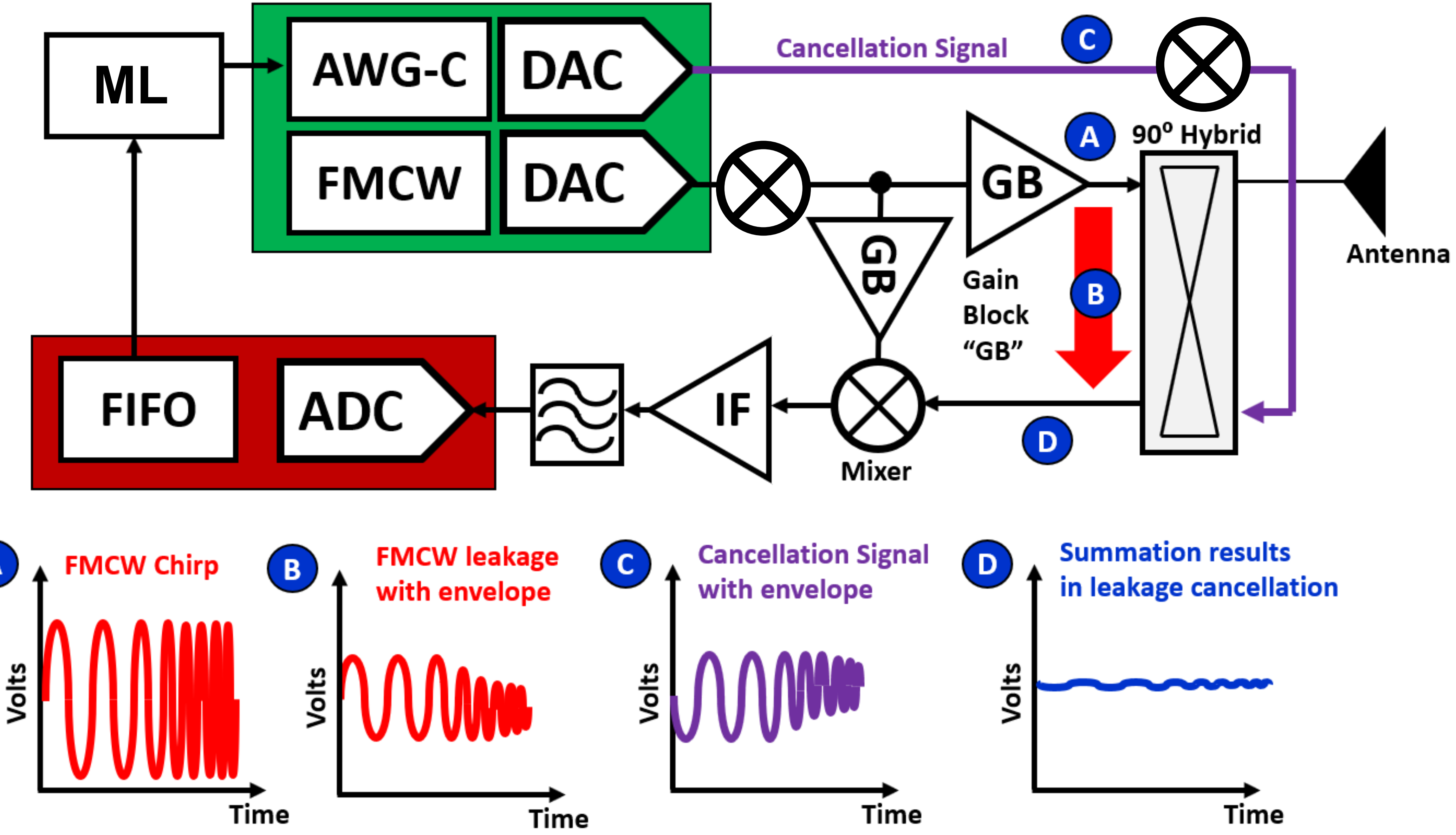



## RF Front End Design Details



# EMTS-1 Leakage Cancellation Engine



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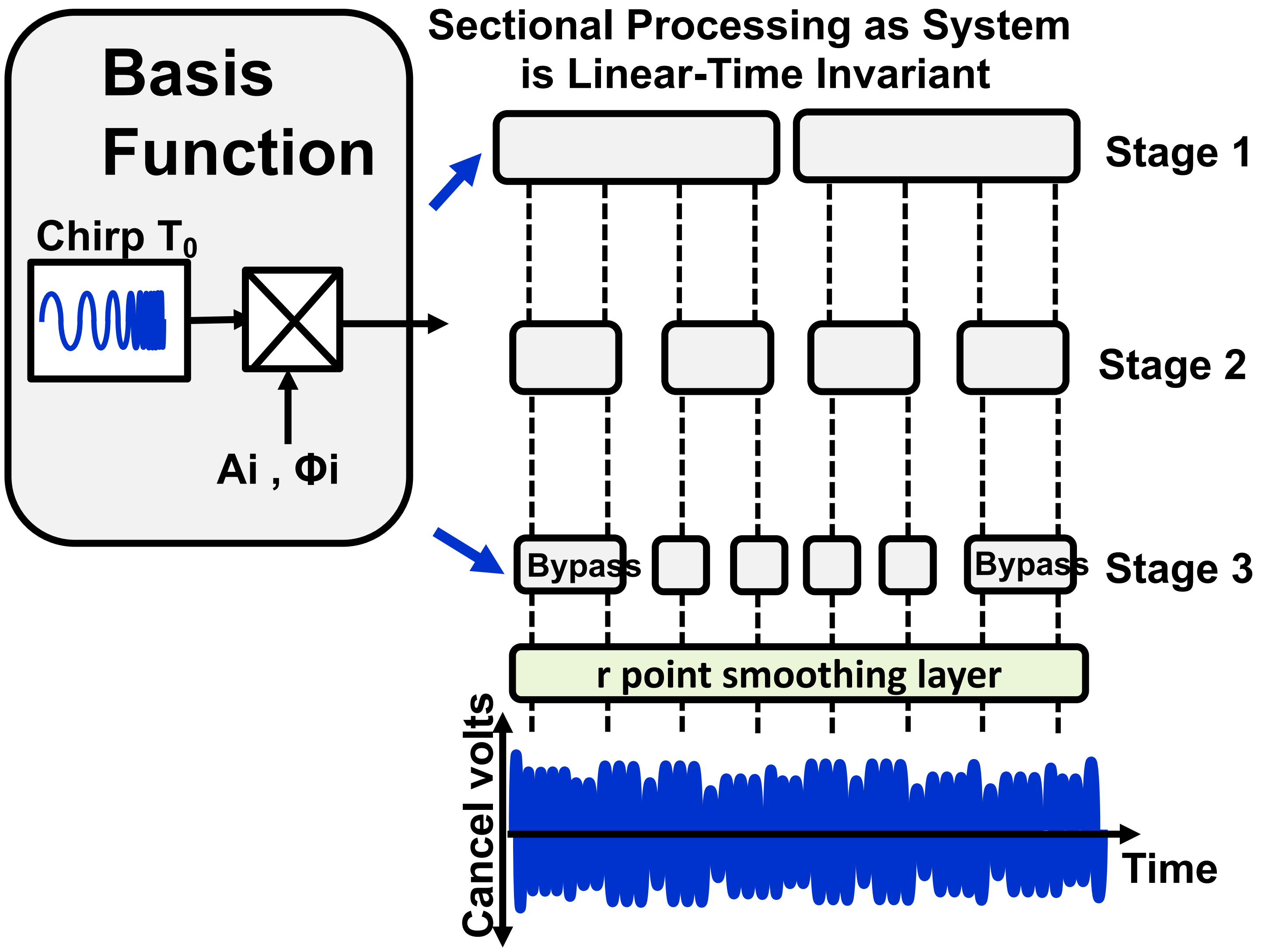
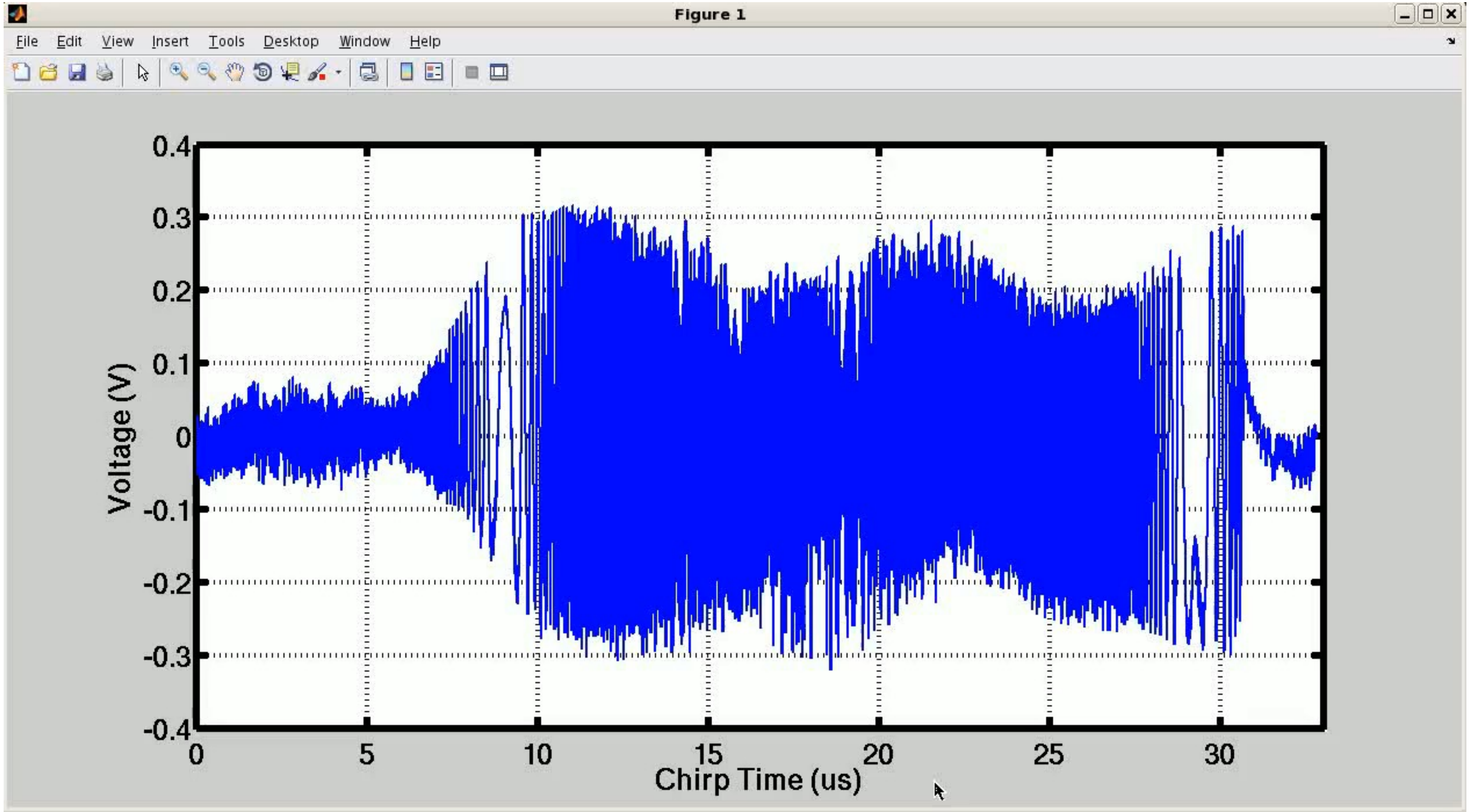
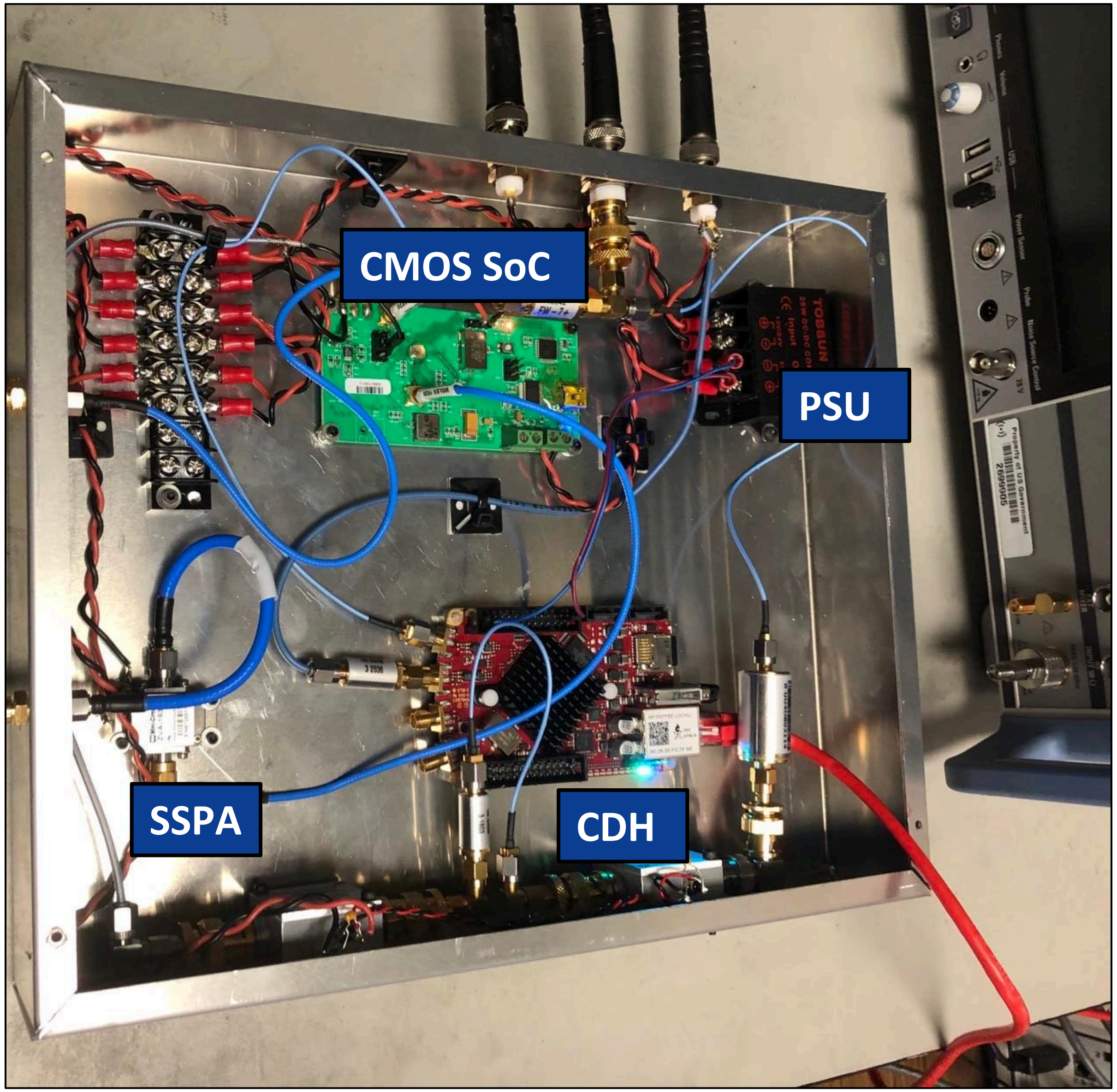


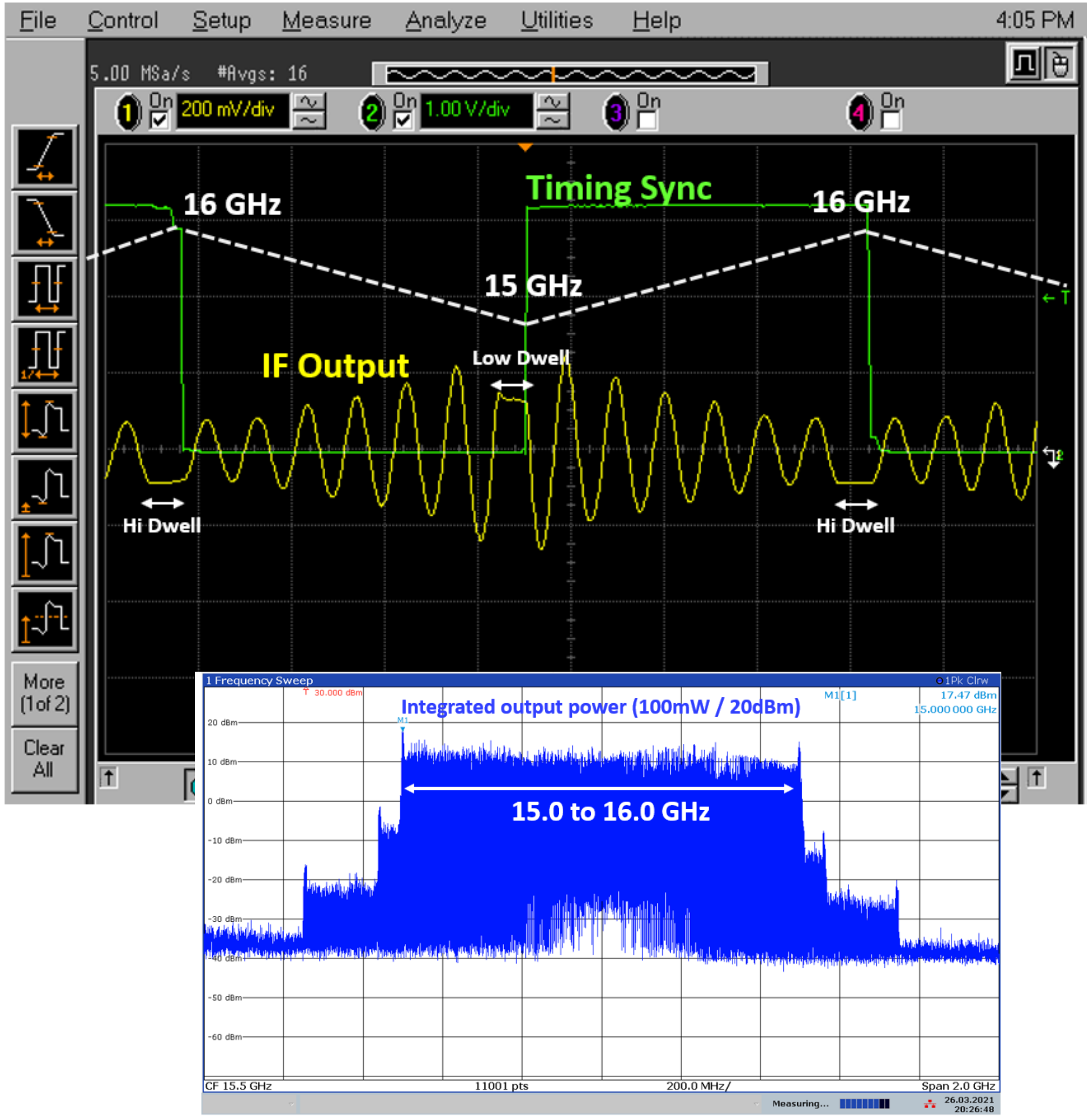

Candidate Cancellation Signal

# EMTS-1 Leakage Cancellation Engine

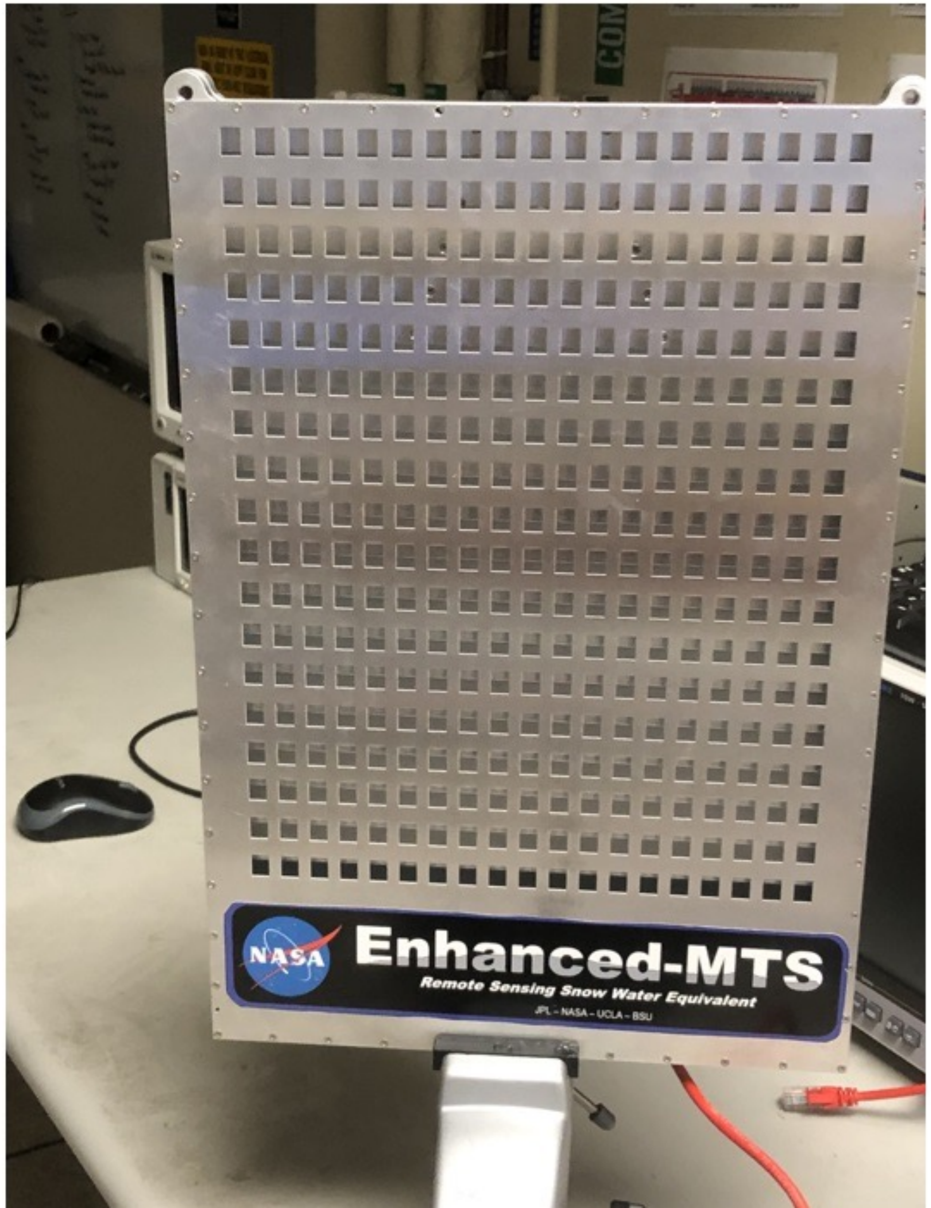


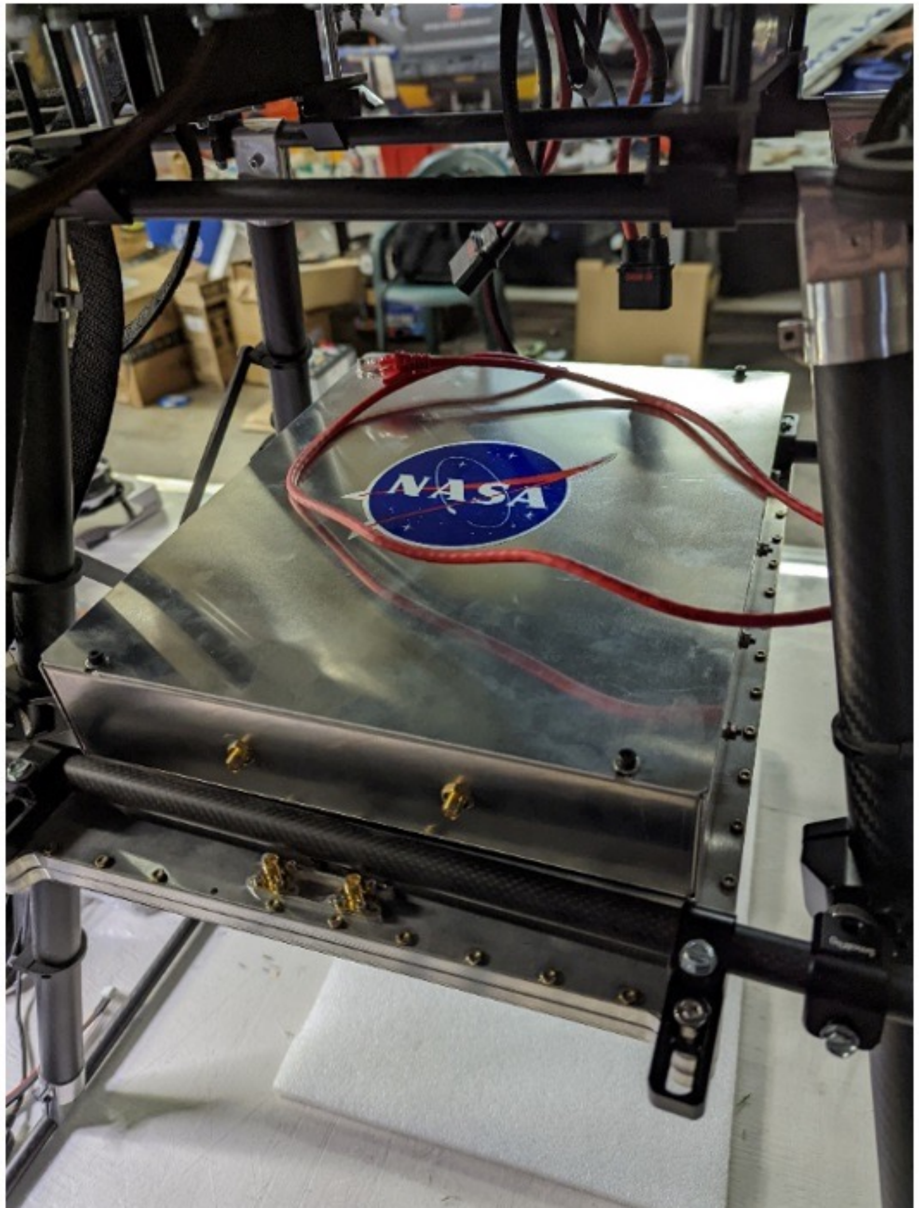
# Design of EMTS-1 (Initial Ku Build)



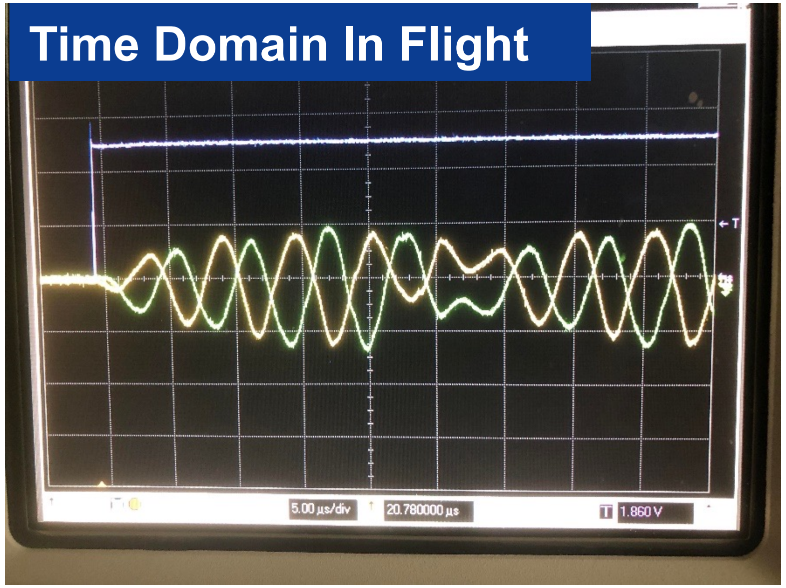
# EMTS-1 Flight Configuration 2021-2022



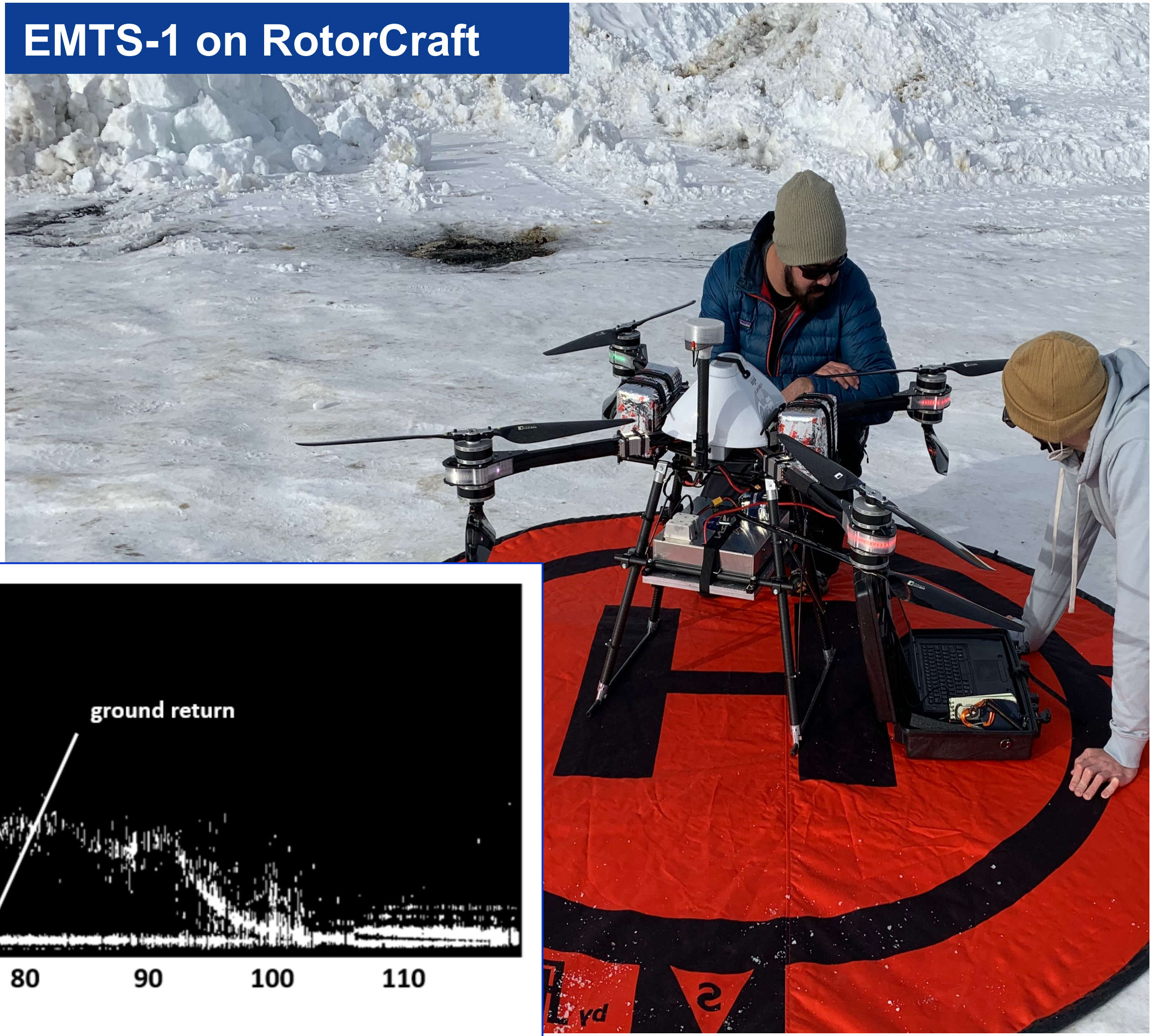



# EMTS-1 (Initial Ku Build) on UAV

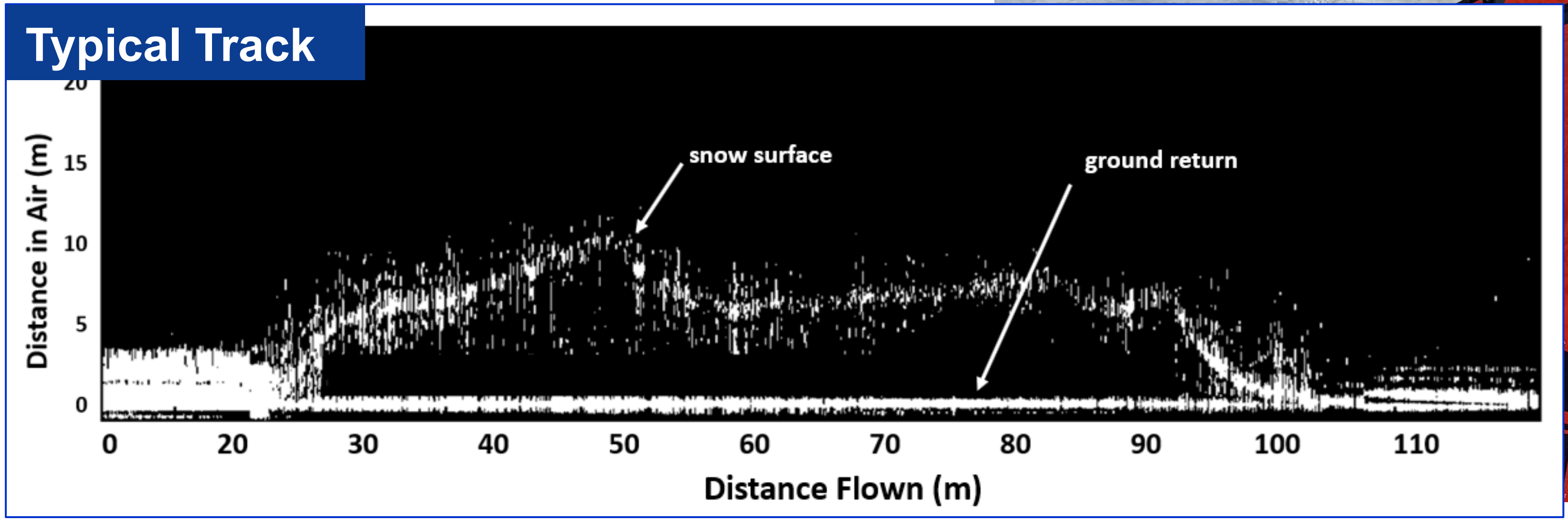
Time Domain In Flight




EMTS-1 on RotorCraft

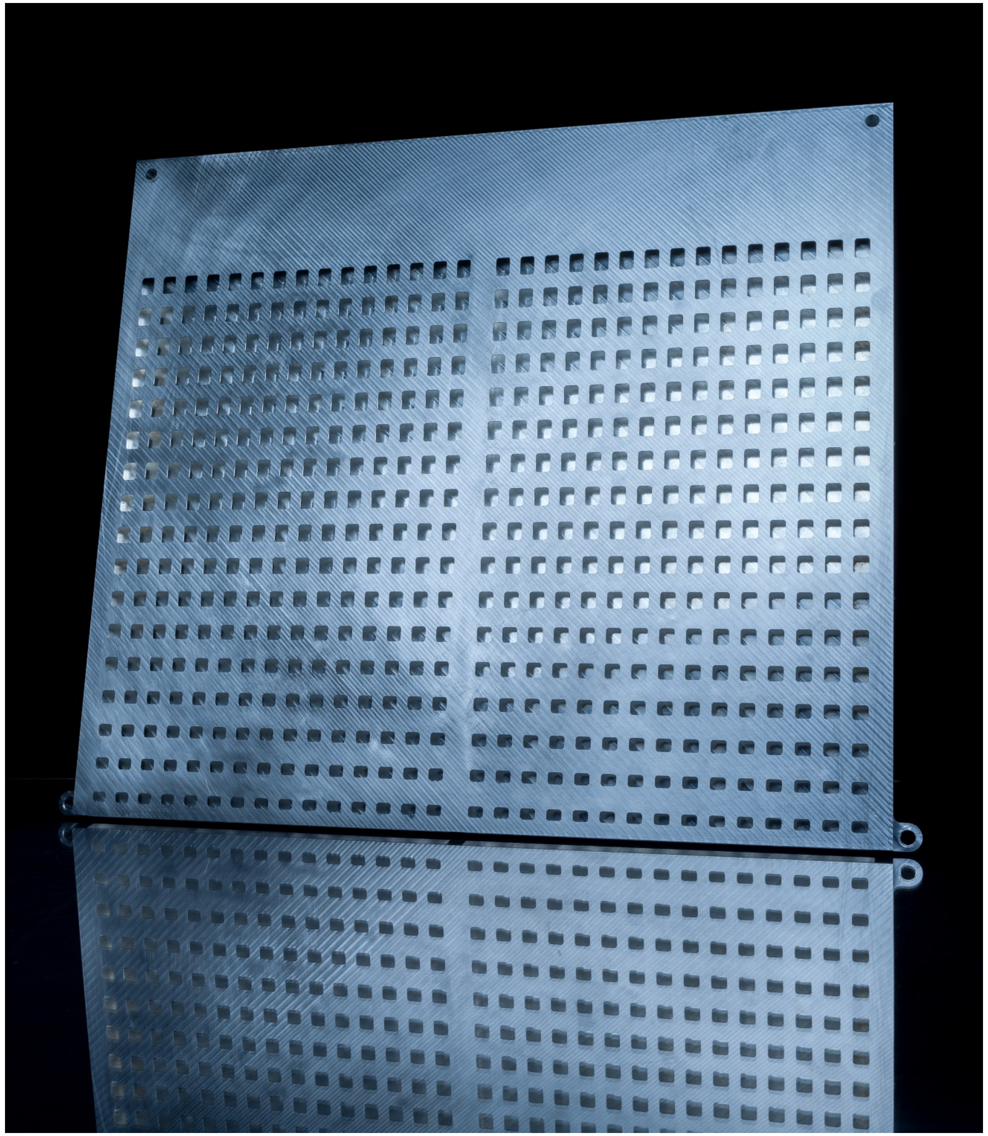


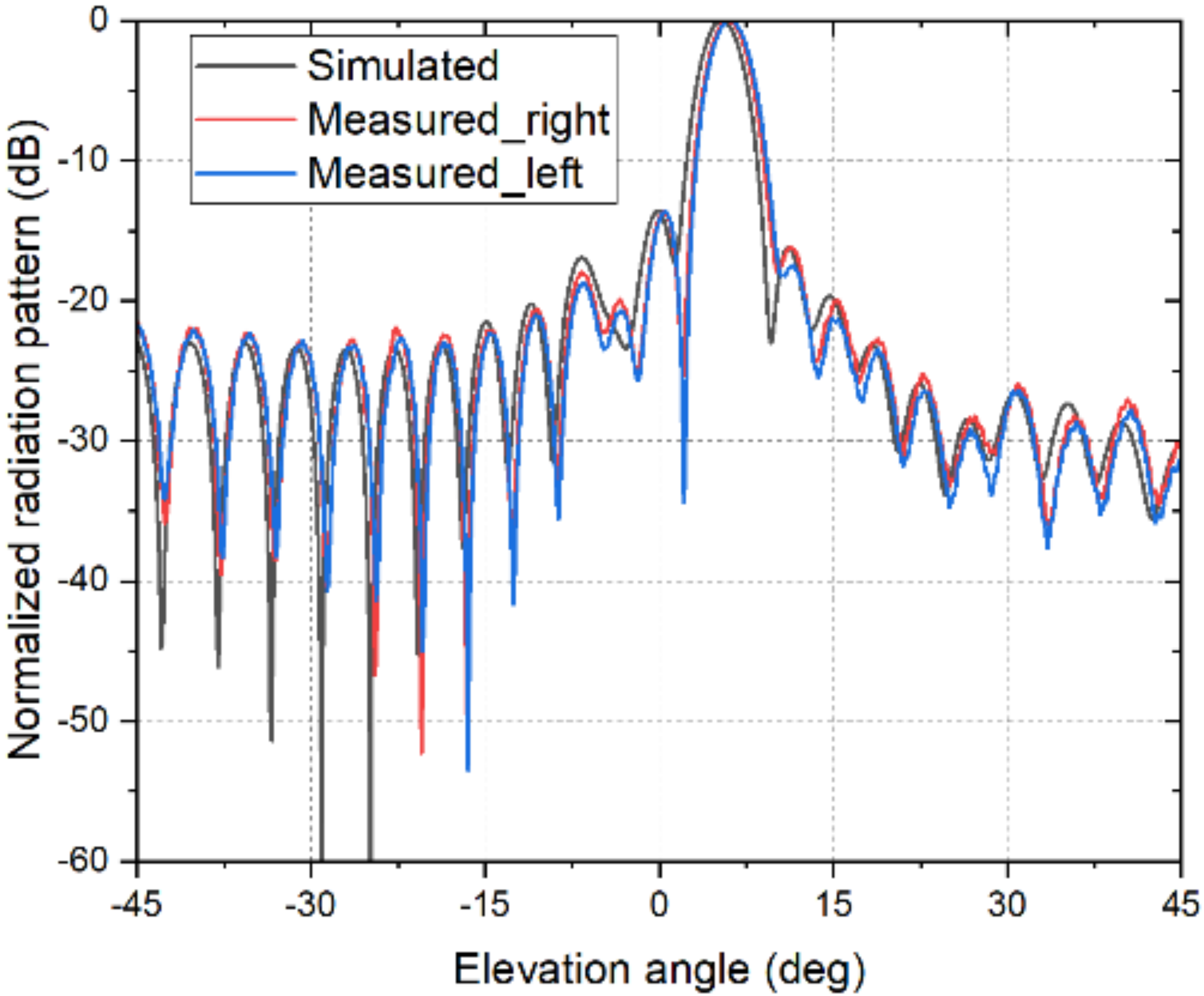
Typical Track



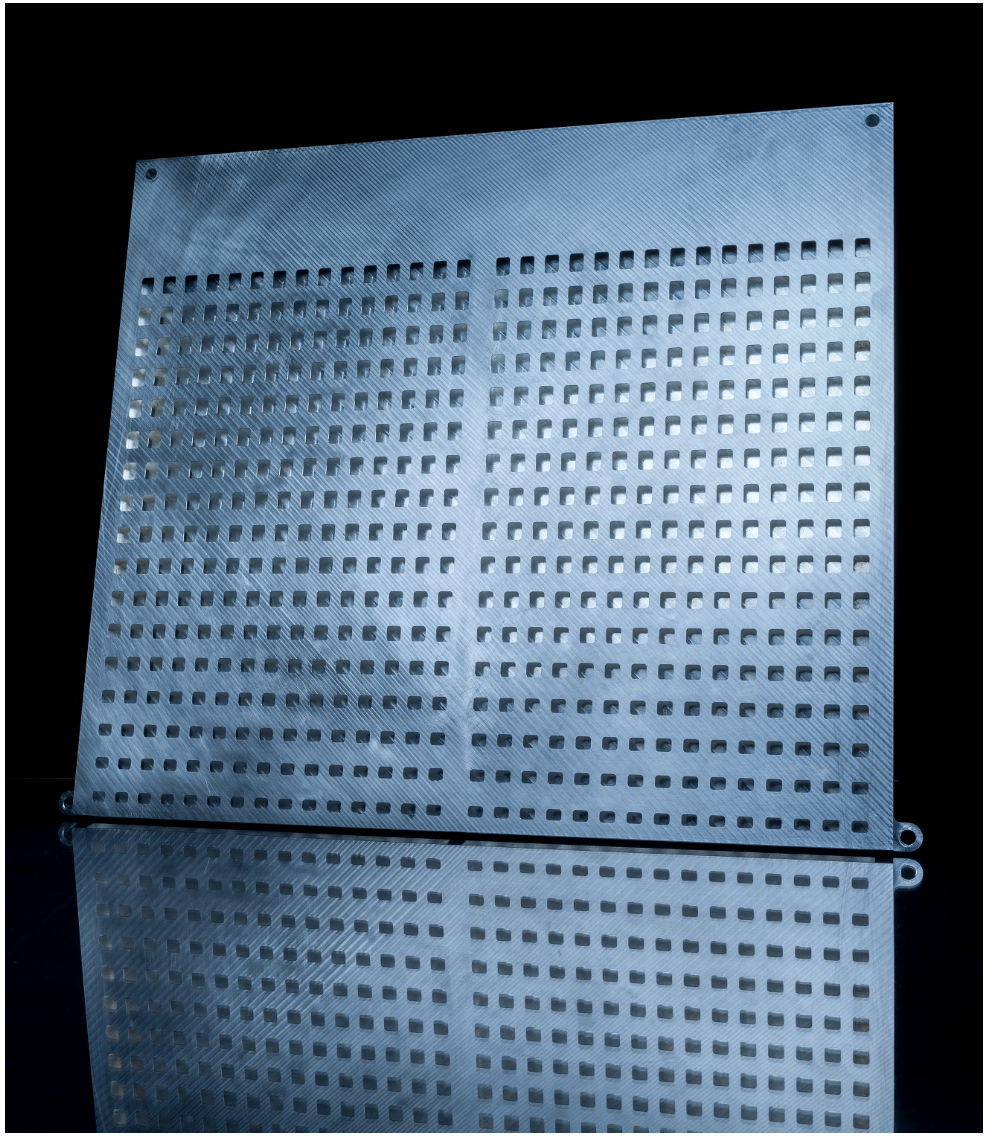
# EMTS 2
# Improved Ku-Band Design

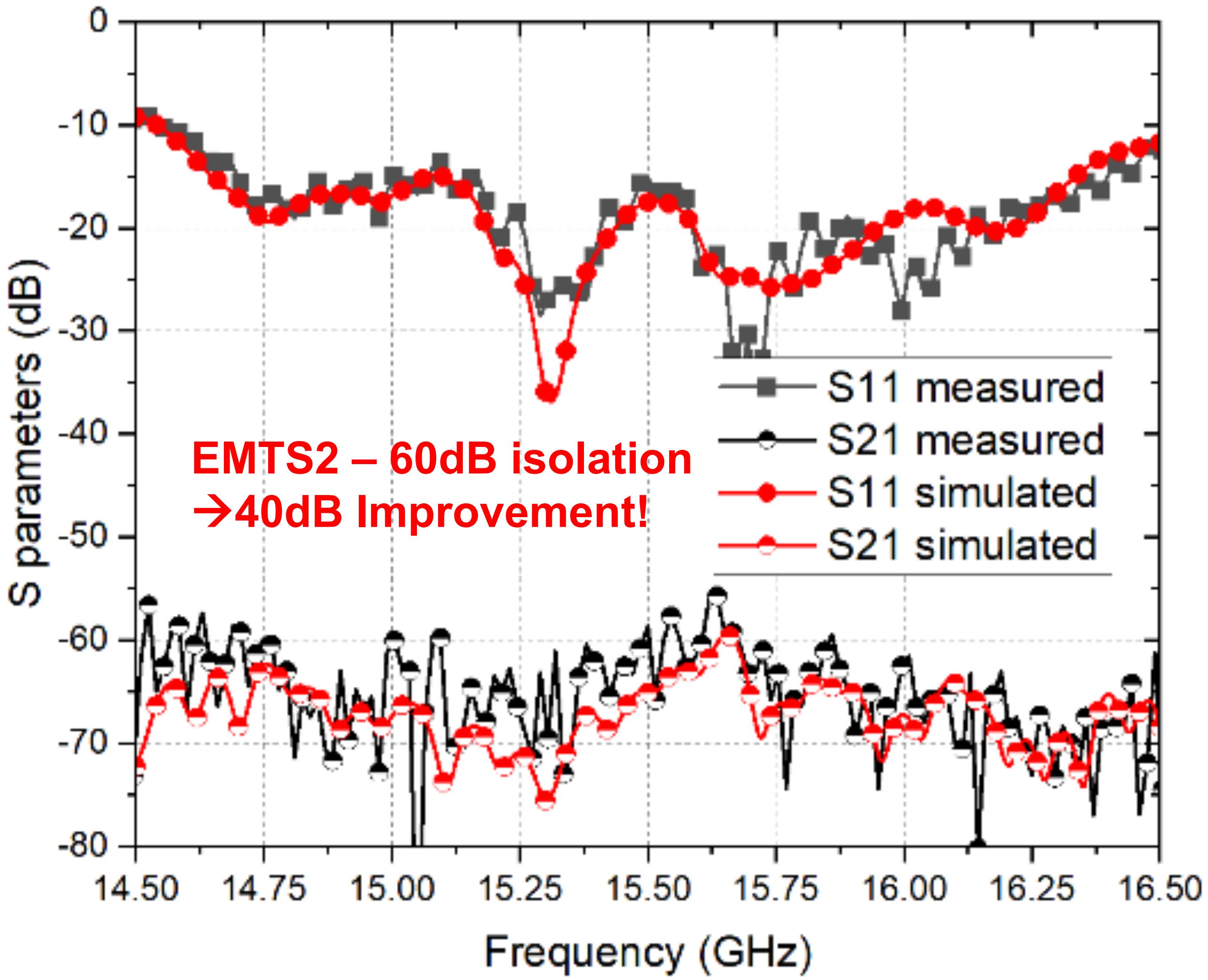
# Design of EMTS-2 MetaSurface



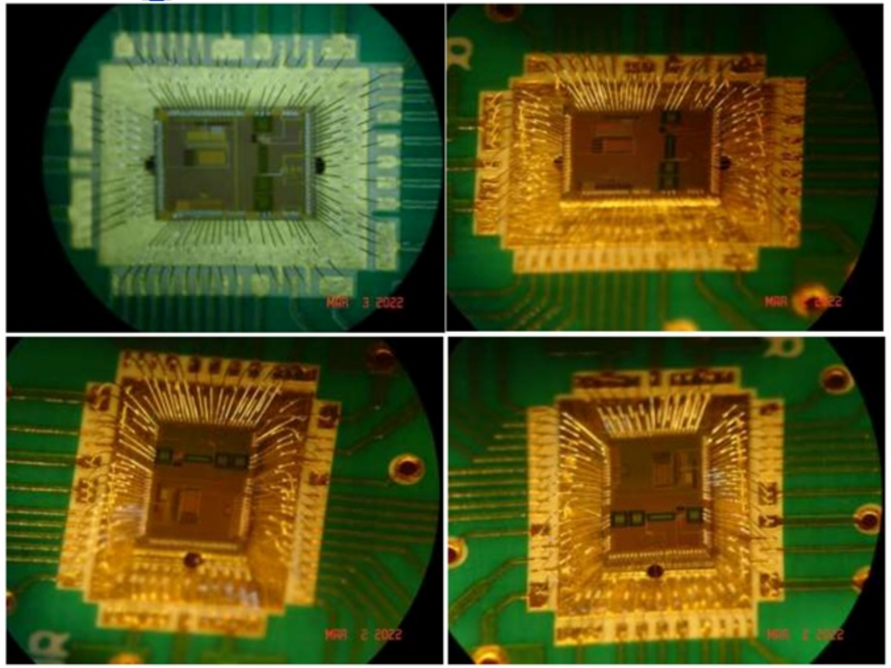


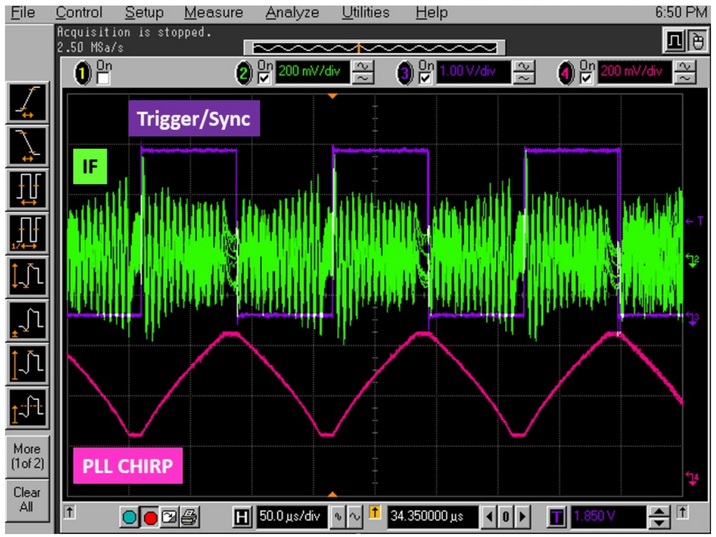
# Design of EMTS-2 MetaSurface

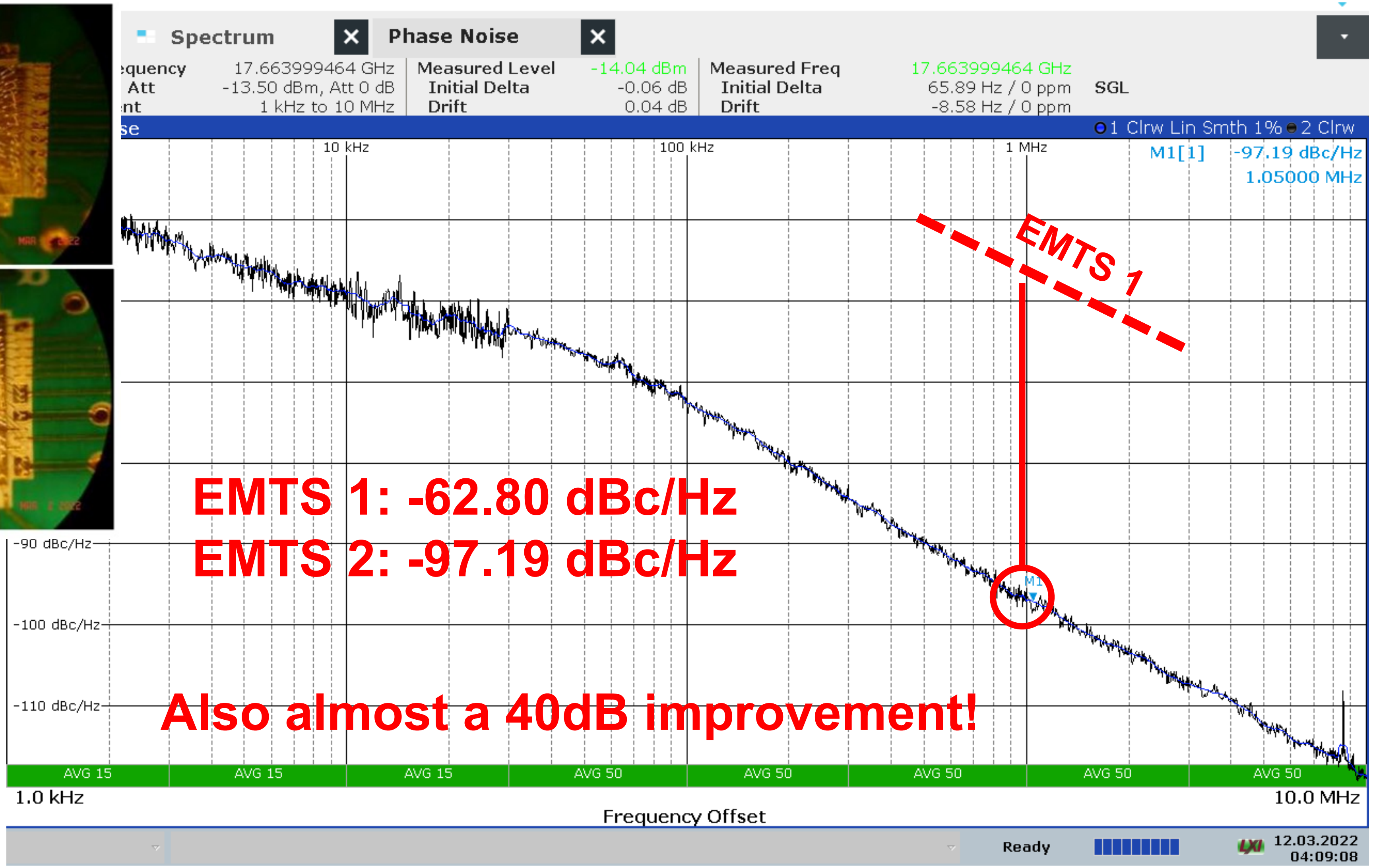




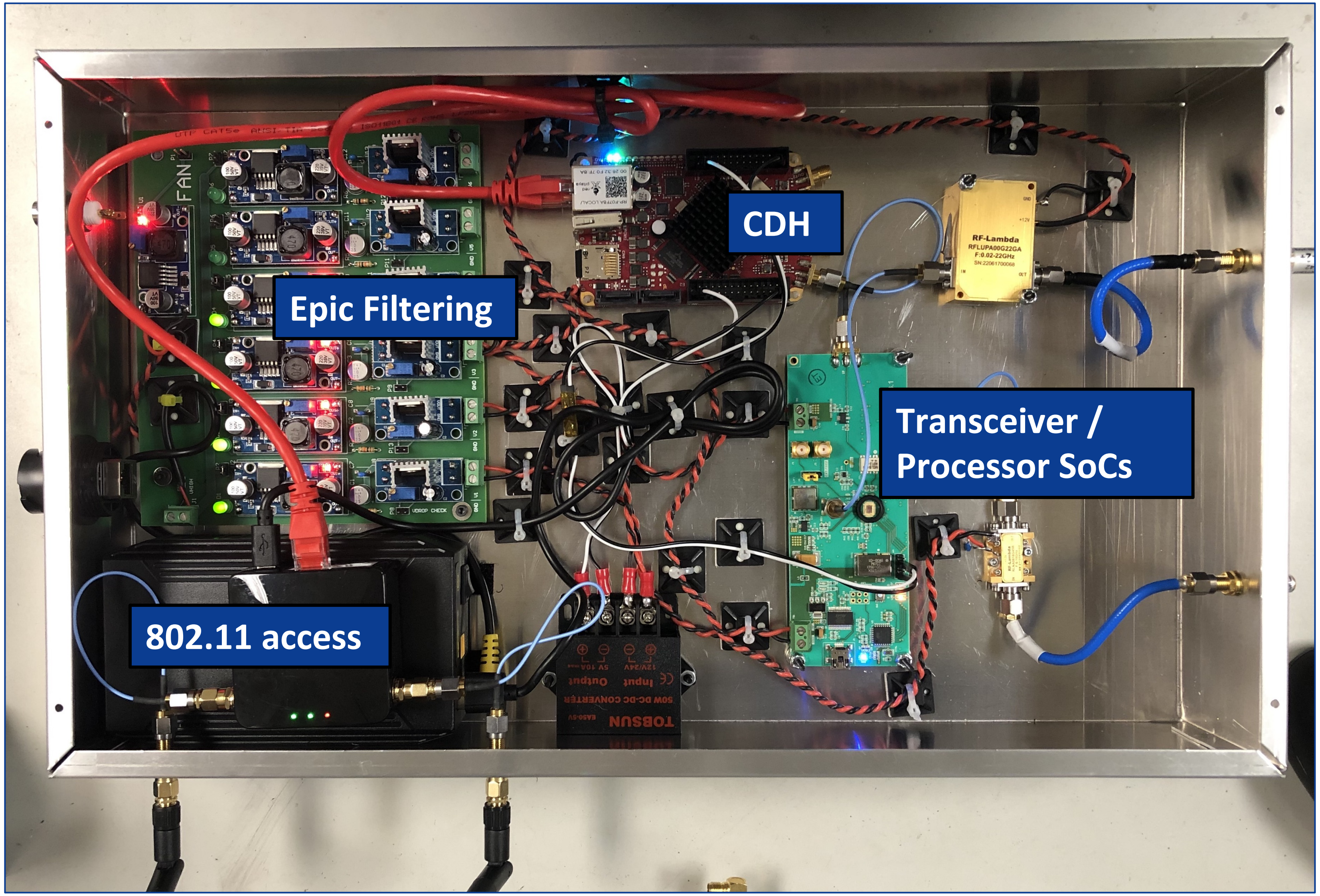
# EMTS-2 Improved TRX PN/Distortion

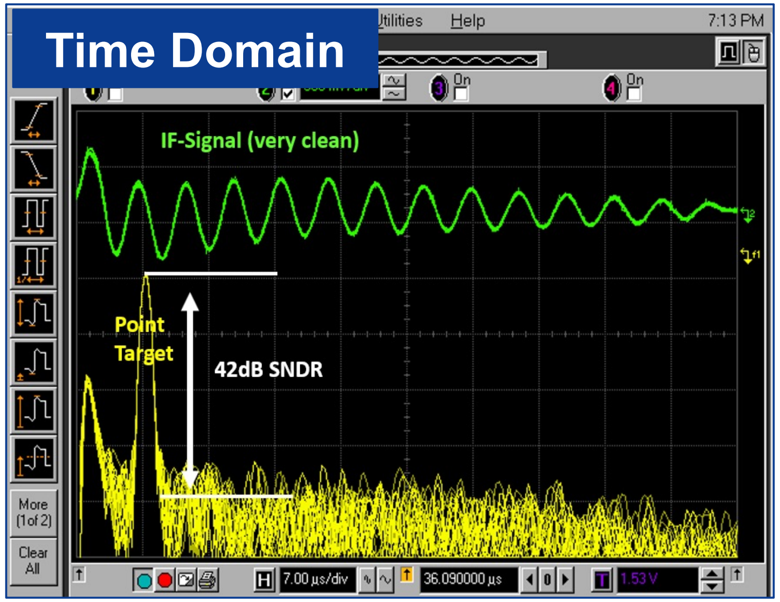


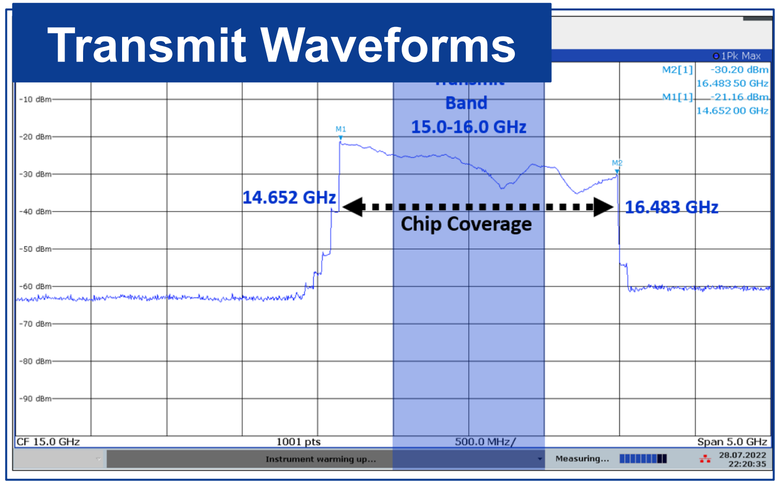


# EMTS-2 Integrated Instrument

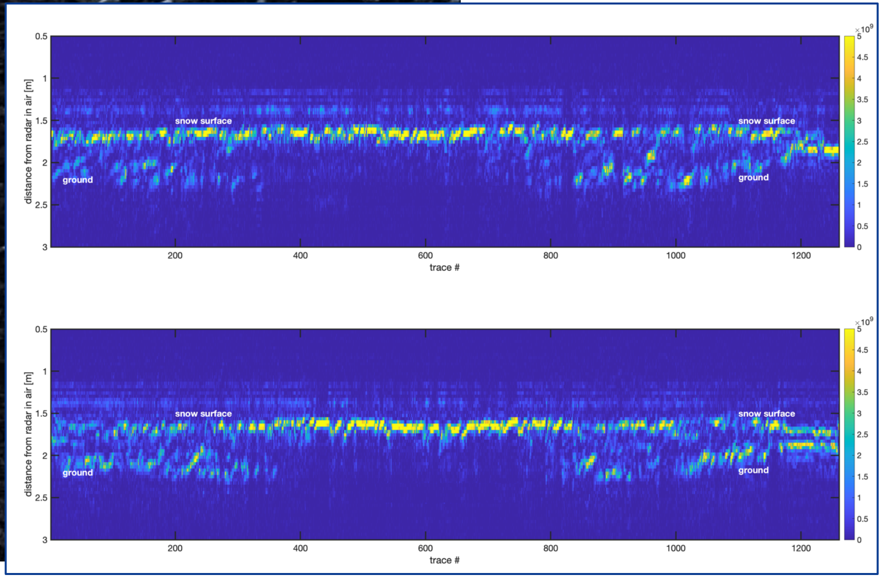


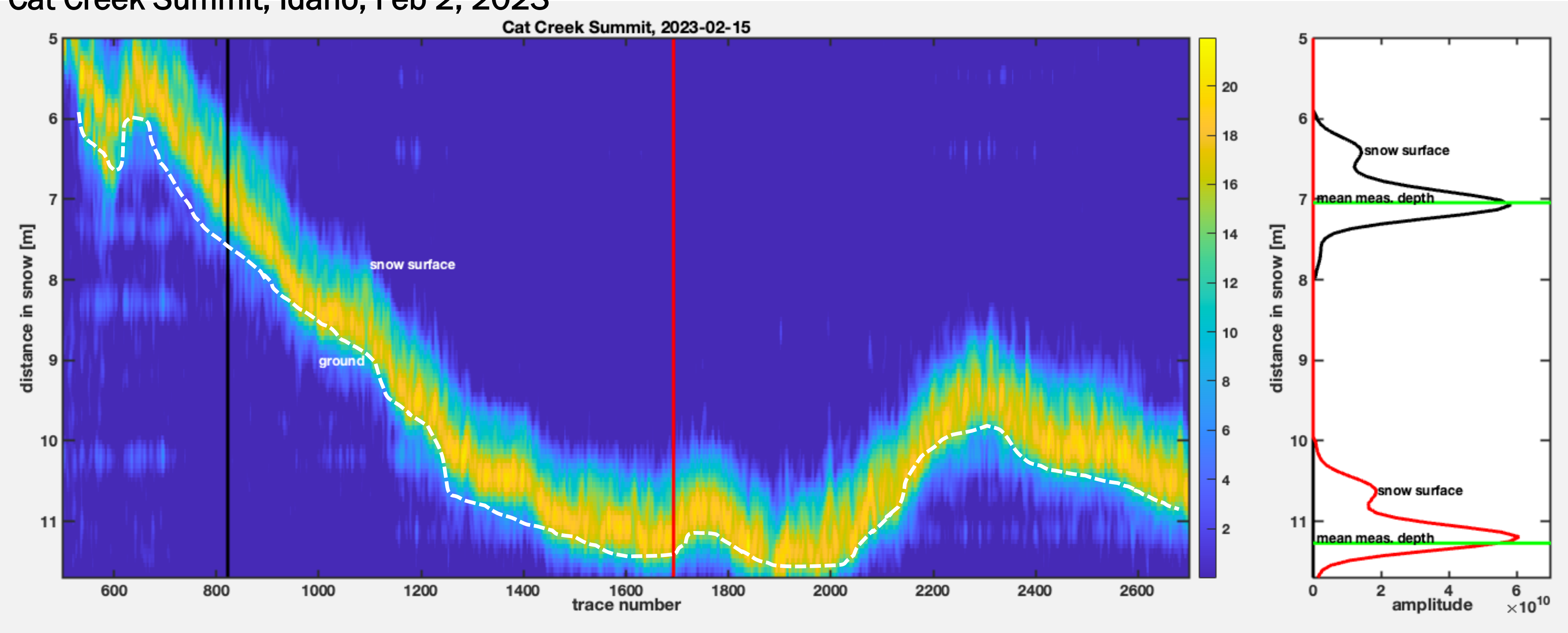
# EMTS-2 Campaign Idaho/Colorado 2022-2023

## EMTS-2 - Idaho



# EMTS-2 Shallow Snowpack Example

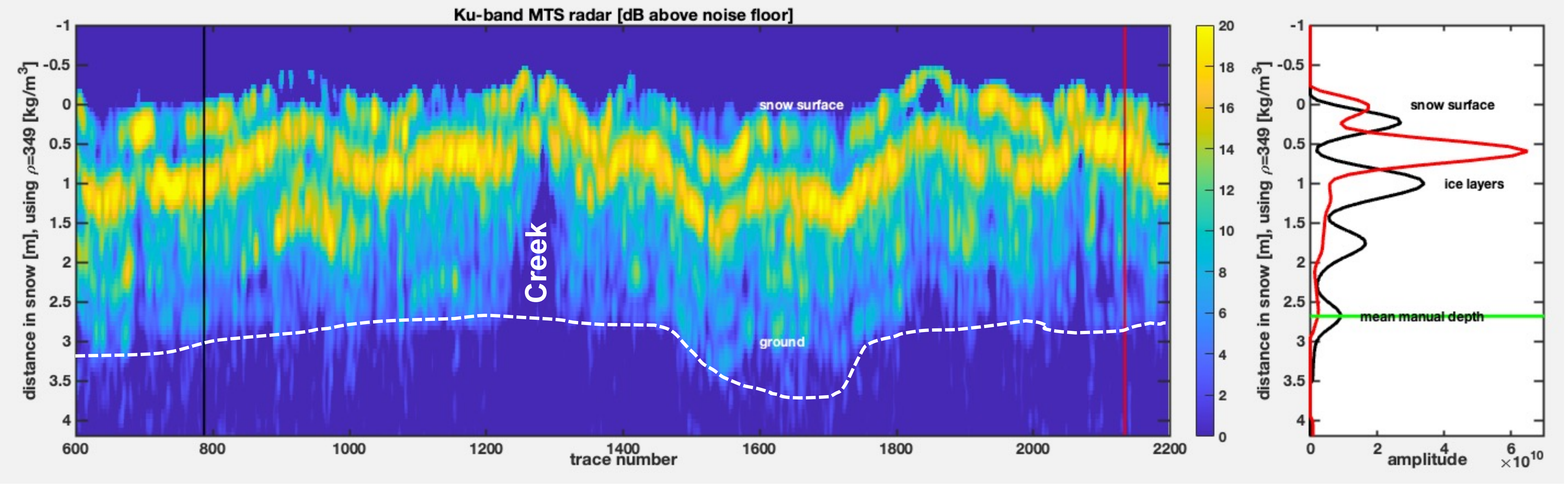
Cat Creek Summit, Idaho, Feb 2, 2023




- Shallow snowpack (mean depth 66cm)
- Average measured depth shows good agreement (green line)
- Black and red lines show location of two trace examples on right

# EMTS-2 Very Deep Snowpack Example

Deep snowpack, Mores Creek summit, Idaho, April 5, 2023

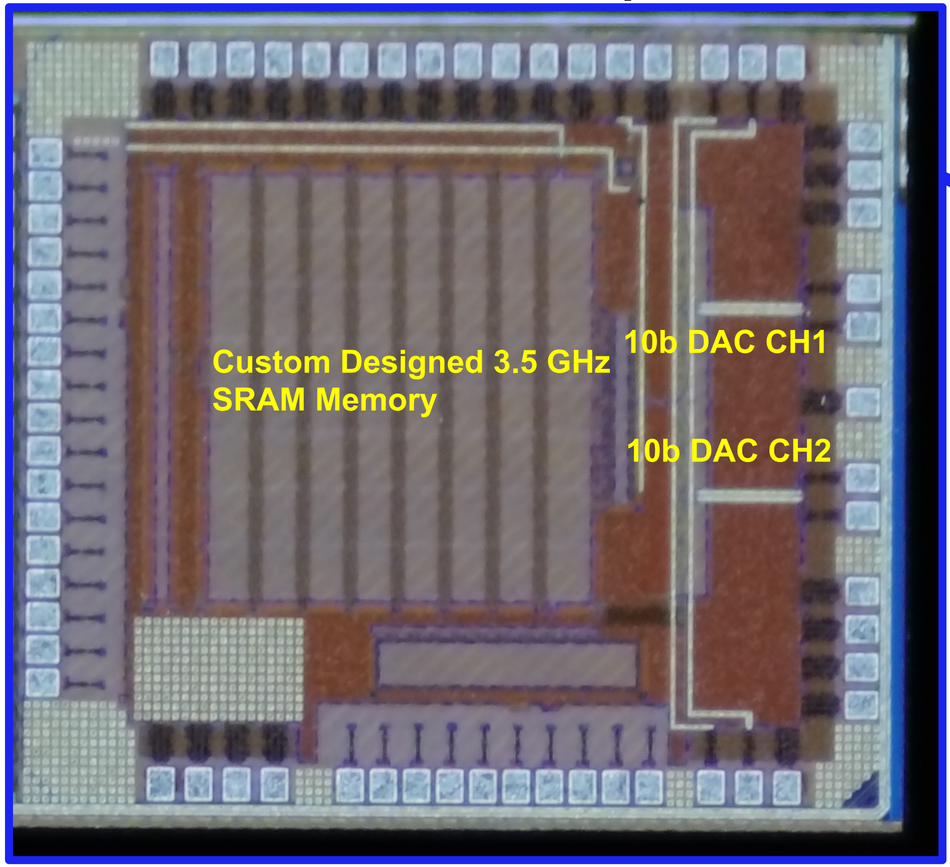


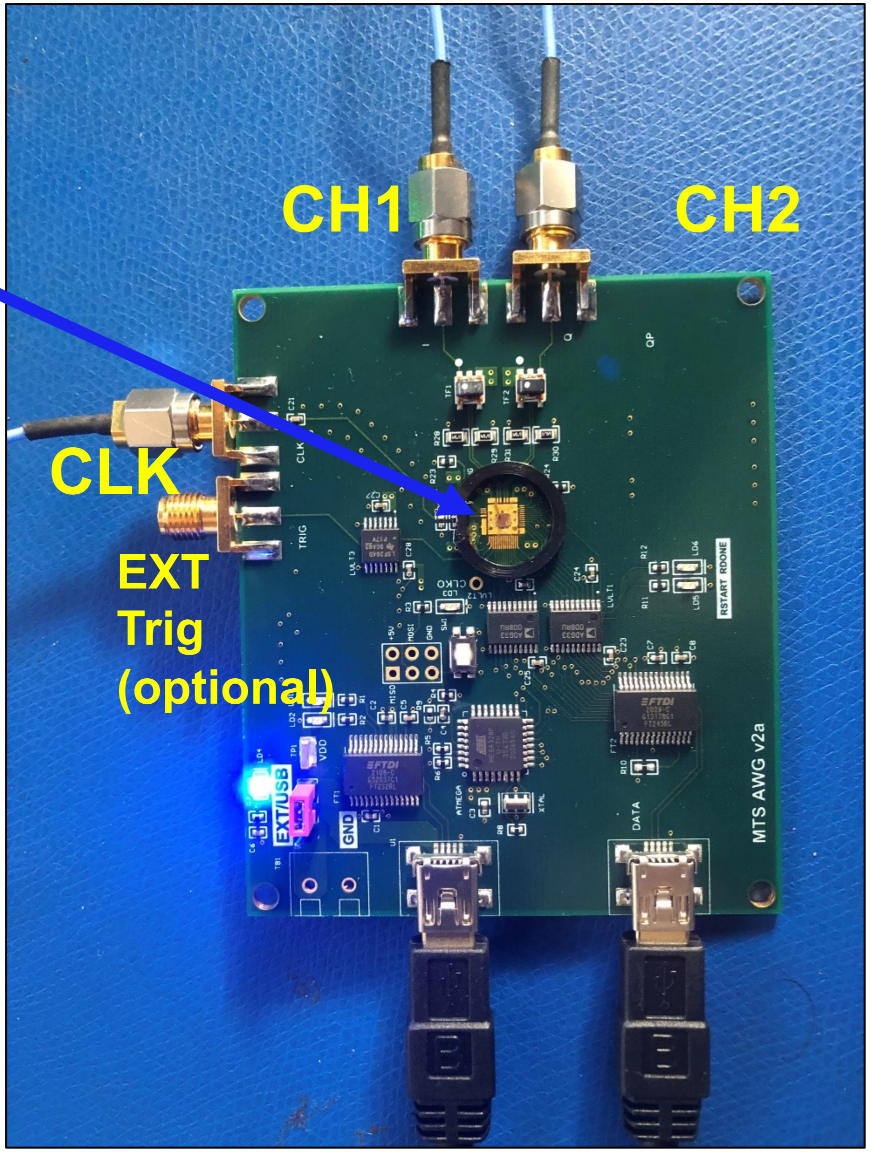

- Very deep snowpack (268cm)
- Two major ice layers cause largest reflections in image
- Creek present at trace ~1250, likely with very wet snow at base

# EMTS 3

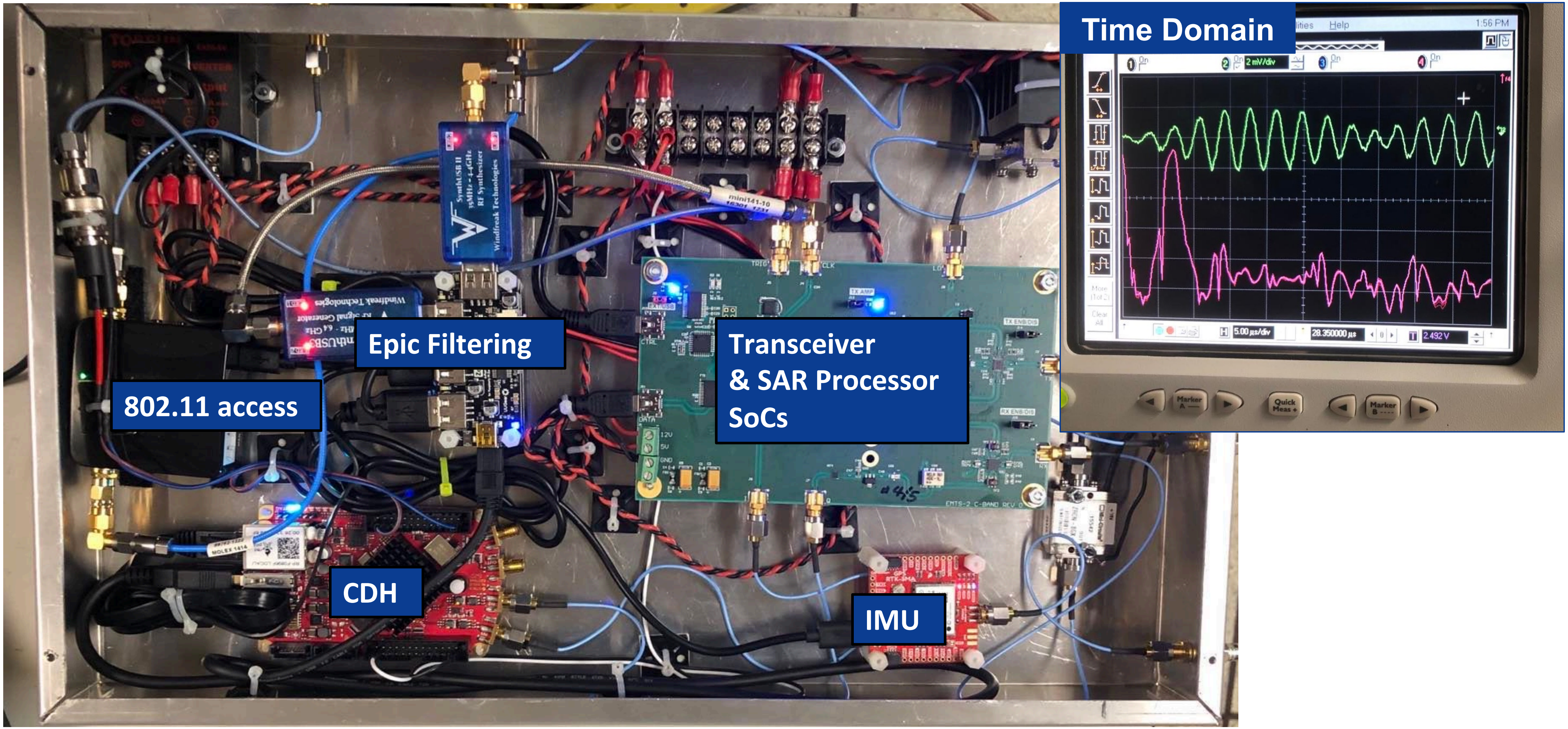
# EMTS-3 C-Band SAR-Ready Chipset

**Custom SoC Chip**



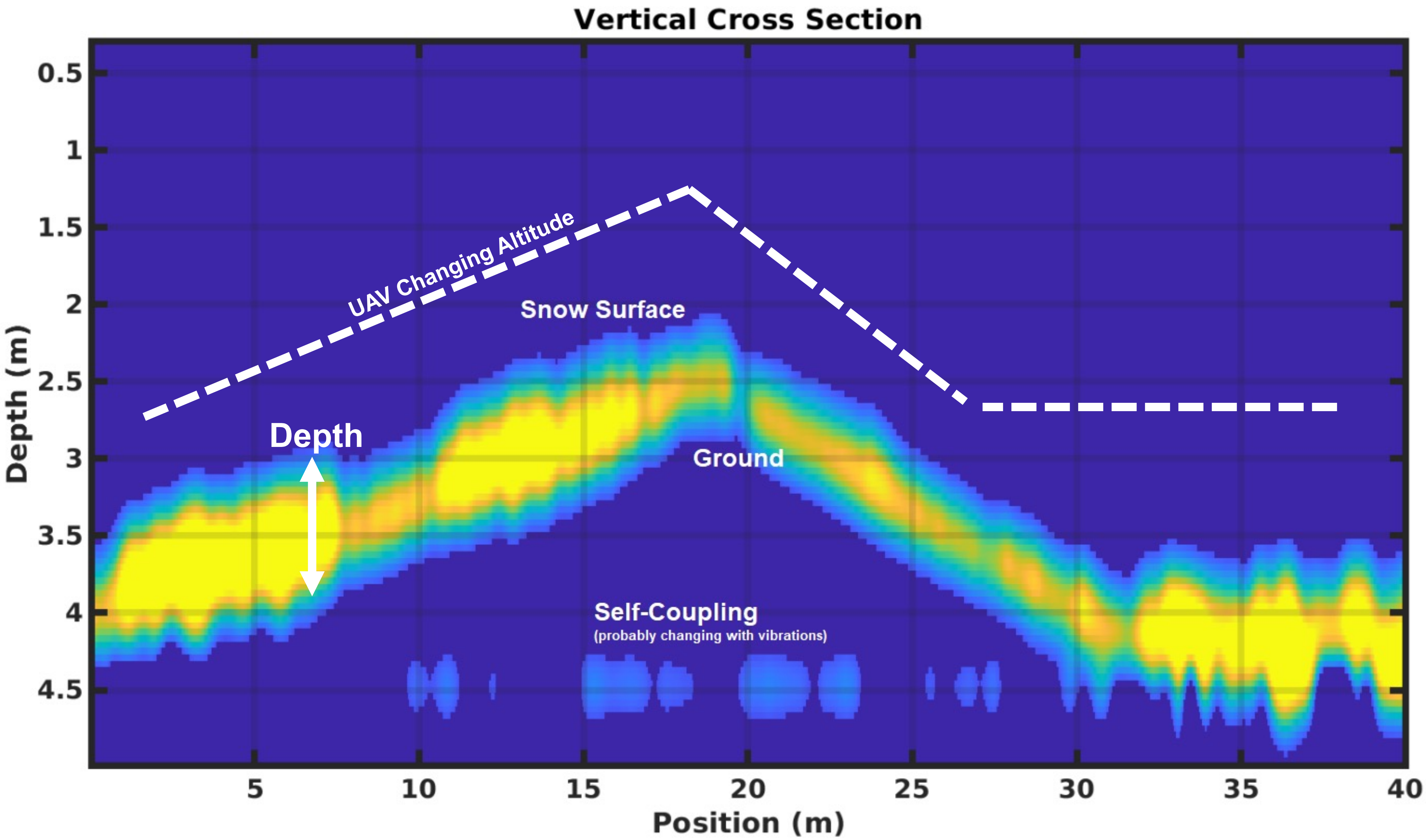



# EMTS-3 (C-Band SAR-ready Instrument)

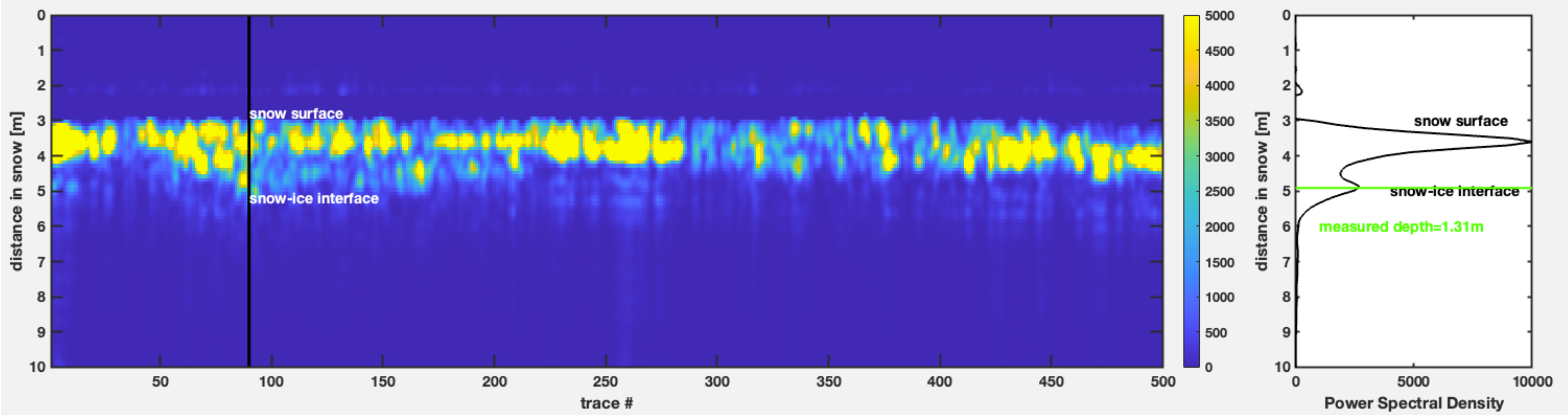


# EMTS-3 (C-Band SAR-ready Instrument)

# EMTS-3 Initial Snow Measurements



# EMTS-3 at Utqiagvik, Alaska on Sea Ice

# Conclusions

- **Tx to Rx Leakage is the major limiter of sensitivity and dynamic range in FMCW radar.**
- **The use of machine learning (ML) provides a pathway to overcome this limitation and produce a radar instrument that has the sensitivity needed to sense a wide range of snow conditions.**
- **Combining CMOS electronics, Metasurface antennas and ML leads to an extremely compact wideband radar suitable for in-situ snow sensing that's competitive with much larger and more power-hungry radar systems.**