On-time EM measurements: UTEM system developments

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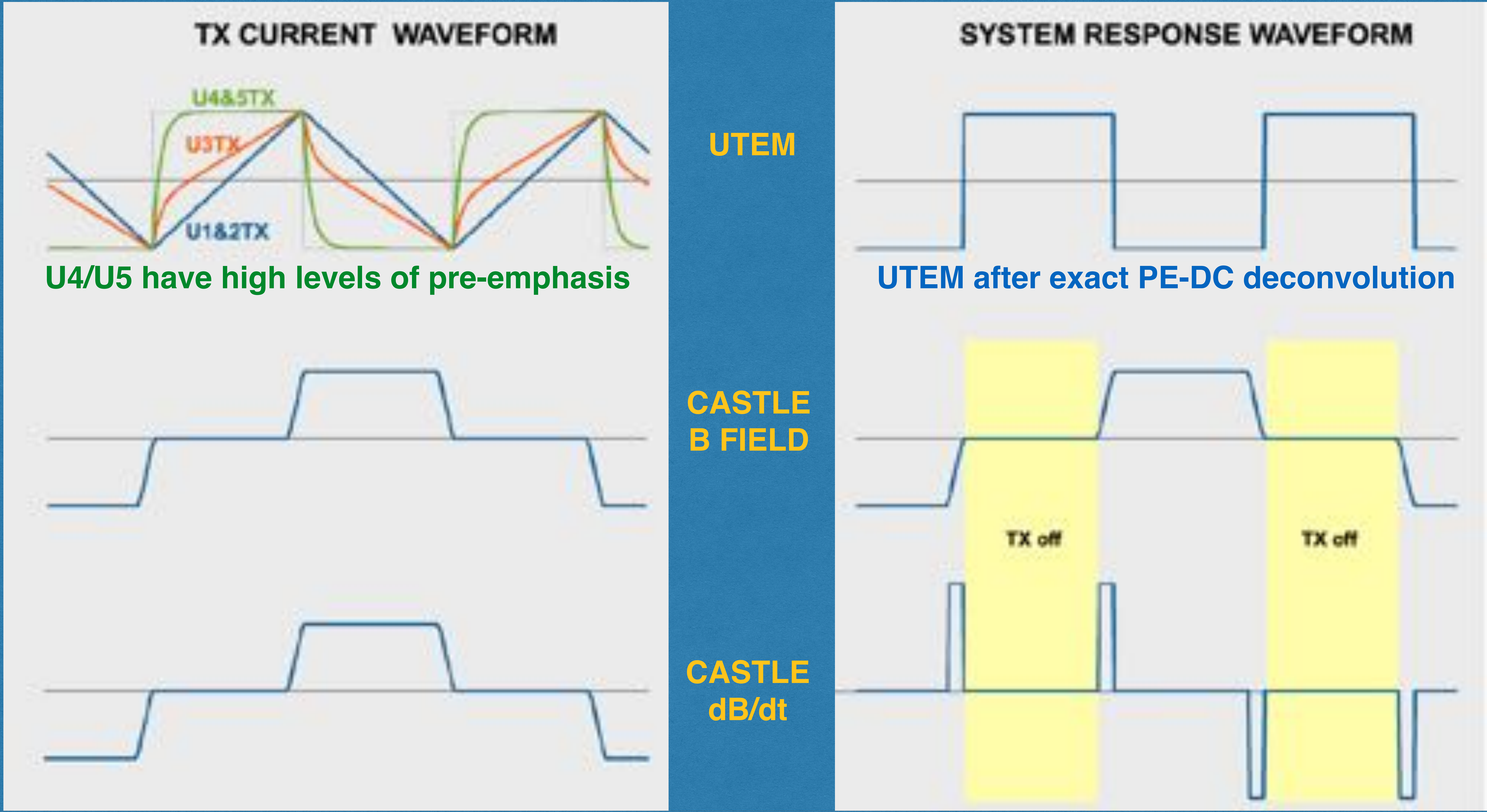
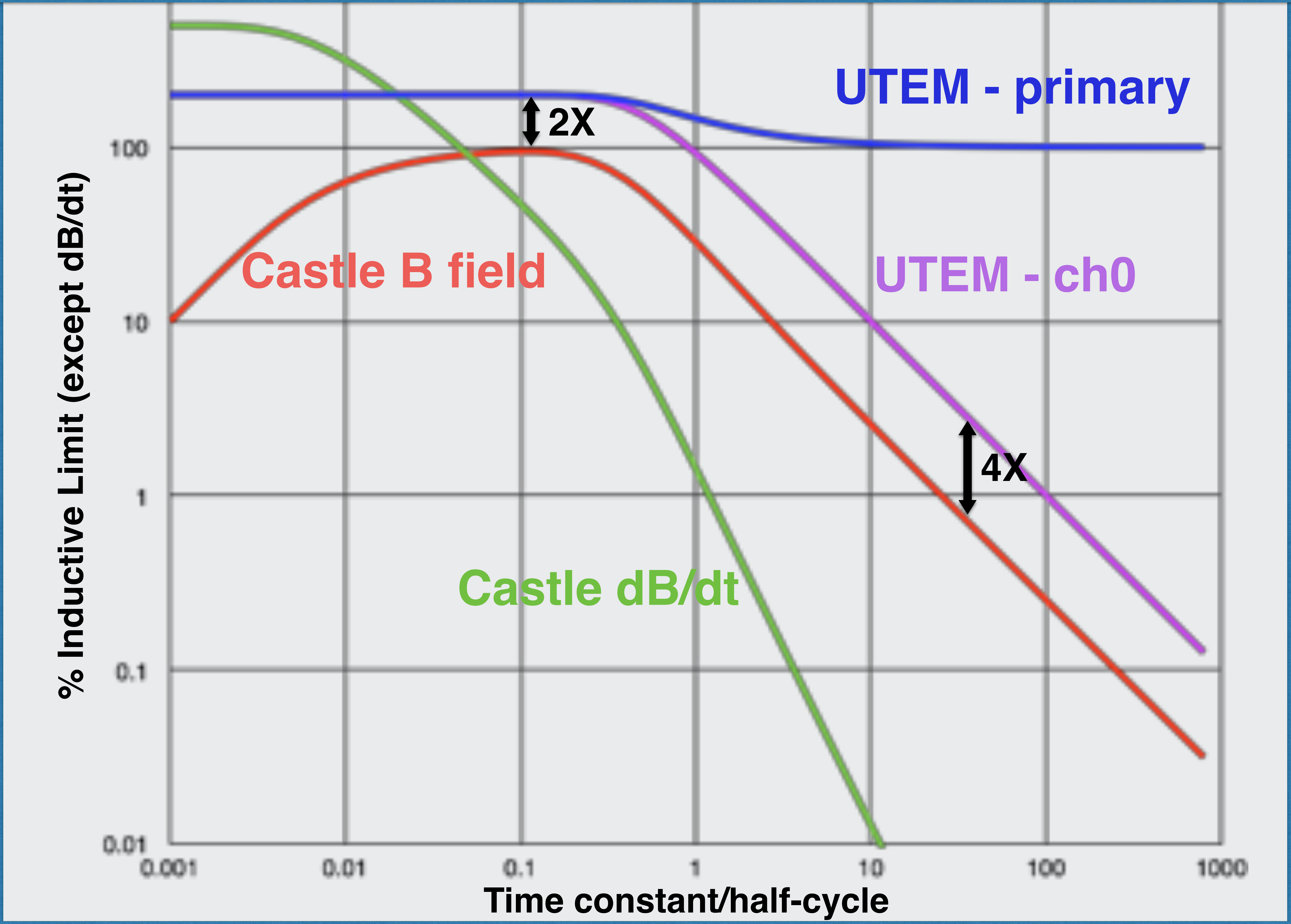
Summary

1. Why “on-time” EM measurements?
2. UTEM transmitter developments
3. UTEM sensor developments
4. UTEM receiver developments
5. System performance in exploration
6. Looking forward

The TX current waveform is not the system response



Sensitivity vs decay time



On-time
vs
Off-time

CONDITIONS

Exponential decays

Same base frequency

Same TX current

Castle waveform:
ramp time/HC = 0.01
off-time sampling

Inductive limit
applies for UTEM
and B field only

UTEM 5 system characteristics

All components of system linear: exact PE-DC possible

Dynamically regulated TX current waveform

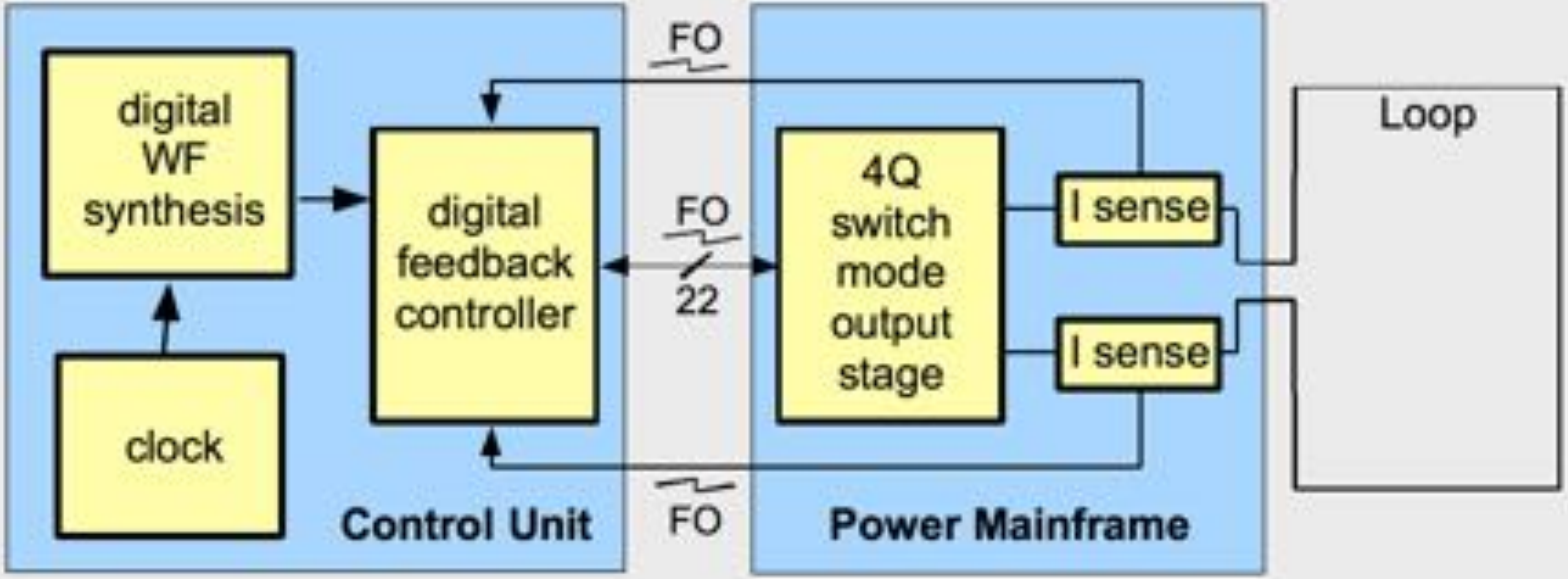
Feedback 3-axis B sensors with wide dynamic range

Advanced signal sampling and stacking

Real time monitoring of measurements

Multiple transmitter operation

UTEM 4 Transmitter block diagram



UTEM 4 / UTEM 5 transmitters

MODEL	year	Working input power	Max output current	Max output voltage	Max output power	Cooling
U4ATX	2002	9 kVA	9	525	4.8 kVA	liquid cooling
U4BTX	2005	11 kVA	11	525	5.8 kVA	refrigeration
U5MTX	2011	8.0 kVA	9	600	5.4 kVA	air cooled
U5HTX	2018	3.5 kVA to 11 kVA	15.5	620	3.0 kVA to 9.6 kVA	air cooled

UTEM 4B Transmitter site

Fibre optic bundle

Control unit

Power mainframe

11 kVA input
5.8 kVA output

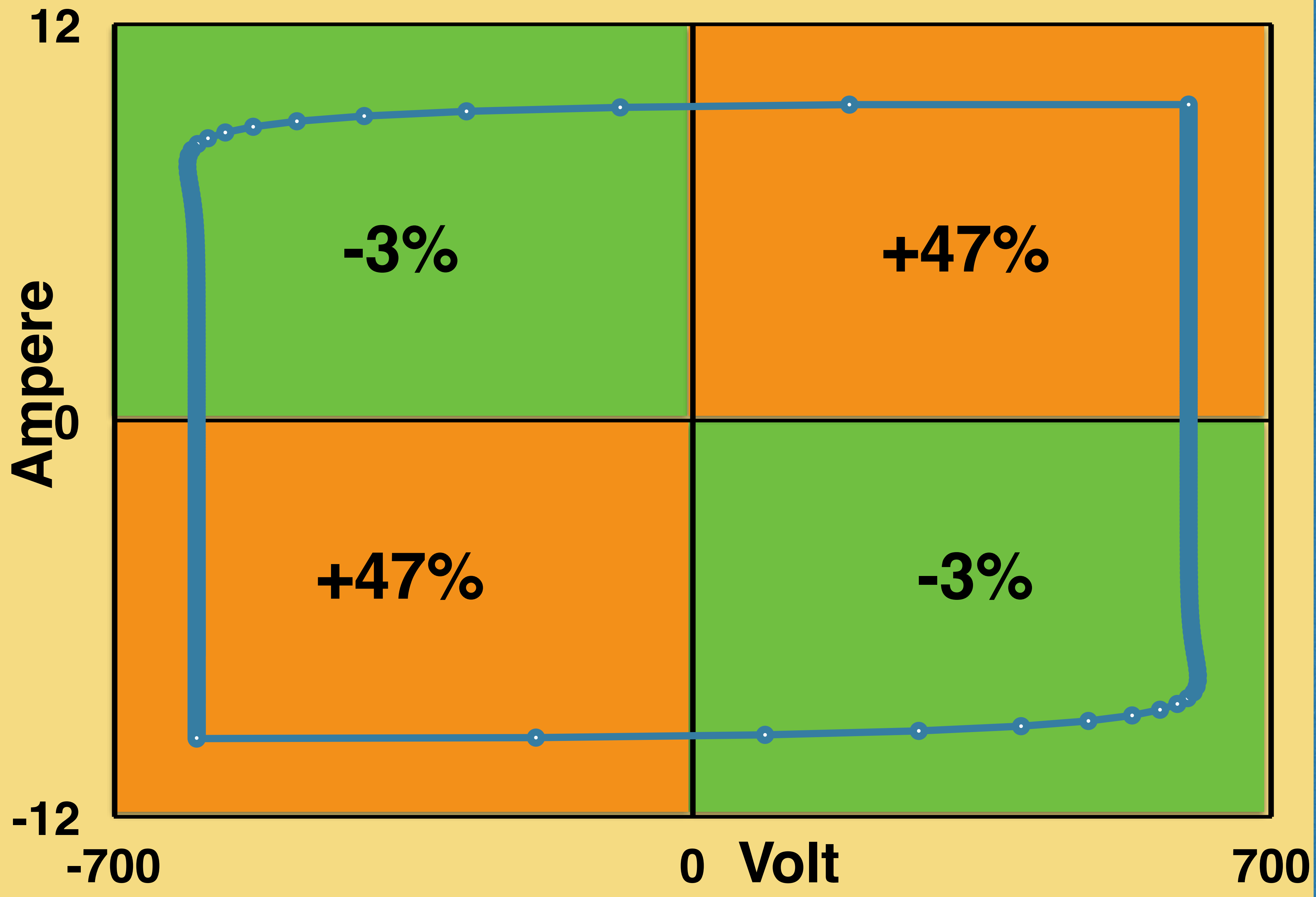
UTEM 5 Transmitter Development

UTEM 5H TX prototype
H for high efficiency

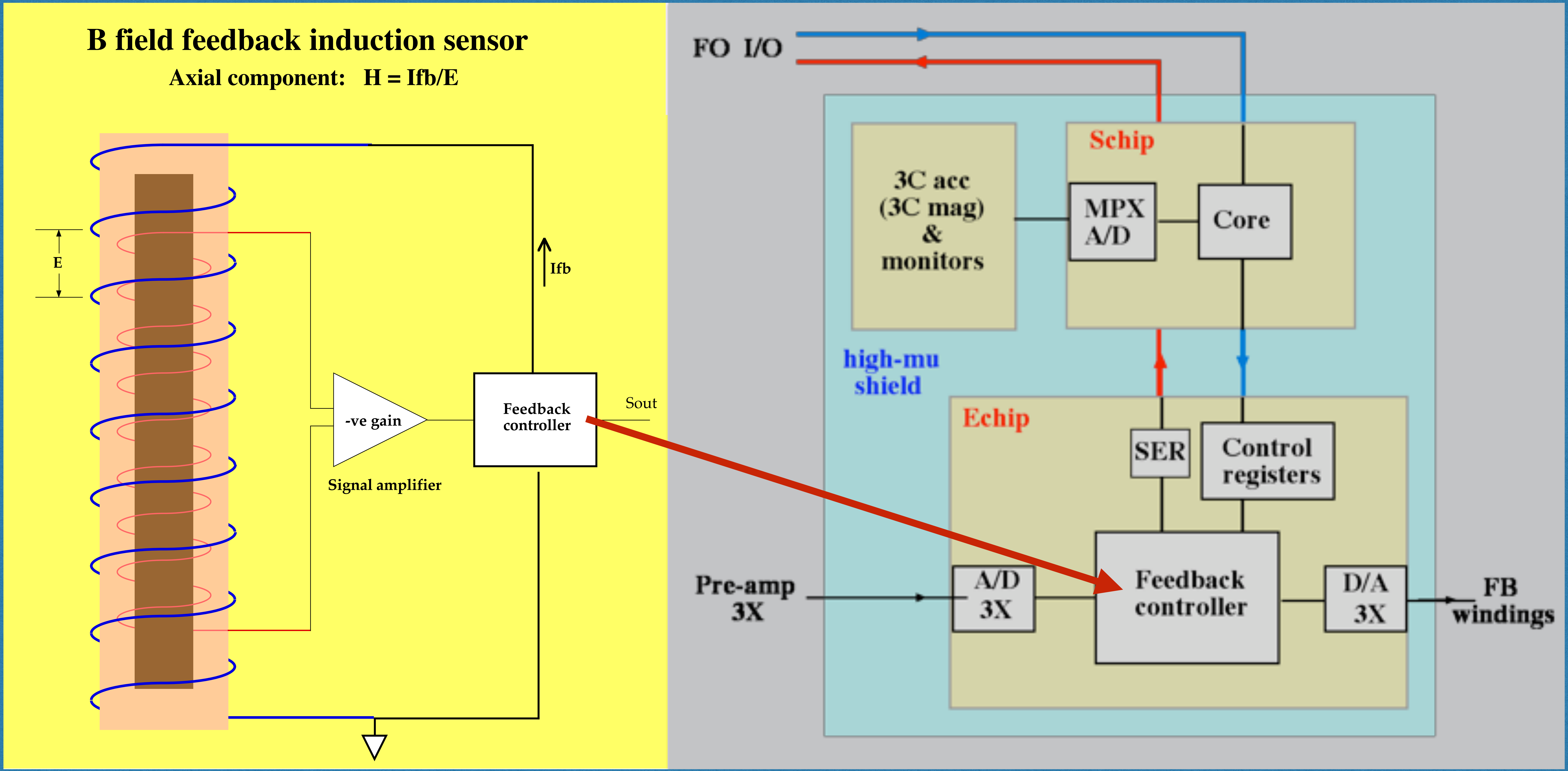
High power compact design

HF switch-mode operation
Current regulation to <0.01%
>90% efficiency

Regenerative 4-Q operation

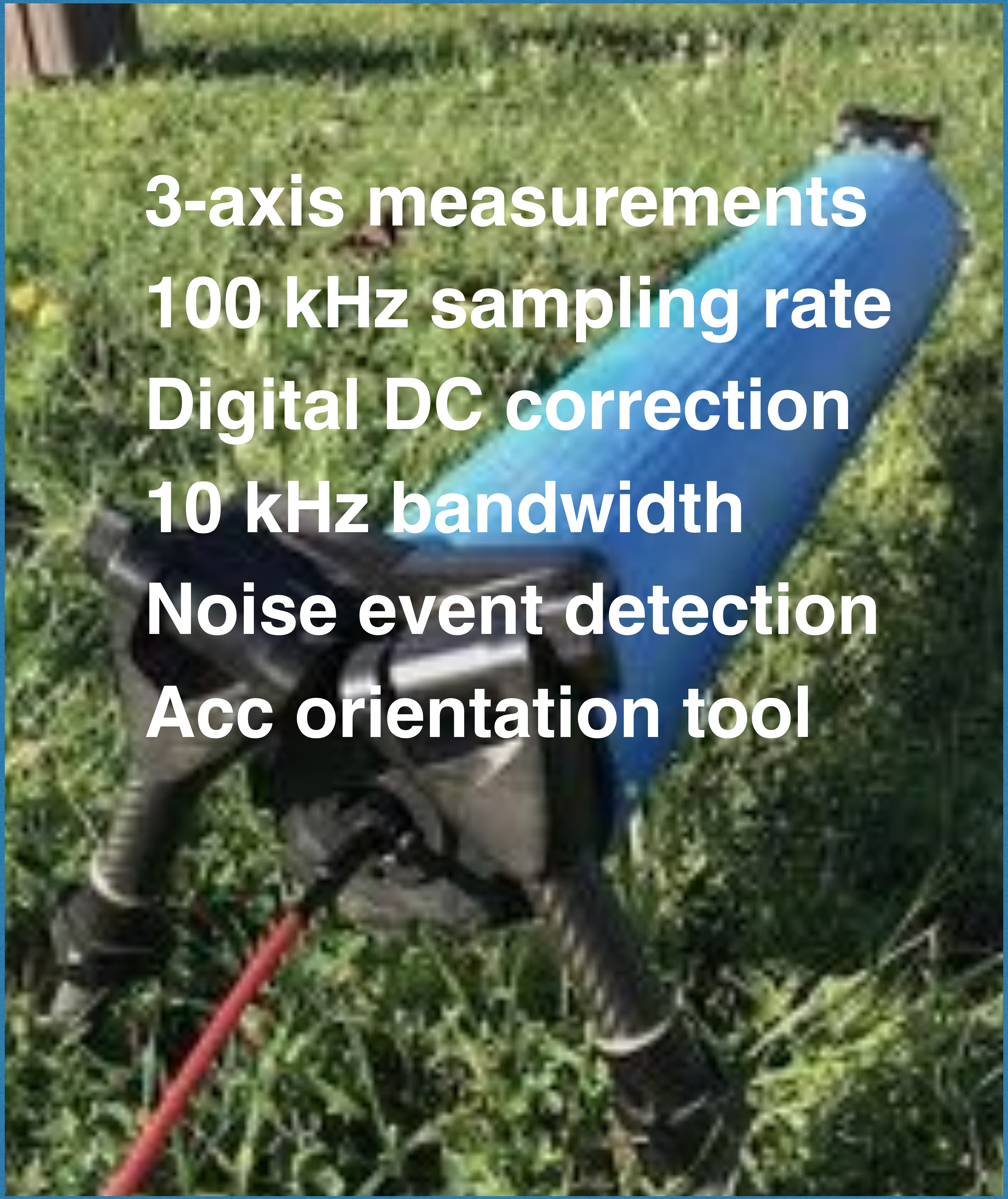


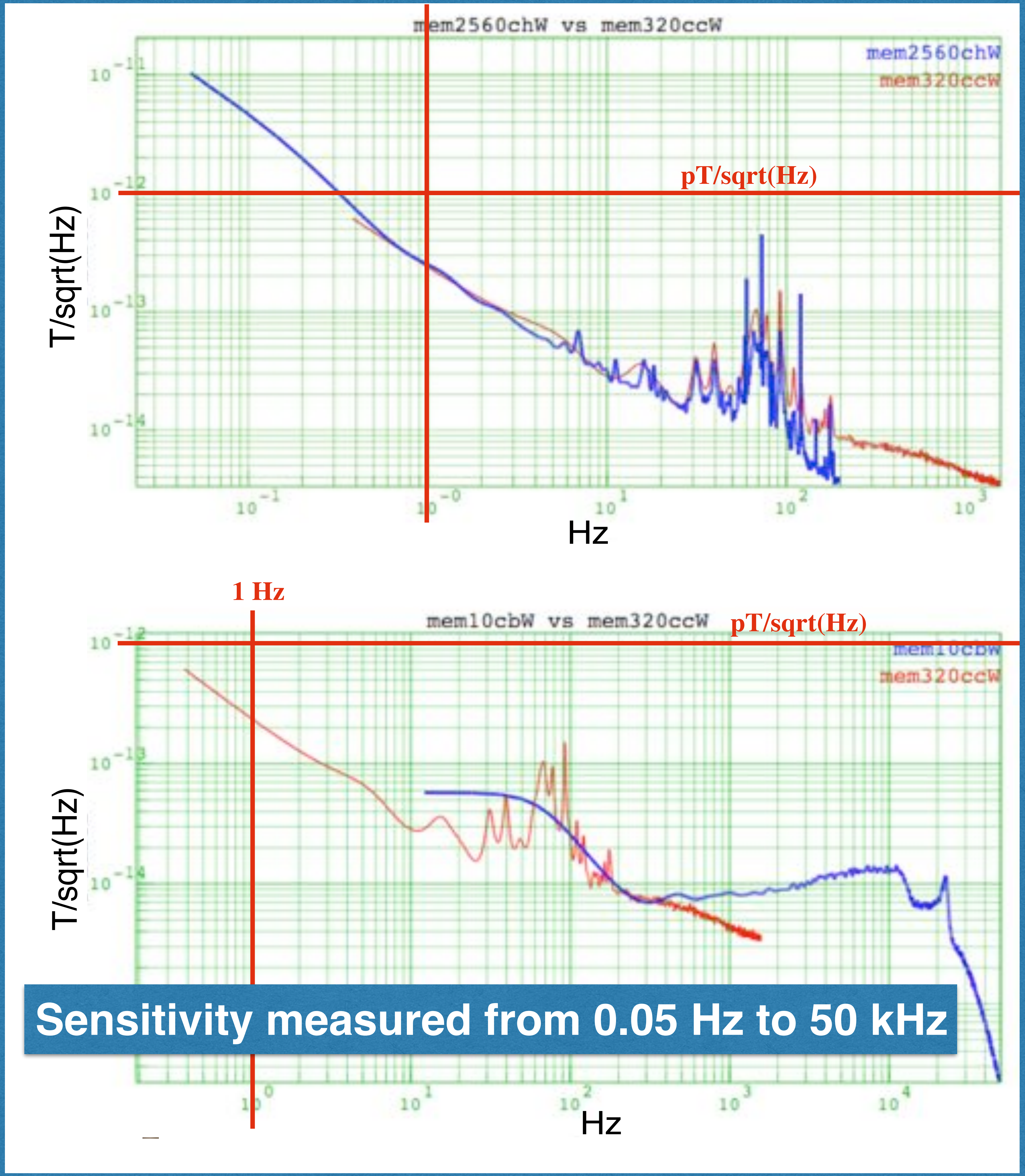
UTEM 5 sensors



Principle of digital feedback B sensor

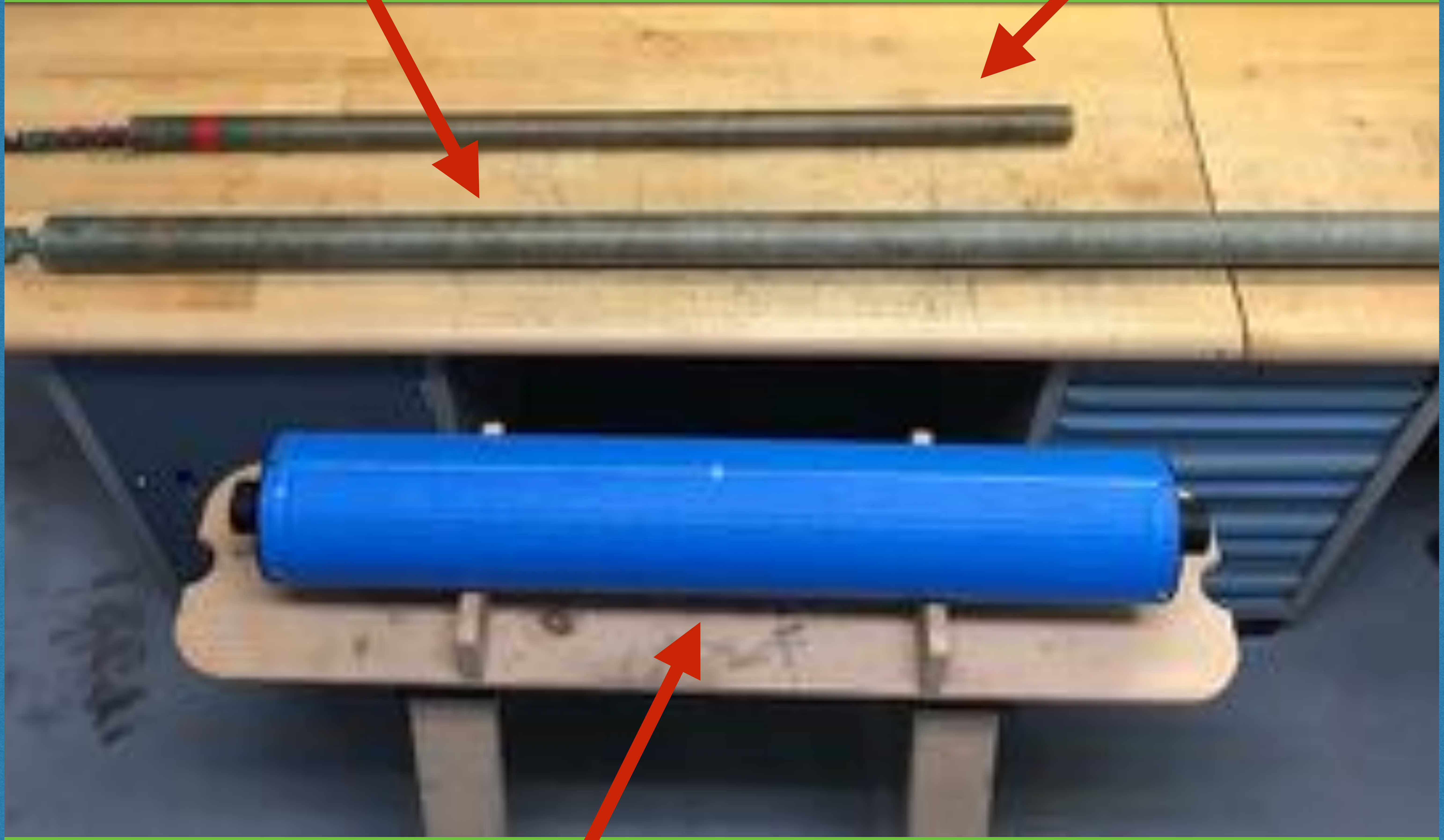
UTEM 5 surface sensor





UTEM 5 sensors under development

UTEM U5BH sensor compared to U4BH sensor

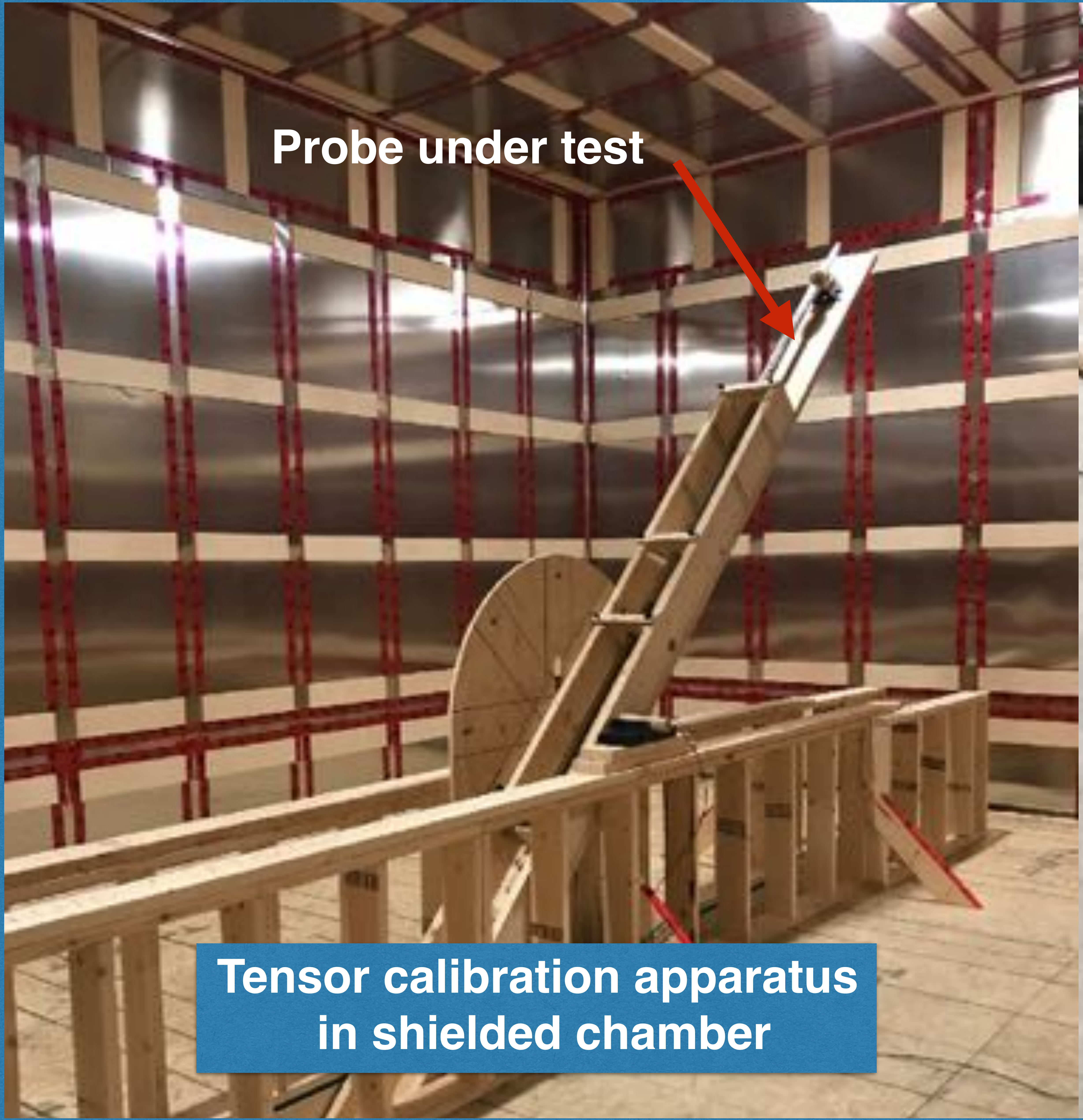


U5S model B 3-axis surface B field sensor:
25% higher sensitivity 10% lighter

UTEM 5 ISR sensor:
3 dipoles, up to 3 TX

Shielded chamber for BH sensor calibration

UTEM 5 BH system development



UTEM 5 receiver input data

Used for all UTEM 4 and UTEM 5 surveys
Fibre-optic digital telemetry from all sensors

B field front end

- simultaneous 3-axis B field data at 100 kHz sampling rate
- 32-bit EM data decoding
- DC correction processing: flat frequency response DC to 10 kHz
- 64-bit time stamps
- Exact deconvolution of transmitter waveform to a square wave

Other data

- 3-axis accelerometer data
- 3-axis magnetometer data (BH)
- Temperature and monitoring data
- All internal sensor and receiver settings

UTEM 5 RX front panel

UTEM 5 receiver in the field

UTEM 5 receiver features

Monitoring, Recording of Measurements

Real time data monitoring during stacking in the field

- Optimized for contract survey work
- Detect and repeat of bad data at survey time
- Immediate in-fill detailing of anomalies

Receiver upload of survey geometry, and reduction settings

Optional viewing of fully reduced data, but raw channel data recorded

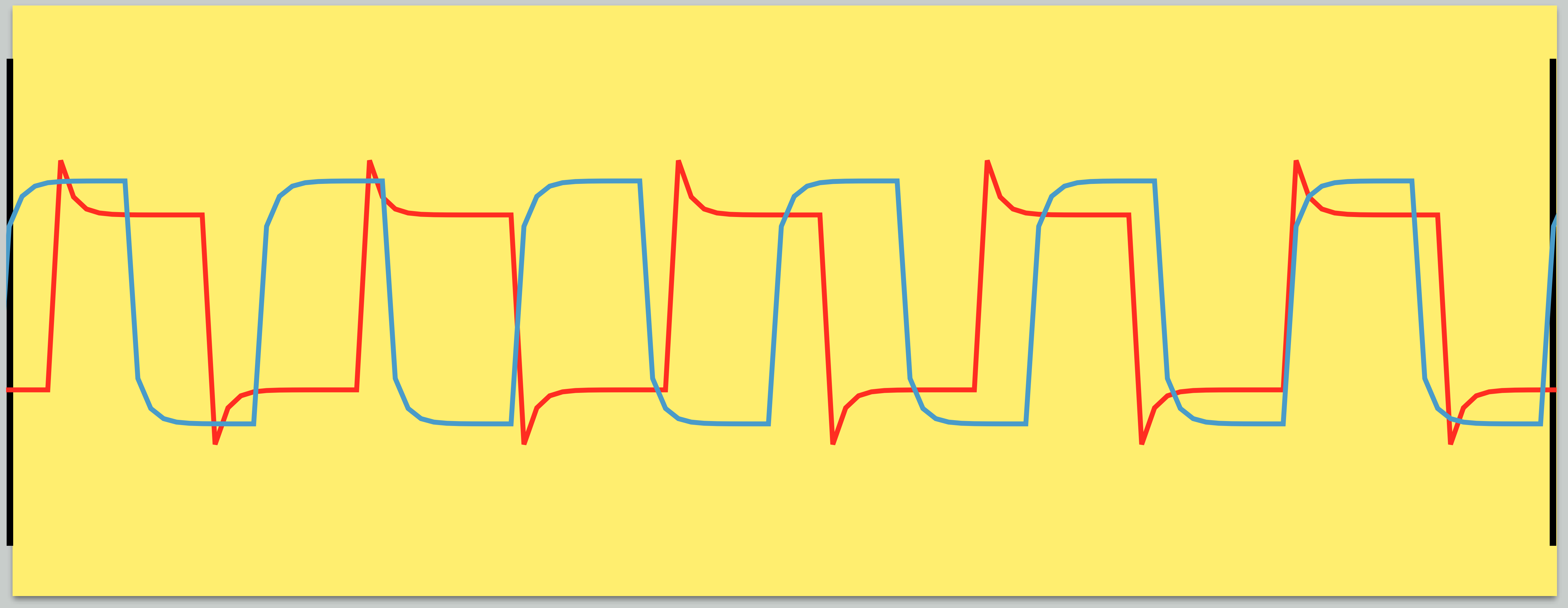
Advanced techniques for noise rejection

- Pre-emphasis deconvolution
- Optional bi-linear tapered channel sampling
- Multi-level binomial pre-stack method -> tapered stacking
- Multi-frequency and cultural noise exact interleaving
- Noise event processing

Sampling of up to 3 sets of channels per component

- Channel samplings can be for same or different frequencies
- Automated selection of up to 3 interleaved UTEM frequencies
- Rejection of cultural noise frequencies

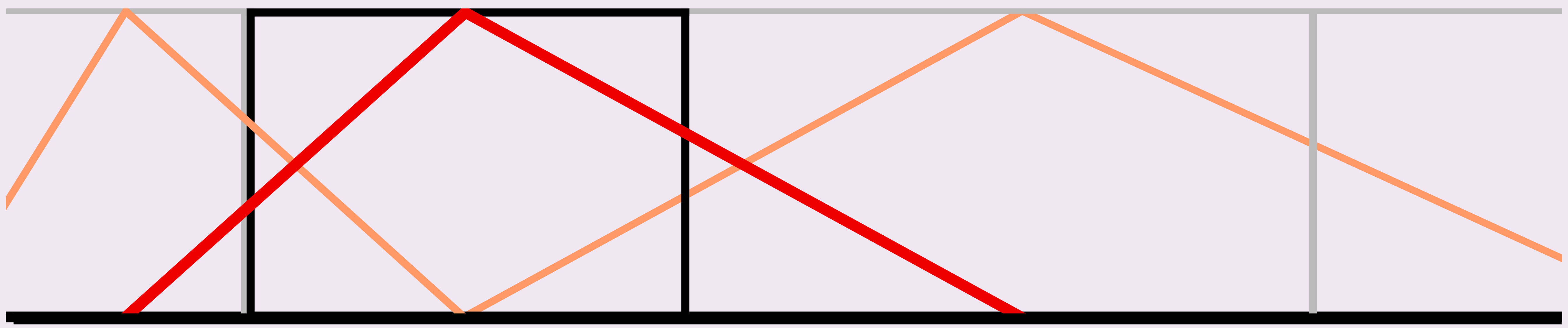
Sub-stack method for frequency interleaving



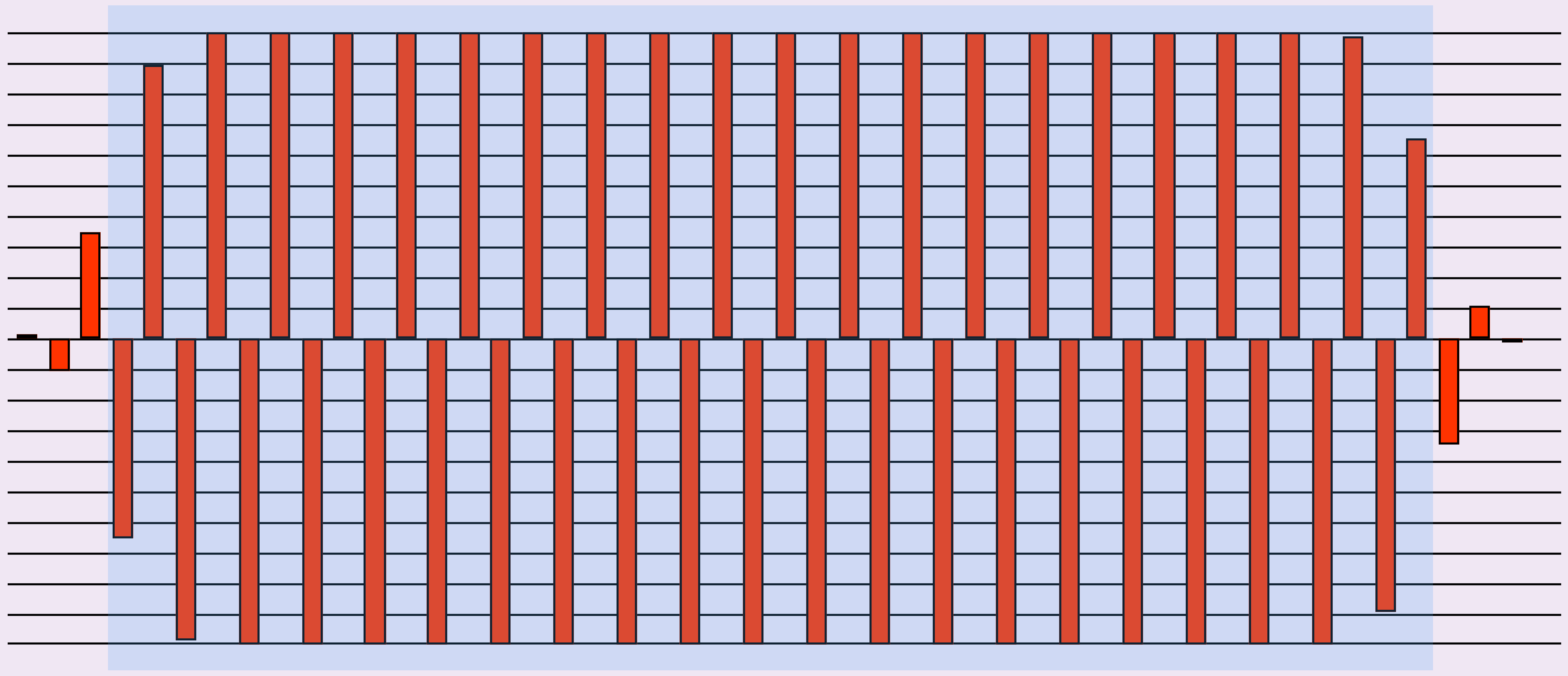
a sub-stack length
interleaving
two base frequencies

UTEM 5 sampling and stacking functions

boxcar and tapered channel sampling functions



Single tapered sub-stack of a boxcar channel



Tapered late channels have much better immunity to non-harmonic power line noise at low base frequency

SAMPLING/STACKING FUNCTION EXAMPLE

Boxcar channel sampling

B_L binomial pre-stacking for L = 5

M half-cycle sub-stack for M = 42

M+L+1 = 48 half-cycles total length

(MN+L+1) half-cycles for N sub-stacks

UTEM 5 receiver regular stacking algorithm

FOR EACH CHANNEL, COMPONENT, SAMPLING

Apply half-cycle polarity to each raw channel data time series

$H_k = (-1)^k R_k$

Using z-transform notation to channel time series with half-cycle sampling interval

$X(z) = H_0 + H_1 z^{-1} + H_2 z^{-2} + \ldots + H_n z^{-n}$

Binomial decimation (pre-stack)

$B_0(z) = (1 + z^{-1}) X(z)/2$	B_0 rejects DC in R_k data
$B_1(z) = (1 + z^{-1}) B_0(z)/2$	B_1 rejects DC and linear drift
…	…
$B_L(z) = (1 + z^{-1}) B_{L-1}(z)/2$	B_L rejects polynomial to degree L
L 9 to 13 usual for UTEM 5 ($L \leq 31$)	≈ gaussian weights for large L

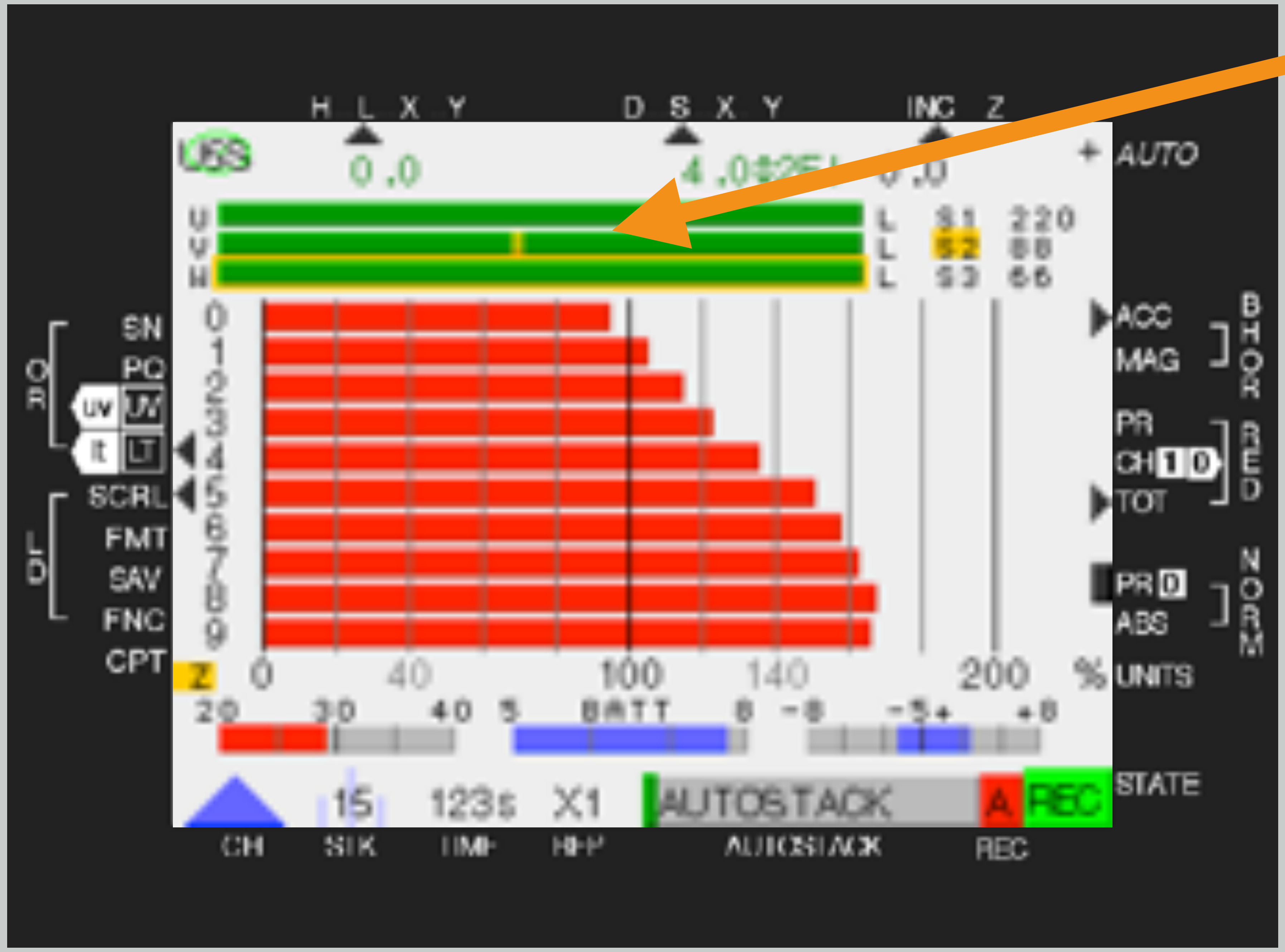
Regular sub-stack

$S_M(z) = (1 + z^{-1} + z^{-2} + z^{-3} + \ldots + z^{-(M-1)}) B_L(z)/M$	length M has exact interleaving

Final regular stacking

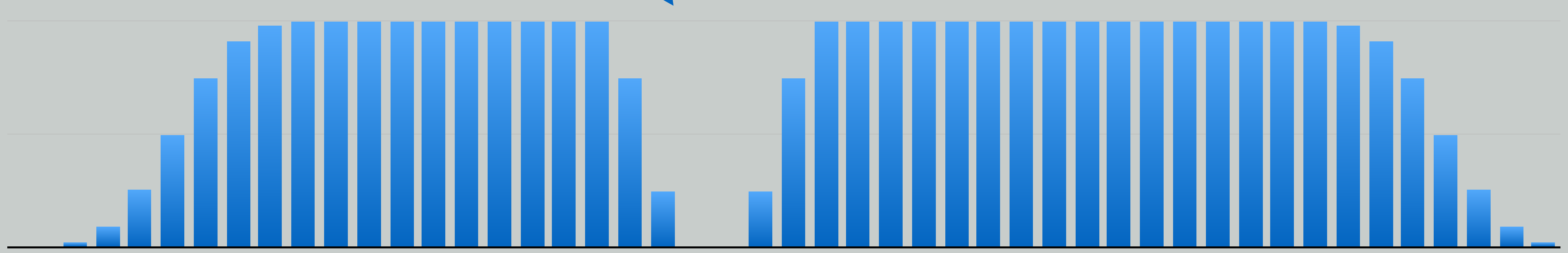
$F_N(z) = (1 + z^{-M} + z^{-2M} + z^{-3M} + \ldots + z^{-(N-1)(M-1)}) S_M(z)/N$	use full sub-stacks only

UTEM 5 noise event processing



OV and OT events indicated in progress bars

Green	OK
Red	OV : -> reject whole stack (“reject”) or reset sensor (“reject-reject”)
Yellow	OT : -> reject whole sub-stack (“trim”) or (experimental speculative processing?) or <u>prune discrete event</u>

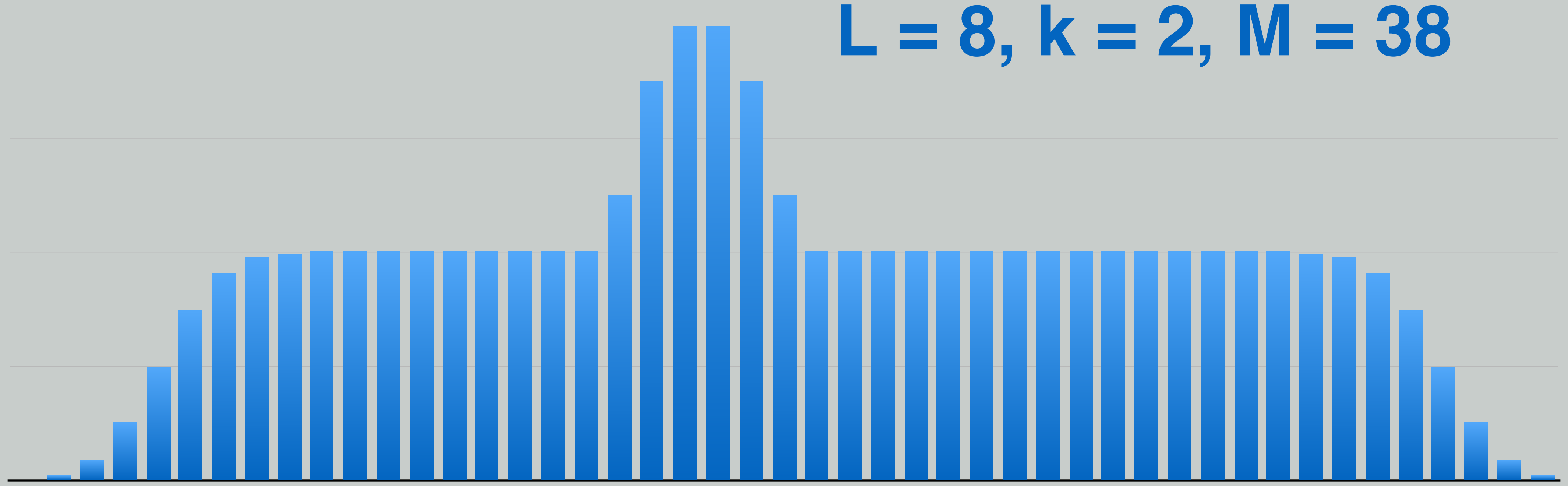


Effective weights when pruning a discrete event

$P_M(z) = S_M(z) - g(B_k(z)\, z^{-n} - B_k(z)\, z^{-n-1} - \ldots)/M \qquad k \leq L$

Usually at low frequency: L=11, k=5

L = 8, k = 2, M = 38



Correcting weights of a later sub-stack to preserve interleaving

$Q_M(z) = z^{+nM} (S_M(z) + g(B_k(z)\, z^{-n} + B_k(z)\, z^{-n-1} - \ldots)/M)$

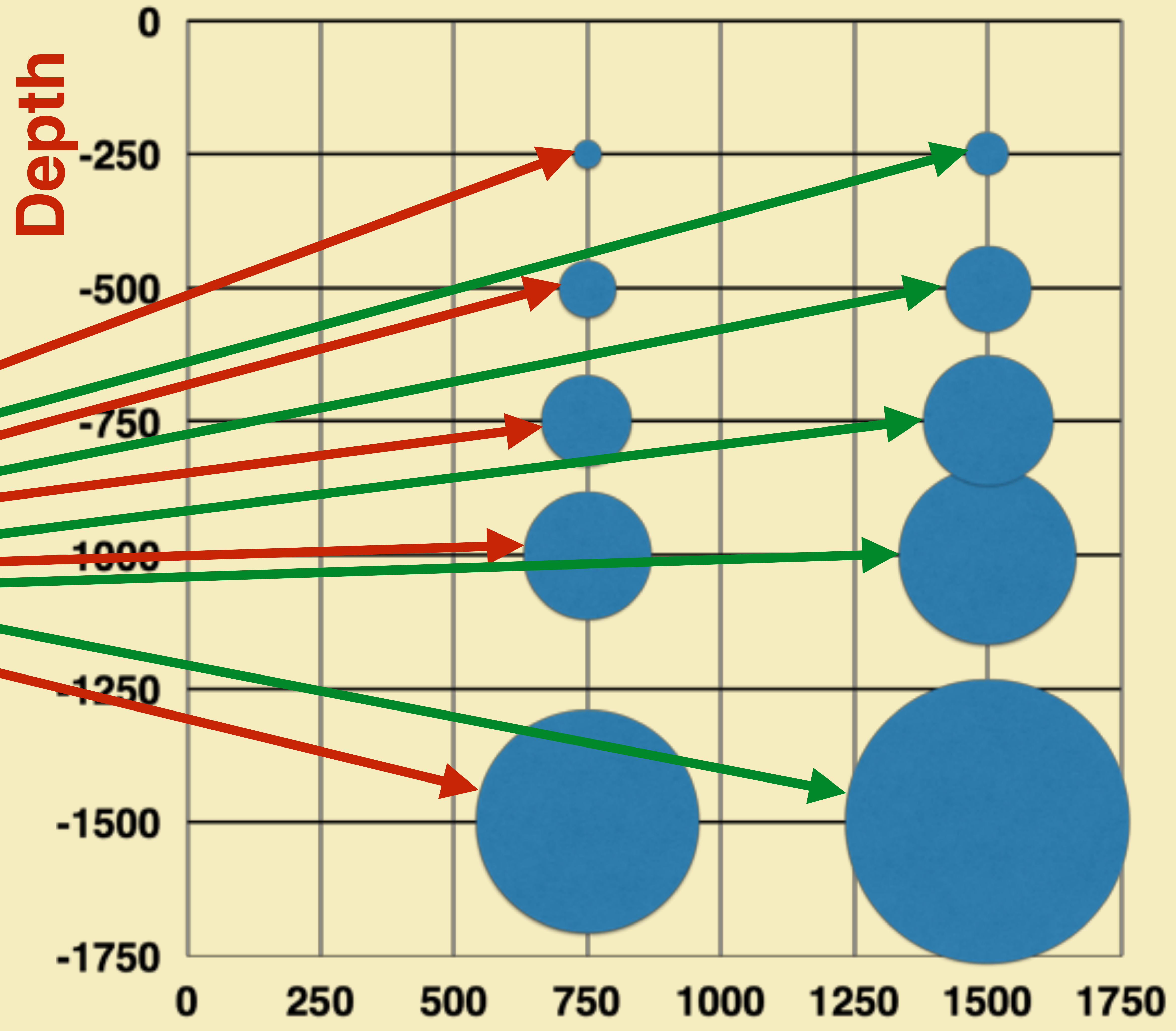
Size of detection from % primary field error and depth

Stack precision in low noise field areas

Freq (Hz)	RMS error	RMS error per A	% at 750m	% at 1500m
4	39 fT	4.6 fT/A	0.005%	0.021%
1	105 fT	12 fT/A	0.014%	0.056%
0.5	218 fT	25 fT/A	0.028%	0.12%
0.22	0.75 pT	88 fT/A	0.098%	0.40%

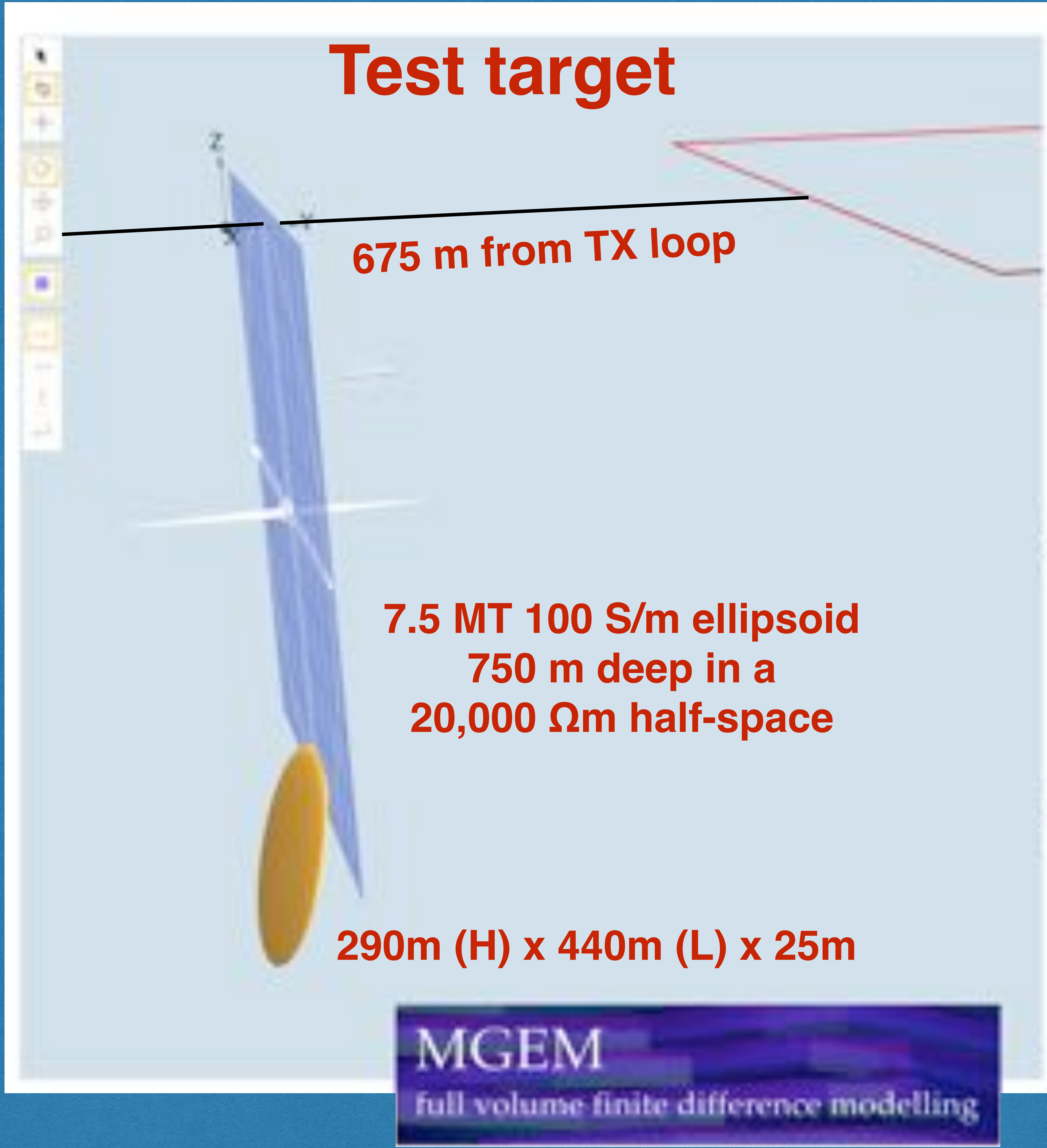
2 to 3 times higher than in a shielded enclosure

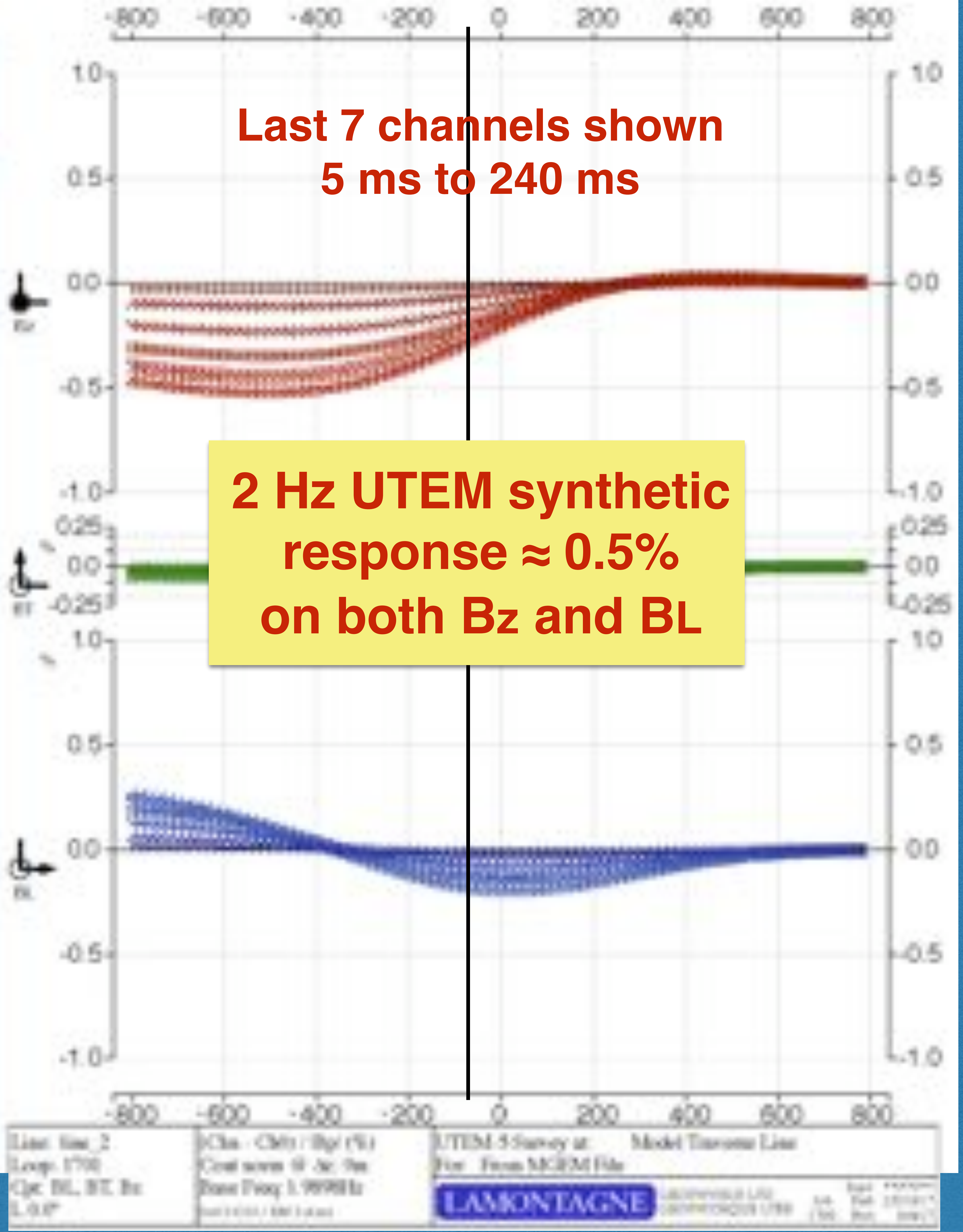
Sphere size for 14X rms error



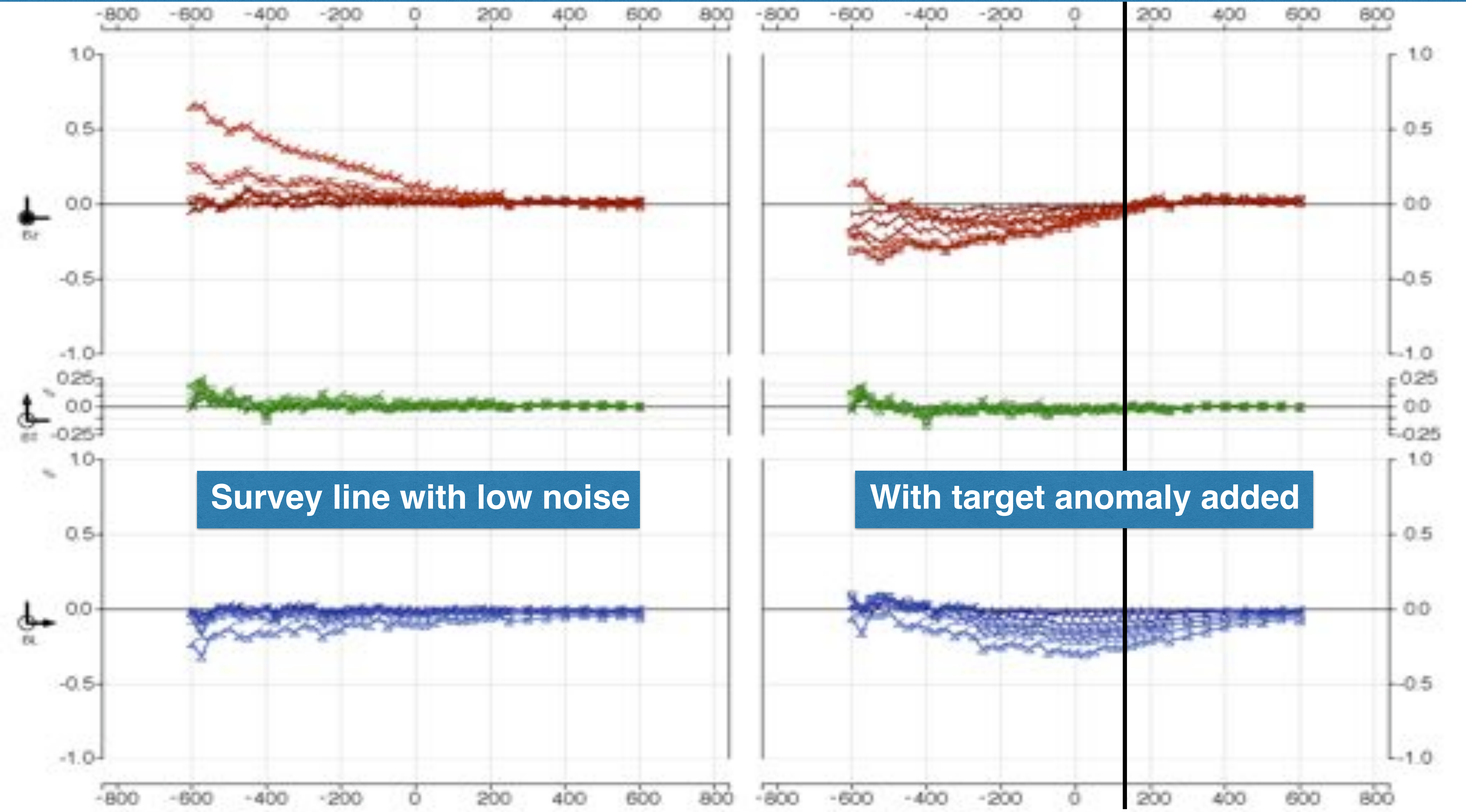
Distance from 1500m loop

Model for a UTEM 5 surface exploration scenario

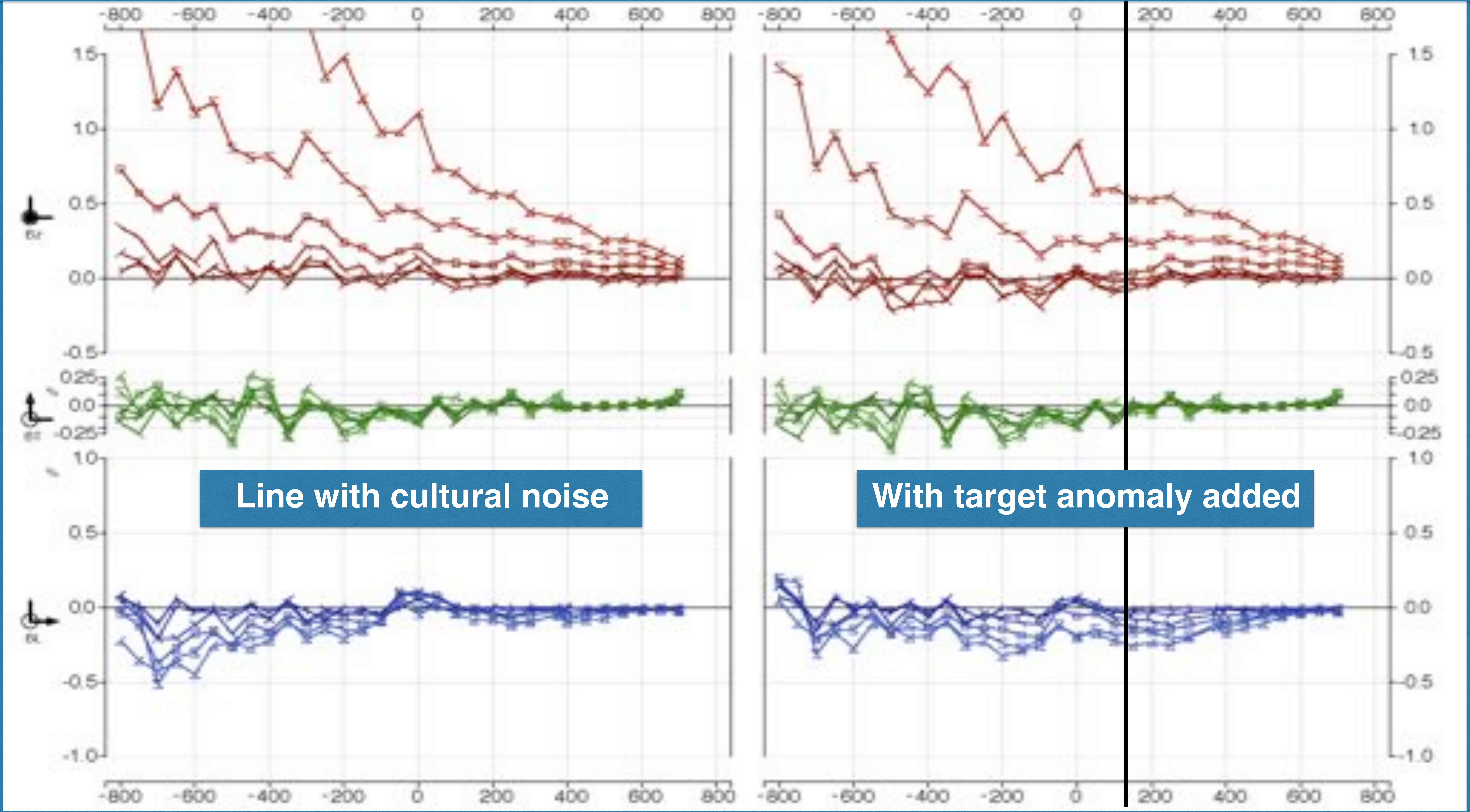


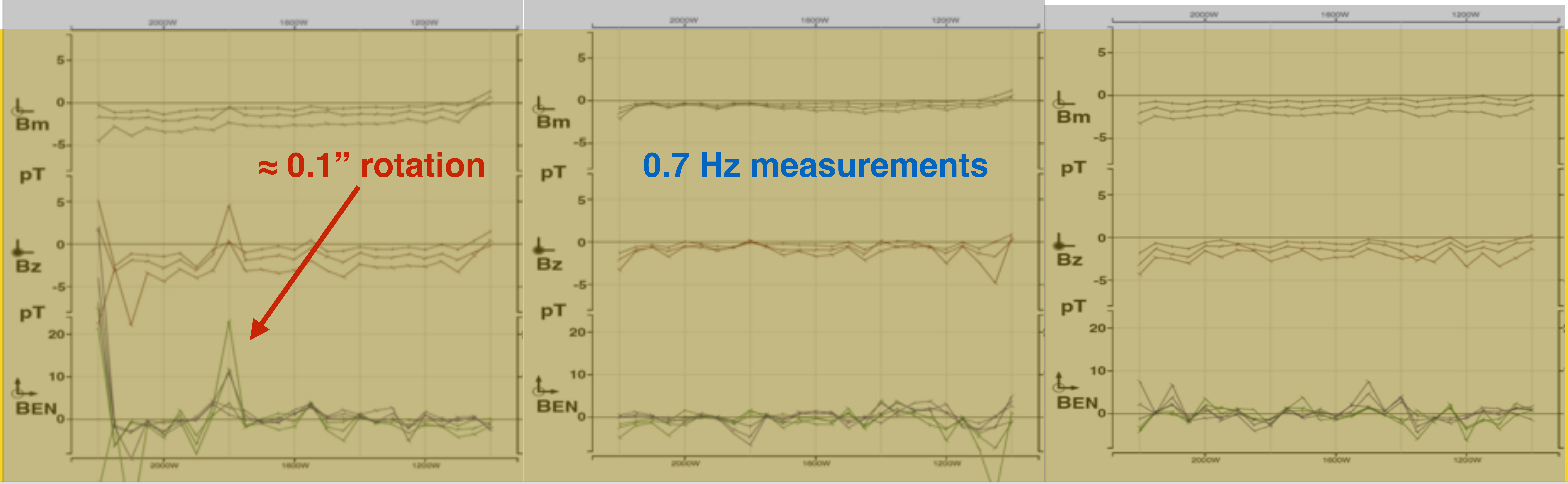


Low noise scenario



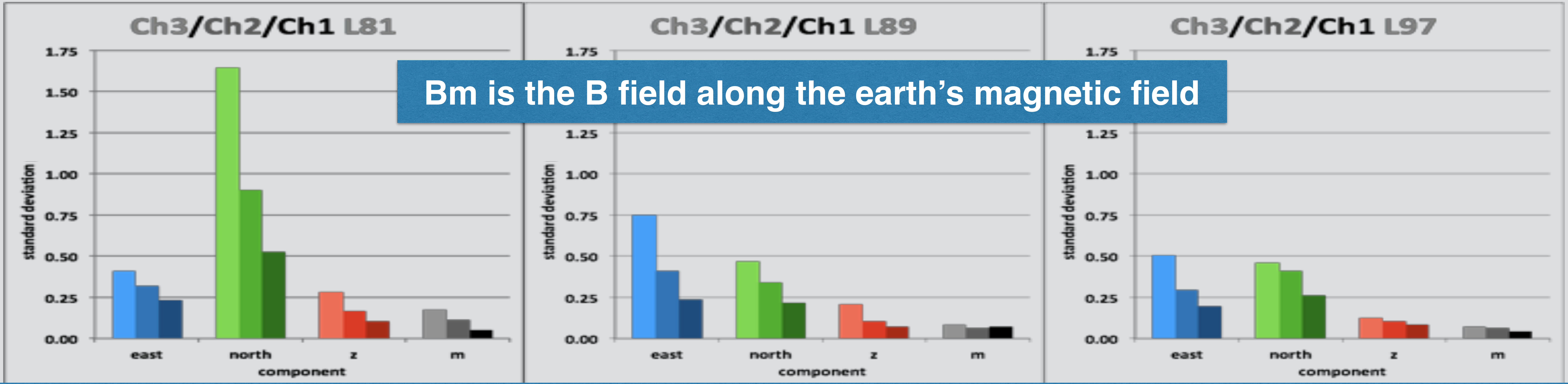
High noise scenario





≈ 0.1” rotation

0.7 Hz measurements



Bm is the B field along the earth’s magnetic field

Looking forward

Surface mineral exploration to more than 1000m depth

Borehole exploration to 1000m distance around deep holes

Using wide bandwidth for target discrimination

Use of 3D volume modelling tools to guide EM exploration

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