"Il radar olografico come nuovo metodo di indagine per la valutazione di elementi strutturali e architettonici"

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Research topics at Laboratorio Ultrasuoni e Controlli Non Distruttivi:

- Ultrasound methods and instruments for Non Destructive Testing and Medical Diagnostics (since 1978)

- Ground Penetrating Radar (since 1992)

- Infrared imaging and sensors (since 1996)

A trade-off is often required among different methods!

Syllabus

1. Physics and Tools

Holographic Radar

2. Applications

Building inspection

1. Rebar in Concrete Beams
2. Radiant Heating Tubes
3. Concrete Masonry Unit (CMU)
4. Floor inspection

Voids, Defects, Flaws

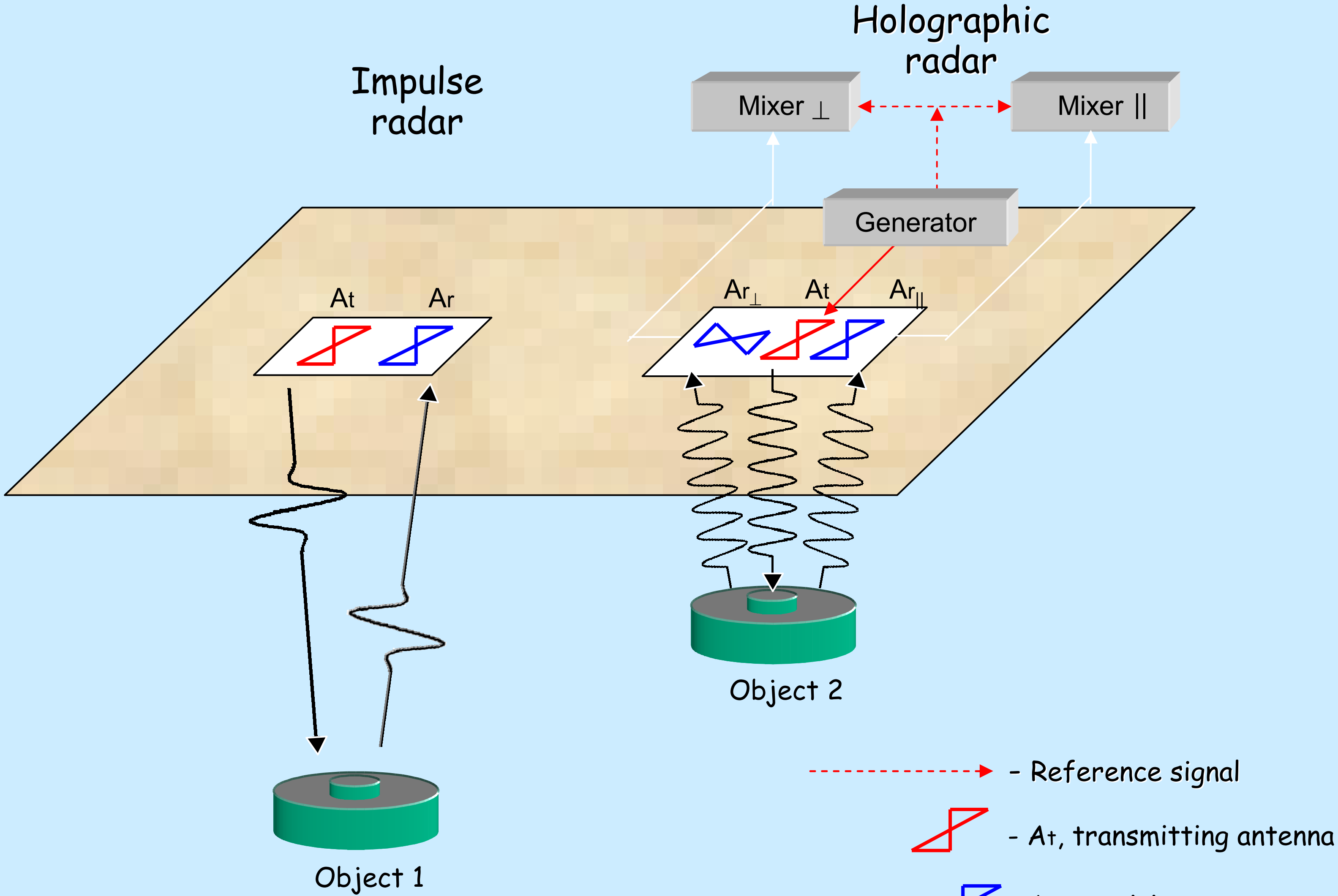
5. Defects and flaws in a Terracotta tiles
6. Wood Damaging Inspection

Moisture

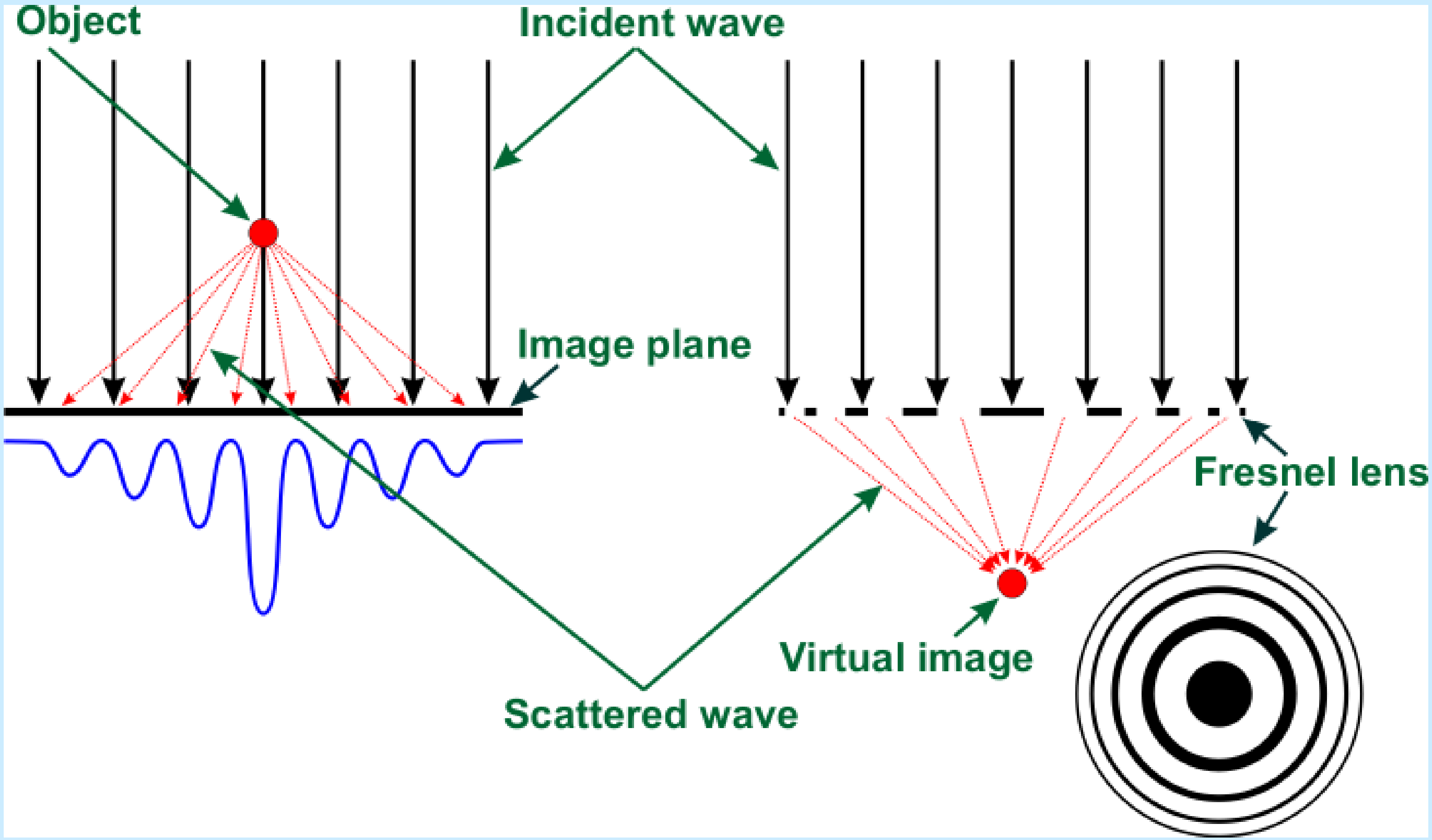
7. Brick wall texture with moisture

Acknowledgements

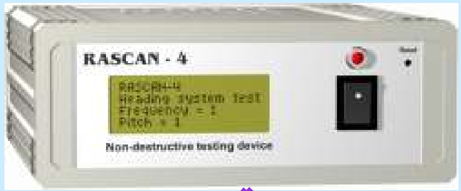
Comparison of Impulse and Holographic Subsurface Radar



Recording a Point Source Optical Holographic Interference Pattern (left). Hologram Reconstruction (right)



RASCAN-series radars



RASCAN-4/4000, 4 GHz
RASCAN-4/7000, 7 GHz

RASCAN-4/2000
2 GHz

The Simplest Mathematical Model of Monochromatic Holographic Subsurface Radar

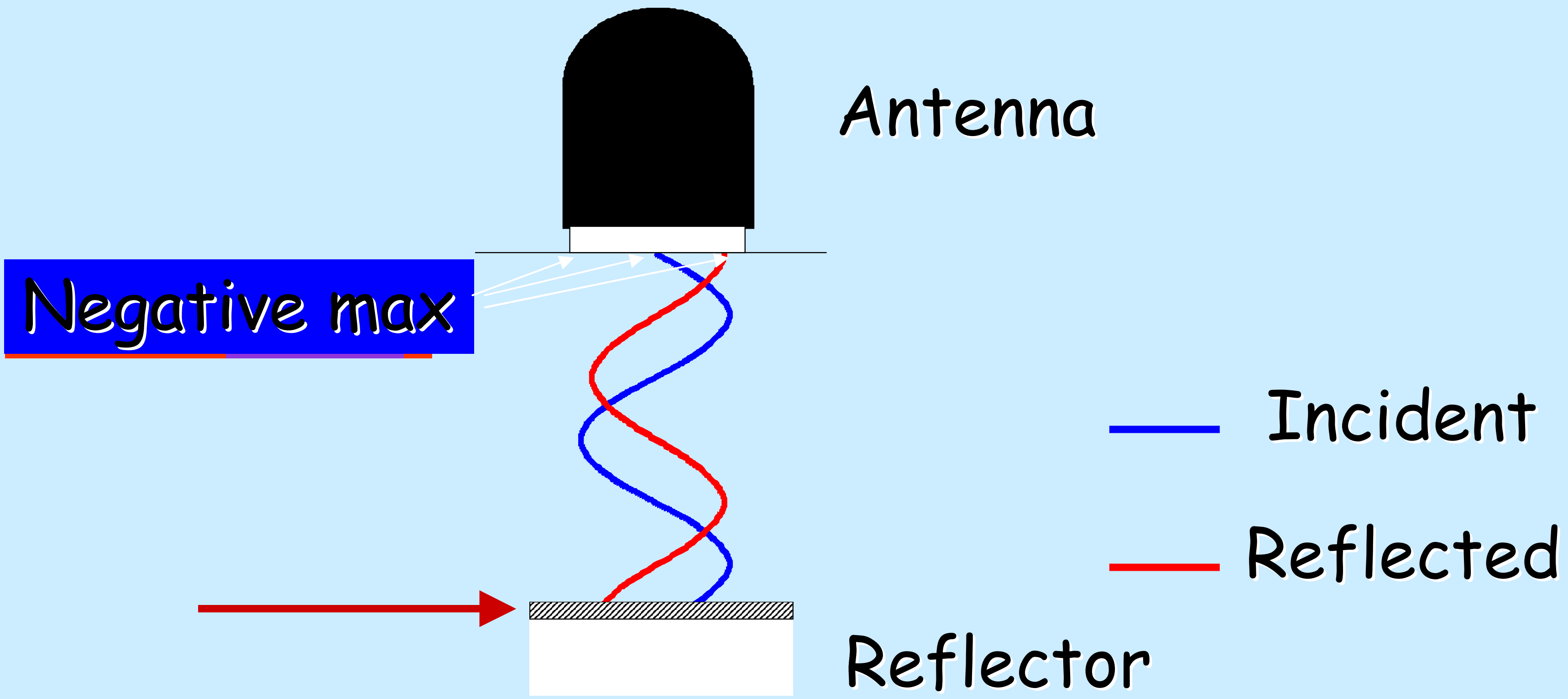
The radar radiates electromagnetic waves at a constant frequency ω whose amplitude and phase do not depend on time. The reflected wave has constant amplitude A_r, but the phase of the reflected wave φ_r depends on the range to the object l

$$\varphi_r = 2\sqrt{\varepsilon}\frac{l\omega}{c}$$

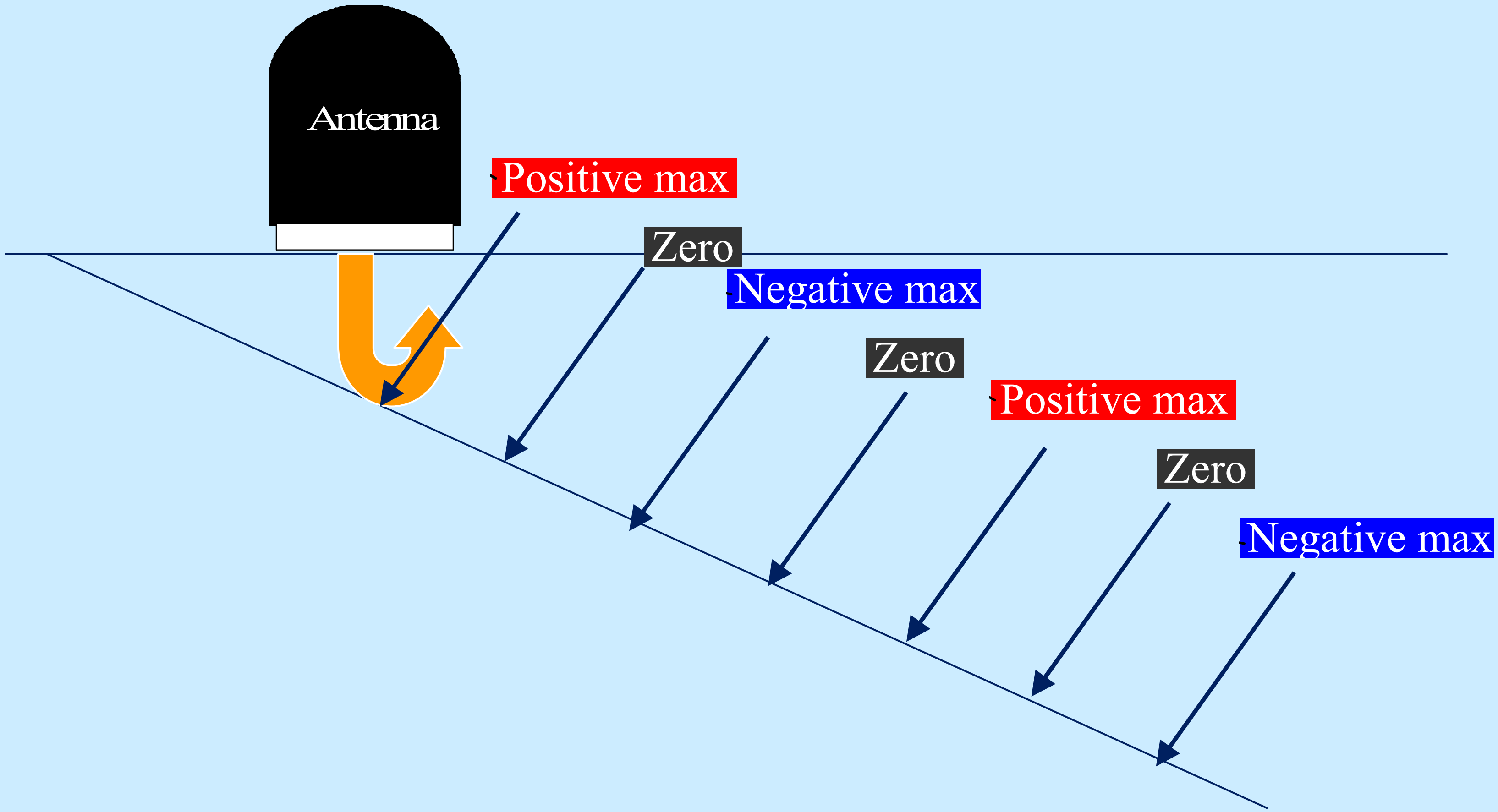
Then, the reflected signal is mixed with the radar reference signal in the mixer (with A_o and φ_o are the amplitude and phase of the reference signal respectively). The amplitude of signal in the mixer output at the difference frequency is given by

$$A_r A_o sin(\varphi_o - \varphi_r)$$

Principle of Holographic radar

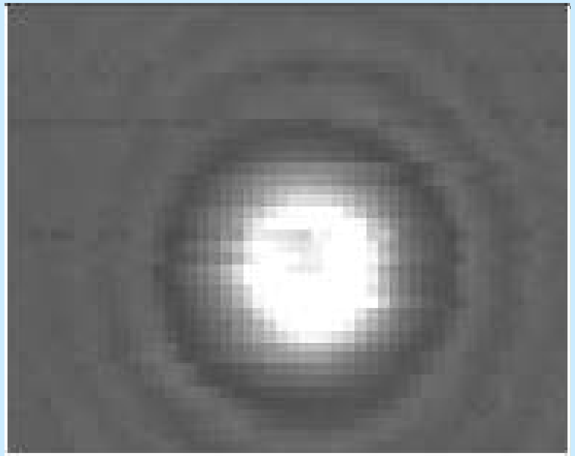


Characteristic appearance



To avoid blind spots holographic radar works with N discrete and programmable frequencies

Interference patterns
(Zebra shift)



A scan in air at 5 frequencies close to
4 GHz (λ= 7.5 cm) of a metal bowl with concavity up.

As frequency increases

Shrinks inwards

Holographic RASCAN-4/4000 (4GHz) radar

Comparison of characteristics of Impulse and Holographic Subsurface Radar

Parameters	Impulse Radar	Holographic Radar	Remarks
Frequency spectrum	Continuous	Discrete	Rascan works with 5 discrete and programmable frequencies
Penetration depth	Up to 10 λ	1-2 λ	λ – wavelength
Resolution at shallow depths in plan of surveying	> λ	0.25 λ	λ – wavelength
Surveying over metal substrate	Hardly possible	Possible	Reverberation prevents using impulse radar over metal surface
Possibility of object's depth measurement	Directly from recorded signal	?	This task for holographic subsurface radar does not have a proper solution yet
Adaptation to the FCC norms	Difficult	Much easier	Frequency spectrum of holographic radar could be selected in advance. Impulse radar has a UWB spectrum that can't be changed or limited arbitrarily
Radar cost, USD	15,000-45,000	8,000-10,000	

RASCAN scans on columns and girders

Instrumentation

- RASCAN head 4GHz with control unit
  - Each point is sampled at 5 frequencies, from 3.6GHz to 4GHz
  - Each point is sampled at two polarisation: *cross* and *cocross*
  - A total of 10 images are produced
- Laptop with control software and USB plug
- Small battery

Site and materials

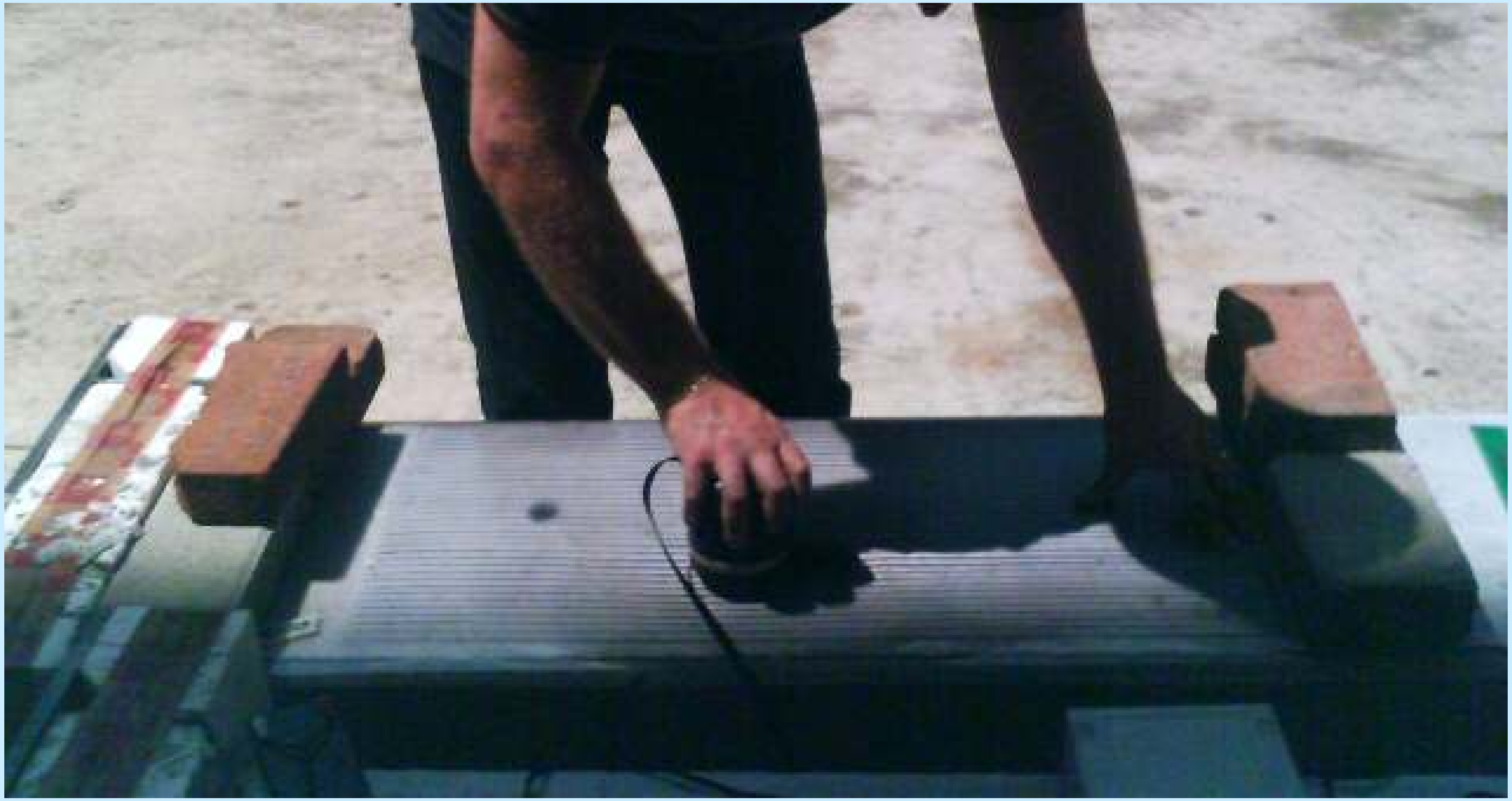
- Date: July, Friday 3 2009
- Place: structures laboratory at DICEA, University of Florence
- Column 1/2: reinforced concrete RCK55 40x40cm^2 (property of DICEA)
- Girder 1: reinforced concrete SCC 30x20cm^2 without transversal bars, broken by destructive load test (property of DICEA)
- Girder 2: reinforced concrete RCK55/FeB44K 30x20cm^2, broken by destructive load test (property of DICEA)

Modus operandi

- A plastic mat with horizontal numbered guiding lines is fixed over the interested area
- The scan area size and binning is configured by using dedicated software
- The RASCAN head, a cylinder of about 5cm by 10cm, is manually slided along successive scan lines
- A double beep signals that the scan grid is completed

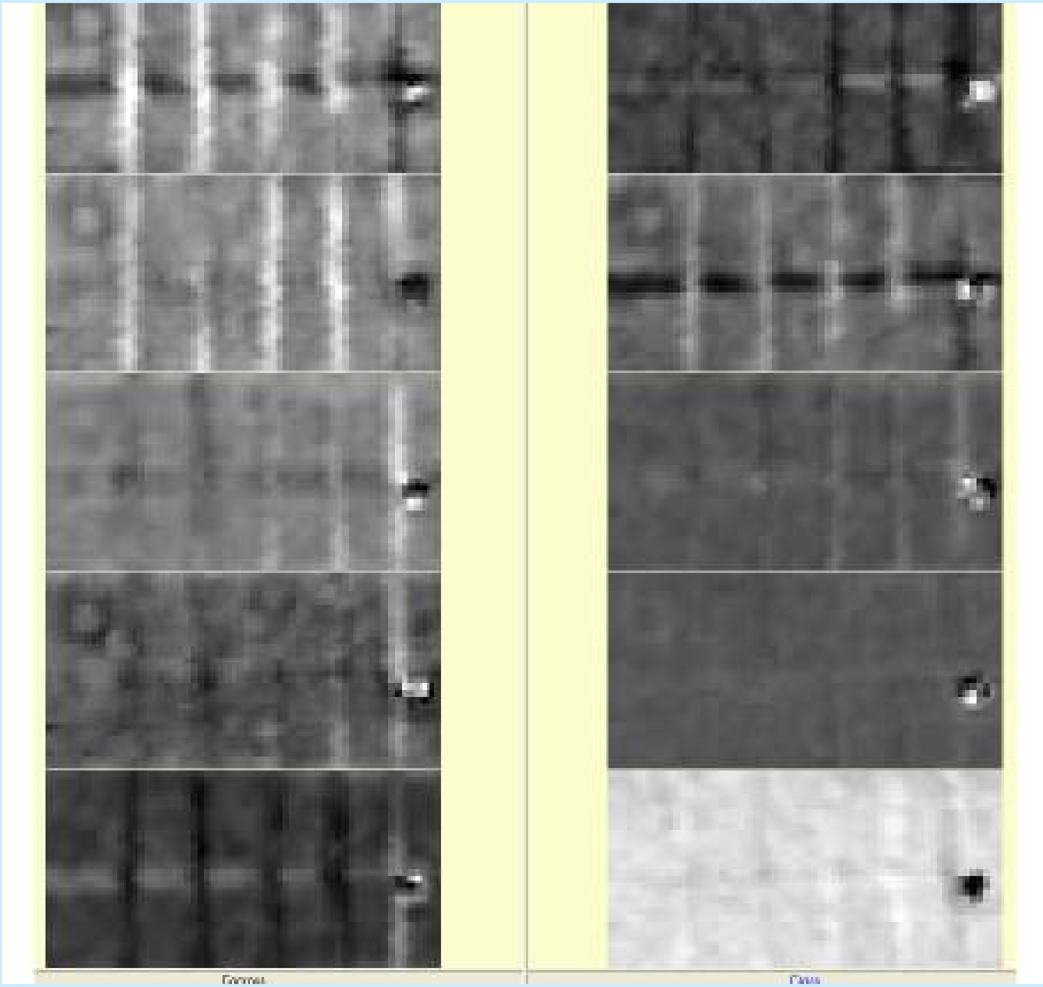
Column 1 Scan 1

Longitudinal scan, 60x30cm^2

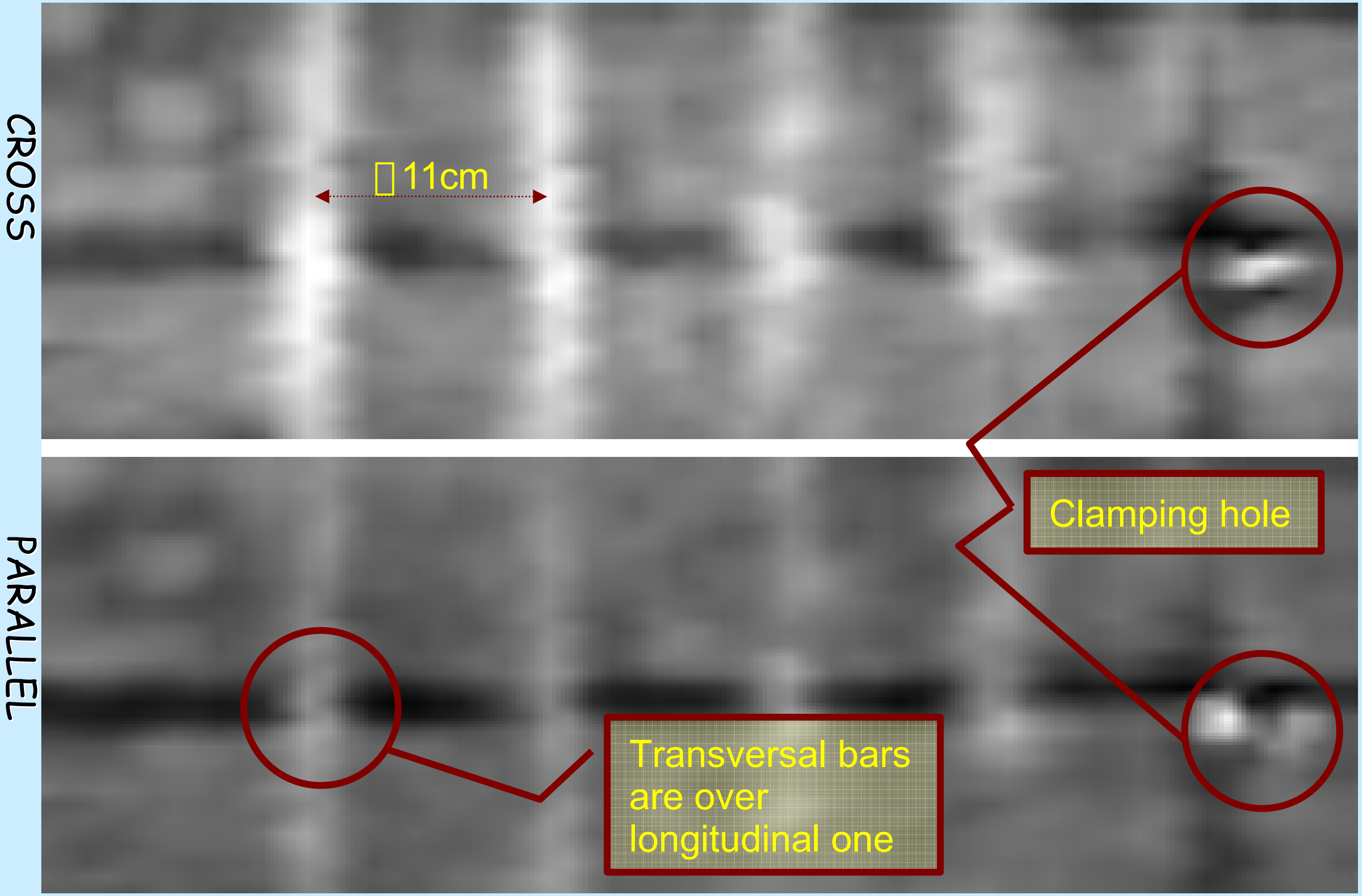


Column 1 Scan 1

PARALLEL CROSS



Column 1 Scan 1

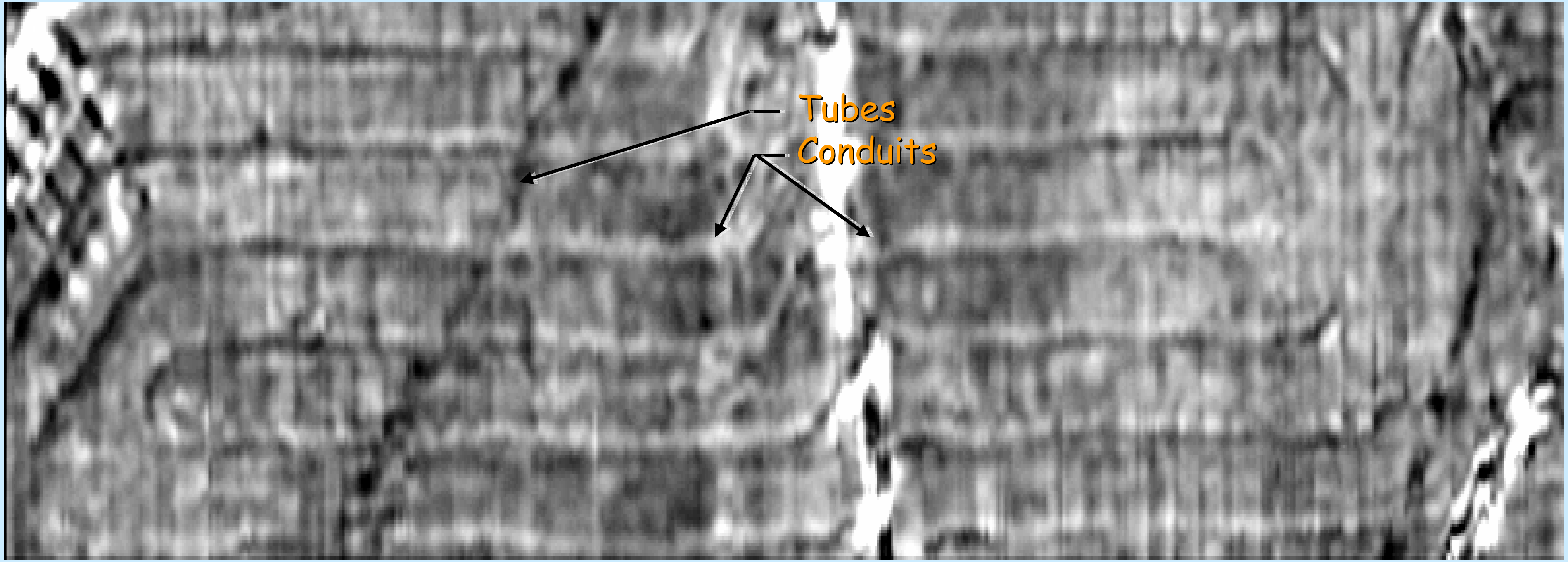


Conclusions

- An experiment has been conducted on civil engineering structural elements, columns and girders, with the aim of detecting reinforcement bars
- By using RASCAN 4GHz, relative positions and mutual distances can be measured directly from the output of the device
- Image is easy to interpret as it reproduces a plan view of the buried structures

Radiant Heating Tubes

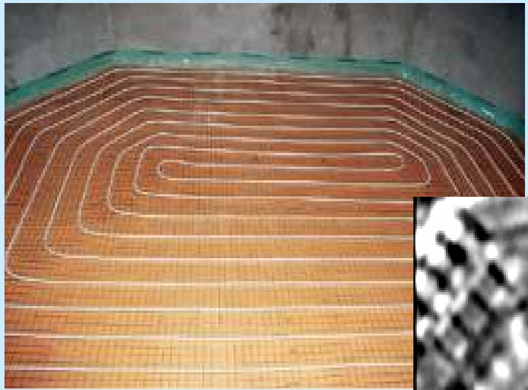
Typical lay-out of heating tubes and reinforcing mesh prior to concrete pour

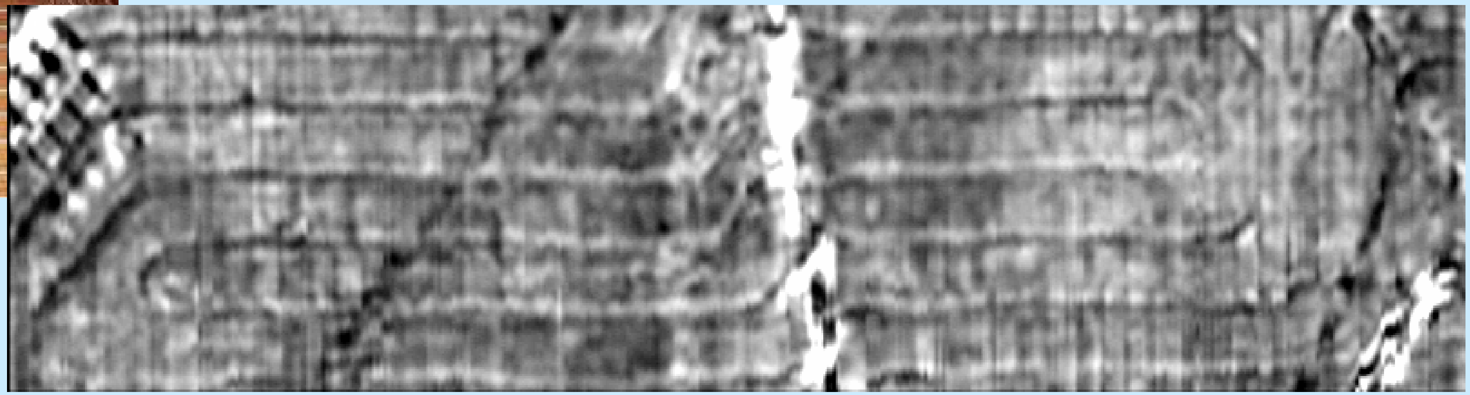


Subsurface features accurately marked on actual the floor

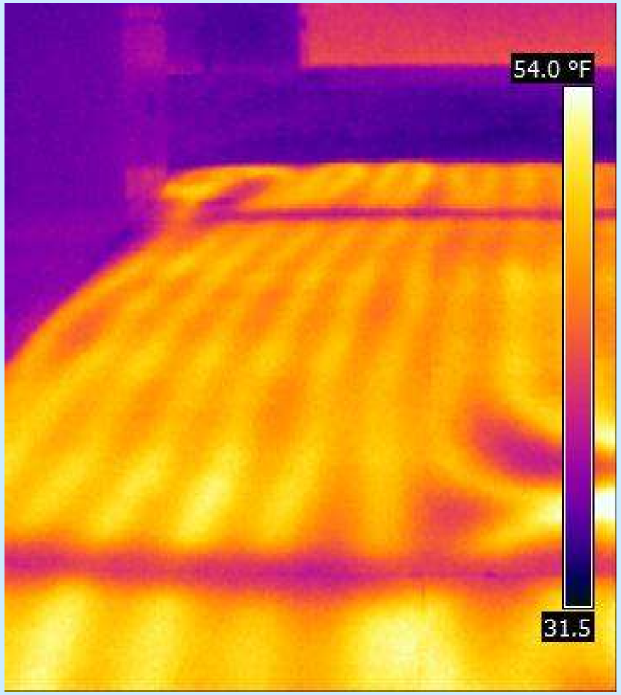
Radar image of unknown pipes in old concrete floor of the Russian Senate Building, Saint Petersburg scan area 1.70m x 8.04m

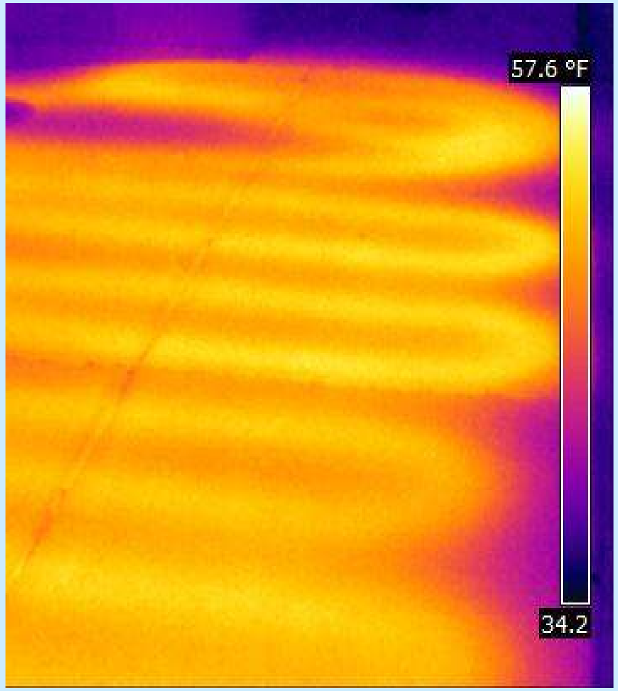
A Comparison with IR





Thermal Images
(warm air in tubes on a cold day)





FLIR i60

Radiography versus IRT

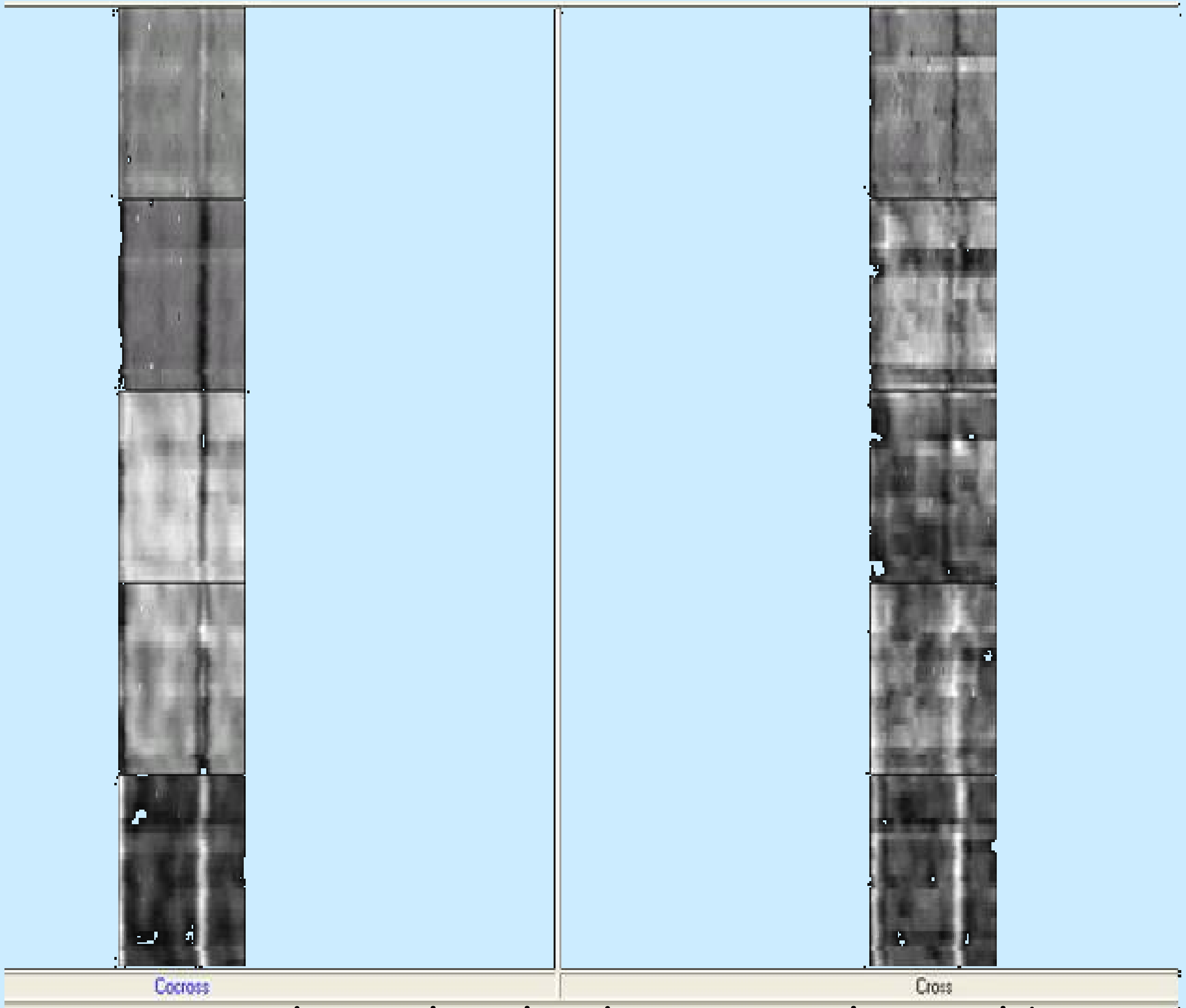
	Radiography (X-Ray)	IRT
Required Access	both sides	one side only
Radiation Hazard	high	none
Licences or Permits	yes	none
Set-Up Time	long	long (heating activated)
Data Collection	slow	rapid
Real-Time Results	none	complete
Data Storage	film	digital
X-Y Target Location	highly accurate	highly accurate
Z Target Location	poor to none	highly accurate
Target Discrimination	poor to none	excellent
Live Line Detection	none	none
100% Guaranteed	no	no

Concrete Masonry Unit (CMU)

Concrete blocks with dimensions about 40x24x20cm^3. The internal part of the blocks has two holes of 12.5x16cm^2

Scanning the wall by using a ruled plastic mat. Wet spots are present

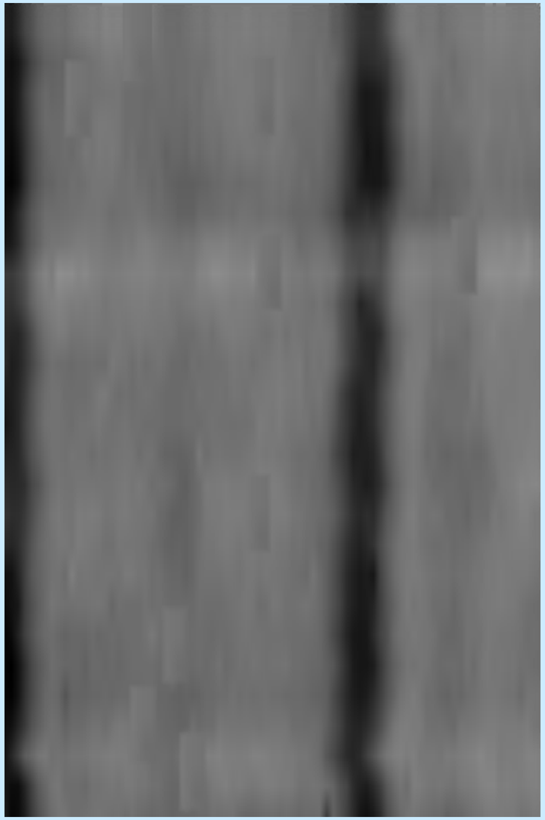
Holographic radar scan (2 GHz)



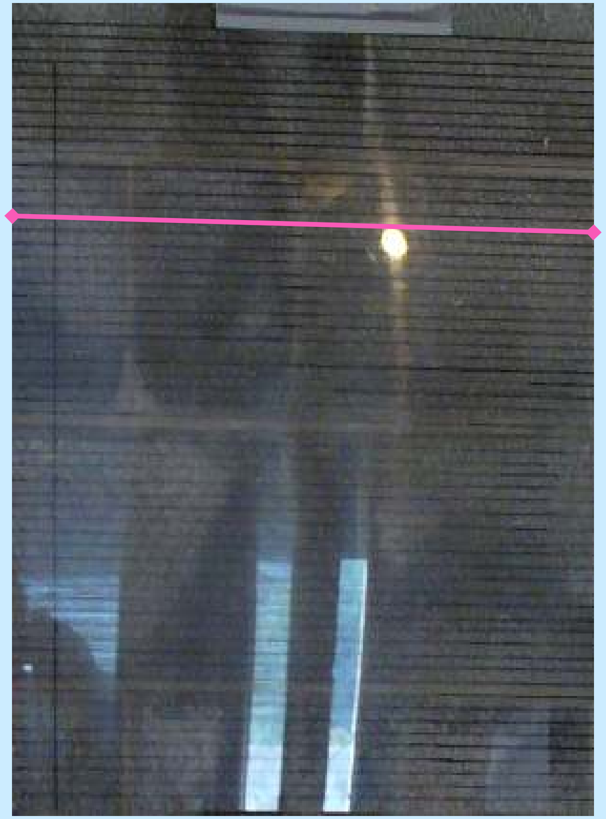
The cocross images show clearly the vertical metal bar on the left and the horizontal joint layers between concrete blocks on the right.

Images 80x27 pixel, pixel size 5x20 mm^2

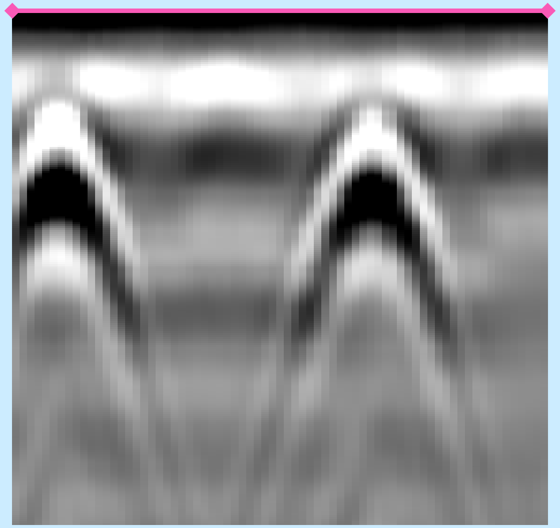
Using Holographic Radar



Holographic Radar



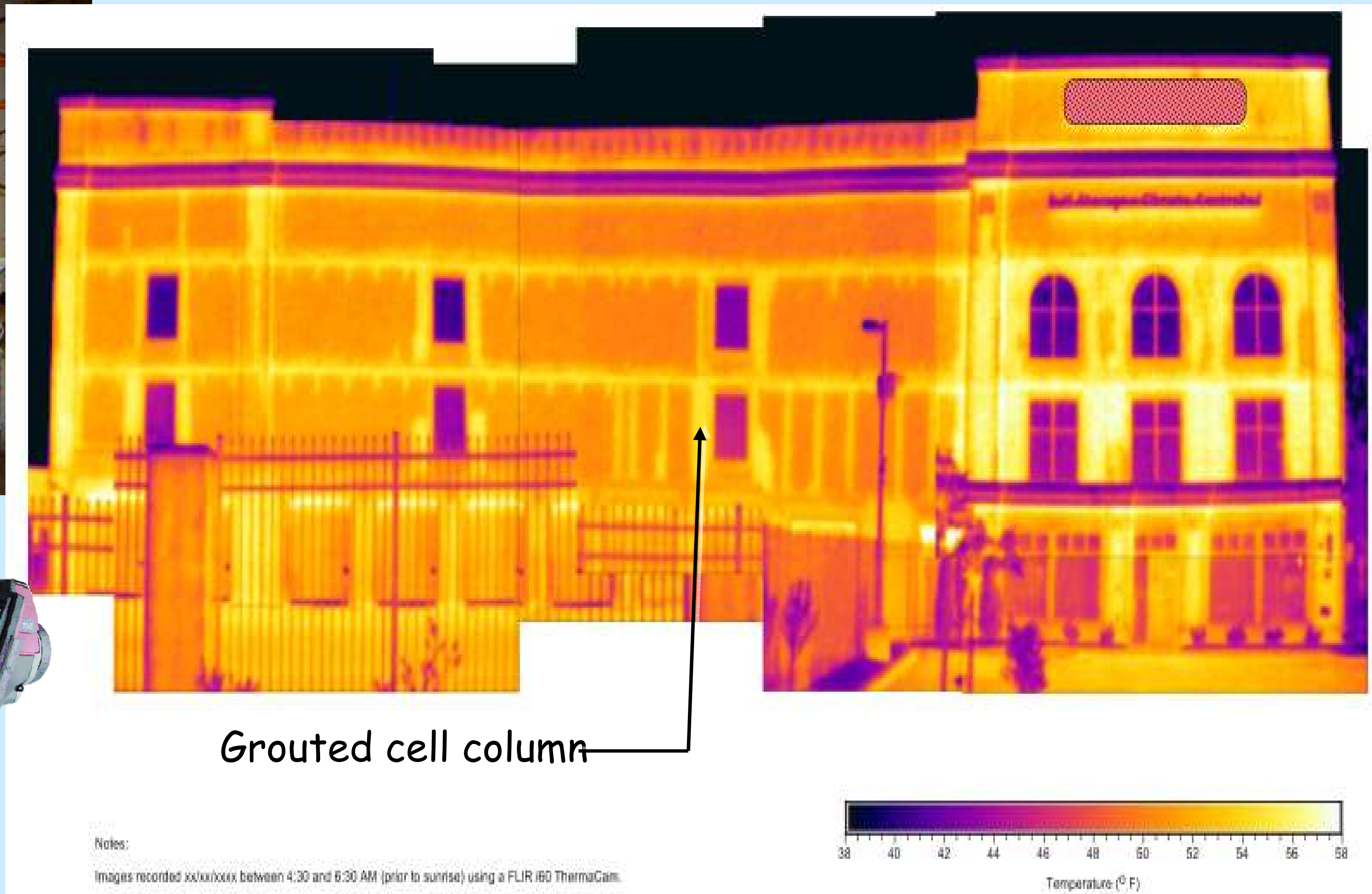
Scan Area on Hospital Wall



Impulse Radar

IR is Faster for large Walls

But, must be supplemented by EMI to locate steel bars



FLIR i60

Floor Inspection at Historic Fackenthal Lecture Hall, Franklin and Marshall College, Lancaster (PA) USA

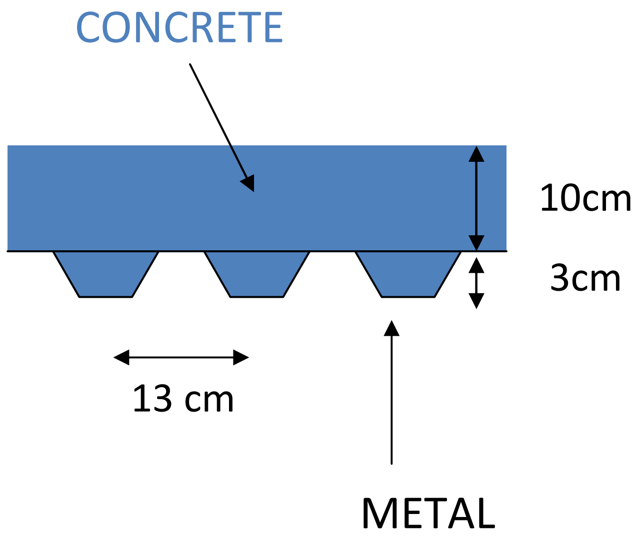
Since 1787, Franklin & Marshall College has provided courses in the liberal arts and the sciences. It is one of the oldest college in USA. Fackenthal Hall is now under restoration works. The floor has been restored by using corrugated metal plates covered with about 10 cm of very old (> 40 years) concrete.

Franklin & Marshall College 1910

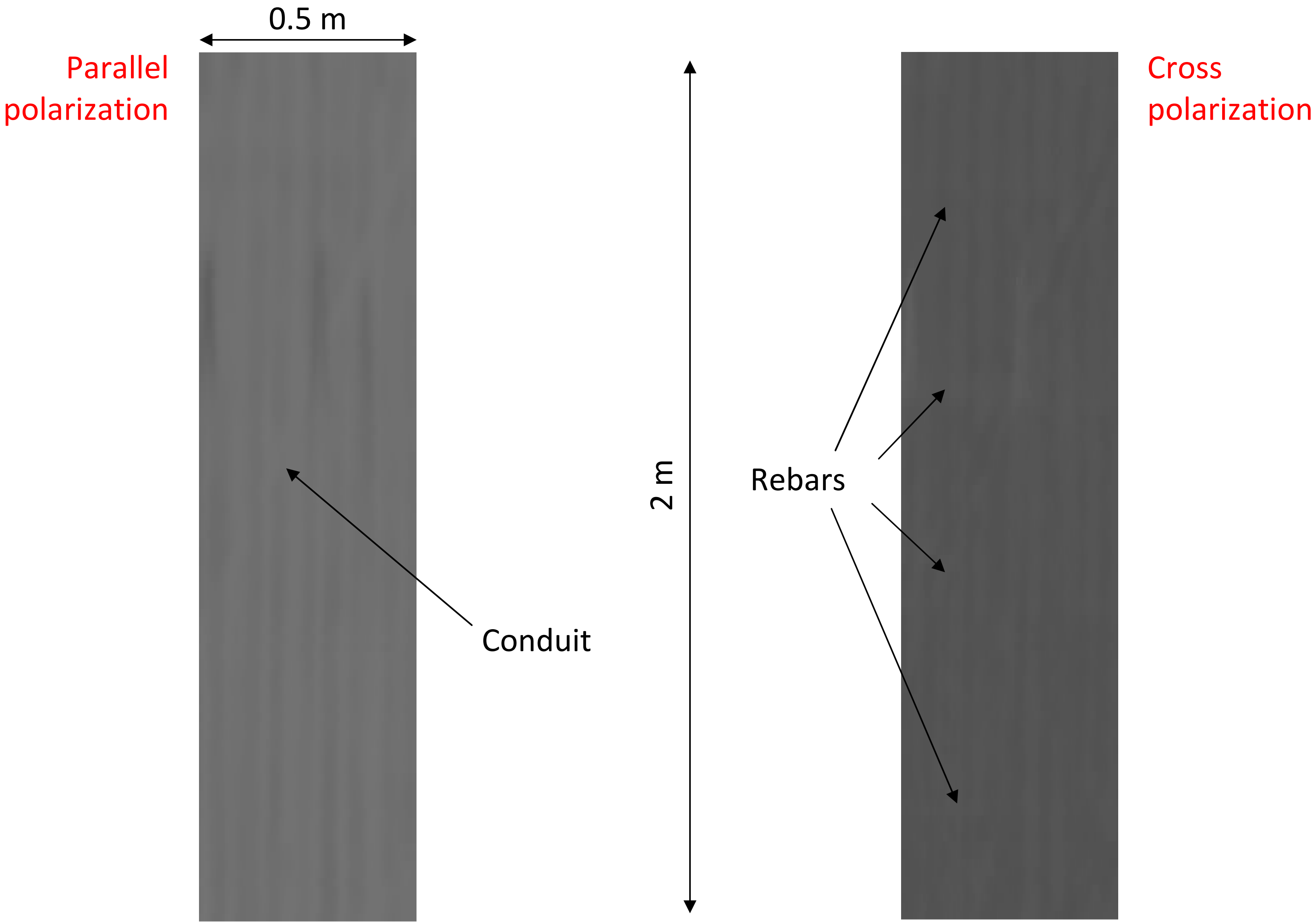
Scan on floor surface with RASCAN 2 GHz

Description of Floor Bottom

The corrugated metal plate was about 3cm deep and separated by 13cm. The concrete also holds rebars and conduits.



Animation of Holographic Radar Images



The scan is perpendicular to the corrugations. The transversal conduit is only visible by RASCAN; a 60Hz live power line detector showed no response.

Conclusions

- Holographic radar images reveal detailed information about subsurface buried objects and variations of electromagnetic properties of construction materials

- Multiple operating frequencies allows to distinguish overlapping objects buried within the penetration depth

- According to material electromagnetic properties, suitable operating frequency spectrum must be chosen within the available RASCAN radar versions (2 GHz, 4 GHz, 7 GHz)

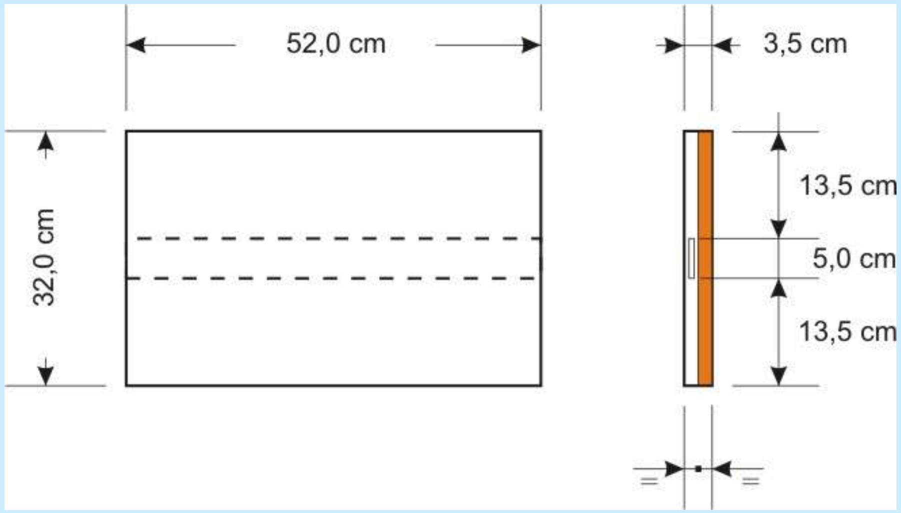
Plaster void detection: comparison of IRT, X-Ray and holographic radar RASCAN method

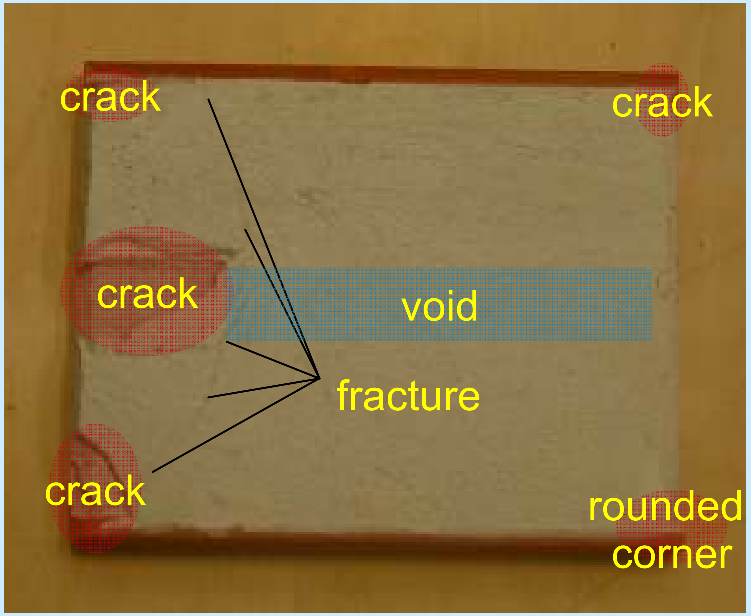
Acknowledge of RIMIDIA project rimidia.det.unifi.it

(Riflettometria a Microonde per la Diagnostica dei beni Artistici)

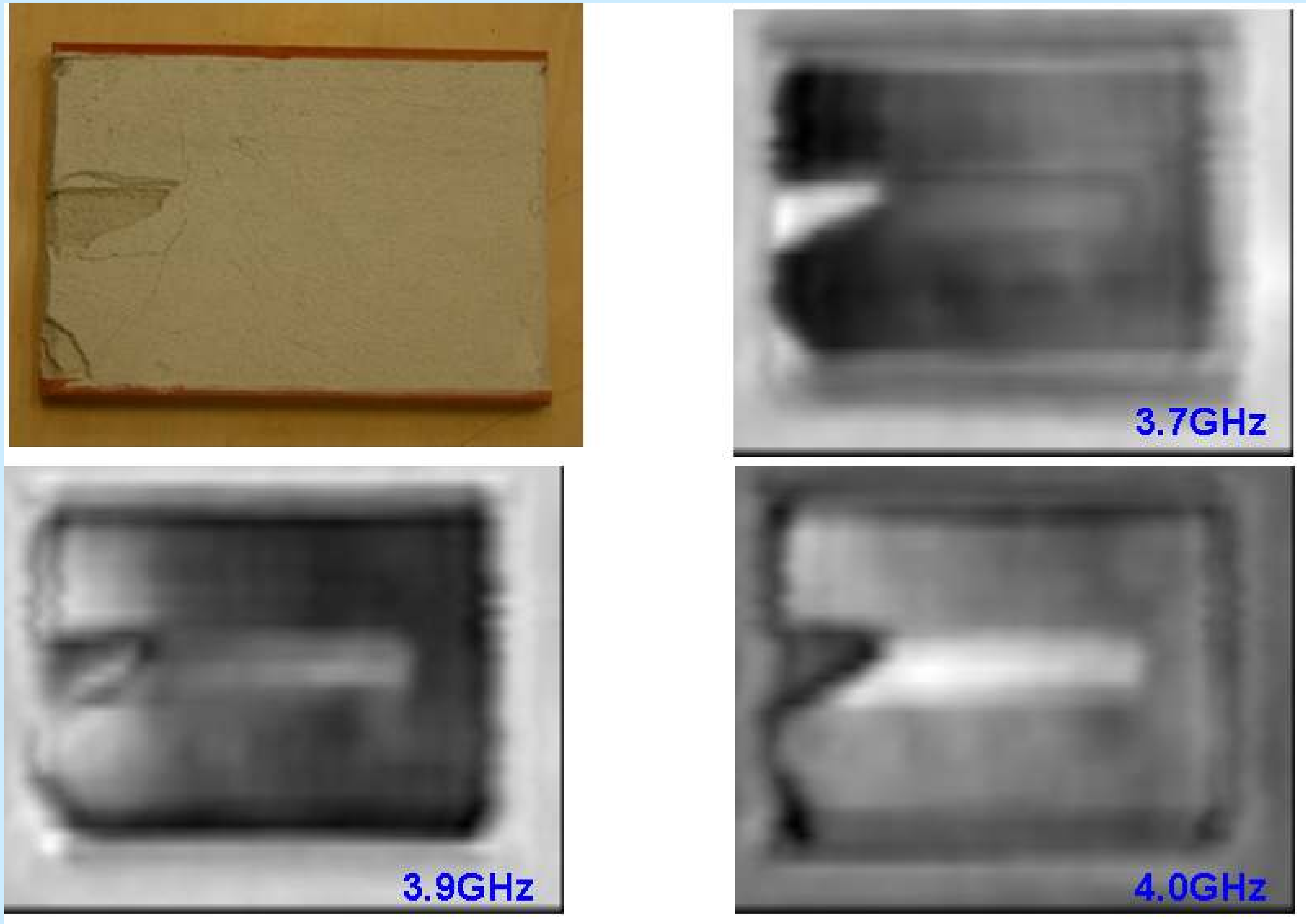
Test object

- Flat tile filled with plaster (arriccio).
- Rectangular void in the middle and a fracture on the left side (see picture).



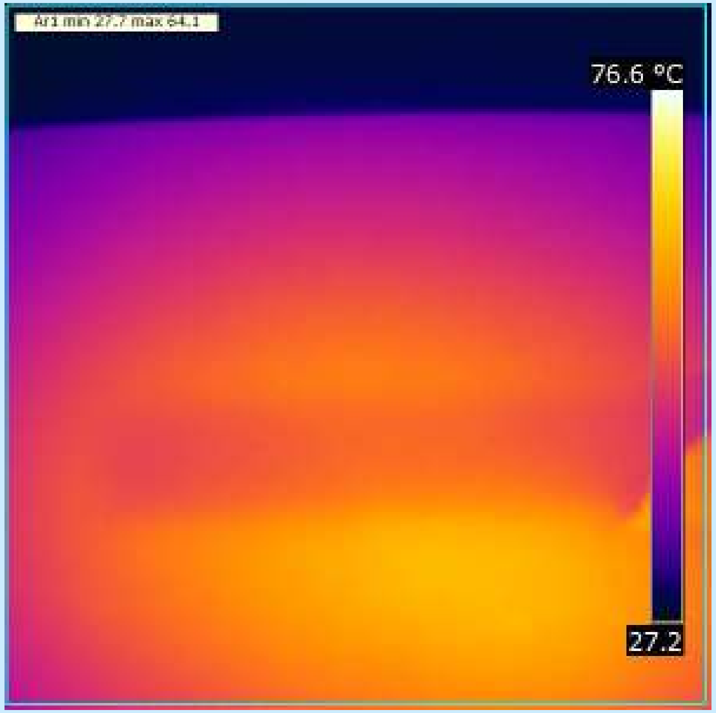


Holographic radar scans at different frequencies



INFRARED MEASUREMENTS

- The test object heated with two high power (500W) lights for 30 minutes
- The IR camera Mod. B60 (FLIR) with sensitivity better than 0,07 °C and focal plane array sensors 180x180 pixels



X-RAY

- X-RAY equipment Gilardoni (max 80kV, 3 mA).
- At 50 kV for 3 minutes (normal setting for imaging wood layers with thickness from 2 to 5 cm) the radiographic film was not imprinted
- By experience of X-Ray imaging of cultural heritage items (Opificio delle Pietre Dure, Firenze, Italy) the following materials are very difficult: mortar, frescos, mural wall paintings.

Termite Damage

- Losses total $1.5 billion per year in the USA alone

- Common in all tropical through temperate climates

- Termites cause the most damage in dollars, but there are many other wood-damaging insects

Detection by Professionals

- Thermal imaging*
- Acoustic emissions
- Radioactive tracer bait (for ants)

Inframation Institute

- all are non-destructive, <u>but</u>
  - Find current infestations *only*
  - Cannot be done during daytime for ground-dwelling nocturnal species
  - Cannot be done during winter when insects are inactive

*more later

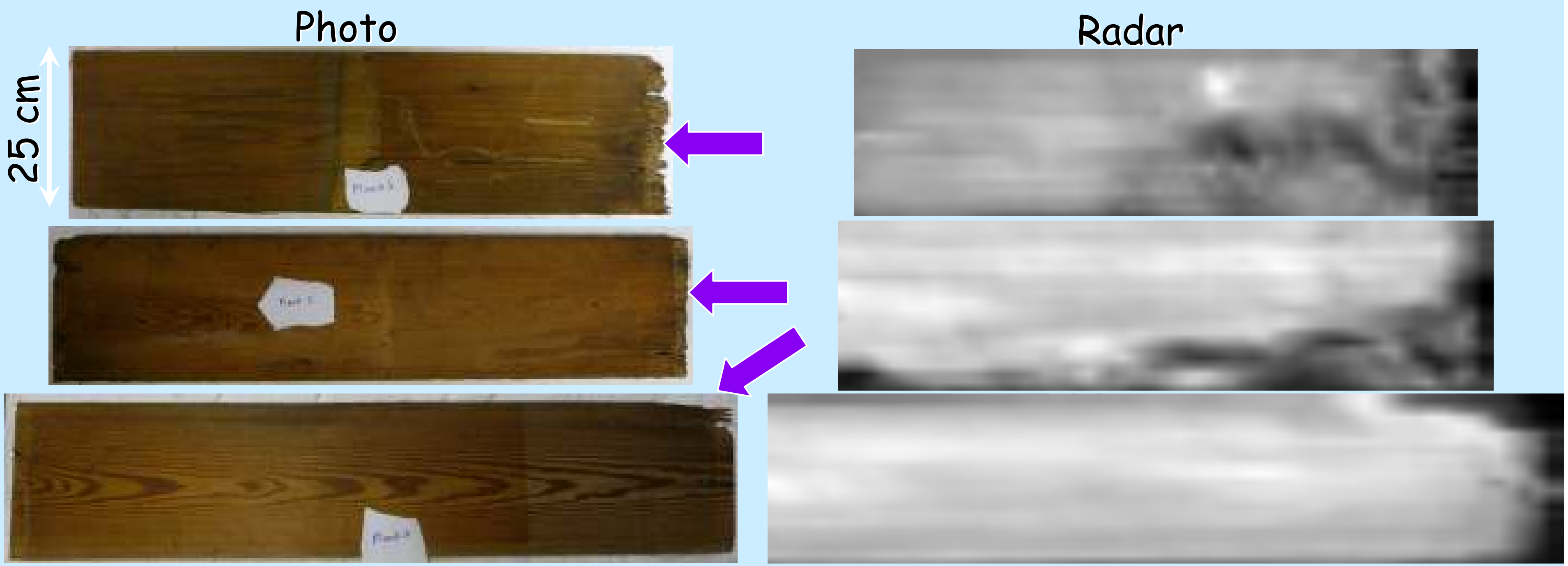
Ole Miss Acoustics Lab

An Ideal Detection Technology

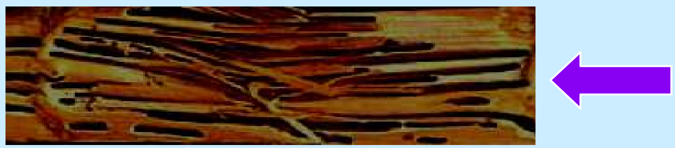
Should be…

- Non-destructive
- Able to detect both active infestations and old damage
- Effective in any season or time of day
- Readily usable by structural engineers, construction workers, pest control workers, etc.
- Limited downtime

Holographic Radar Test on Boards with Known Damage



Tunnels visible on edge of boards only, but radar reveals internal variations also.

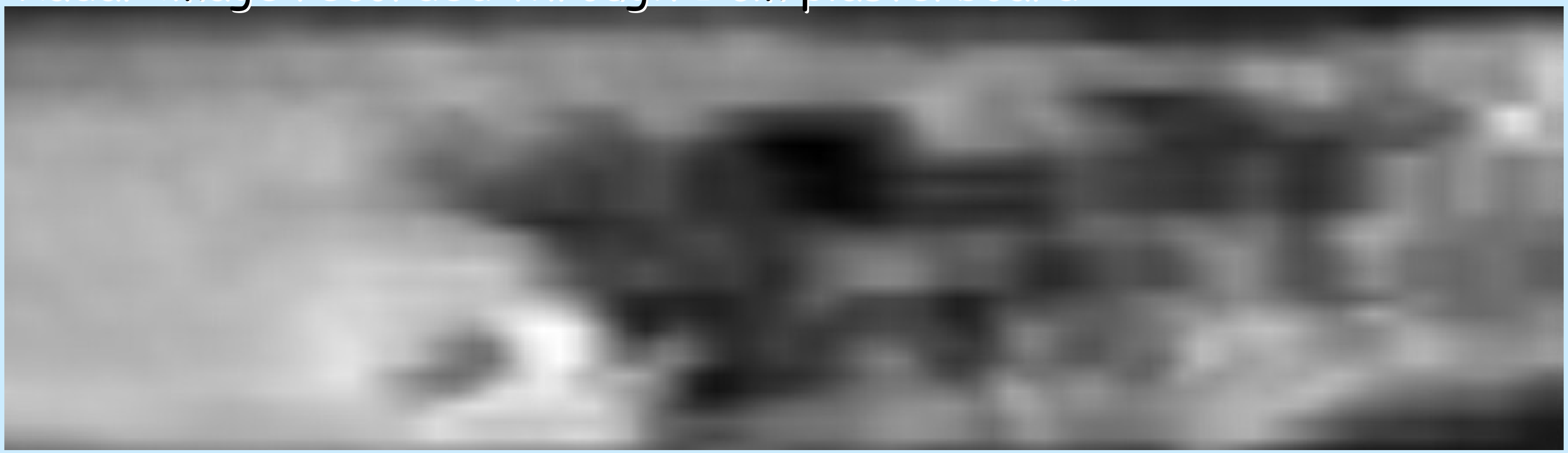


Close-up of edge of board

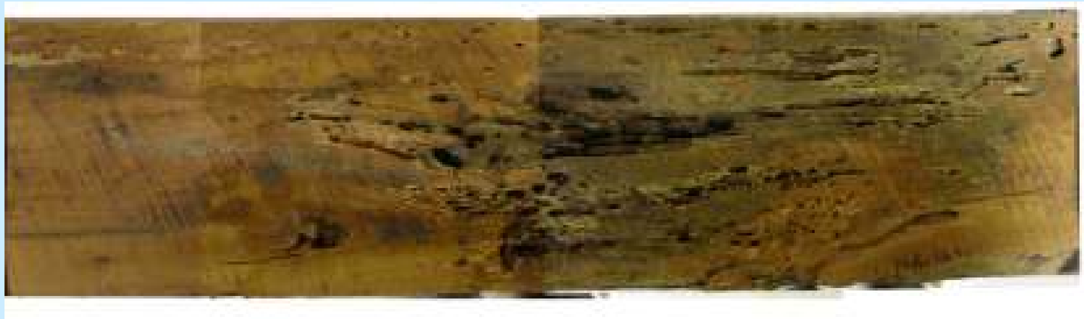
Test on a Board with Known Damage behind Mock Wall Covering

90 x 31 cm board exposed

Radar image recorded through 1 cm plasterboard

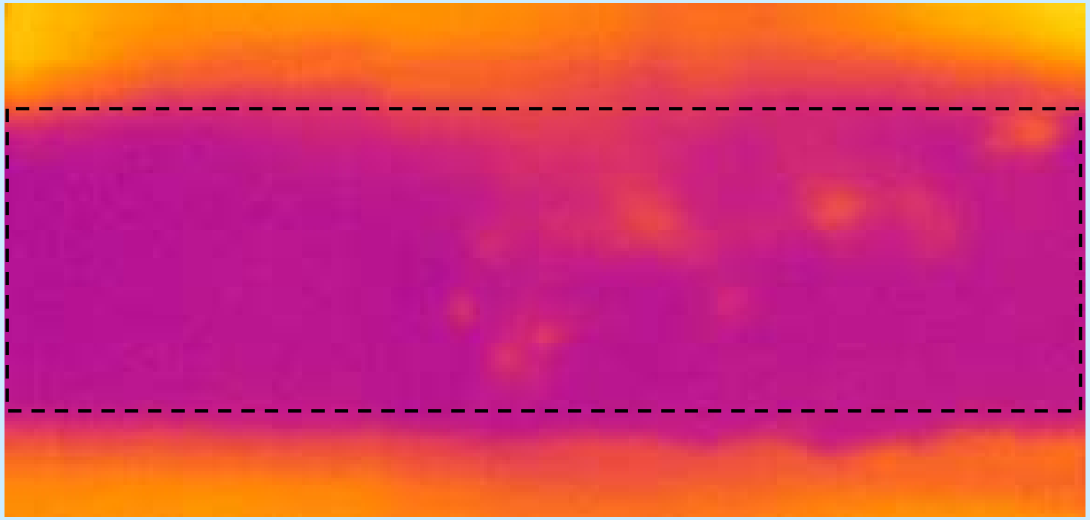


IRT vs. Radar



90 x 31 cm board exposed

RASCAN image recorded through 1 cm plasterboard

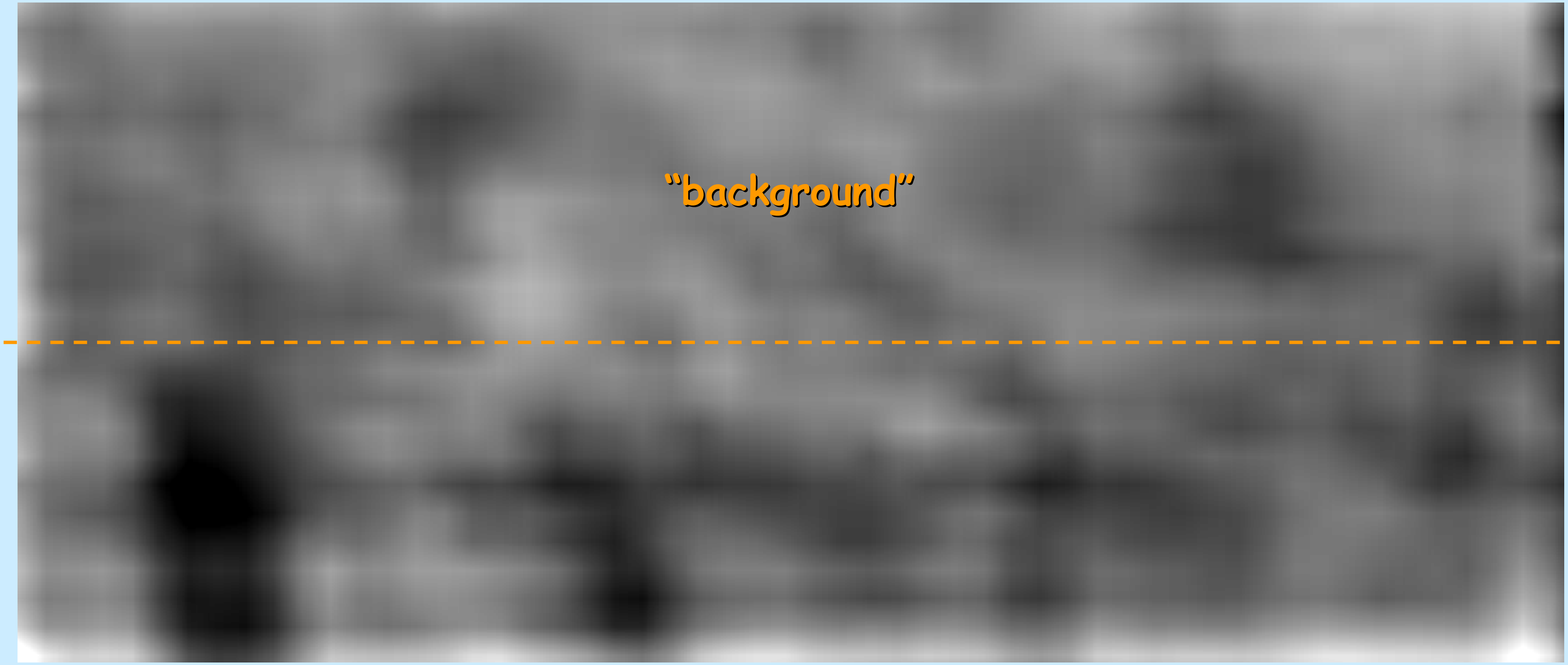


FLIR i60 image recorded through 1 cm plasterboard, with space heater behind board. Appearance of damage is transient only.

Radar Test on Board with Mock Damage

Tunnels mimicked by 5 mm diameter horizontal holes, drilled 12 cm lenght from edge in groupings of 1, 2, 4, and 8.

Radar Image of Board with Mock Damage



8 holes 4 holes 2 holes 1 hole

- 8 holes clearly visible – 4 and 2 progressively less so
- 1 hole is indistinguishable from background

Blind Test for Actual Damage

Radar was used in a building with heavy termite damage, from an old (>10 years ago) infestation.

Much damage is exposed following destructive testing and repairs.

Is there hidden damage that remains undetected?

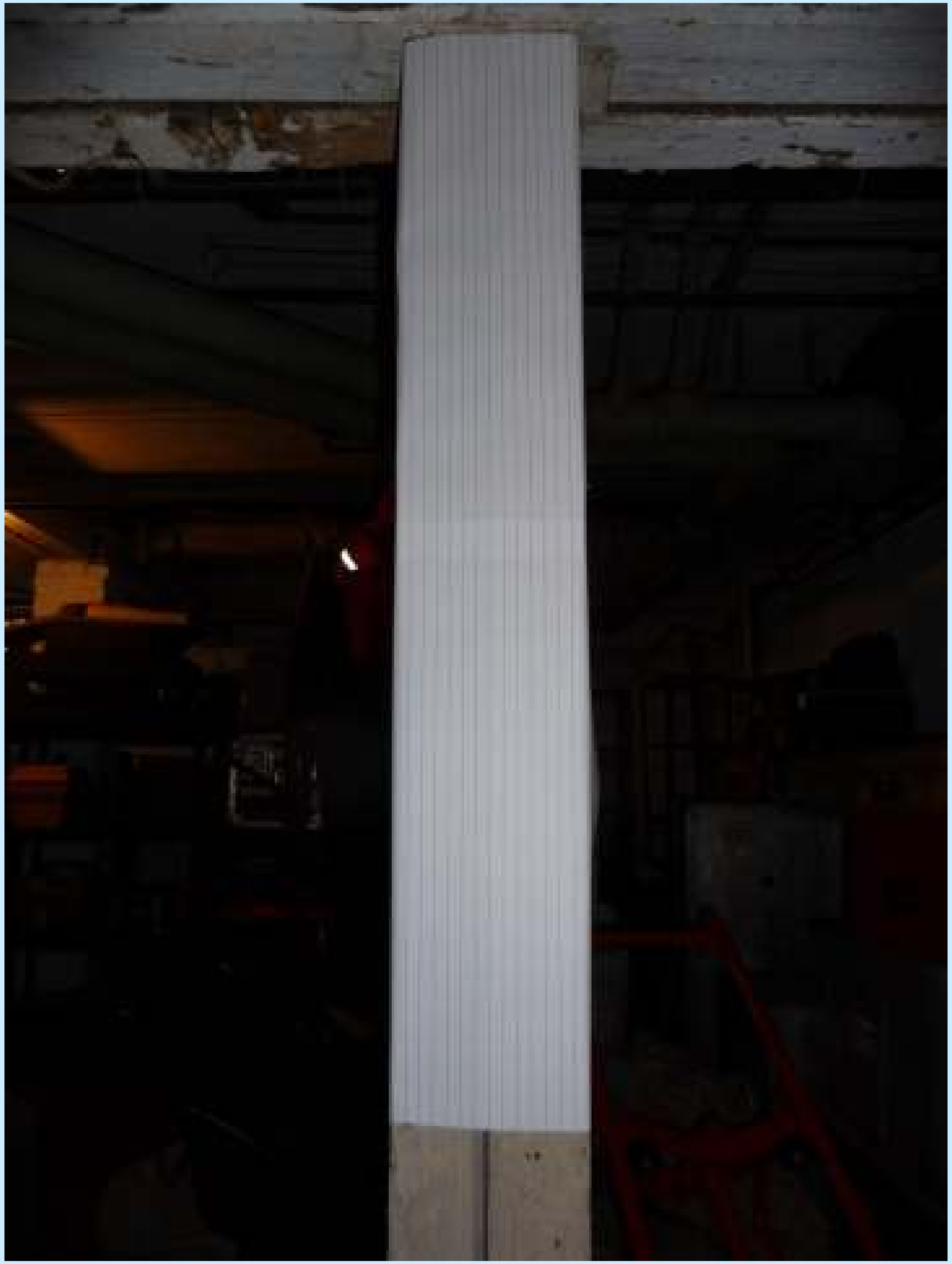
A Suspicious Location

This double post shows no visible surficial damage, but the beams above do.

Eastern subterranean termites nest in the ground, and rise into structures at night to feed.

Undetected tunnels in the post would provide hidden access from the earth to the damaged beam above.

Radar Testing



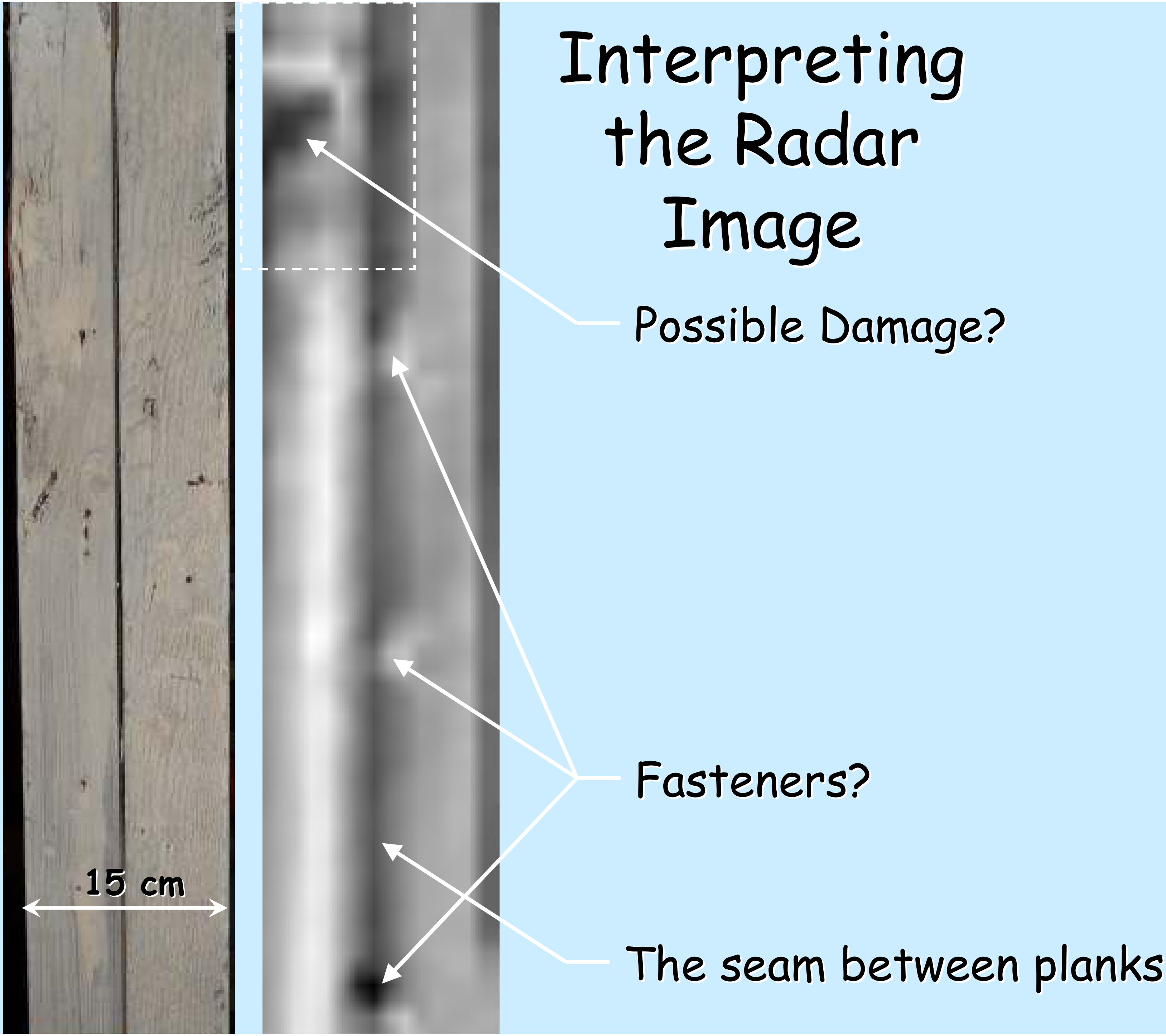
The post was scanned with RASCAN-4/4000 along lines spaced at 1 cm.

The scan extended 65 cm down from the damaged beams.

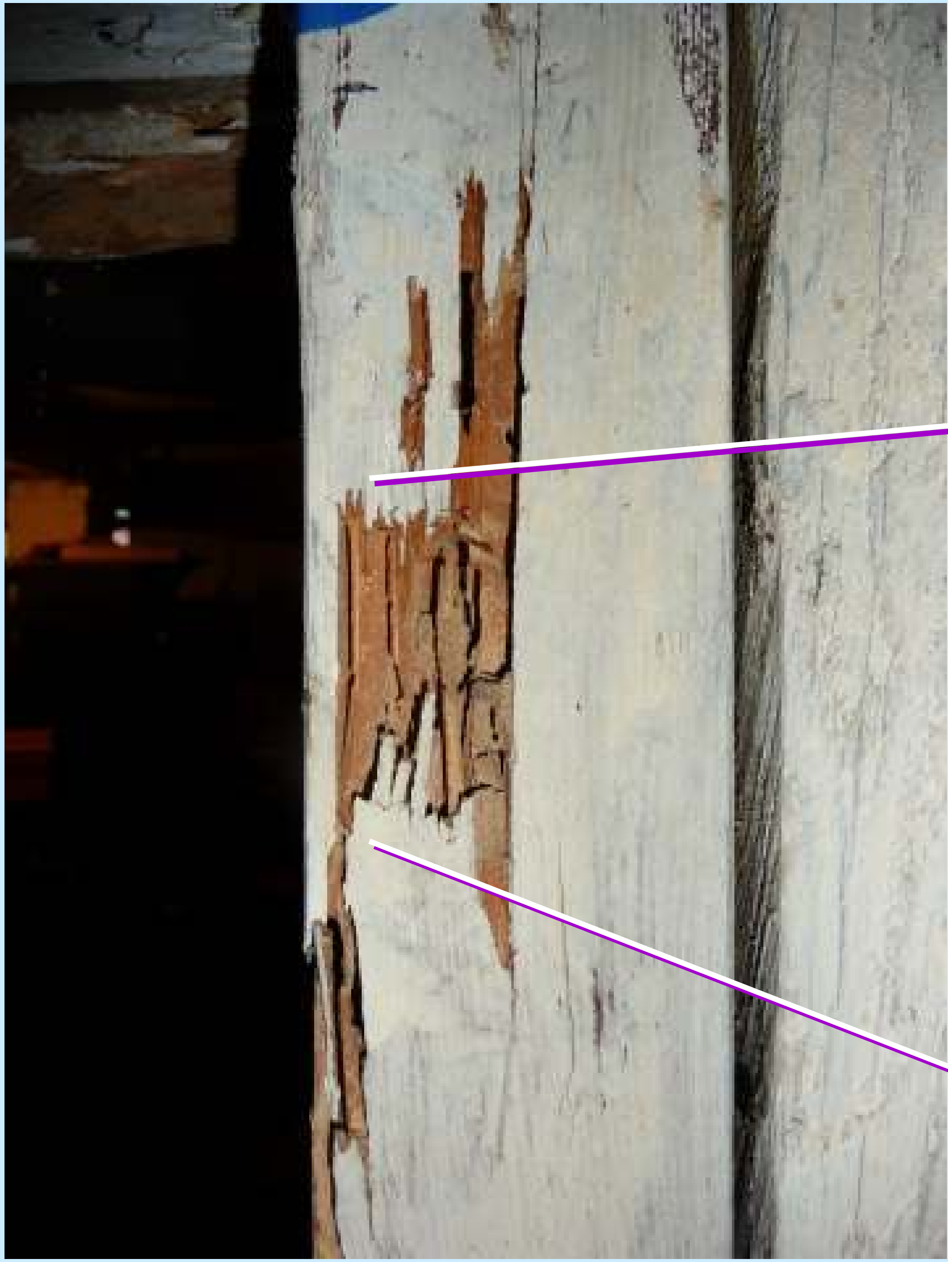
Scanning took less than five minutes.

Results were immediate.

Interpreting the Radar Image

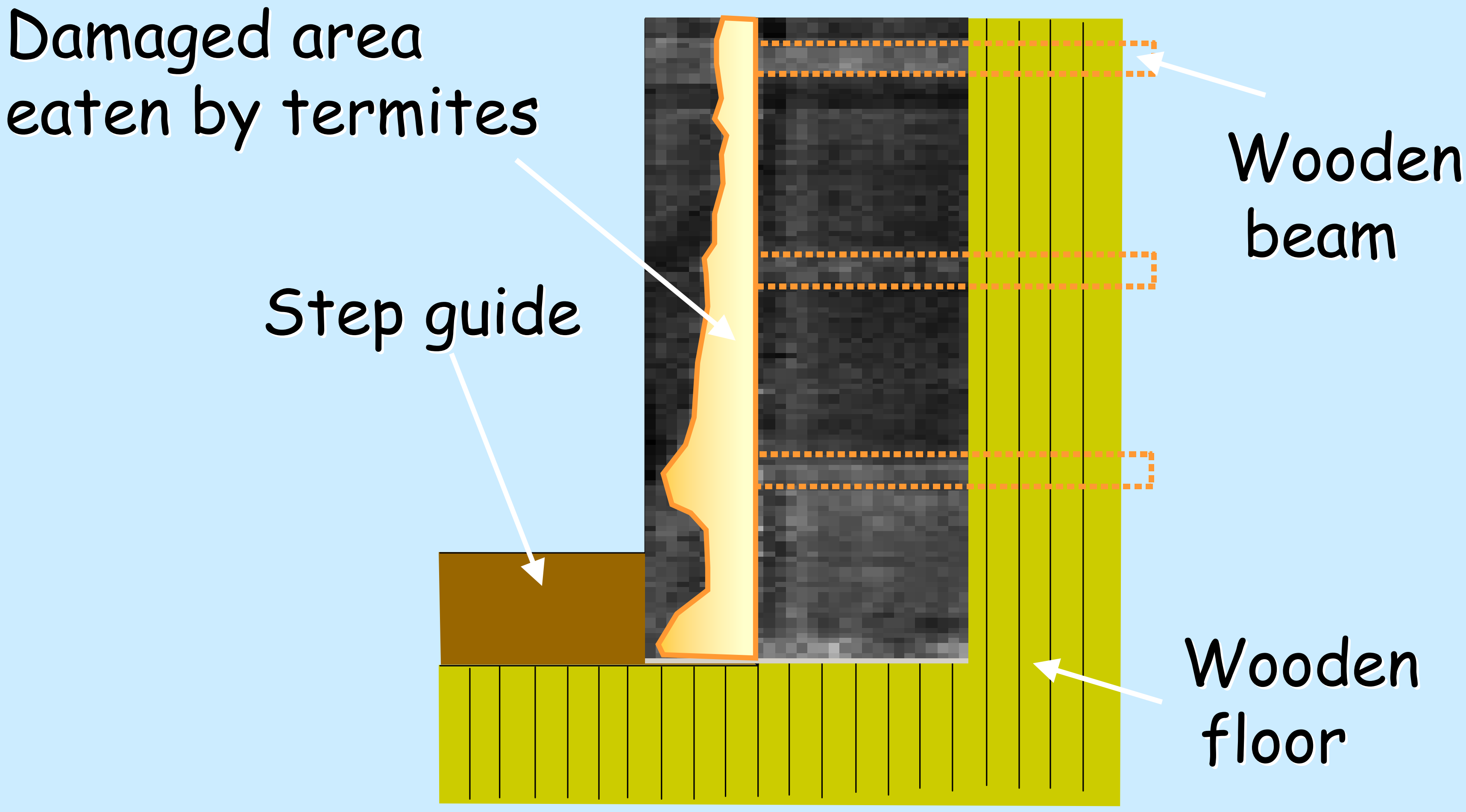


Damage Revealed



The Radar anomaly was probed with a screwdriver, revealing hidden tunnels.

Another Example



Investigation of plaster coated wall texture with holographic radar 4GHz – RASCAN 4000

SITE DESCRIPTION

The measurements have been carried out on an internal wall of a basement floor of a building built on about 1920.

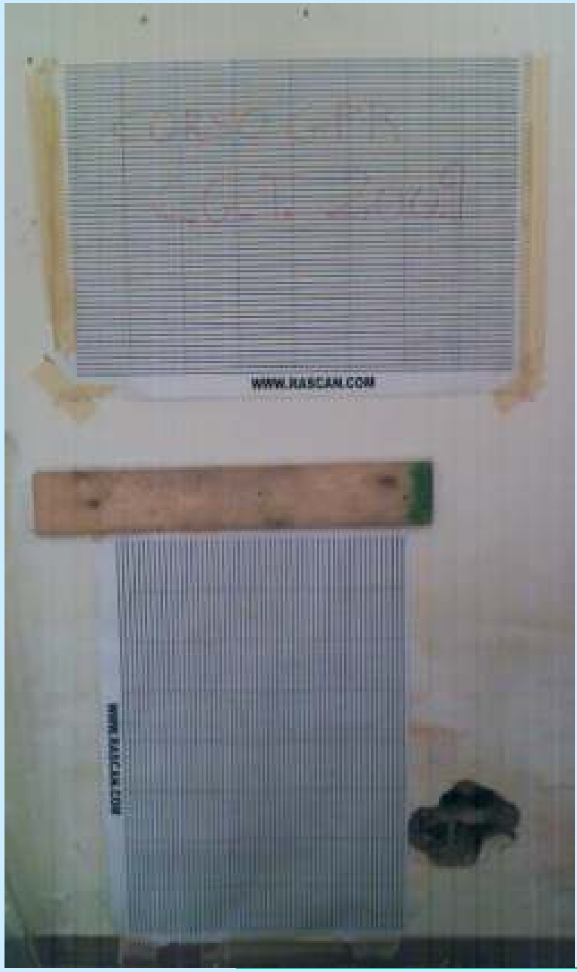
PICTURES OF THE WALL

Higher area- low moisture

Lower area–high moisture and delaminations

The section of the original bricks (about 100 years old) has dimension 28 cm x 4 cm , separated by mortar with thickness of about 2 cm. The plaster coating has a thickness of 1.5 cm for area #1 and about 3 cm in the lower moisten area

SCANNED AREAS



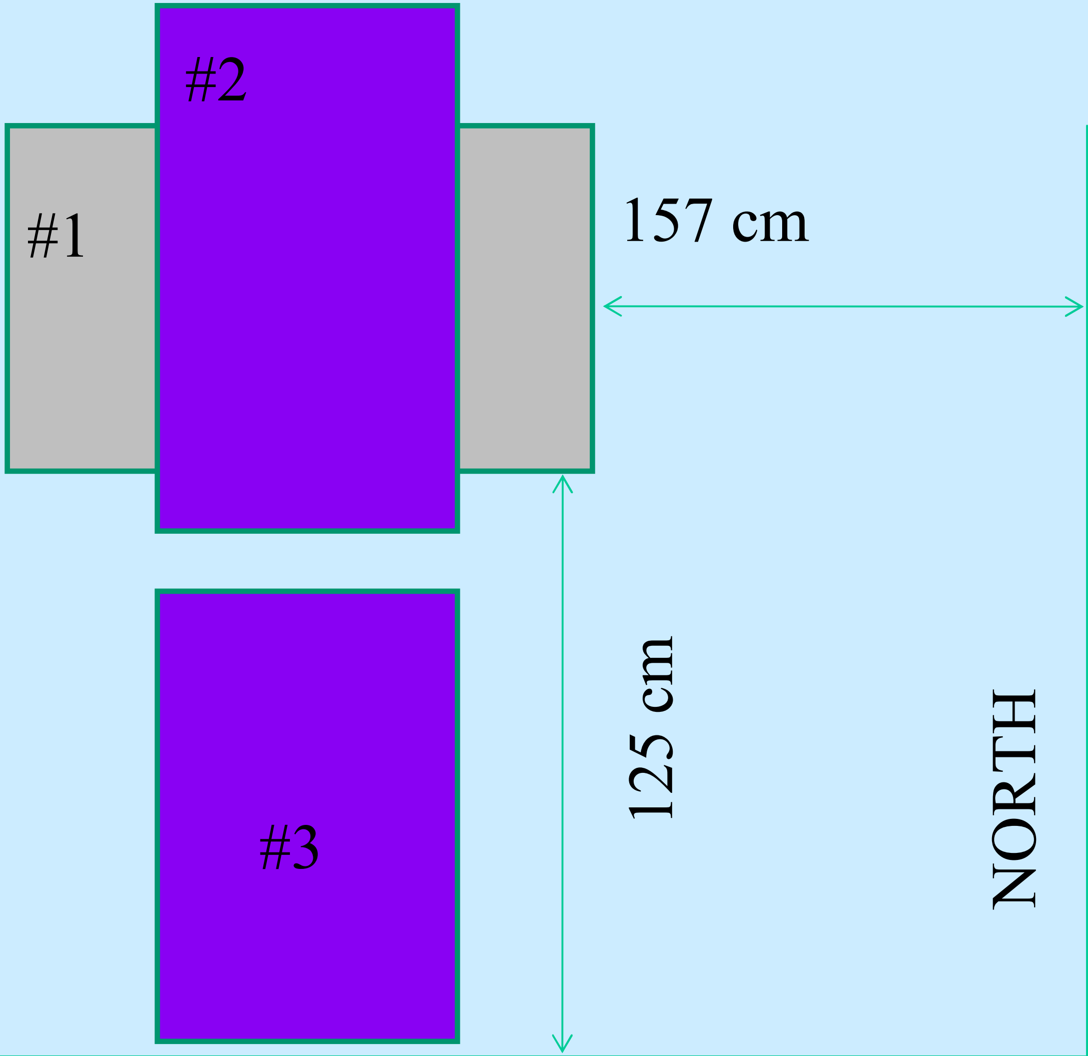
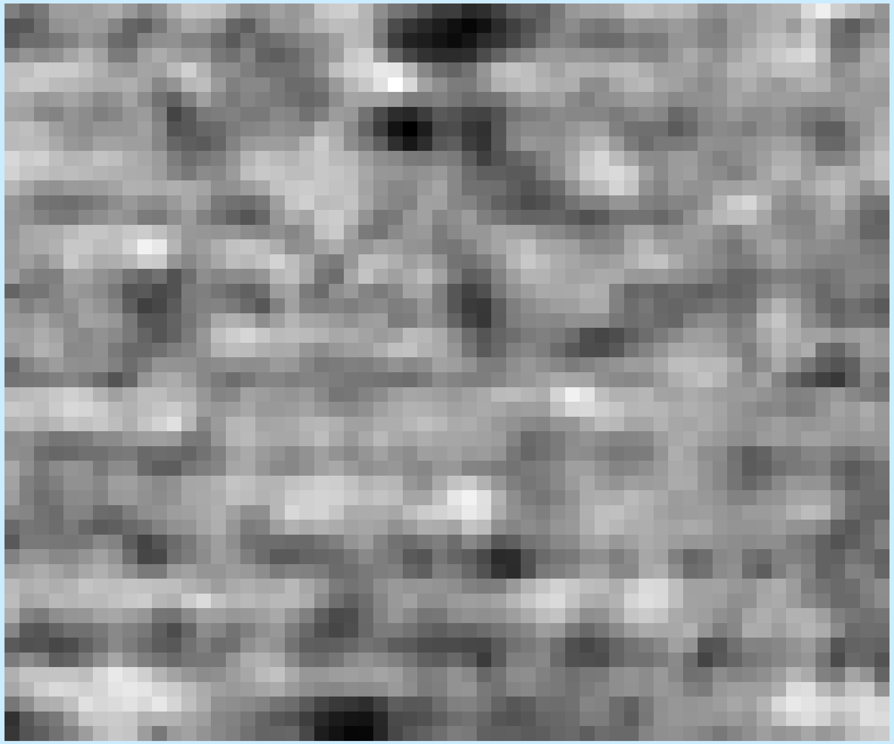


Image scans

Area #1



Polarization cross

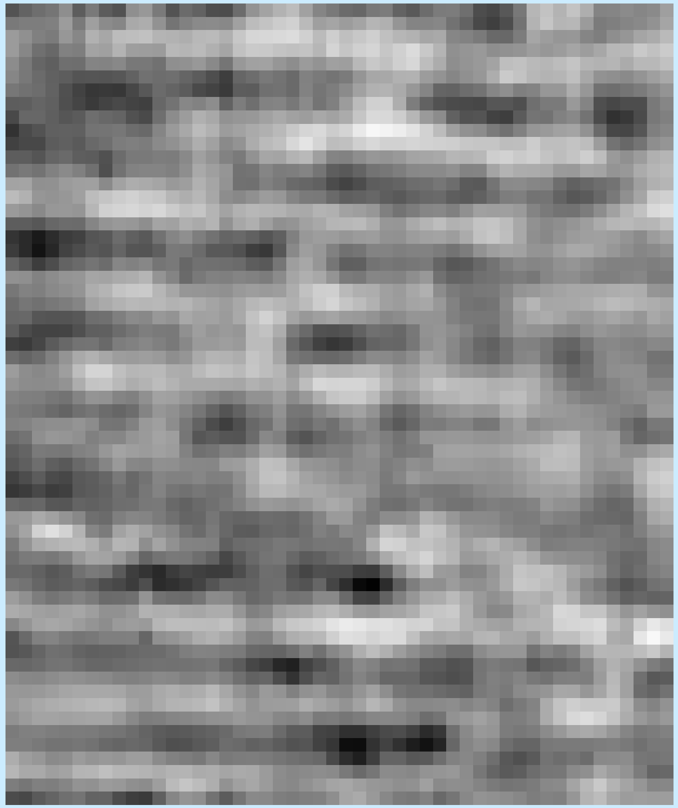
Freq_2

Scan direction horizontal

50 cm x 60 cm

Pixel 1cm x 1 cm

Area #2



Polarization parallel

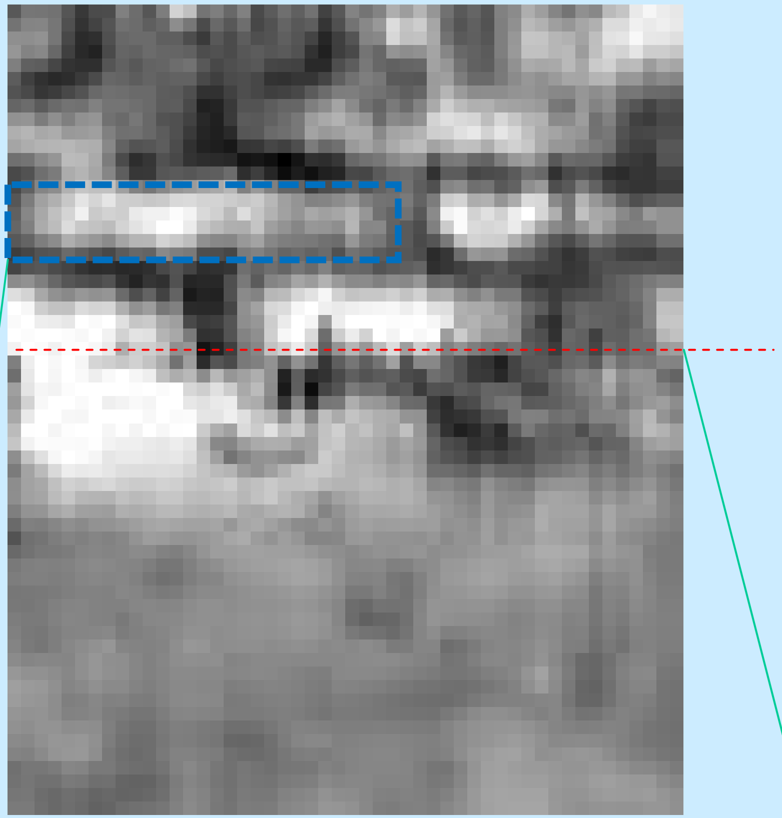
Freq_2

Direction of scan vertical

50 cm x 60 cm

Pixel 1cm x 1 cm

Image scan Area #3



Polarization cross.

Freq_2

Direction of scan vertical

50 cm x 60 cm

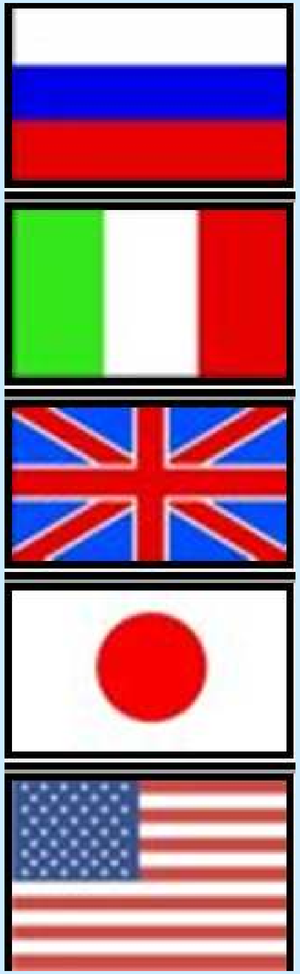
Pixel 1cm x 1 cm

Real dimension of the bricks
(29cm x 4 cm)

Red line coincide with the height evaluated as top of the moisten area from the floor

Observations

- For the case study considered, the 4 GHz frequency is appropriate to penetrate a plaster coating with thickness from 1.5cm to 3cm
- The system has enough spatial resolution to reconstruct the dimension of the bricks sections and to evaluate the wall texture and eventual cavities or inhomogeneities.
- The texture can be observed by exploiting the two polarizations of the radar. The better situation is with parallel polarization and direction of scan perpendicular to the longest brick dimension (29 cm in our case)
- The presence of moisture accumulated during at least 50 years in the wall has deteriorated the plaster coating and its thickness increased from 1.5cm in the normal dry area up to 3cm in the moisten area.
- In several area delaminations occurred causing low penetration in the brick wall due to the plaster-air interface
- Between some bricks on the sampled area were observed lack of mortar creating small cavities. Some artifacts in the images can be attributed to small (1.5 cm size) air filled cavities.



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Pierluigi Falorni, Tim Bechtel, Sergey Ivashov, Andrey Zhuravlev, Vladimir Razevig, Igor Vasiliev, Masharu Inagaki, Colin Windsor and all partners of the project *Rimidia* :

“Diagnostica non distruttiva con radar a microonde per opere d’arte murarie e lignee”

(http://rimidia.det.unifi.it/) finanziato dalla Regione Toscana (2010-2012)