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Evaluation of XRpad2 HWx-i For Mobile Non-Destructive Testing

Authors: B. Niederländer, M. Yap, S. Arnold

Abstract

This paper introduces the new Varex industrial wireless Digital Detector Arrays XRpad2 3025 HWx-i and XRpad2 4336 HWx-i. The third generation of XRpad digital detector arrays (DDAs) are engineered for the field of mobile non-destructive testing as required in the oil and gas industry for detection of deposits and corrosion as well as for weld inspection. The device has excellent resolution and outstanding image quality. The new DDAs provide features like continuous imaging with up to 9 fps, on-board averaging, power saving, Automatic Exposure Detection (AED) and backscatter shielding. The detector is designed to work with pulsed X-ray sources as well as continuous wave X-ray sources and gamma sources like Se and Iridium.

In this paper, the usability of the XRpad2 HWx-i DDAs for mobile NDT will be studied. Image quality performance at operational temperatures ranging from -20°C to 50°C will be summarized.
The overall results indicate that the XRpad2 HWx-i detector family, due to its outstanding image quality, fast image acquisition, mobility, and ease of integration is well suited for mobile NDT.

Introduction

Non-destructive Testing (NDT) based on Gamma and X-ray is one of the various methods used in industry to inspect parts for cracks or other defects during the manufacturing process. Usually the inspection is maintained inside a production line, but some parts such as shipyards, aircrafts, as well as pipes, and oil/gas tanks are in the field. The use of mobile sources (X-rays or gamma rays) along with a lightweight portable detector as imager is required.

Figure 1. Left: X-ray image of a wire penetrameter 13 FE EN (EN 462-1) on 6 mm steel. The smallest visible wire has a diameter of 0.05 mm.
Middle and right: X-ray images of ASTM-E-1025 penetrameters. Both measured on 6 mm steel. Middle: Thickness: 0.1'' = 1T-hole. Right: Thickness: 0.05'' = 1T-hole. The 1T-holes are clearly visible

Nowadays, digital X-ray radiography is increasingly becoming a technology for on-site inspection. It is beginning to replace film, as digital imaging is more cost efficient and real-time imaging offers the advantage of immediate on-site image evaluation and thus an improvement in inspection efficiency. In addition, due to the high safety guidelines for the inspection of pipelines, high requirements lend themselves to the image quality of such a mobile FPD.
Figure 1 shows an example of the outstanding image quality of the new XRpad2 HWx-i. These X-ray images benefit from the high spatial and contrast resolution of this detector, which allows for a clear identification of cracks and defects.

XRpad2 HWx-i Overview

This section presents the main features and operating modes of the XRpad2 HWx-i detector.

Features and Operating Modes

The industrial XRpad2 detector is available in two imaging sizes, featuring an imaging area of 43 × 36 cm^2 or 30 × 25 cm^2 as shown in Figure 2. It can be used wirelessly and wired. The design is lightweight (below 4.3 kg), robust, ergonomic with scalloped edges for easy lifting. Featuring a 100 µm pixel pitch with several scintillator options that include: high resolution CsI, high efficient CsI, or Gadox scintillators. The XRpad2-i detector series provides excellent image quality with X-rays and isotopes.

Figure 2. XRpad2 3025i and 4336i detector with an imaging size of 30 × 25 cm^2 and 43 × 36 cm^2

The device has been designed to withstand point loads of 30 Newtons and to support imaging under load conditions. The DDAs are also equipped with a two-level shock sensor monitoring with a warning shock level at a sensitivity of 1000G and critical shock level at 4000G. The shock sensors are always active. Additionally, it is IP54 rated.

For a quick and simple system integration and field usage, the detector includes features such as Automatic Exposure Detection (AED), on-board corrections, on-board storage, **on-board averaging**, fast preview image presentation in binned mode and wireless access point mode.

On-board averaging allows for the detector to automatically average frames on-broad and only transfer the resulting averaged frames to the laptop or PC for analysis. The images can also be stored and retrieved later. A maximum of 1024 frames can be averaged. The number of frames must be a power of 2 (2^n) with n = 1, ..., 10. (Steps: 2, 4, 8, 16, 32, 64, ..., 1024).

Different synchronization/trigger modes including Automatic Exposure Detection (AED) simplify the integration with various X-ray sources, including battery-driven pulsed sources, constant potential sources, as well as industrial radiography isotopes (e.g. Iridium and Selenium).

In addition, a backscatter shielding has been introduced between the panel and electronics to avoid scattering artifacts from electronic components. This leads to a better Signal to Noise Ratio (SNR) and contrast to noise ratio (CNR) helping smallest cracks and voids to be detectable as demonstrated in Figure 3.

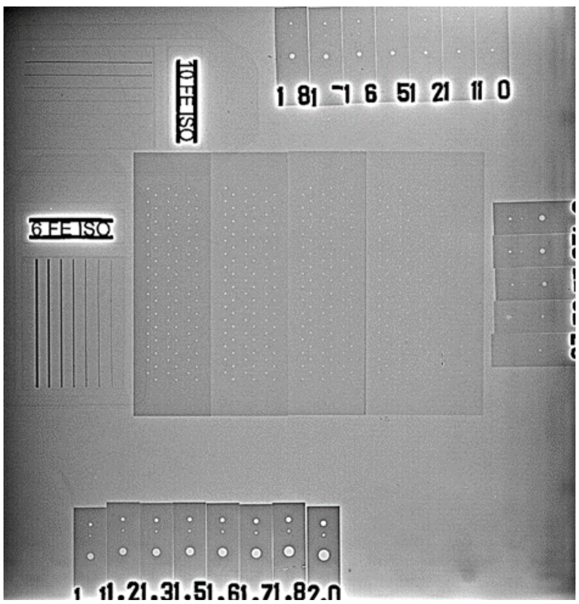

Figure 3. X-ray image acquired with an XRpad2 HWJ-i (DRZ Fine) by using a Selenium gamma source.

Resolution of the XRpad2 Detector

A duplex-wire phantom (IQI EN462-5) was directly positioned on the detector and was imaged to demonstrate the resolution capability of the XRpad2 HWx-i detector. High Resolution CsI was used as scintillator material. The image was acquired with the following X–ray tube settings and geometry: 220 kVp, 4 mA, integration time: 180 ms, 32 averages, a 100 cm source-to-image distance, and a 5 mm tube focal spot with a 0.5 mm Cu filter. Offset gain and bad pixel corrections were applied. Figure 4 shows the profile plot along the red rectangle drawn in the image of the duplex wire phantom

(Fig. 4, bottom). The profile data have been averaged across the red rectangle as defined in the ASTM standard E-2597M-14 [1]. The D10 line pair can be clearly resolved with an accuracy better than 20%. The iSRB (interpolated Basic Spatial Resolution) measured in this image is 98.4 µm.

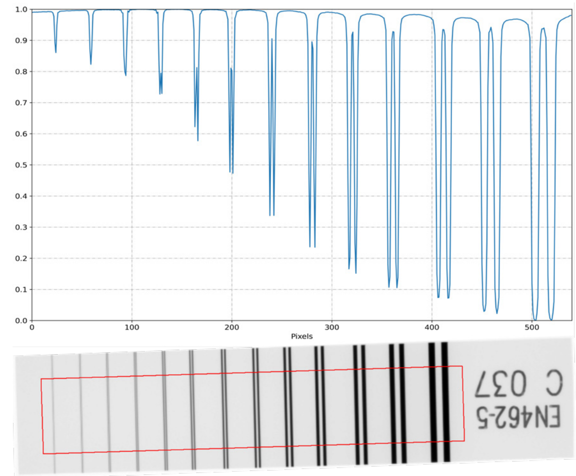

Figure 4. Resolution of the XRpad2-i detector with thin CsI: (bottom) duplex wire phantom, (top) averaged and normalized profile plot across the red rectangle. The D10 line pair can be clearly resolved with >20%.

Temperature Study

The XRpad2 HWx-i is designed to withstand various ambient conditions such as observed in pipe inspection in the desert at 50°C or in cold regions at -20°C. This section studies the impact of temperature on the detector performance. XRpad2 HWx-i detectors were placed in a climate cabinet, while continuously powered by an external power supply and continuously triggered by a PC. The temperature within the climate cabinet was varied from -20°C to +70°C increased in 10°C steps.

The temperature levels were maintained at -20°C, -10°C, 0°C, 40°C, 50°C, 60°C, and +70°C for 24 hours and at 10°C, 20°C, and 30°C for 2 hours, respectively. Thus, the test was performed continuously for about 174 hours.

Impact of Ambient Temperature on Internal FPD Temperatures

The XRpad2-i detector allows measuring the internal temperature with five temperature sensors installed in different positions on the mainboard. Table 1 shows the internal averaged temperature over all internal sensors, the temperature at the analog board 1 (minimum) and digital board (maximum) compared to the ambient temperature set in the climate cabinet. The values of the internal sensors at 60 °C and 70 °C exceed the limit of 70 °C specified for the electronics. For this reason, it is recommended to use the DDAs up to an ambient temperature of about 50 °C.

Ambient Temperature [°C]	Internal Mean Temperature [°C]	Analogboard.1 Temperature [°C]	Digitalboard. Temperature [°C]
-20	- 7.55	-15.20	- 0.91
-10	+ 1.64	- 5.91	+ 8.13
0	+11.20	+ 4.00	+17.52
+10	+21.17	+13.99	+27.52
+20	+31.17	+23.96	+37.51
+30	+41.19	+34.00	+47.51
+40	+51.19	+44.00	+57.51
+50	+61.11	+54.00	+67.55
+60	+71.20	+64.00	+77.99
+70	+81.41	+74.00	+88.48

Table 1. Measurement of the internal temperatures at a constant ambient temperature level. The red and yellow marked rows exceed the limiting temperature of the electronics of 70 °C. It is not recommended to use the detectors at 60 °C ambient temperature and above.

Impact of Ambient Temperature on Image Quality

No functional issues were observed while operating the detectors over this expanded temperature range. Images were acquired using internal triggering with an integration time of 500 ms and framewise mode. During the test, every 10 minutes a dark image was taken and stored, only images captured at the temperature plateaus were used to study the influences of temperature on the dark signal.

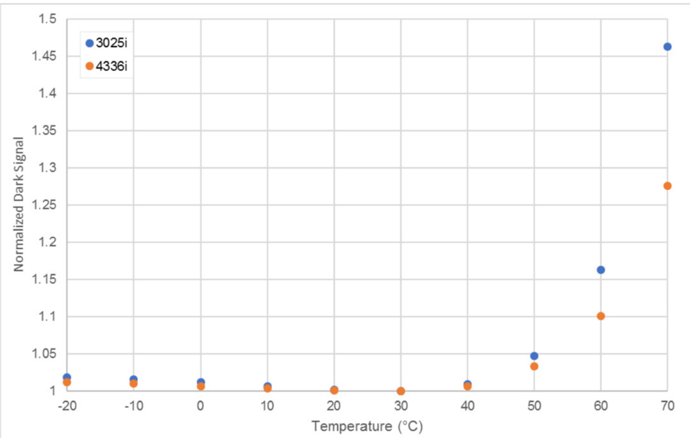

Figure 5. Normalized dark signal versus temperature in (°C) for an XRpad2 3025i and 4336i detector. The noise standard deviation in all acquired images was lower than 0.2%.

Figure 5 shows the normalized median dark signal calculated from a set of images captured at constant temperature versus the ambient temperature for the two detectors (4336i and 3025i) under test. In both measurements the noise level in all acquired images was below 0.2 % (standard deviation/median). For all temperatures below 50°C the median dark signal varies by less than 5 % for both detector types.

The variation of dark signal with temperature follows the same trend for both detectors. However, the drift at temperatures greater than 60°C is more pronounced for the 3025i, caused by the compact design of the detector. The overall variation is still negligible when compared to the 16-bit, 65535 maximum gray level.

With direct sunlight falling on the detector like in the desert the internal temperature of the detector easily increases to 60°C+. However, it could be shown that a white cover (i.e. adhesive film) around the detector can lower the heat absorption and reduces the internal temperature by several degrees.

Detective Quantum Efficiency (DQE)

The Detective Quantum Efficiency (DQE) is a measure of the efficiency with which a detector passes signal to noise ratio from its input to its output. DQE is the principal objective measurement used to determine imaging performance.

Figure 5 compares the DQE (measured with RQA5 beam quality) of the five available scintillators on the aSi-panel with 100 µm pixel pitch used for the XRpad2 HWx-i family: High Efficient CsI (HE CsI), High Resolution CsI (HR CsI), DRZ[1] Fine (Gadox), DRZ[1] Plus (Gadox), and DRZ[1] Standard (DRZ STD, Gadox). The excellent DQE data indicate that the XRpad2 HWx-i provide exceptional imaging performance even at low dose levels and ensure a fast digital radiographical imaging even with gamma sources.

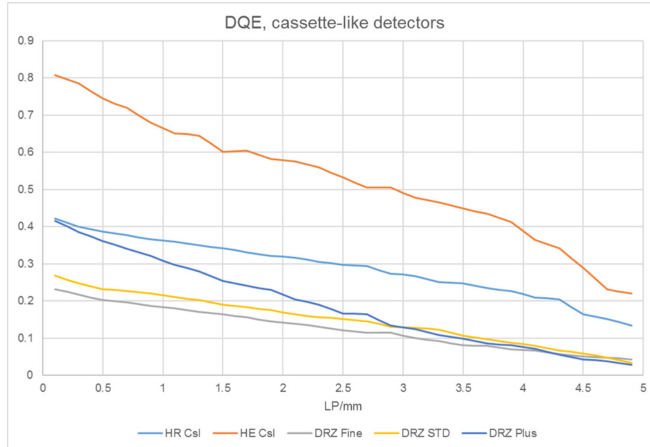

Figure 5. DQE curves of the available scintillators on the aSi-panel with 100 µm pixel pitch used for the XRpad2 HWx-I family measured with RQA5 beam quality.

Characterization of the XRpad2-i in accordance with ASTM E-2597-14 Standard

The XRpad2-i DDA has been evaluated with accordance to the Characterization of Digital Detector Array ASTM E-2597M-14 [1]. This practice is intended for use by manufacturers or integrators to provide quantitative results of Digital Detector Arrays (DDA) for NDT users. This standard defines several factors that must be determined to characterize a DDA. The following 5 factors have been evaluated for different XRapd2-i (definitions are from the standard):

- **Interpolated basic spatial resolution (iSRb):**
  Indicates the smallest geometric detail, which can be resolved spatially using a digital detector array with no geometric magnification.
- **Achievable contrast sensitivity (CSa):**
  Optimum contrast sensitivity obtainable using a standard phantom with an X-ray technique that has little contribution from scatter.
- **Image Lag:**
  Residual signal in the DDA that occurs shortly after the exposure and readout is completed.
- **Efficiency at 1 mGy:**
  Detector SNR-normalized at 1 mGy. This parameter is used to measure the response of the detector at different beam energies and qualities.
- **Specific material thickness (SMTR):**
  Material thickness range that is achieved within a certain image quality.

Procedures to collect and process data to retrieve the different factors are clearly defined in the code of practice. Figures 6,7 and 8 show the spider charts diagrams for the XRpad2 4336i at 3 frames per second (fps) and with different scintillator materials (High Efficient CsI (HE CsI), DRZ Fine, DRZ Plus). Figure 9 displays the spider chart diagram for the XRpad2 3025i with high resolution CsI (HR CsI) at 3.7 fps. All charts are measured in full resolution.

1 DRZ is a registered trademark of Mitsubishi Chemical

The diagrams include values for Aluminum, Titanium and Inconel used as filters which are standard materials inspected in NDT.

Due to the small pixel pitch of 100 µm of the XRpad2-i, all analyzed Depending on the thickness of the scintillator the iSRb varies, the thinner the scintillator the better the resolution.

The efficiency of HE CsI outperforms with a relatively good resolution the other types due to its excellent conversion of X-rays into visible photons and its crystal structure.

The overall results are excellent, and this makes the XRpad2-i a good candidate for mobile NDT fulfilling the high-quality needs

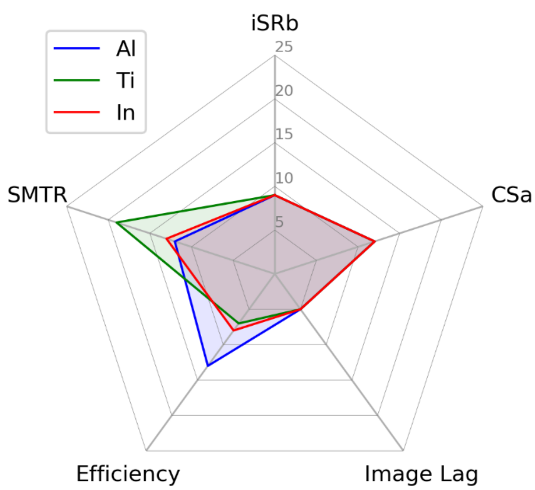

Figure 6. ASTM Spider charts of the XRpad2 4336 HWC-i (high efficiency CsI) for Aluminum, Titanium and Inconel measured with 3 frames per second.

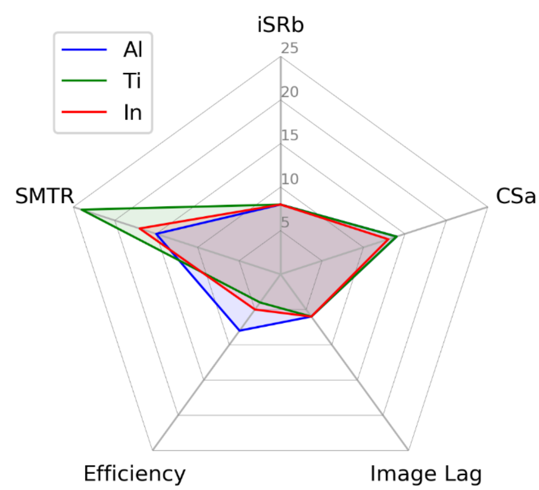

Figure 8. ASTM Spider charts of the XRpad2 4336 HWN-i (DRZ Plus) for Aluminum, Titanium and Inconel measured with 3 frames per second.

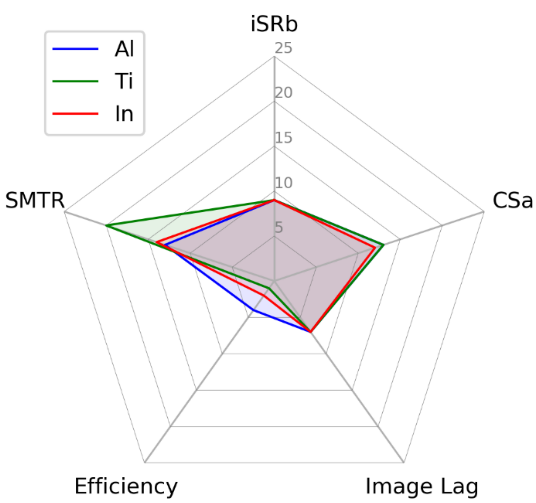

Figure 7. ASTM Spider charts of the XRpad2 4336 HWJ-i (DRZ Fine) for Aluminum, Titanium and Inconel measured with 3 frames per second.

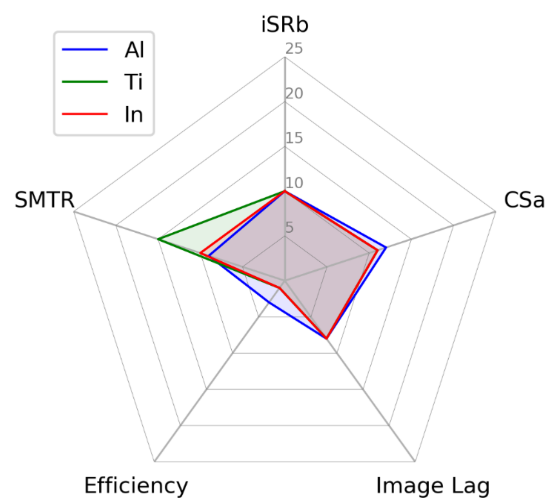

Figure 9. ASTM Spider charts of the XRpad2 3025 HWA-i (high resolution CsI) for Aluminum, Titanium and Inconel measured with 3.7 frames per second.

Conclusion

This study leads to the following main conclusions:

The XRpad2-i detector has a stable response over a wide temperature range from -20 °C to +50 °C. In the case that the device is used at temperatures out of the recommended range of operation, care should be taken to refresh the offset in order to get well corrected images.

The characterization of the XRpad2-i in accordance with the ASTM standard E2597-14 showed that the device exhibits good quality numbers such as the resolution that ranges in the size of the pixel pitch as well the excellent SMTR for Titanium.

The results also show that the XRpad2 HWx-i with DRZ Fine or HR CsI are perfect for the High-Quality ISO 17636-2 Cass B testing and with DRZ Plus and HE CsI for fast Class A testing.

The XRpad2 HWx-i with DRZ Plus or HE CsI are also well perfect for high quality and fast inspection of Corrosion and Deposits in pipes (ISO 20769) with the optional binning function and continuous imaging with up to 9 frames per second.

Results from this study also demonstrate the suitability of Varex Imaging's XRpad2-i X-ray detectors for a wide range of mobile NDT application with its reliability and robustness at a wide temperature range.

The outstanding image quality and high resolution, fast image acquisition, mobility and ease of integration enable X-ray systems manufacturers to optimize their products, and to simplify the task of inspection teams on site.

Acknowledgment

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References

1. ASTM E2597M-14 – Standard Practice for Manufacturing Characterization of Digital Detector Arrays
2. ISO 17636-2, Non-destructive testing of welds - Radiographic testing - Part 2: X- and gamma-ray techniques with digital detectors
3. ISO 20769-1/2, Non-destructive testing — Radiographic inspection of corrosion and deposits in pipes by X- and gamma rays

Unless otherwise specified, Varex Imaging Flat Panel X-ray Detectors are components intended to be integrated into products by X-ray system manufacturers. System manufacturers are responsible for qualifying and validating their products for their intended uses and meeting all applicable regulatory requirements.

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Varex Industrial

USA

HEADQUARTERS
Salt Lake City, UT
P: +1-801-972-5000

Germany
Deutschland AG, Walluf
P: +49-6123-971-300

China
Wuxi, Jiangsu
P: +86 (510) 8820 1652

For a complete listing of our global offices, visit www.vareximaging.com

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