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Civil Engineering Applications
of Ground Penetrating Radar

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Development and testing of an improved reconfigurable step-frequency GPR

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Talk Layout

- The reconfigurable GPR system
- The implemented prototype
- Interference mitigation
- GPR results
- Conclusions

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The reconfigurable GPR system

- **Reconfigurable antennas**
- **Reconfigurable power**
- **Reconfigurable integration time**

The reconfiguration is conceived in the spectral domain and takes into account the background medium at hand.

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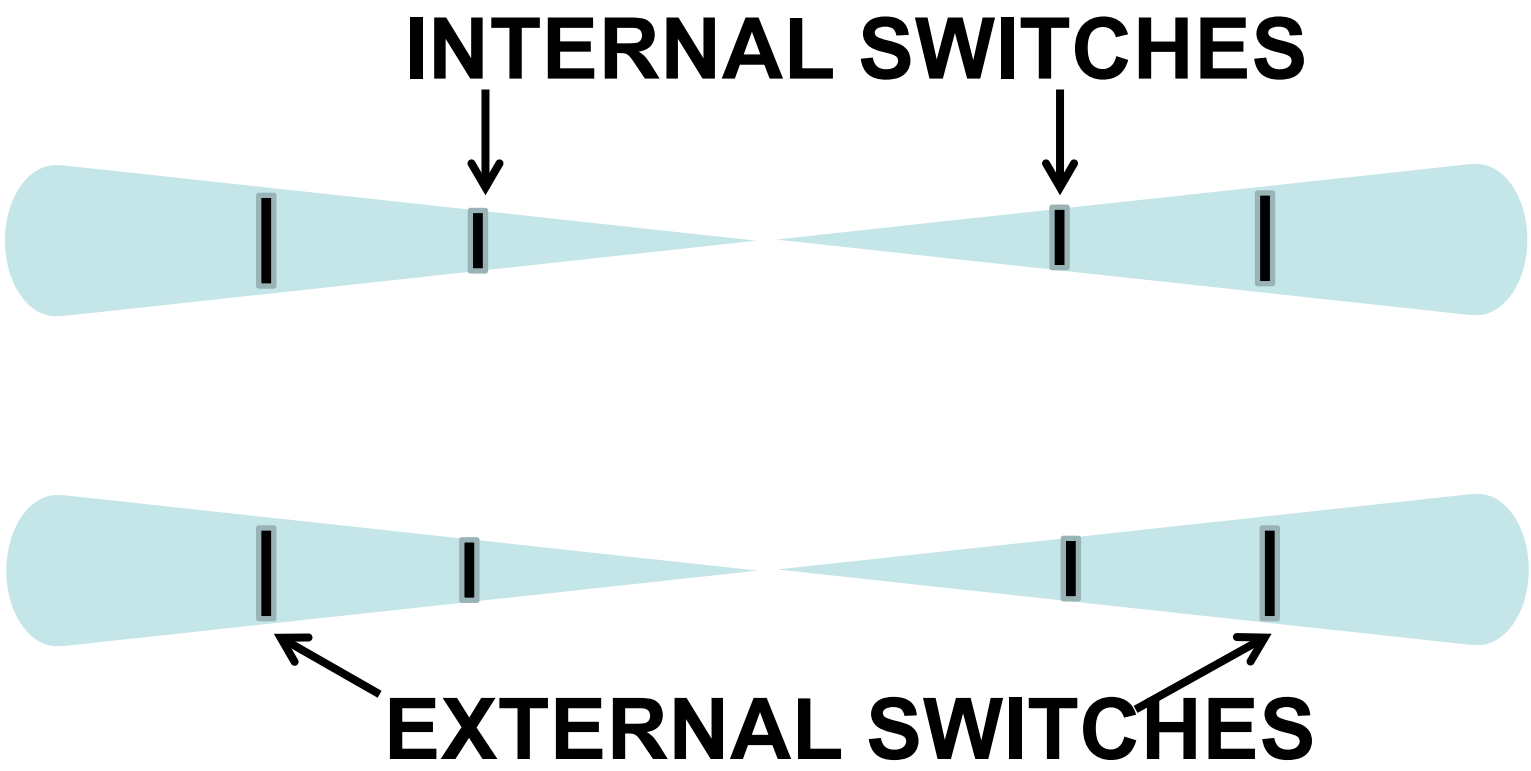
Reconfigurable GPR antennas



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The implemented prototype

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Three equivalent antennas with the same gap.

Three operation bands covering an ultra wide frequency range from 50 to 1000 MHz, with central frequency at about 120, 240 and 550 MHz.

One, two or three couples of antennas can simultaneously acquire data.

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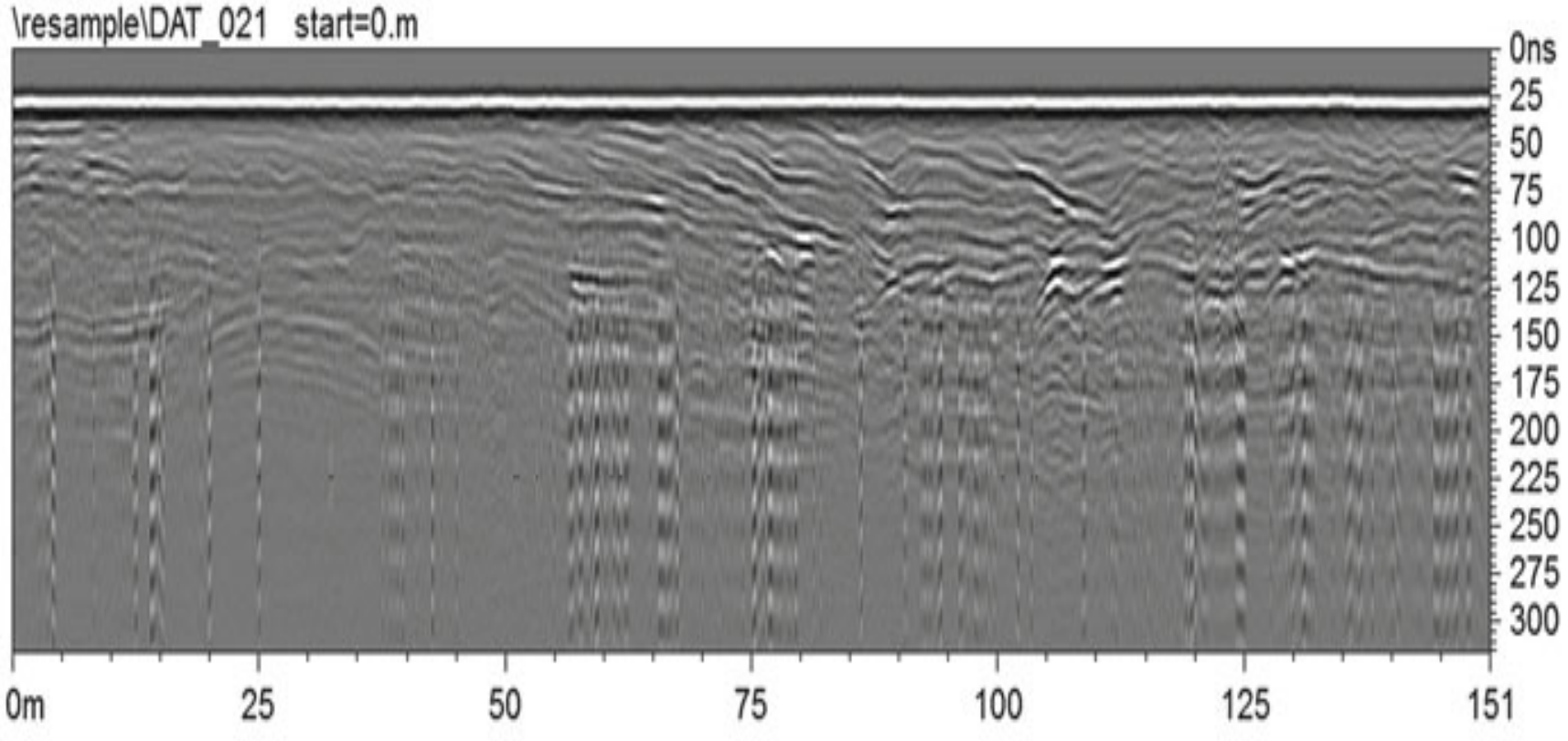
Interference mitigation



Dean Goodman and Salvatore Piro, GPR Remote Sensing in Archaeology, Springer, 2013.

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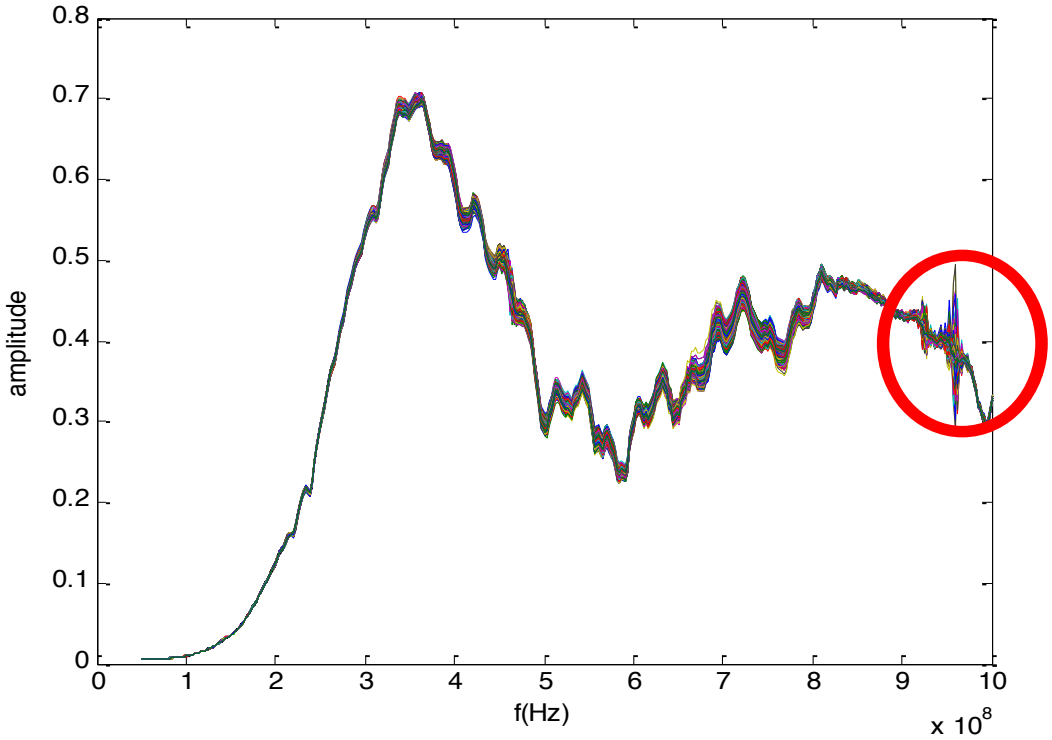
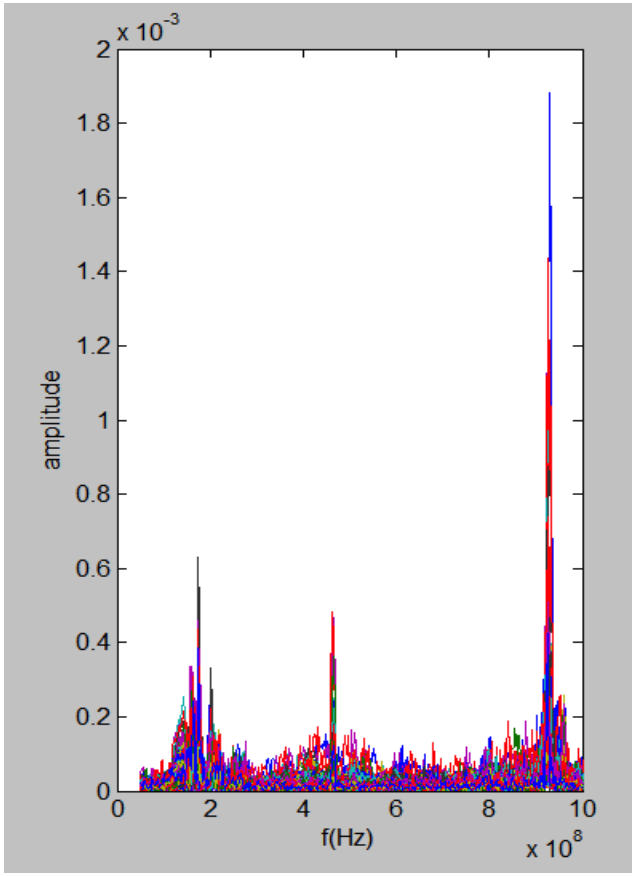
How can we recognize the “interferenced” frequencies?



The spectrum of the data



Spectrum’s slope

….too ambiguous and case driven results…

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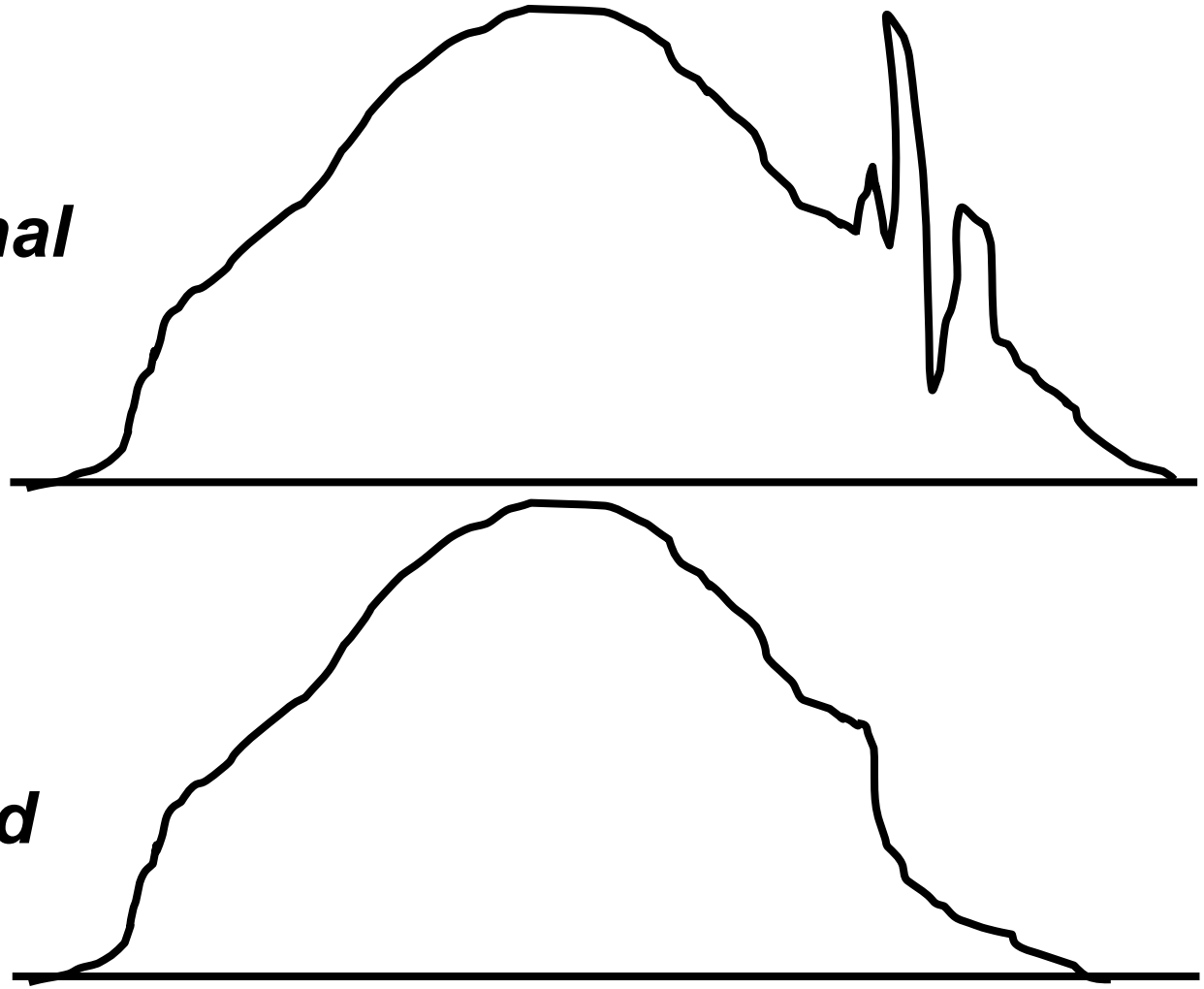
First solution: filtering



Drawbacks: loss of information and possible artifacts

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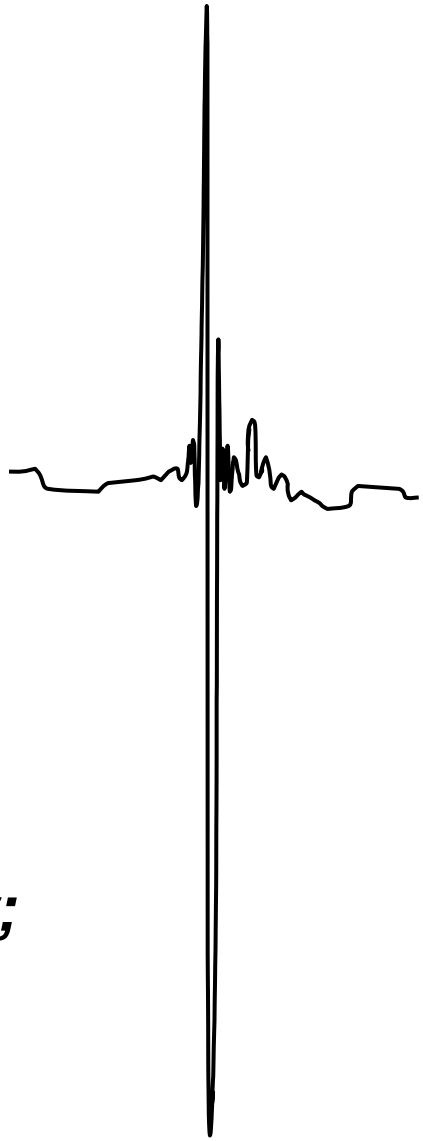
Second solution: radiating more power

…more power…



Drawbacks:
saturation or even damaging the receiver;
illegal or even harmful operation

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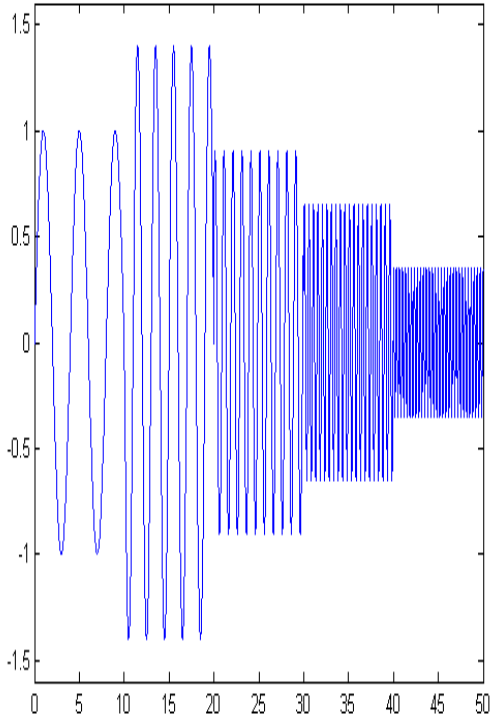
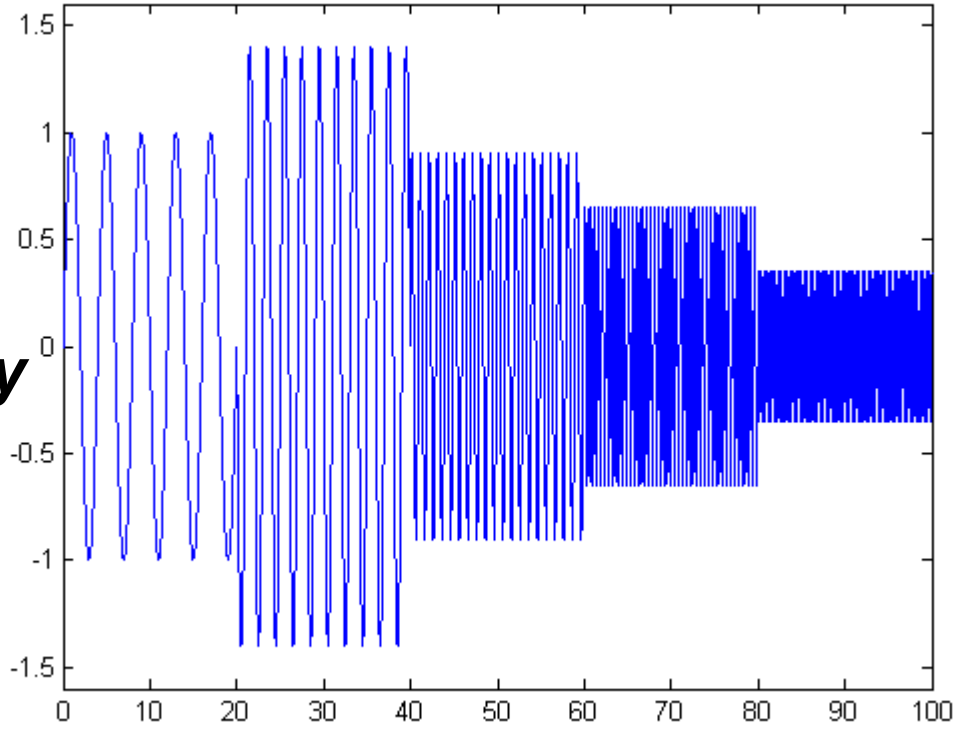
Third solution (step frequency systems): prolonging the integration time of all the harmonics



...more energy



Drawbacks: the required time is likely to become quite long

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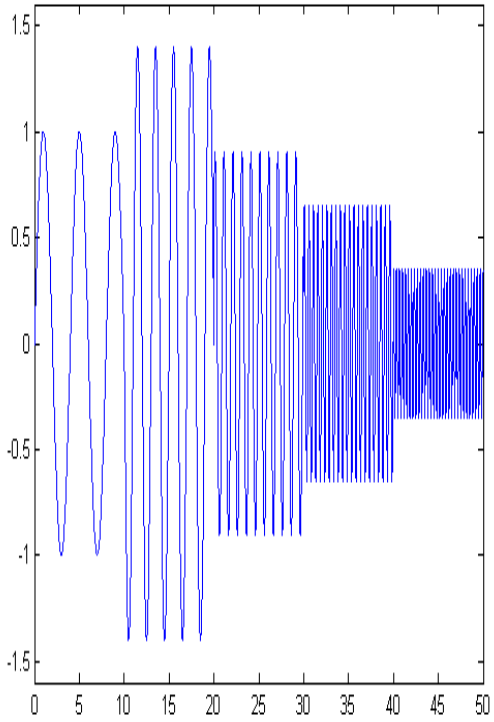
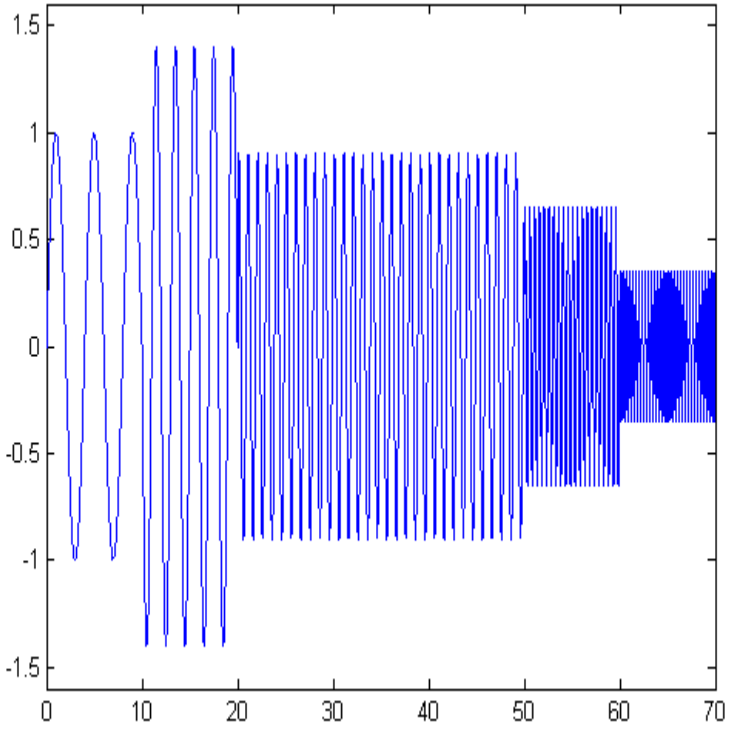
Proposed solution: selective prolonging of the most “disturbed” harmonics



…more energy, but only where needed!



Pros: No filtering, no increase of radiated power, limited prolongation of acquisition time.

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Proposed solution: selective prolonging of the most “disturbed” harmonics

Requirements:

A reconfigurable system is needed (hardware),
the disturbed frequencies have to be identified,
an algorithm has to be developed and implemented (software)

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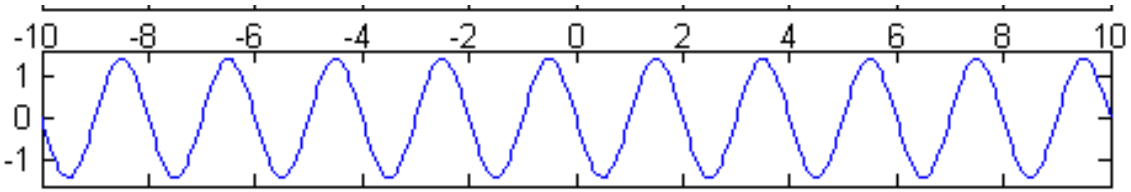
Identification of the interference from the data: retrieving *I* and *Q* components



$$A\cos\left(2\pi ft+\phi\right)=A\cos\left(\phi\right)\cos\left(2\pi ft\right)-A\sin\left(\phi\right)\sin\left(2\pi ft\right)=$$

$$=I\cos\left(2\pi ft\right)+Q\sin\left(2\pi ft\right)$$

$$I=A\cos\left(\phi\right)\qquad Q=-A\sin\left(\phi\right)$$

I and Q are the in-phase and in-quadrature components of the received harmonic and are extracted from the received harmonic signal, knowing the transmitted one.

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Averaging on N in-phase and in-quadrature samples

$$I_m = \frac{I_1 + I_2 + I_3 + ...I_N}{N}$$

$$Q_m = \frac{Q_1 + Q_2 + Q_3 + ...Q_N}{N}$$

The praxis for <u>any</u> stepped frequency system is to measure N consecutive times the I and Q components and retain the average (or medium) value.

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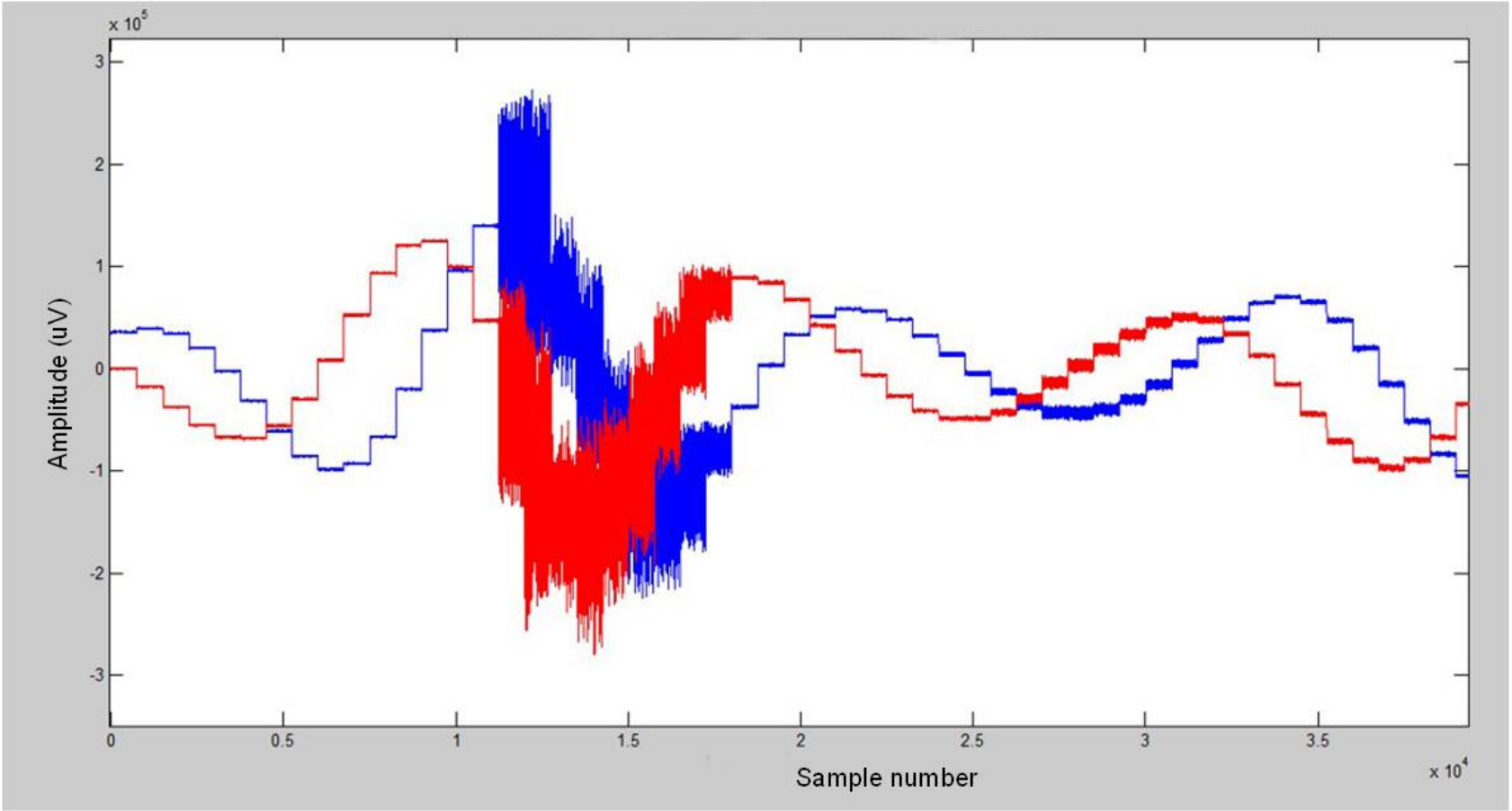
Representation of the *I* (red curve) and *Q* (blue curve) samples frequency by frequency in an experimental case



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The Variance of the samples

$$\begin{cases} \sigma_I^2 = \dfrac{I_1^2 + I_2^2 + \ldots I_N^2}{N} - \left(\dfrac{I_1 + I_2 + \ldots I_N}{N} \right)^2 \\ \sigma_Q^2 = \dfrac{Q_1^2 + Q_2^2 + \ldots Q_N^2}{N} - \left(\dfrac{Q_1 + Q_2 + \ldots Q_N}{N} \right)^2 \end{cases}$$

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The Matrix of variance

$$MI(k,h) = \sigma_I^2(f_k, tr_h) + \sigma_Q^2(f_k, tr_h)$$

The Index of Interference

$$VI(k) = \max_h MI(k,h)$$

The enlargement factor (= 1 for M=1)

$$W_k = \min\left[10, Ceil\left(M \frac{VI(k)}{\max(VI)}\right)\right]$$

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Reconfiguration “Protocol”

- ***Gather a calibration B- Scan***
- ***Evaluate the interference index (for each couple of antennas) and the B-Scan***
- ***Set optionally an integer number M (for each couple of antennas) meaning “how many times you would like to prolong the most disturbed tone”***

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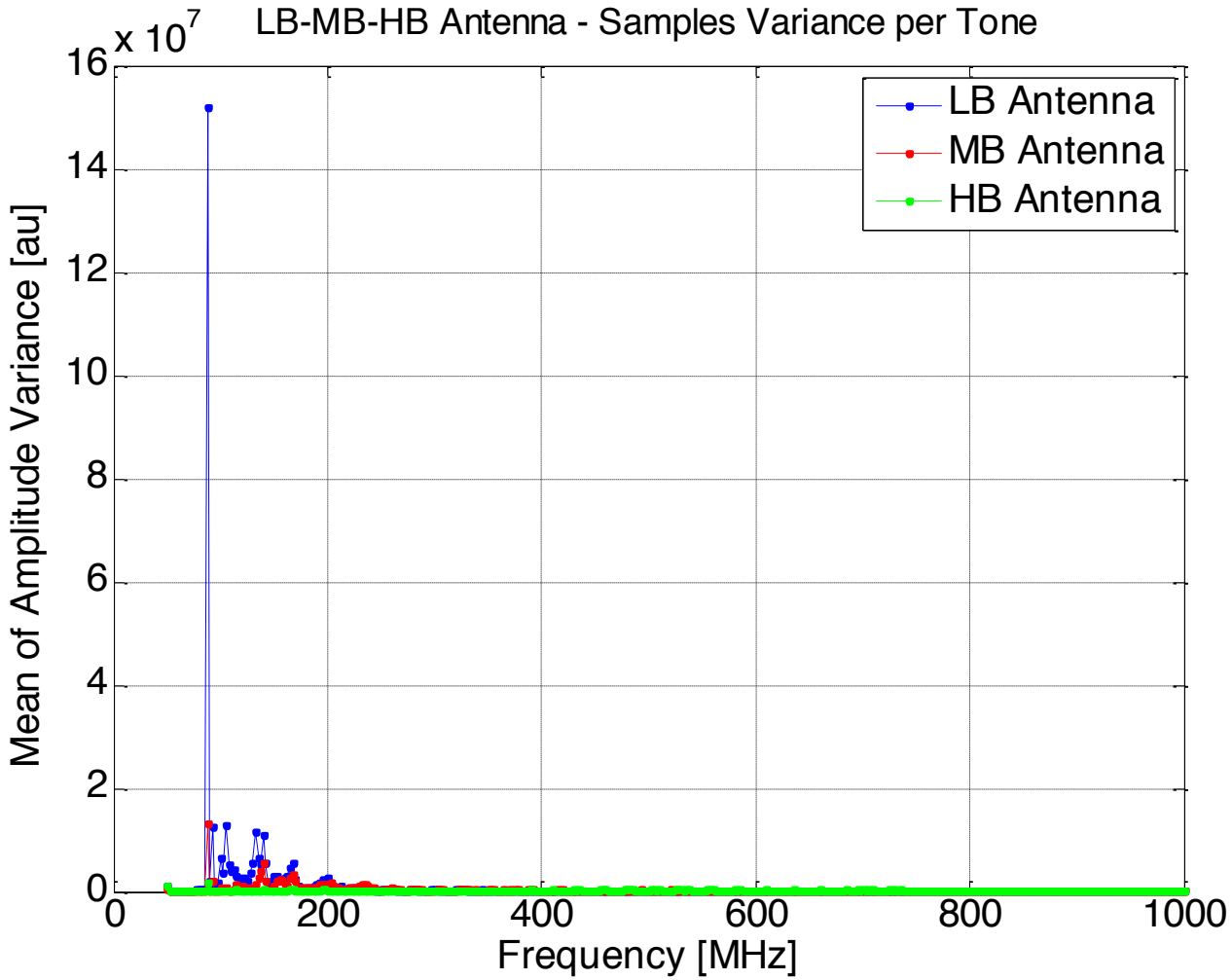
A preliminary experiment indoor at IBAM-CNR



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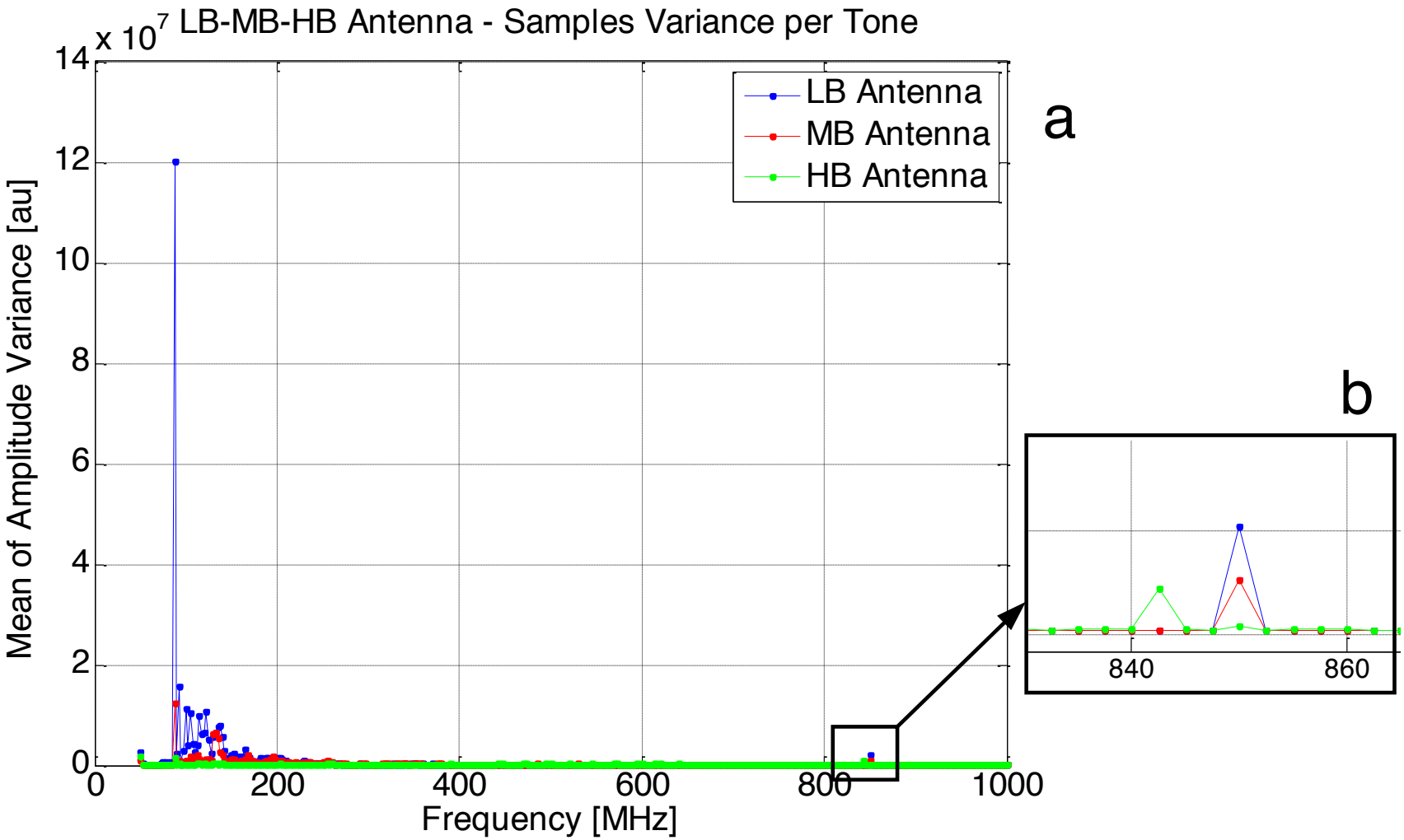
The same experiment with two mobile phones calling each other



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Effects in a practical case

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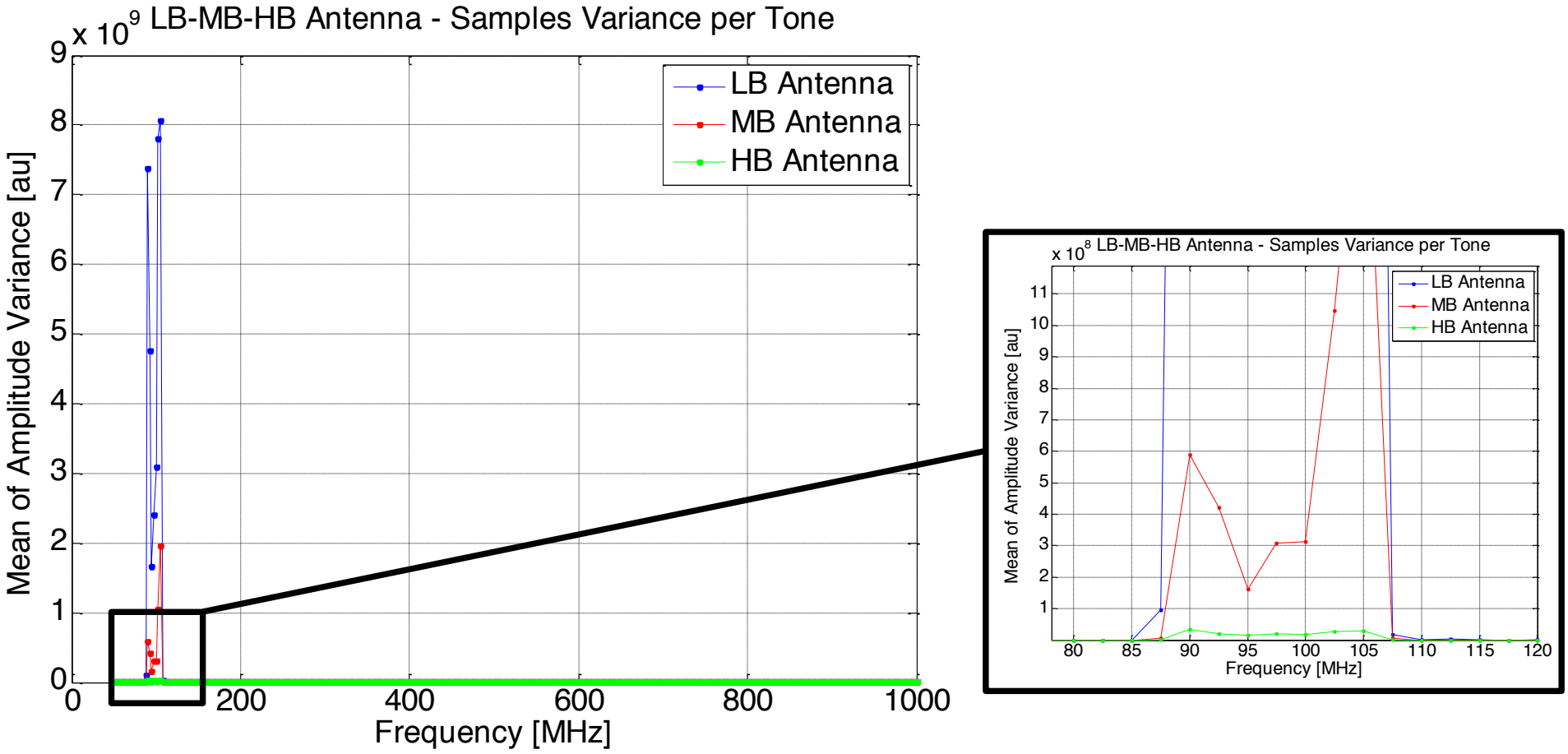
Measured Interference Index

Interference from FM-broadcast radio transmissions



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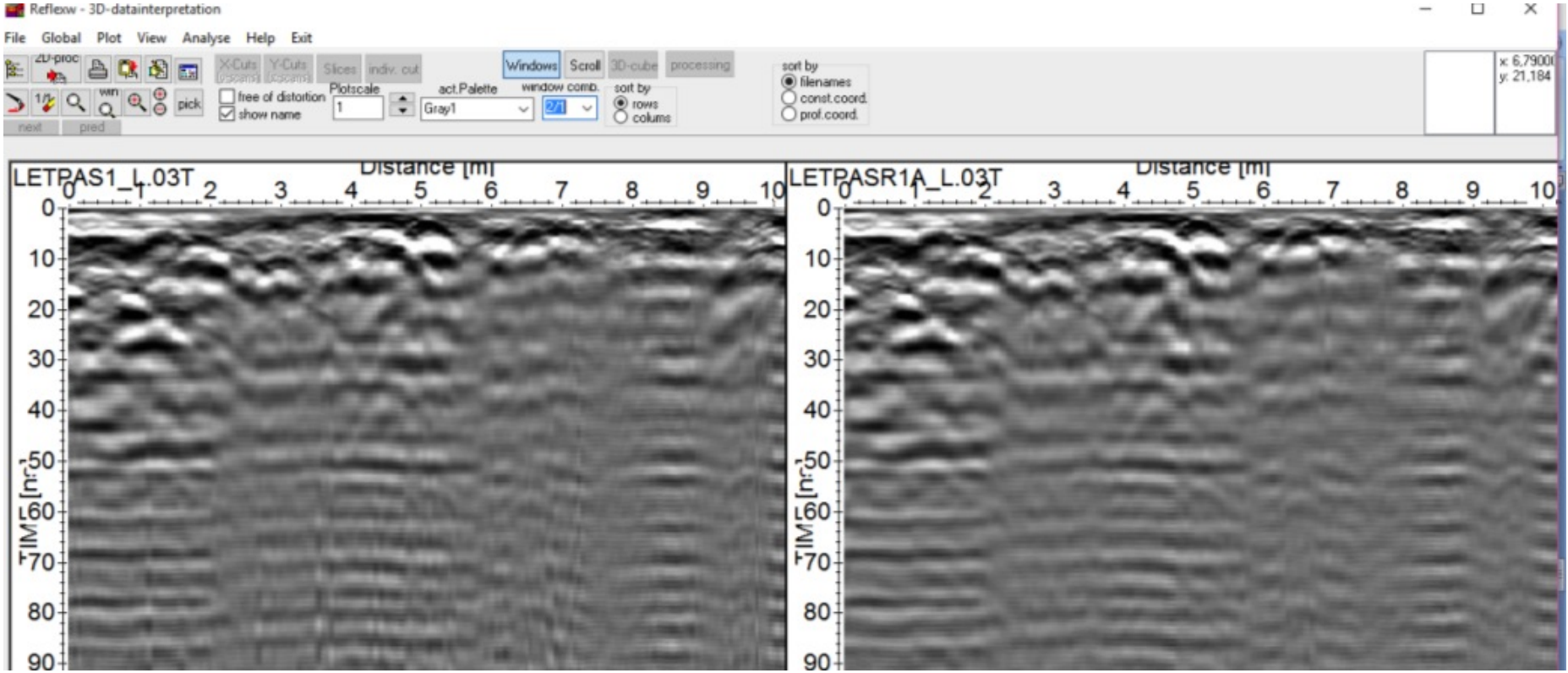
Results of our prototype

Data without reconfiguration

Data with reconfiguration



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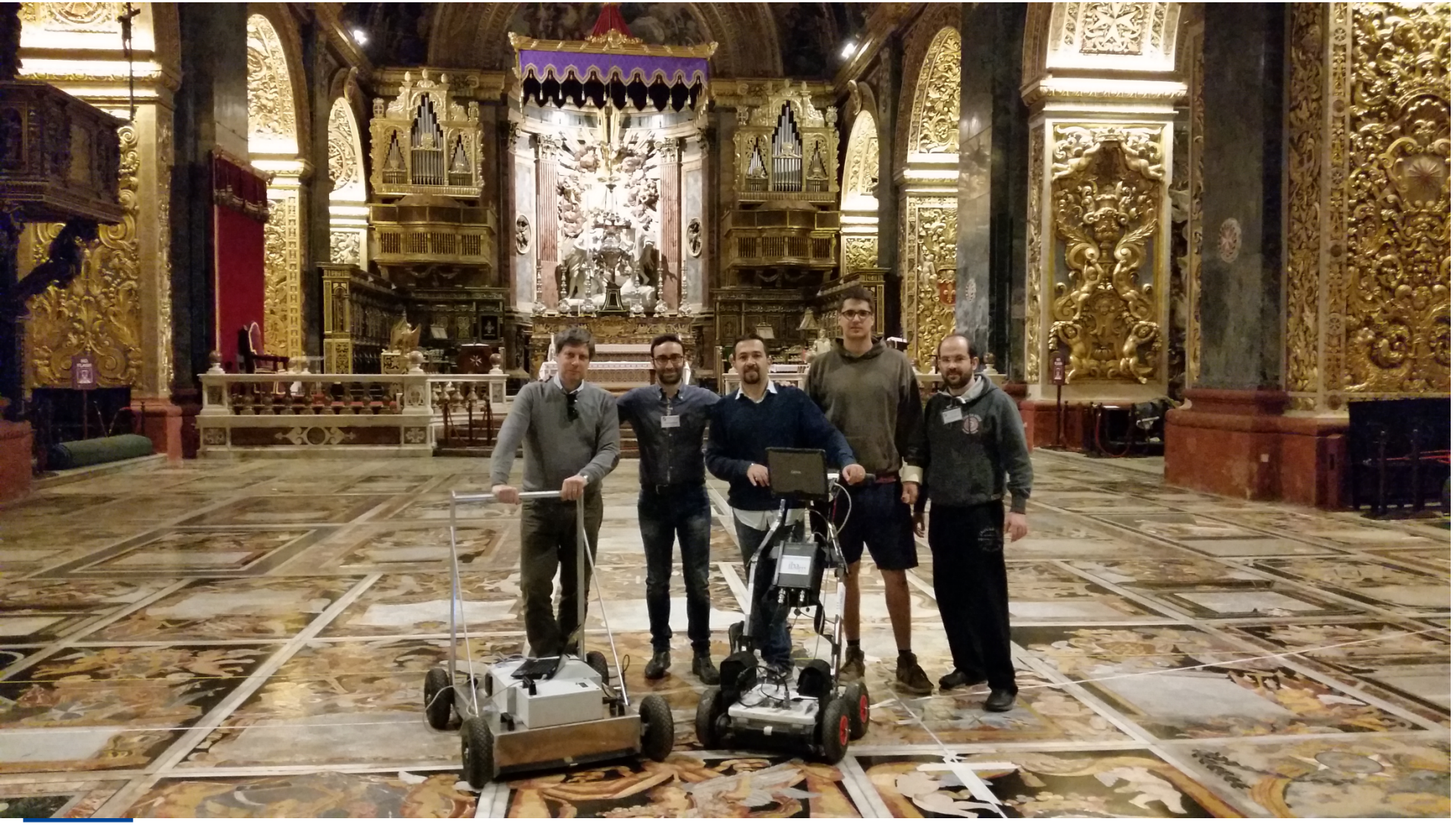
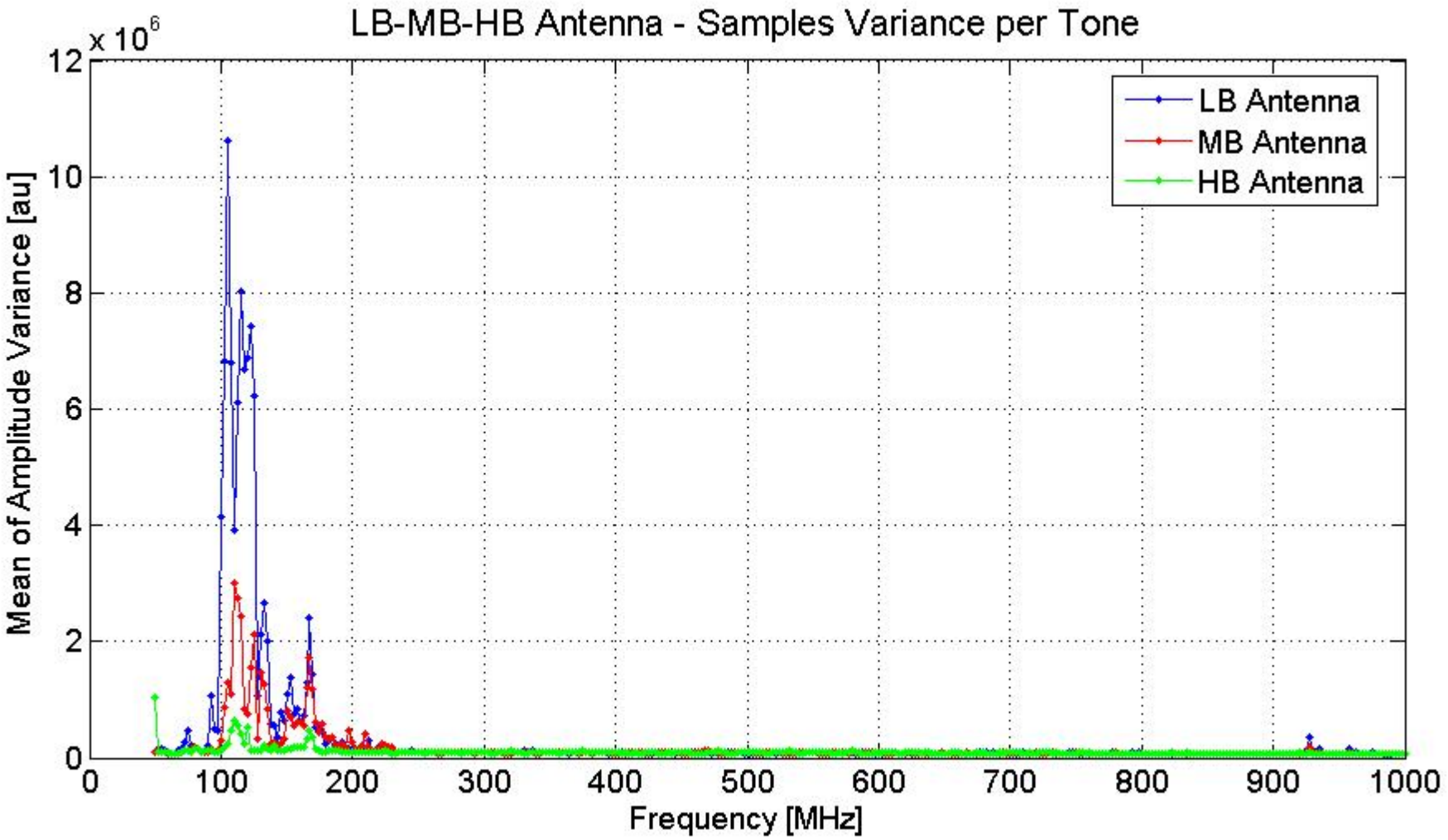
Experiments in the Chapel of Aragone, Co-cathedral of St. John in Valletta, Malta



Index of interference in "standard" conditions



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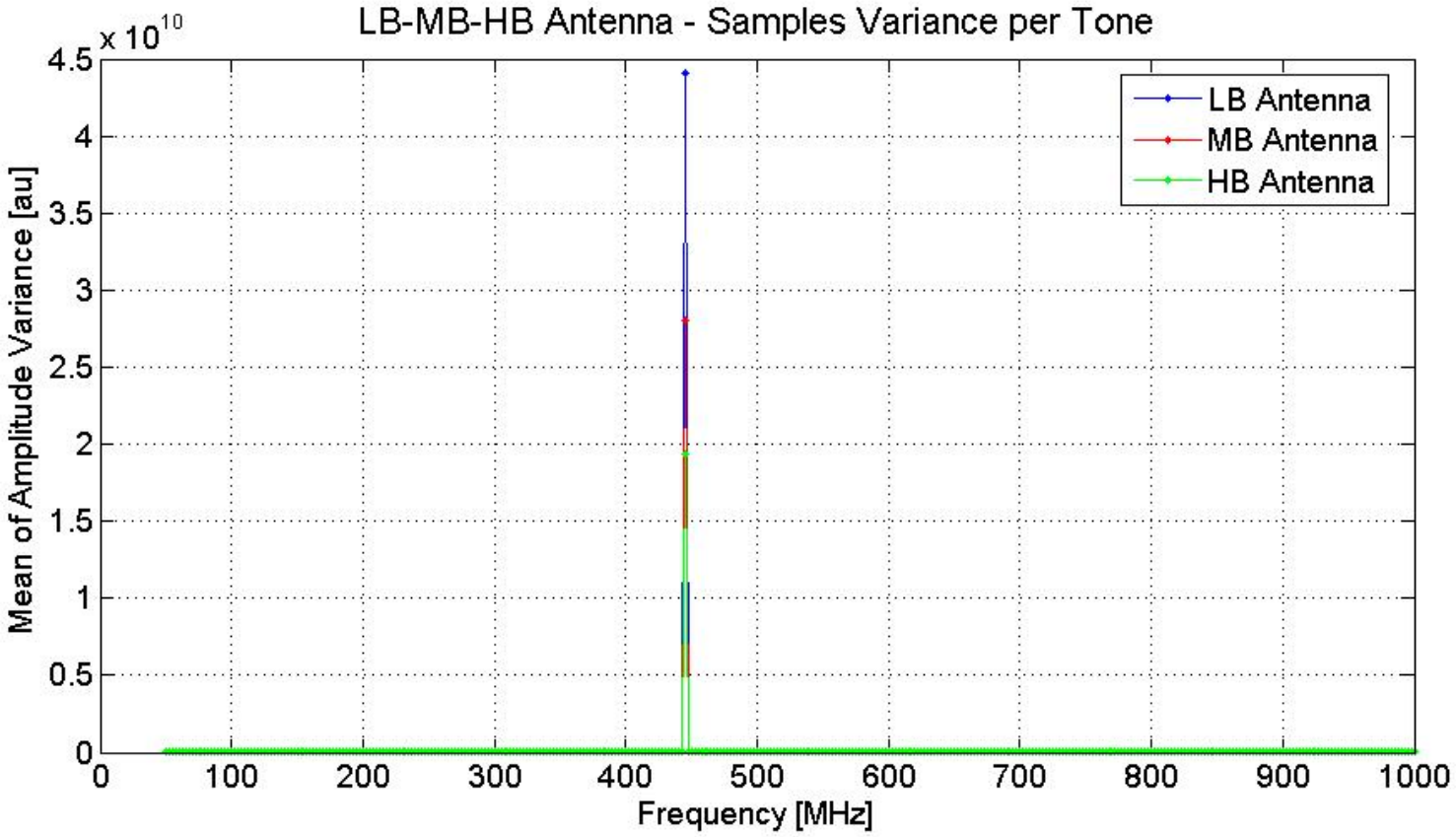
Index of interference with a transceiver of the staff active



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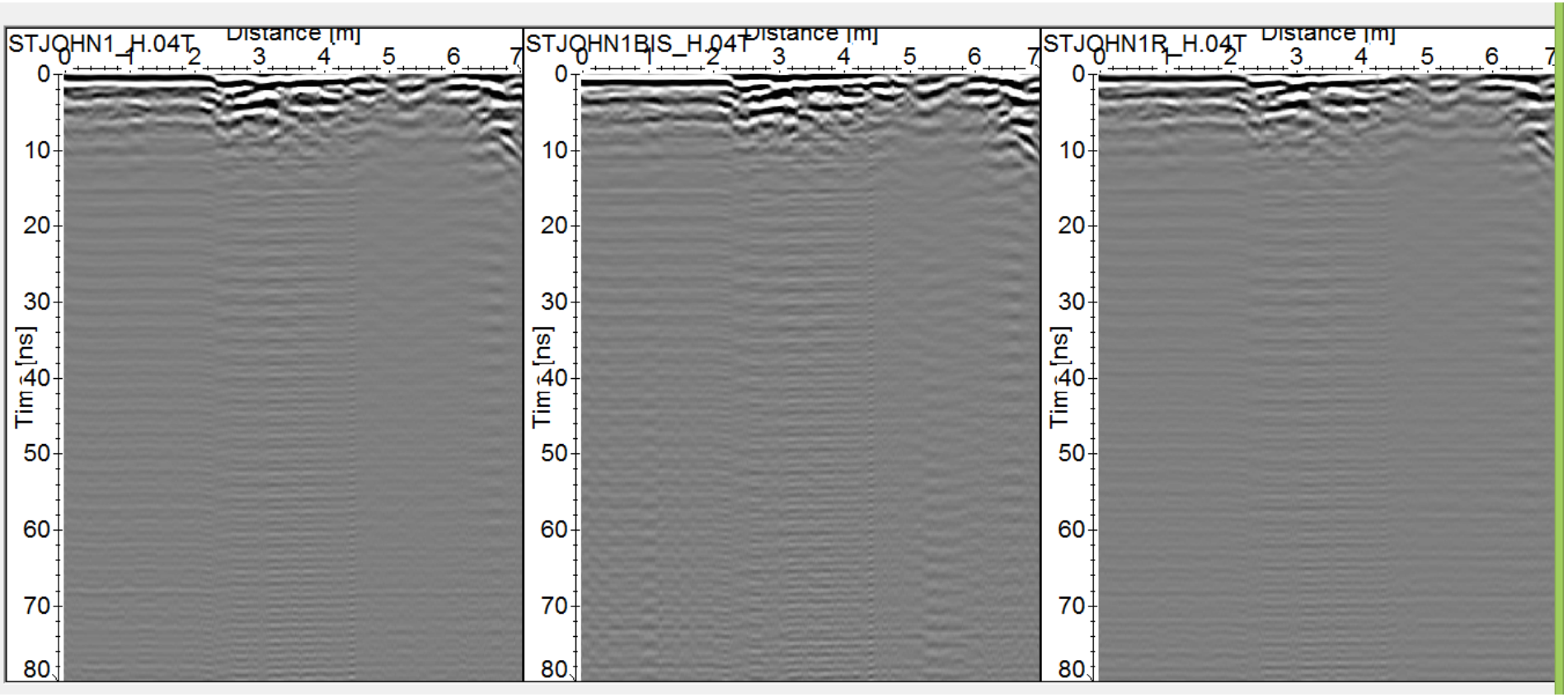
Reconfiguration results



default integration times transceiver not active

default integration times transceiver active

reconfigured integration times, transceiver active

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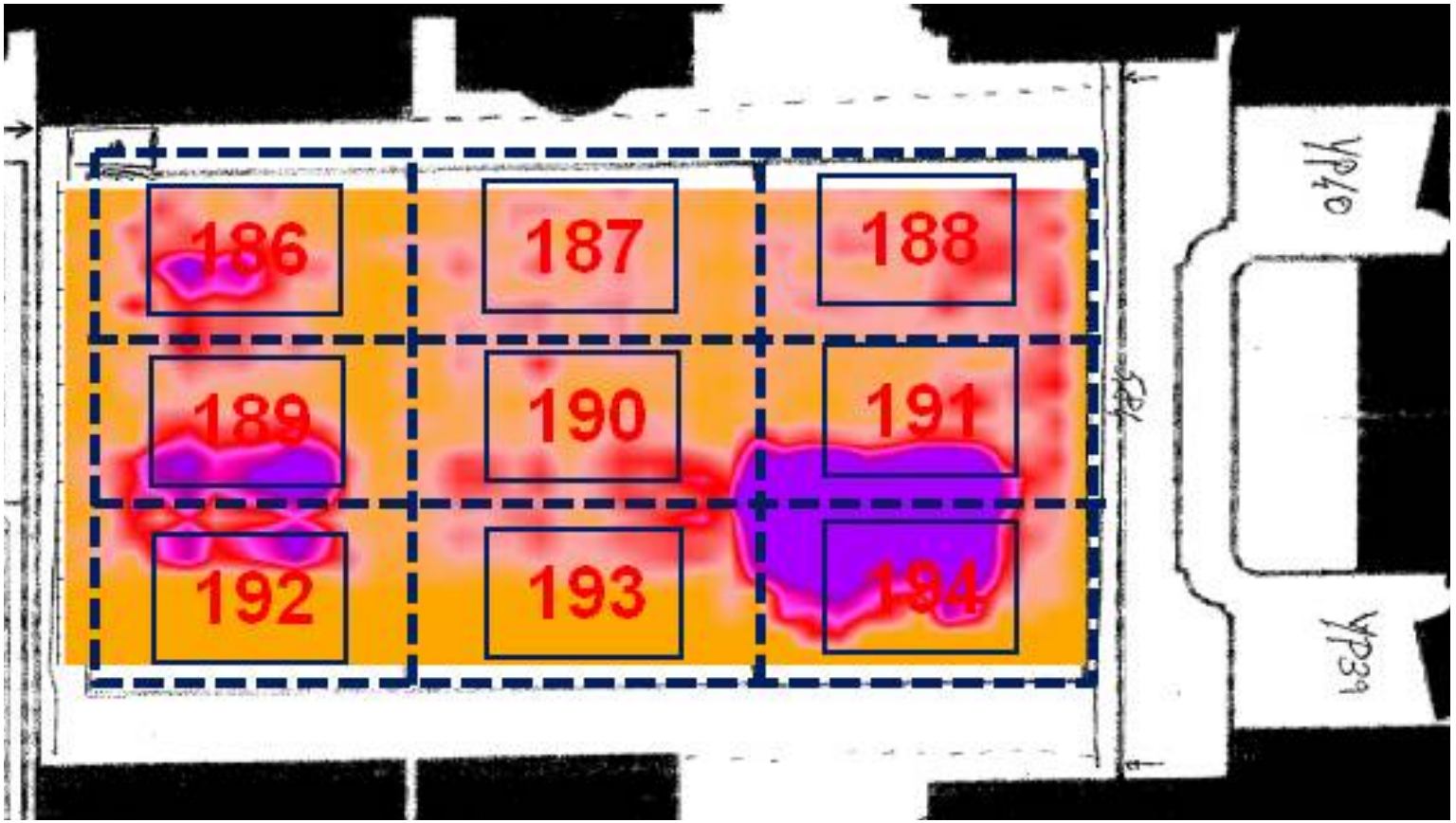
Slice at about 35 cm in the chapel of Aragon



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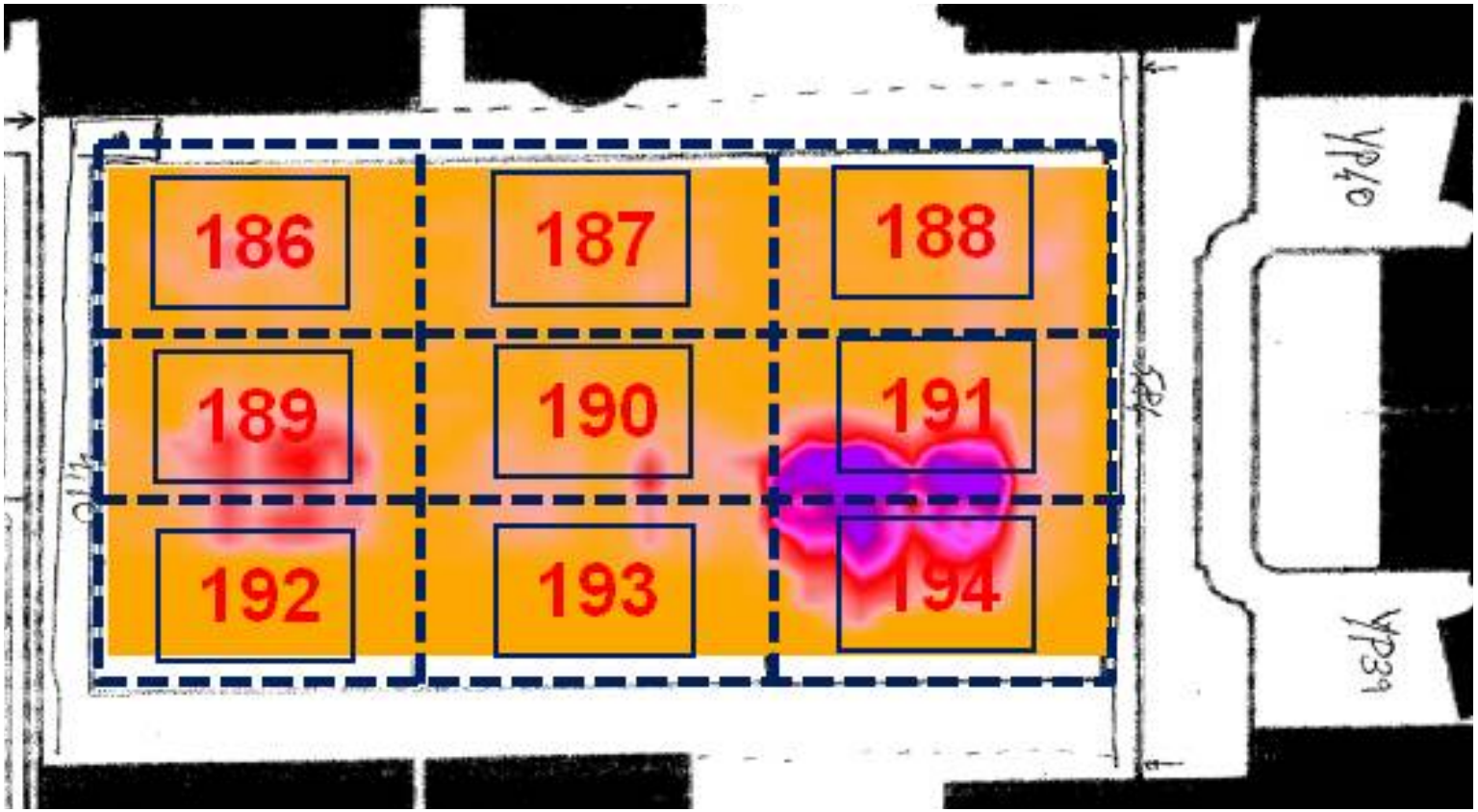
Slice at about 60 cm in the chapel of Aragon



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Further experiment with transceivers

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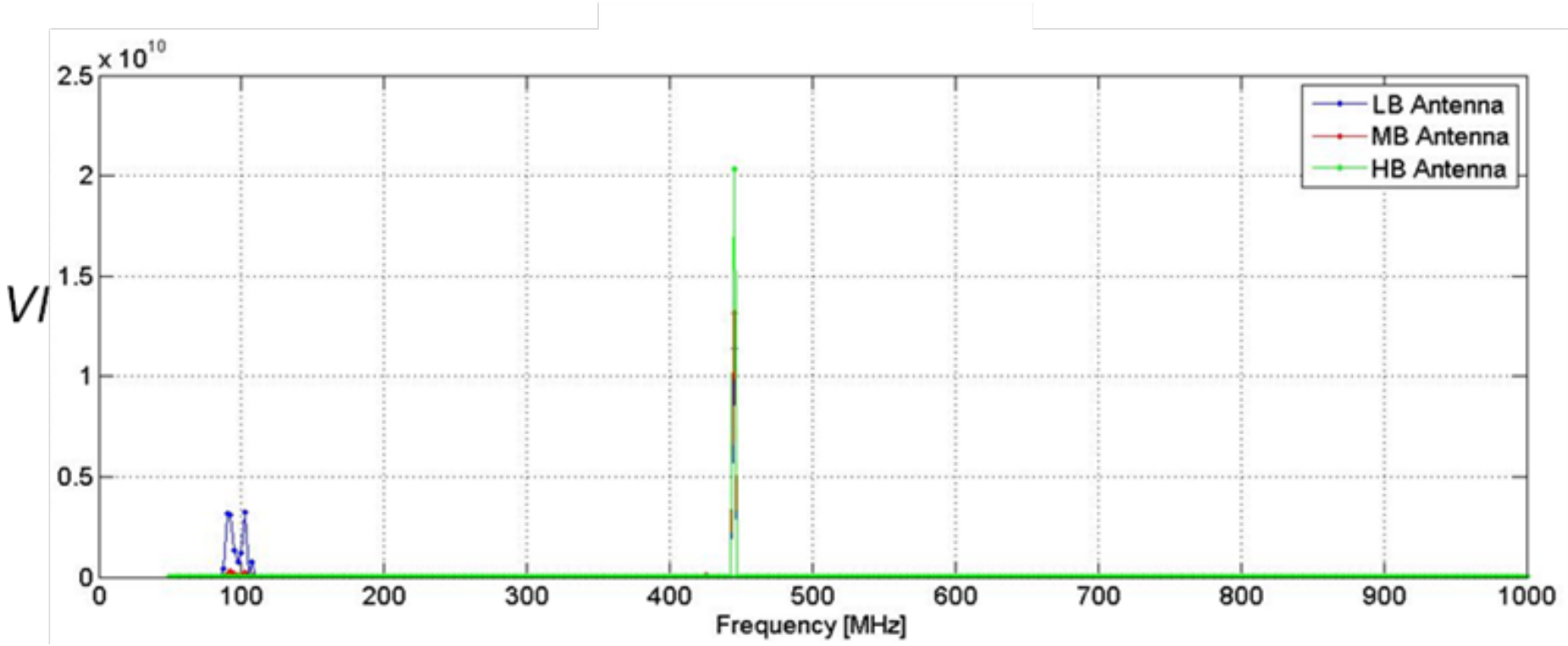
The Index of Interference



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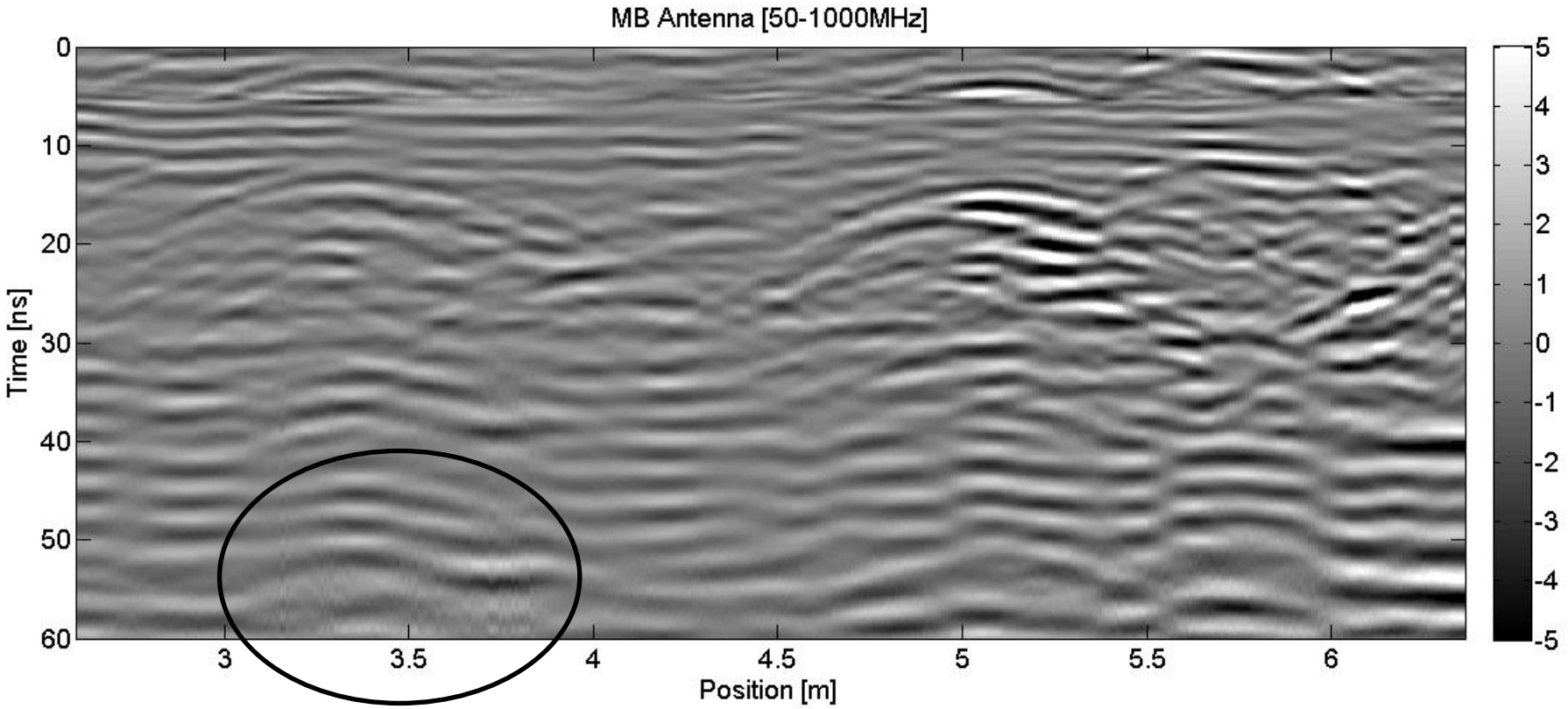
Data without reconfiguration



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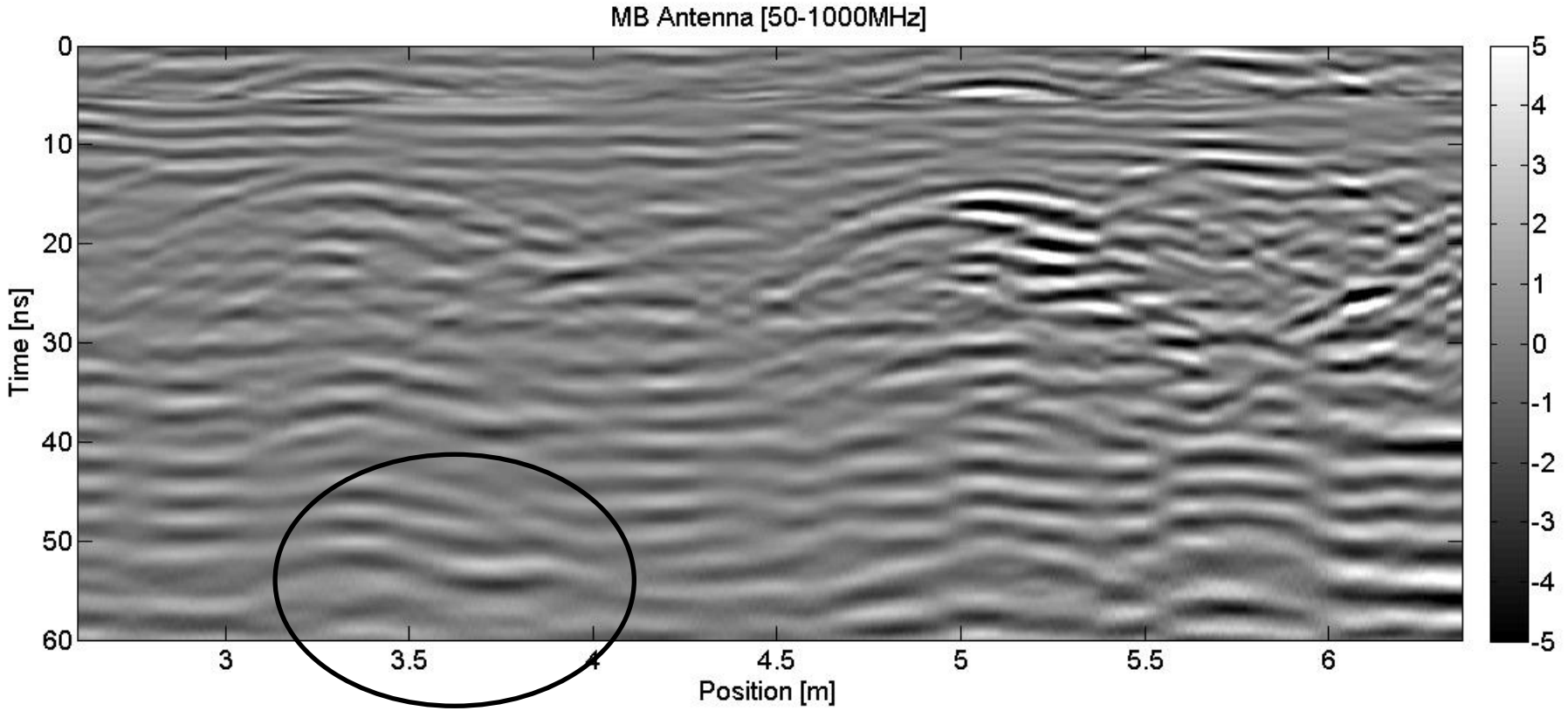
Data with reconfiguration



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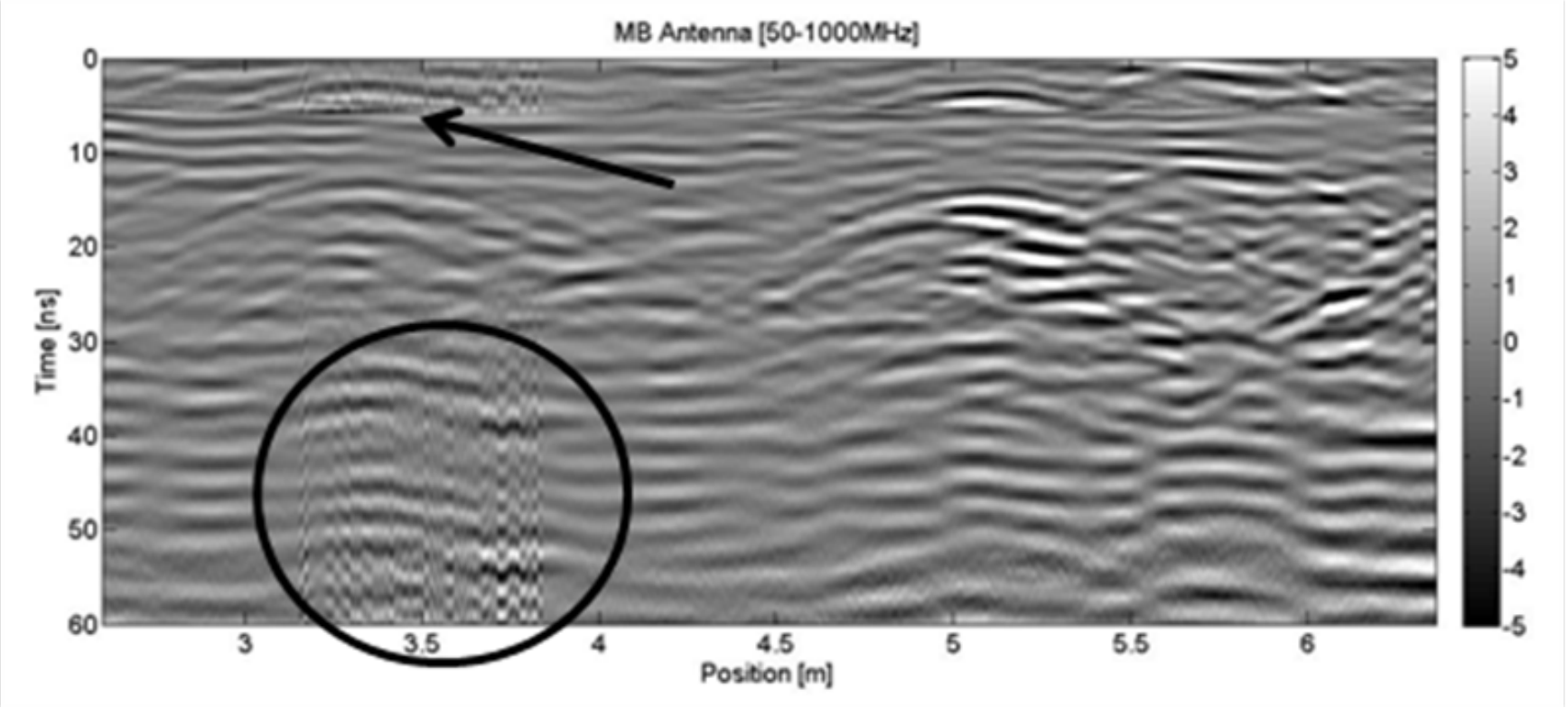
Data without reconfiguration with 10 samples instead of 63 as before



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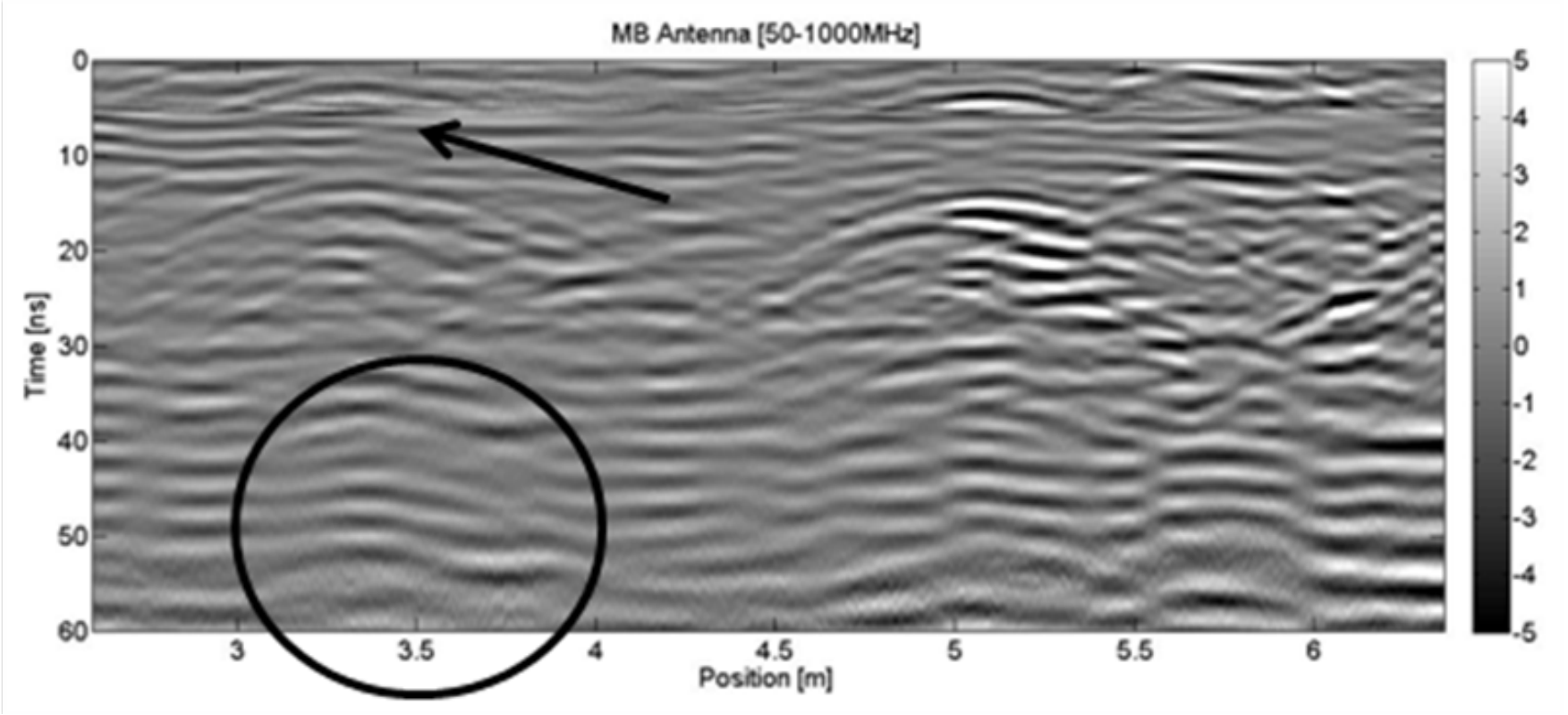
Data with reconfiguration with 10 samples instead of 63 as before



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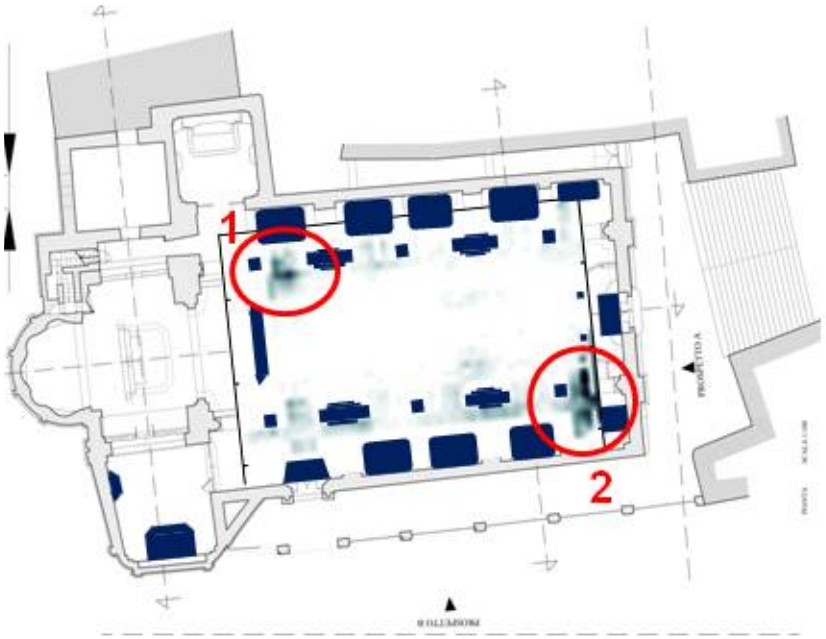
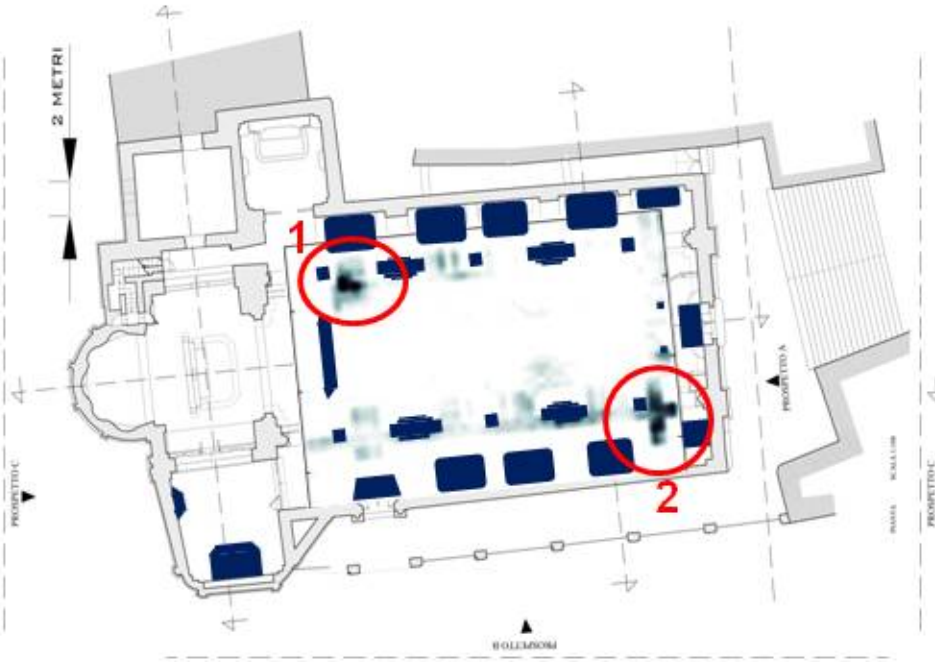
Parabita

Slice at 95cm

Low frequency antenna of the prototype



Medium frequency antenna of the prototype

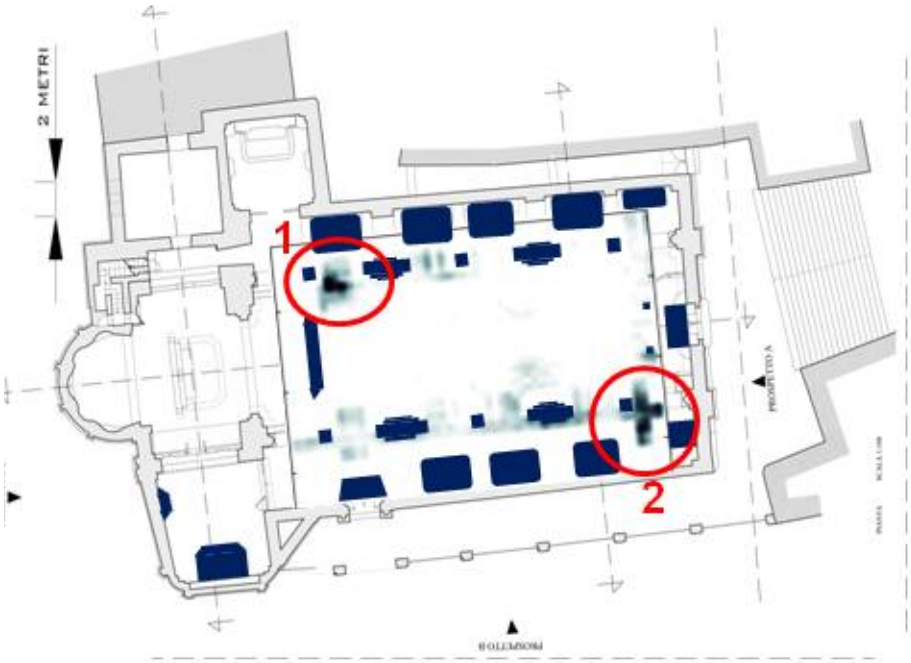


'.2b

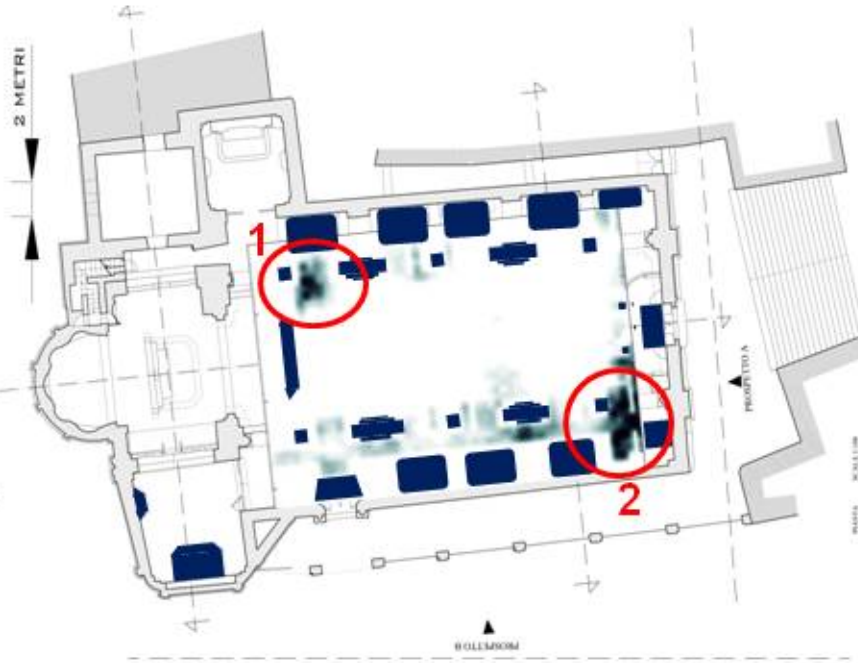
Parabita

Slice at 95cm

Medium frequency antenna of the prototype



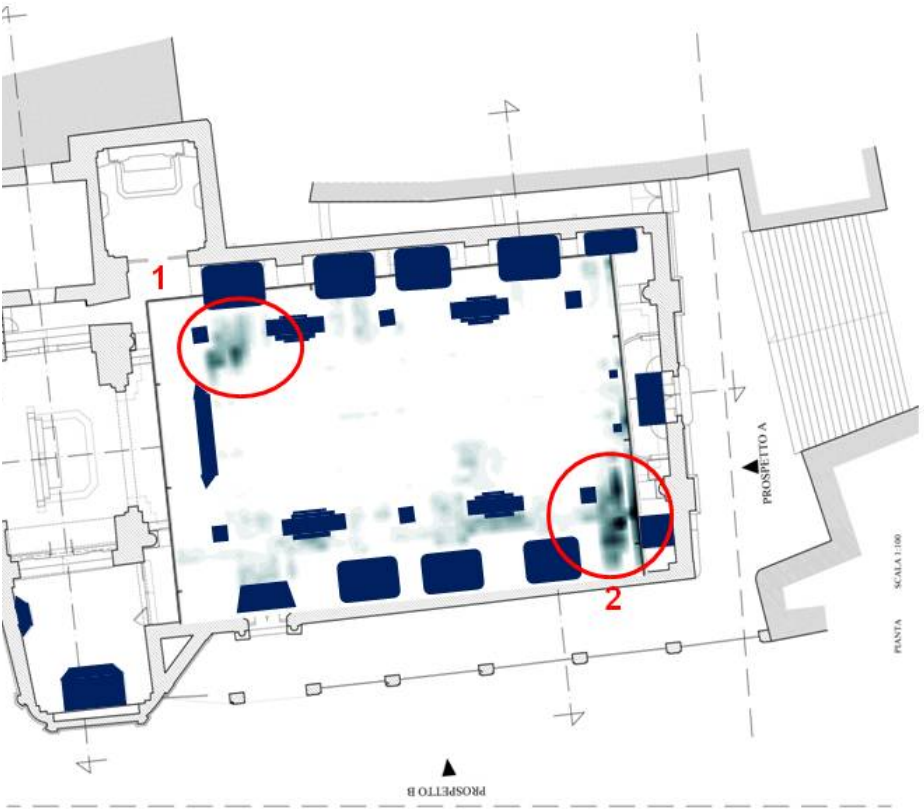
High frequency antenna of the prototype



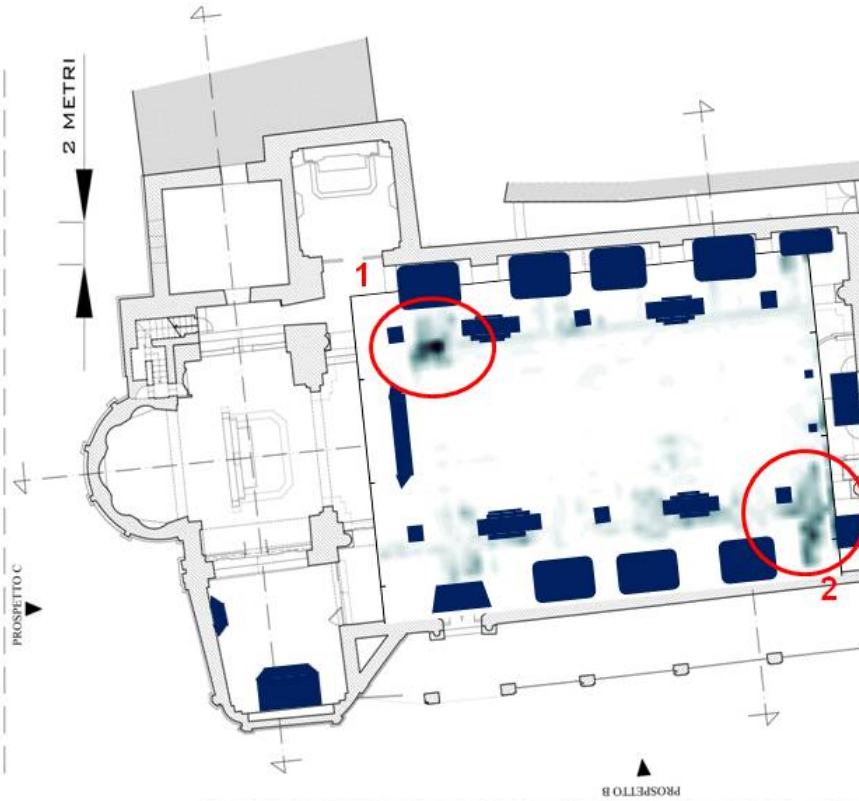
Parabita

Slice at 95cm

pulsed system antenna at 600MHz

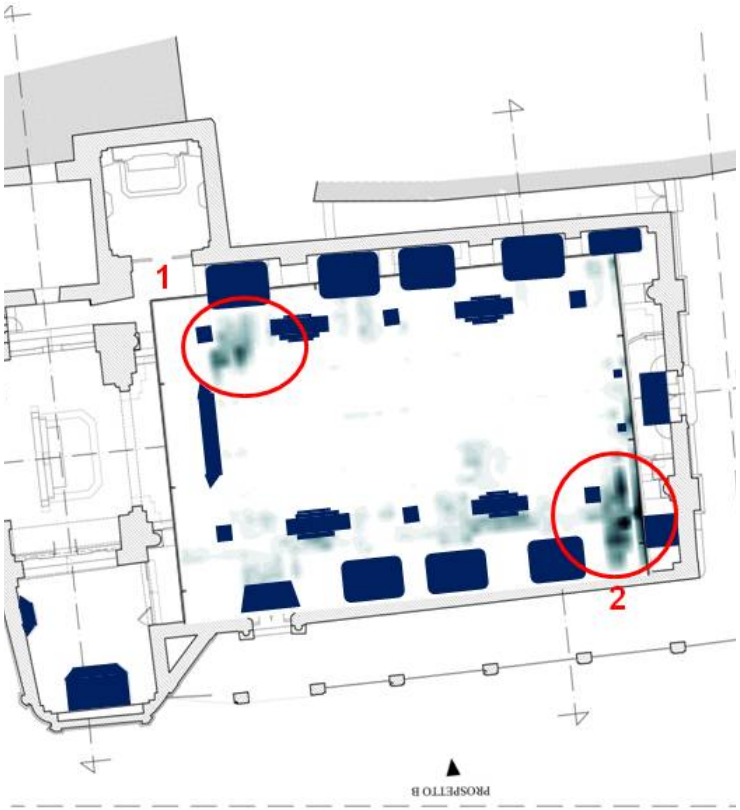


pulsed system antenna at 200MHz

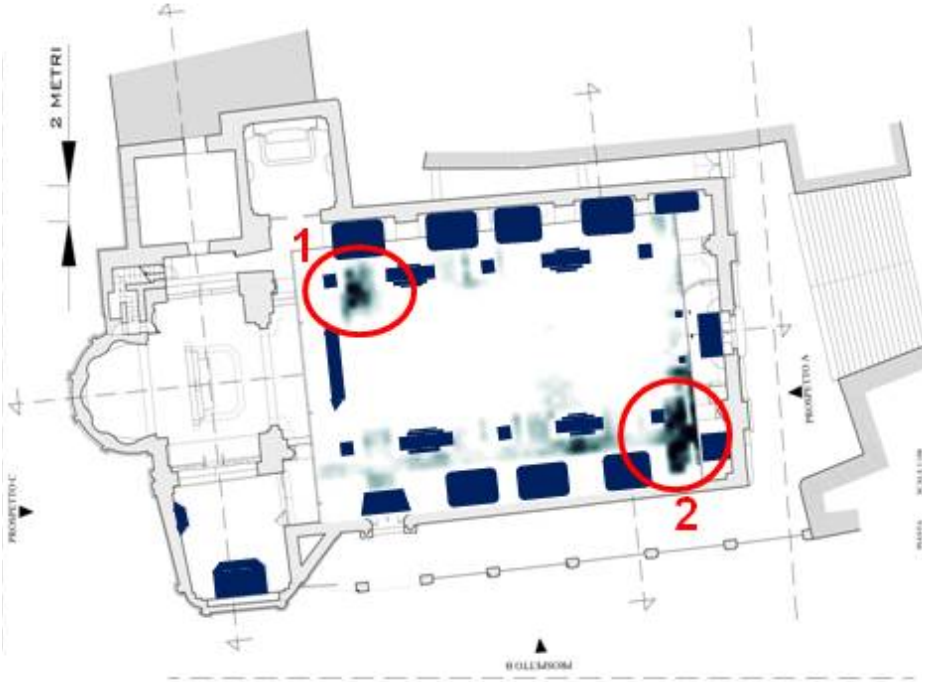


Parabita

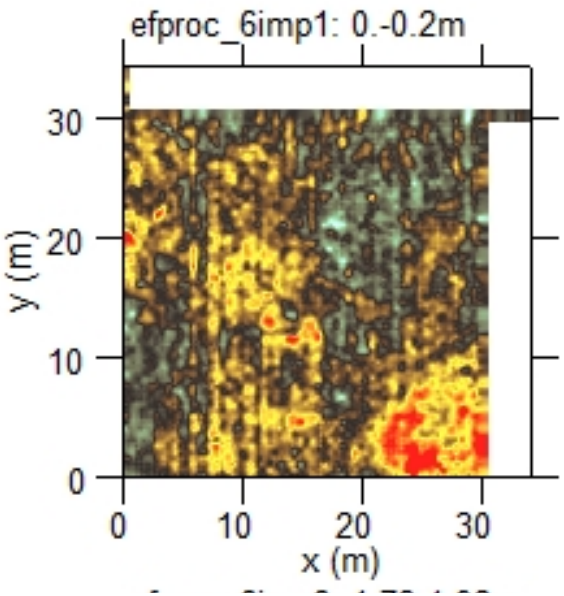
pulsed system antenna at 600MHz

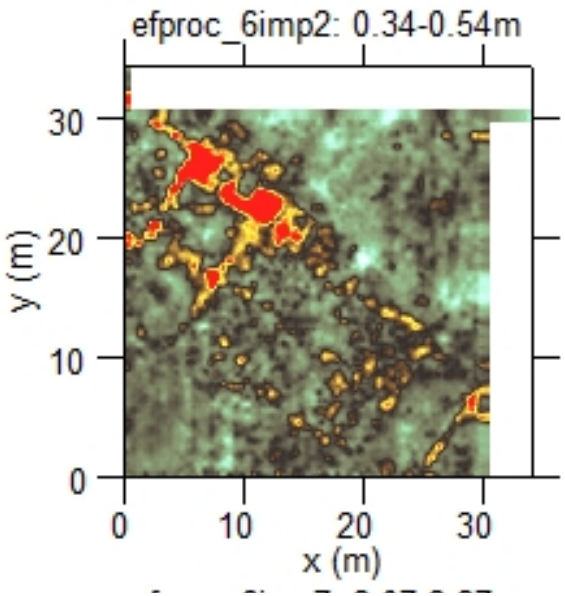


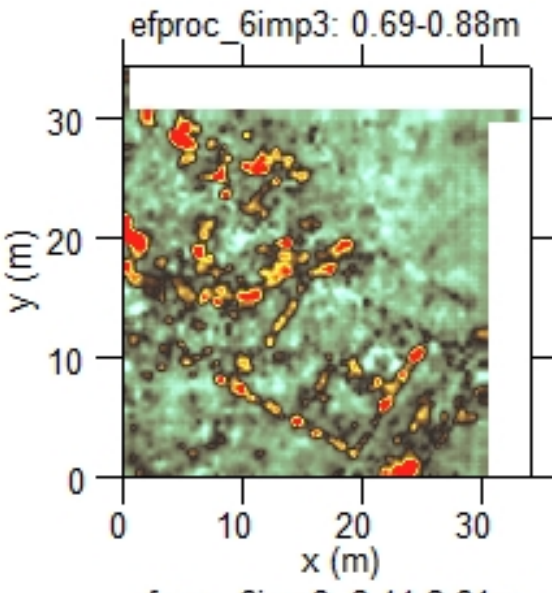
High frequency antenna of the prototype



Egnatia: Pulsed system, antennas at 600 MHz

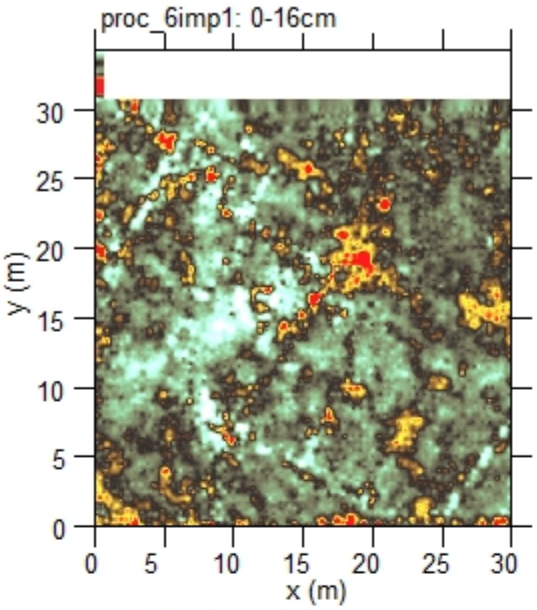


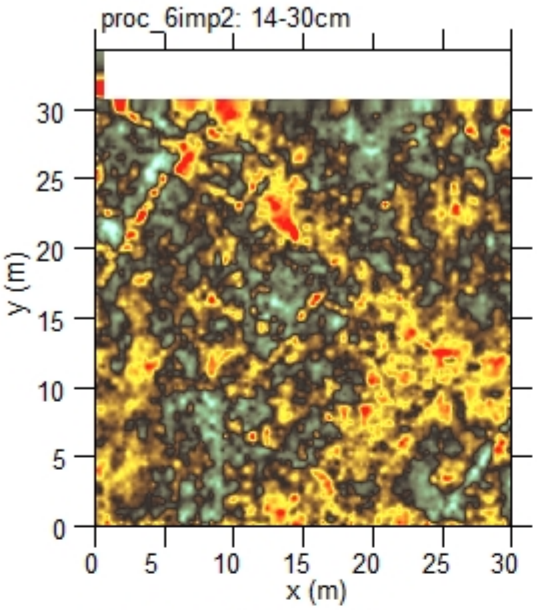


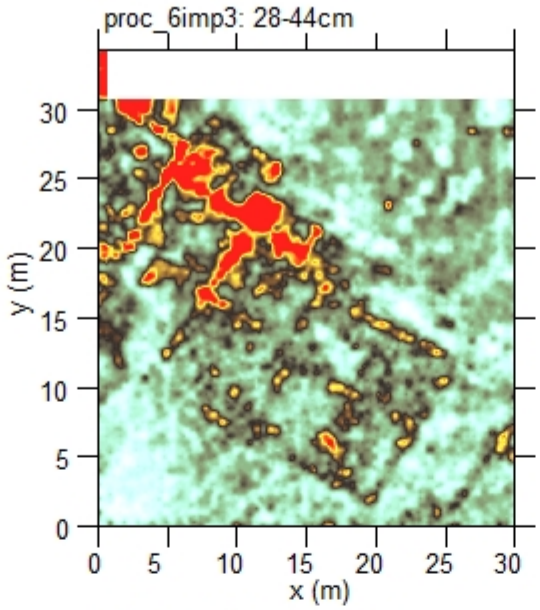


Egnatia: Pulsed system, antennas at 200 MHz

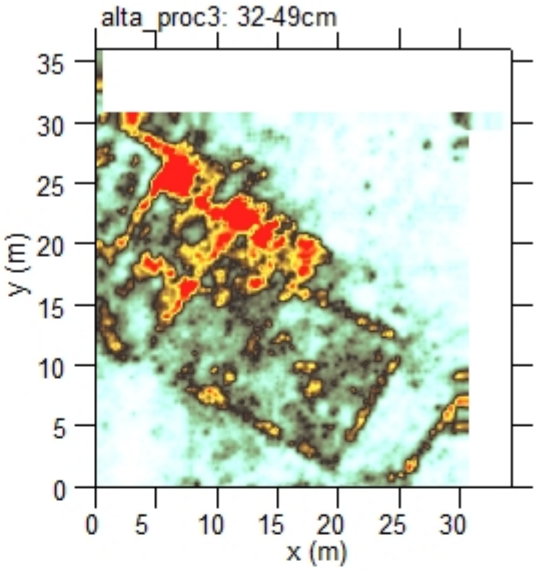
profili incro_antenna a 200
Egnazia area nuova

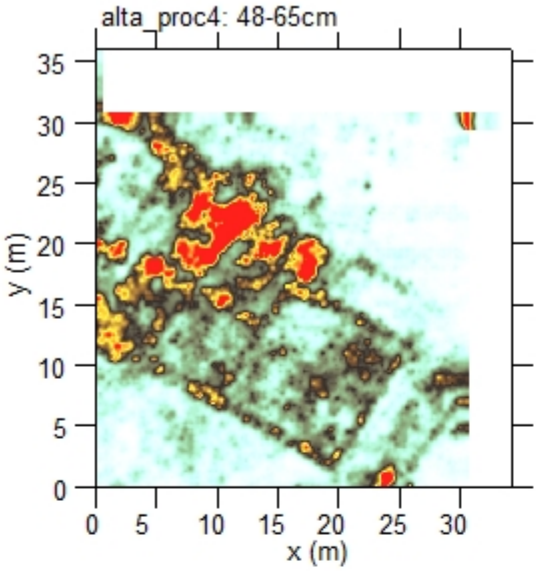


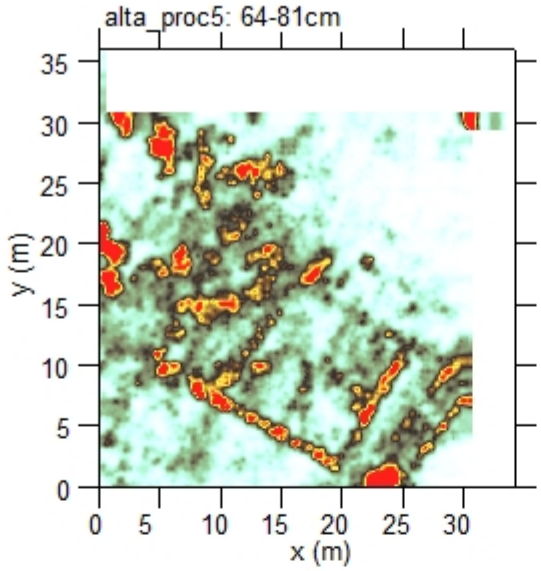


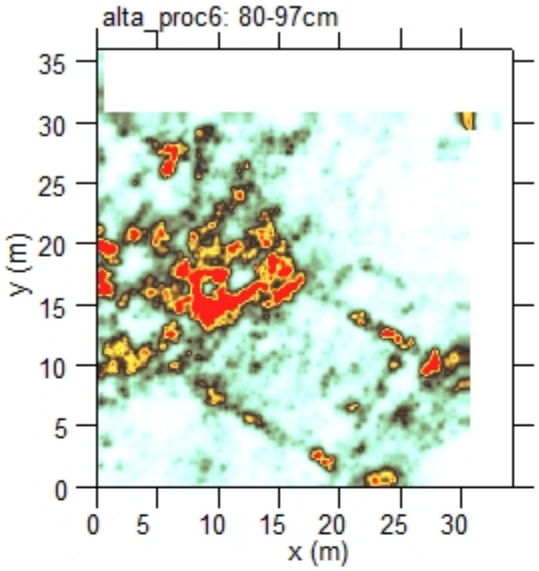


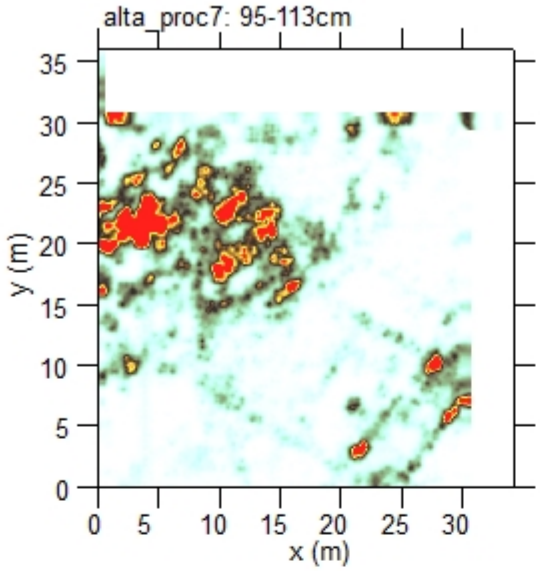
Egnatia: Prototype, high frequency antennas

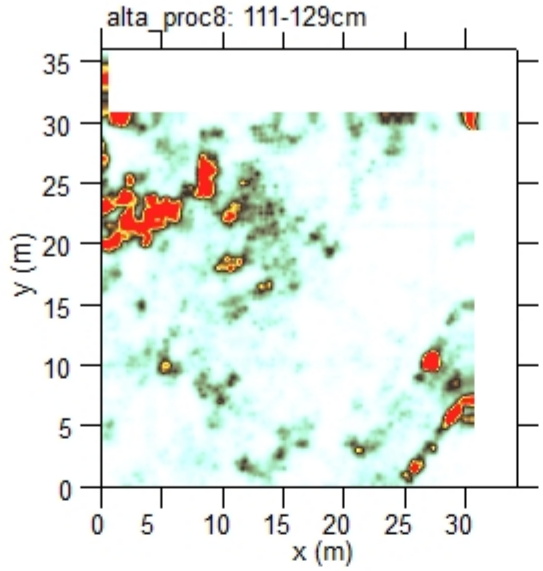




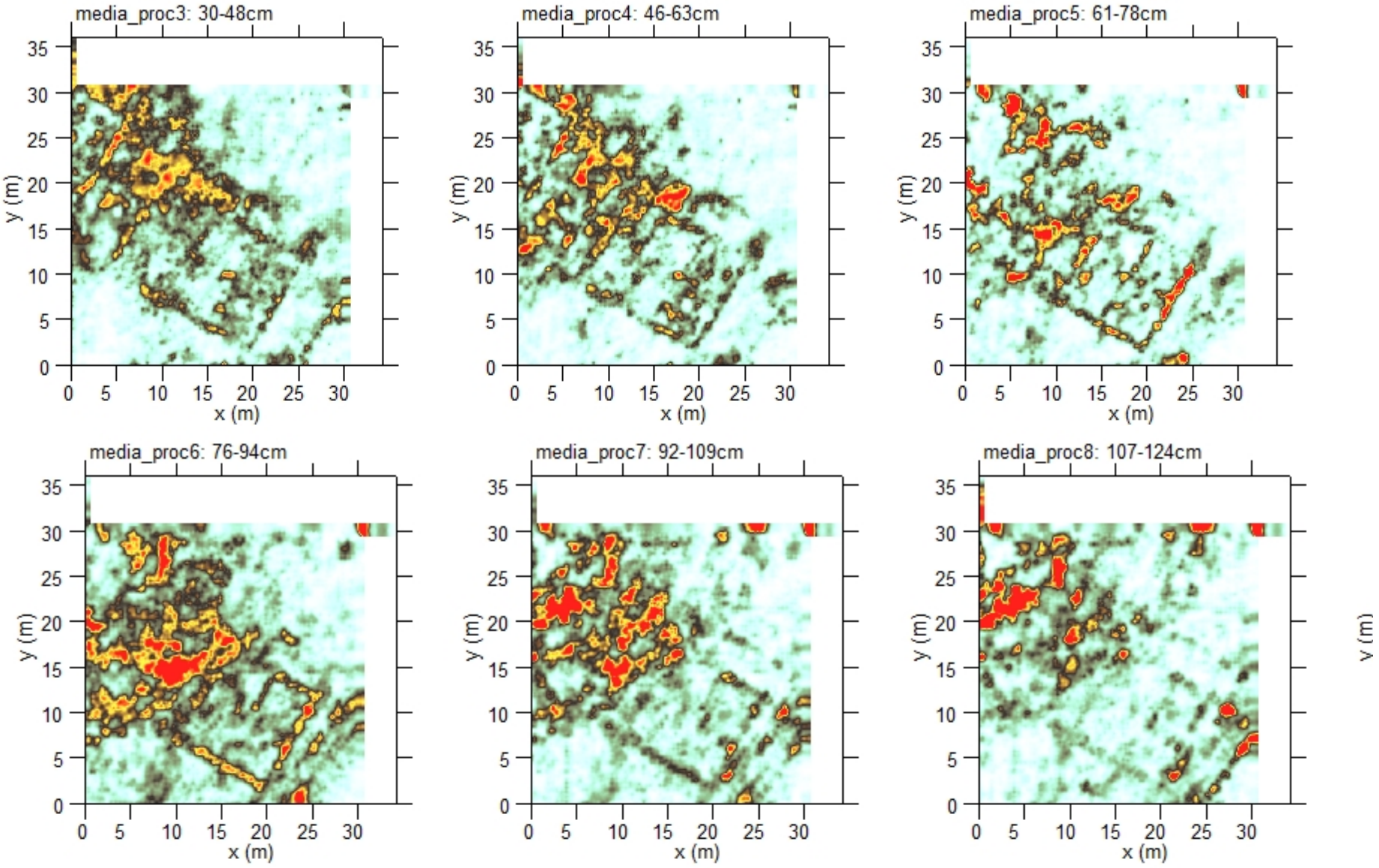




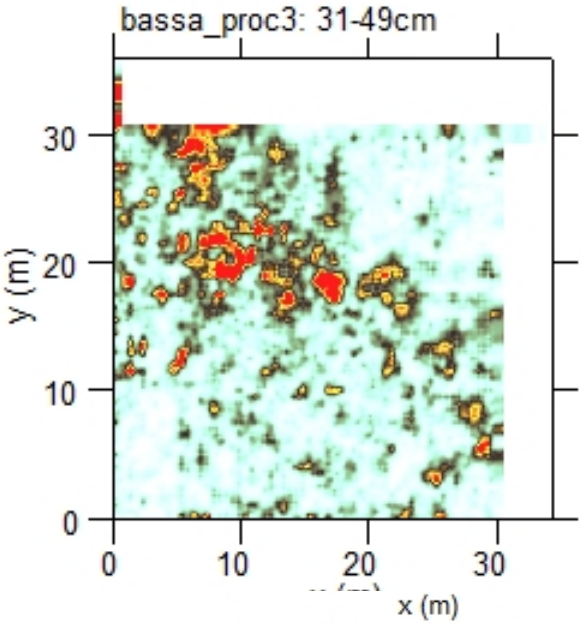


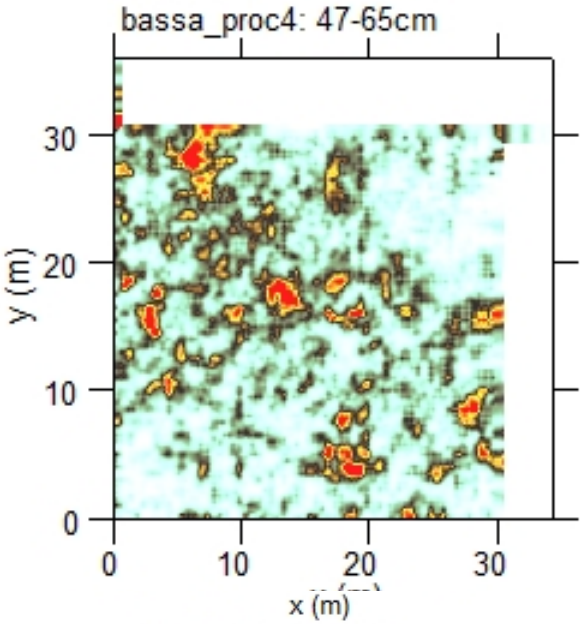


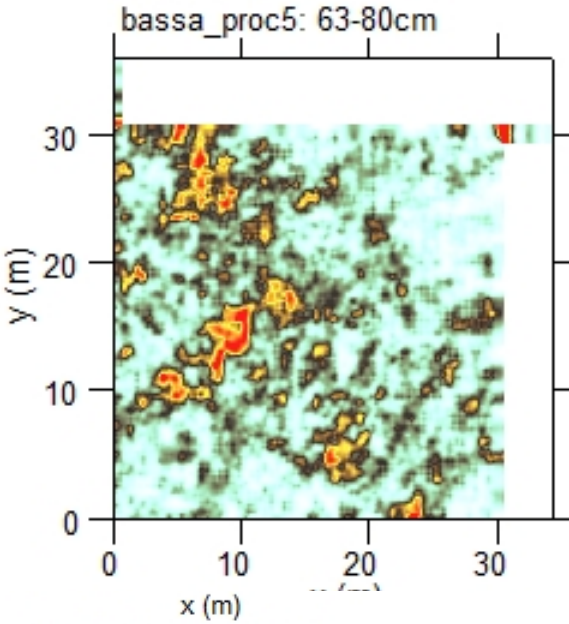
Egnatia: Prototype, medium freq antennas

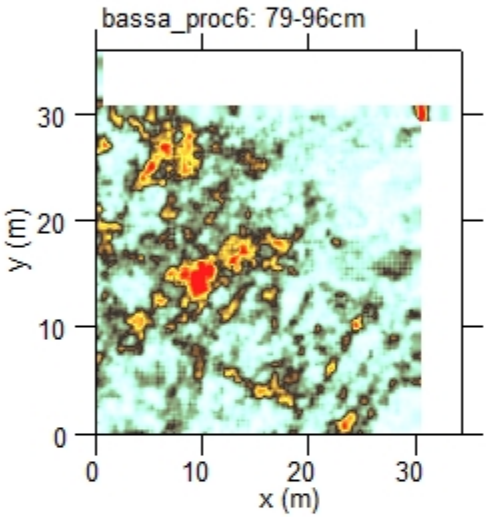


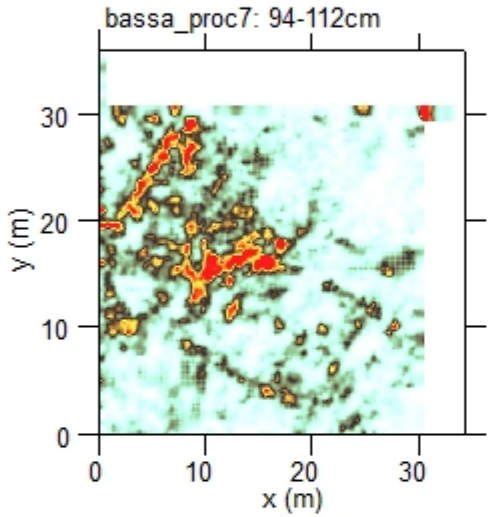
Egnatia: Prototype, low freq antennas

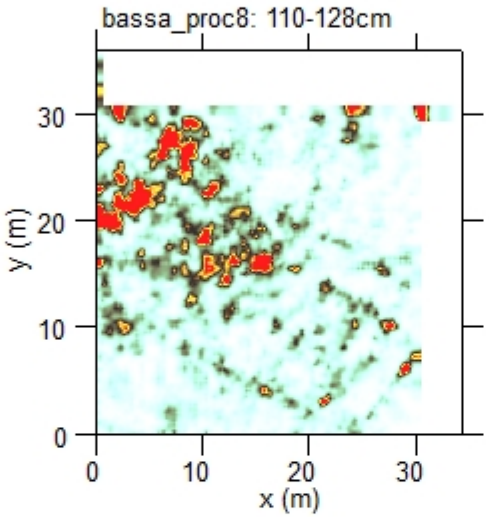












References

[1] R. Persico, D. Dei, F. Parrini, L. Matera, Mitigation of narrow band interferences by means of a reconfigurable stepped frequency GPR system, *Radio Science* 51.8 (2016): 1322-1331.

[2] R. Persico, G. Leucci, Interference Mitigation Achieved with a Reconfigurable Stepped Frequency GPR System, *Remote Sens.* 2016, *8*(11), 926; doi: 10.3390/rs8110926

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