Whitepaper

Fast, high-resolution wide-angle digital breast tomosynthesis with MAMMOMAT B.brilliant

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Content

Introduction

As of today, full-field digital mammography (FFDM) still is the most commonly used imaging modality for breast cancer screening in Europe [1]. While it delivers high-resolution 2D images of the breast in a short time, tissue superimposition remains a challenge in FFDM. Lesions masked by tissue above or underneath it might be invisible and result in false-negative findings. In addition, superimposition of normal fibroglandular tissue in the breast can mimic lesions and lead to false-positive findings. To overcome these limitations, digital breast tomosynthesis (DBT) has been introduced in clinical practice. It provides 3D information on breast tissue by acquiring data at different angles and computing stacks of slice images with reduced tissue overlap. Screening studies have shown higher cancer detection rates using DBT [2,3]. Over the last years, DBT has been becoming a more and more established method in breast imaging, and in the near future it could even replace digital mammography as the breast screening imaging modality of choice [4].

DBT hasn't made 2D images superfluous in breast cancer screening and diagnosis: It's considered faster and easier to compare a time series of 2D images than to scroll through a time series of DBT slices. In particular, 2D images provide an excellent overview and facilitate the detection of right/left asymmetries, microcalcification clusters, and comparisons with prior 2D mammograms. However, combining FFDM as an adjunct to DBT results in a significantly higher overall radiation dose. But dose should be kept as low as reasonably achievable, especially in breast cancer screening. Therefore, Siemens Healthineers developed a 2D synthetic mammogram, Insight 2D, with the intention of providing synthetic, FFDM-like images computed from DBT data sets without additional radiation dose. Using Insight 2D also improves patient comfort by reducing breast compression time compared with examinations that are acquiring both DBT and FFDM images. Studies have shown that DBT plus Insight 2D results overall in superior diagnostic accuracy compared with FFDM alone [5,6] and non-inferior diagnostic accuracy compared with DBT plus FFDM [5], respectively.

Nevertheless, some malignant microcalcifications can be less conspicuous or suspicious on DBT and synthetic mammograms compared with FFDM. The most commonly cited disadvantages of synthetic mammograms in a survey among active members of the Society of Breast Imaging were faulty calcification characterization and decreased overall image quality [7]. Therefore, some centers in the United States where DBT is already implemented in breast cancer screening are continuing to perform DBT plus FFDM, even though their DBT systems have the capability of utilizing 2D synthetic mammography [7].

DBT systems with a wider angular range have significantly higher out-of-plane spatial resolution, and consequently better overcome tissue overlap. In the past, this was at the price of a longer acquisition time. Narrow-angle DBT systems have short acquisition times, but these systems provide images with an intrinsically lower out-of-plane spatial resolution.

To facilitate the paradigm shift of replacing FFDM by DBT plus synthetic mammography in breast cancer screening, Siemens Healthineers developed a next-generation 50° wide-angle DBT system: the MAMMOMAT B.brilliant. MAMMOMAT B.brilliant retains all benefits of wide-angle DBT systems and realizes short acquisition times known from narrow-angle systems. At the same time, it shifts the in-plane resolution of DBT into the high-resolution range of FFDM. To conclude, MAMMOMAT B.brilliant combines the benefits of wide-angle DBT for optimal soft-tissue lesion visibility with unique innovations for higher performance in speed and image sharpness to improve microcalcification visibility.

Design objectives of the next-generation breast tomosynthesis system

Siemens Healthineers' 50° wide-angle DBT is the only breast tomosynthesis technology today that has demonstrated superior cancer detection in screening, while reducing both the overall radiation dose (thanks to using a one-view approach) and compression force as compared with FFDM [2]. Increasing the angular range in DBT effectively results in a higher out-of-plane spatial resolution. Out-of-plane spatial resolution determines how well low-contrast soft-tissue findings, i.e. architectural distortions and masses, can be resolved from overlapping tissue. Reducing overlapping tissue, the main limitation of FFDM, triggered the introduction of DBT in the first place. Therefore, developing a DBT system with a wide angular range became the main design priority for Siemens Healthineers ever since the company produced its first-generation DBT system.

Given the above, the design goals for Siemens Healthineers' next generation DBT system, MAMMOMAT B.brilliant, included:

- Maintaining the wide-angle DBT design that overcomes the main limitation of FFDM – tissue superimposition – for optimal soft-tissue lesion visibility
- Improving microcalcification visibility in DBT and Insight 2D in order to bring the diagnostic performance for detecting microcalcifications close to the performance of FFDM
- Reducing acquisition and breast compression time to reduce the risk of patient movement and improve patient comfort
- Further reducing artifacts in DBT and Insight 2D to minimize the probability of missing information in the areas that are overlapped by artifacts
- Providing a customizable DBT image impression to even better meet the radiologist's preference

This white paper discusses the three technical components that contributed most to these design goals for Siemens Healthineers' next-generation DBT system, MAMMOMAT B.brilliant. First, the clinical benefits of wide-angle DBT are described. Second, the new X-ray tube with a flying focal spot is introduced, and its impact on DBT acquisition time and image quality is explained. Third, the effects of the new reconstruction algorithm in both DBT and Insight 2D on the overall image quality are illustrated.

Wide-angle breast tomosynthesis for optimal soft-tissue lesion visibility

DBT involves multiple projections with a moving X-ray tube acquired across an arc, rather than one single central projection that's acquired with FFDM. In contrast to computed tomography (CT), projections are obtained over a limited angular range. The angular range (⊖) refers to the maximum angle (in degrees) that the X-ray tube moves from first to last projection and varies from 15° (narrow-angle) to 50° (wide-angle) in currently available clinical DBT systems. For an angular range of 50°, the X-ray tube moves from −25° to +25° or vice versa.

Siemens Healthineers made the system design decision that specifically addresses the main limitation of FFDM (tissue superimposition), and the company was the first vendor to introduce 50° wide-angle DBT into the market. The geometrical benefit of a wide-angle DBT acquisition is illustrated in Fig. 1. The outer projections in wide-angle DBT allow for better separation of overlapping breast tissue compared with FFDM and with narrow-angle DBT, where the outer projections are limited regarding the separability of such overlapping structures. As a result, a wider angular range acquires more 3D information on structures in the breast and therefore a more accurate visualization of the true shape and margins of breast lesions (Fig. 2).

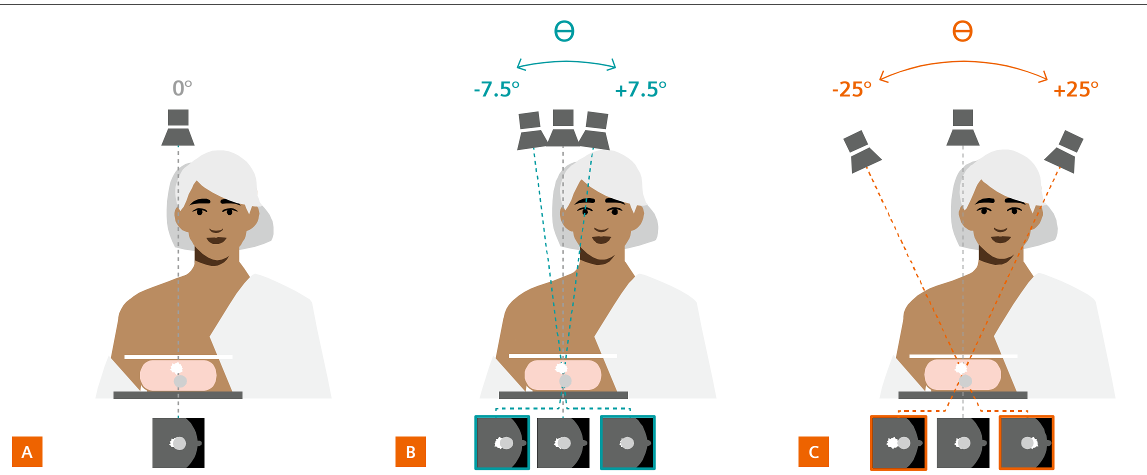

Figure 1: Differences between FFDM (A), narrow-angle DBT (B), and a wide-angle DBT acquisition (C). With narrow-angle DBT, the X-ray tube moves over a 15° angular range (⊖), and the outer projections can't clearly separate the two overlapping structures within the breast. With wide-angle DBT, the X-ray tube moves over a 50° angular range, and the outer projections can separate the overlapping structures much more clearly.

The clinical benefit of a wider angular range can also be explained with a schematic illustration of the frequency domain. In general, because of its limited angular range compared with CT, a DBT acquisition measures a limited number of spatial frequencies along the z-axis (tube-detector direction) in the frequency domain (Fig. 3). For all limited angular ranges (less than 180°), frequencies along the z-axis are better measured at high spatial frequencies along the x-axis than in the low-to-mid spatial frequency range. As a result, larger low-to-mid-frequency structures like masses and fibroglandular tissue are less resolved in the z-direction, while smaller high-frequency structures like microcalcifications are better resolved.

Compared with narrow-angle DBT, higher spatial frequencies along the z-axis are measured using wide-angle DBT, leading to an improved out-of-plane resolution in the z-direction. Especially in the low-to-mid frequency range along the x-axis, where diagnostically relevant soft-tissue lesion and fibroglandular tissue are present, this leads to a relative significant reduction of anatomical overlap in adjacent reconstructed DBT slices across the breast's thickness. In other words, improved out-of-plane resolution reduces anatomical noise originating from breast structures in adjacent slices. This means that with a wider angular range, low-contrast soft-tissue lesions can be better resolved from overlapping dense breast tissue [8,9].

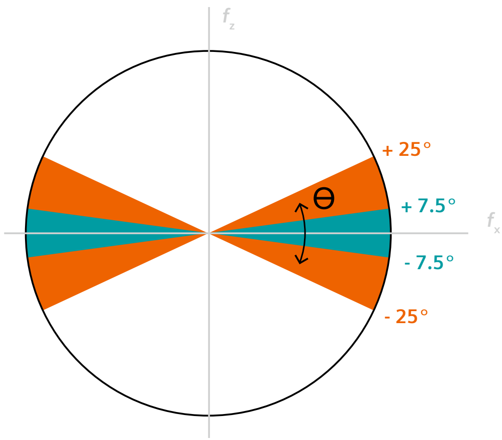

Figure 3: Schematic view of the frequency domain showing the spatial frequencies measured along the z-direction and x-direction with an angular range (Θ) of 15° (petrol) and 50° (orange). Compared with 15° narrow-angle DBT, higher spatial frequencies along the z-axis are measured using 50° wide-angle DBT (indicated by the orange area).

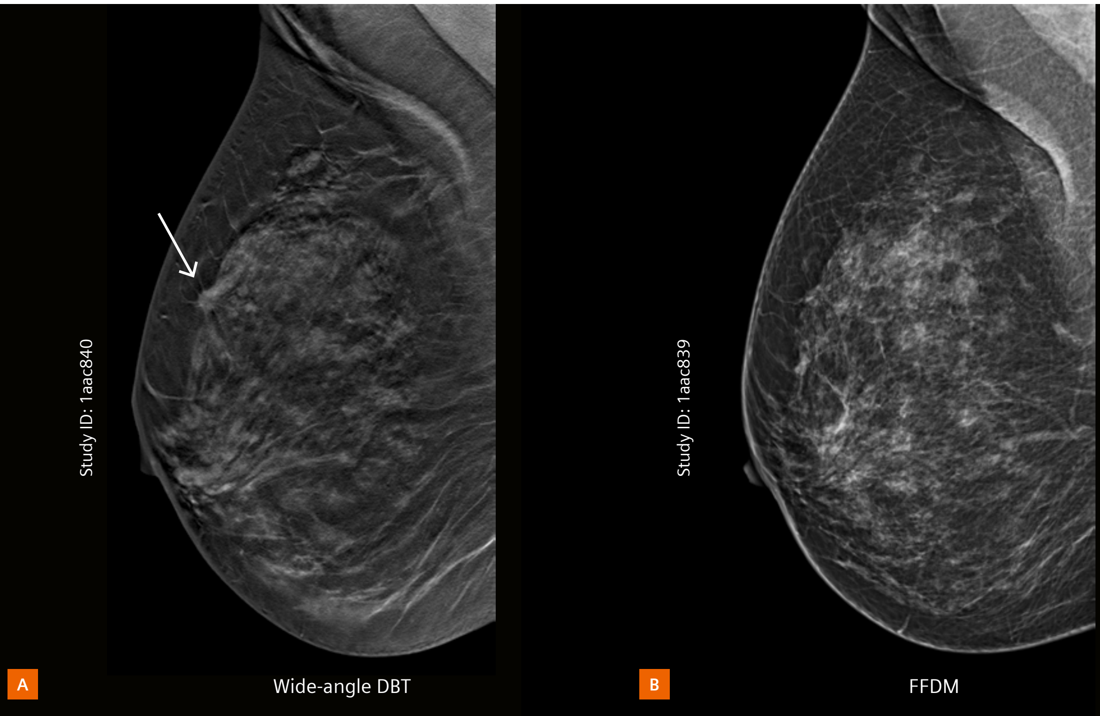

Figure 2: Wide-angle DBT (A) shows a cT1 invasive lobular carcinoma grade 3 in a heterogeneously dense breast. The lesion presented as an architectural distortion is much more conspicuous in wide-angle DBT than in FFDM (B).

Continuous X-ray tube motion with a flying focal spot technology for increased speed and reliable visibility of microcalcifications

Current DBT systems use either continuous tube motion or the step-and-shoot technique. Each concept has its advantages, and each comes with a cost. Continuous tube motion enables a faster acquisition time for tomosynthesis but has the disadvantage of a smeared-out focal spot (in other words, a larger effective focal-spot size) in the direction of the tube movement during the image acquisition. Conversely, the step-and-shoot approach minimizes enlargement of the effective focal spot size. However, the overall acquisition time is longer due to mechanical limitations, as the acquisition should ideally start after the oscillations of the swivel arm, which are produced by the fast acceleration, have completely declined.

The MAMMOMAT B.brilliant system utilizes Siemens Healthineers' newest X-ray technology: our unique X-ray tube with a flying focal spot. This cutting-edge innovation enables continuous tube motion with a twofold clinical benefit (Table 1). First, the focal spot size is held effectively stable with respect to the intrinsic focal spot size of the tube during each projection, leading to a higher in-plane resolution – which is an important system characteristic for detecting and classifying microcalcifications. Second, this concept enables a significantly faster acquisition time, because the effective focal spot size is no longer impacted by the tube's movement speed. Therefore, the tube can move faster, which reduces the risk of artifacts from patient motion and may improve patient comfort.

	Step-and-shoot	Continuous tube motion without a flying focal spot	Continuous tube motion with a flying focal spot technology
Effective focal spot size	Focal spot might only be smeared out by the oscillations of the swivel arm resulting from fast acceleration	Focal spot smeared out in movement direction due to tube movement during the x-ray pulses	Focal spot size is held effectively stable with respect to the intrinsic focal spot size of the tube (similar to FFDM)
Acquisition time*	Slow acquisition	Faster acquisition	Fastest acquisition

Table 1: Tube motion concepts in digital breast tomosynthesis.

* Acquisition time for a predefined number of projections and angular range.

In addition to the system motion concept, there are several important characteristics that impact acquisition time, among them the number of projections, angular range and the angular tube speed. Thanks to its unique tube with a flying focal spot, MAMMOMAT B.brilliant enables a fast, high-resolution 50° wide-angle tomosynthesis acquisition with 25 projections in just 4.85 seconds* [10]. Only in case of very thick and/or extremely dense breasts, measured by the automatic exposure control, an acquisition time of 8.1 seconds is used [11].

In principle, the X-ray tube with a flying focal spot utilizes an electron beam that's accurately deflected by an electromagnetic field. During an X-ray pulse, the focal spot on the anode plate is linearly moved in the opposite direction compared to the tube movement. The focal spot is thus stationary when observed from the outside (Fig. 4). After each X-ray pulse, the focal spot is deflected back to its starting position on the anode. The result, similar to FFDM, is that the effective focal spot size in tomosynthesis is 0.3 according to IEC 60336 [12].

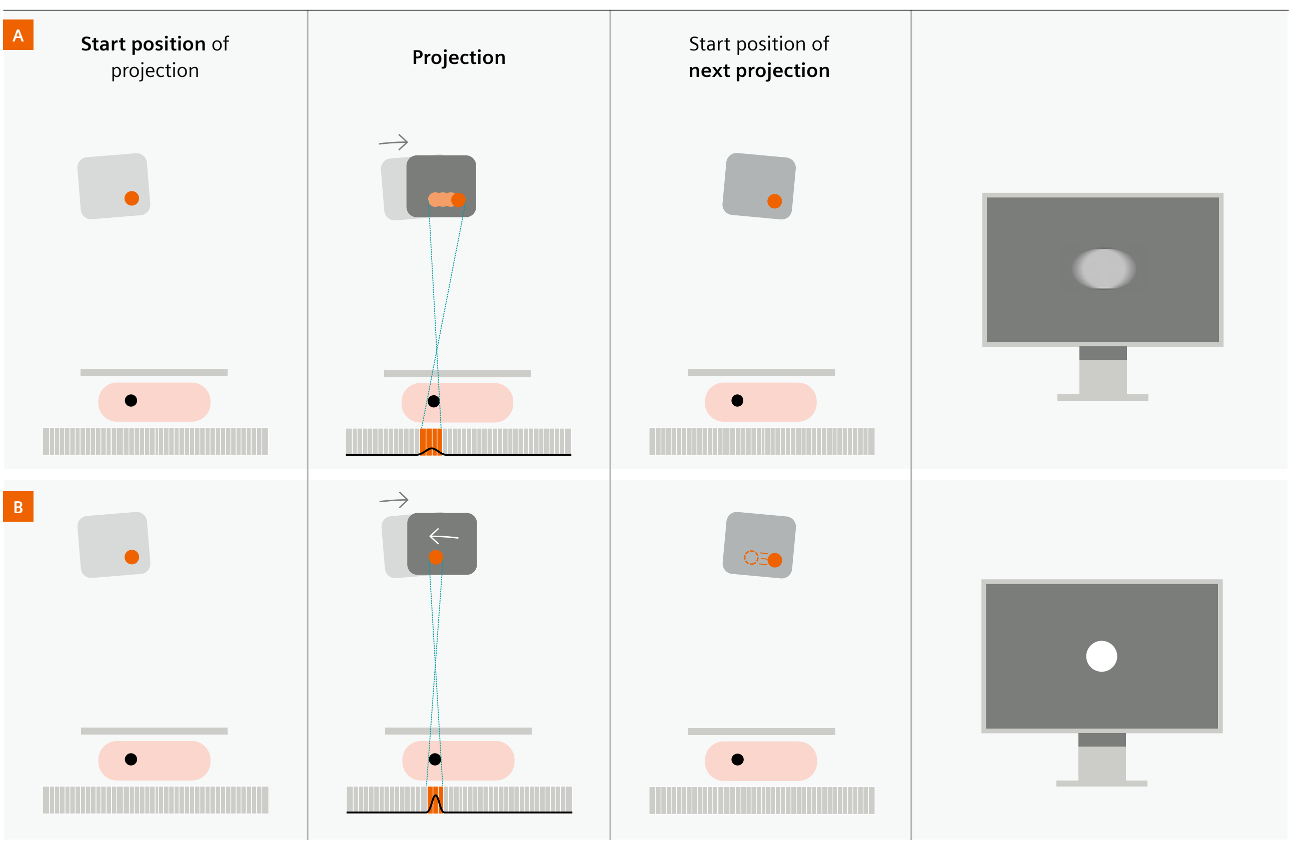

Figure 4: Schematic illustration of the tube and focal spot movement observed from the outside. A) The top row illustrates a projection using continuous tube motion without a flying focal spot. The focal spot size is smeared out in the tube-movement direction, resulting in a blurred visualization of the object. B) Projections using continuous tube motion with a flying focal spot (bottom row) result in a sharper visualization of the object.

* Acquisition time is defined as time from start of first to end of last (25th) projection view.

A smaller effective focal spot size leads to a higher in-plane resolution of each projection view, as measured by the effective Modulation Transfer Function (eMTF). The eMTF is a description of the system's ability to transfer contrast at a specific frequency from the object to the image. A higher eMTF curve represents a higher in-plane resolution, which can be translated in sharper images. Figure 5 shows the averaged eMTF curves that were calculated from the flat field corrected projection images. eMTF curves were calculated by imaging a thin wire positioned at a slight slant (2°) with respect to the perpendicular tube motion direction, at different heights above the breast support table.

The following conclusions can be drawn from these eMTF curves:

- The MAMMOMAT B.brilliant DBT acquisition achieves a similar in-plane resolution as FFDM (Fig. 5A).
- The MAMMOMAT B.brilliant system has a significantly higher in-plane resolution in the tube-movement direction than the wide-angle DBT system with no flying focal spot (i.e., MAMMOMAT Revelation) (Fig. 5B).
- The MAMMOMAT B.brilliant DBT's in-plane resolution in the tube-movement direction degrades less with increasing height above the breast support table compared with the MAMMOMAT Revelation.

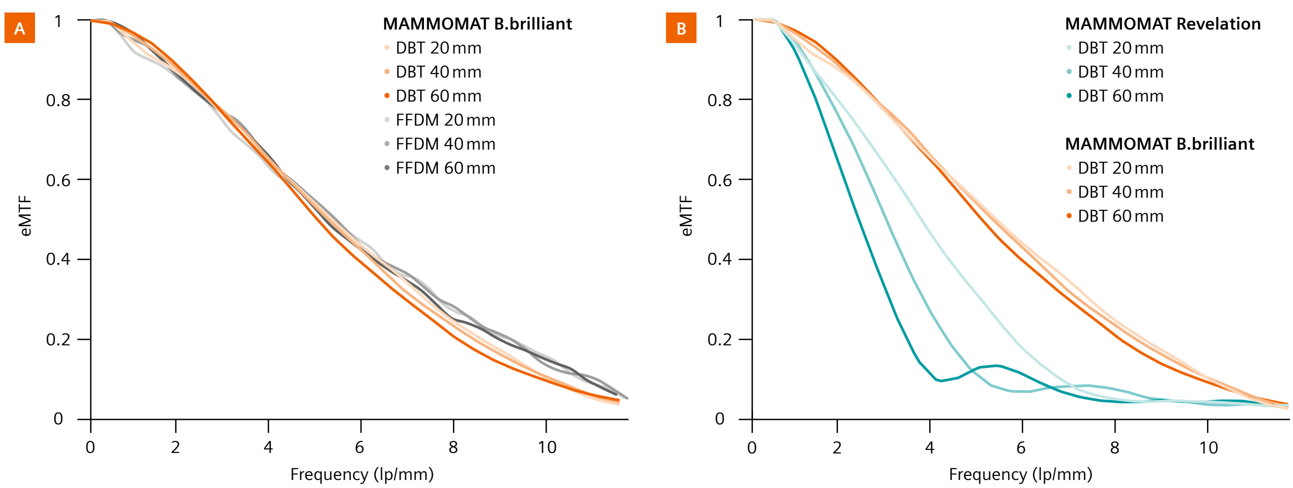

Figure 5: MAMMOMAT B.brilliant DBT eMTF curves, averaged across all 25 projections, in the tube-movement direction using a wire test object positioned at 20, 40, and 60 mm above the breast support table in comparison to FFDM scans (A) and DBT scans on the MAMMOMAT Revelation (B).

New reconstruction algorithm for optimal overall image quality and microcalcification visibility

PREMIA, Siemens Healthineers' third-generation reconstruction algorithm, builds on the previous EMPIRE algorithm, with new components in the reconstruction pipeline that aim to decrease artifacts and noise while enhancing microcalcification visibility.

Improvements in DBT

The new PREMIA reconstruction algorithm essentially relies on three main components. First, image impression, referred to as "flavor", can be adjusted to better integrate into different clinical setups and to even better meet radiologist's preferences. This is achieved by customizing sharpness, contrast and brightness, as well as a suppression of dark-overshoot artifacts. With the suppression of dark-overshoot artifacts, contrast and brightness settings beyond normal Window/Level adjustments are achieved. Similar to FFDM, image impressions in DBT differ among systems from different vendors. Radiologists might prefer the image impression of the DBT system where they were trained or develop a specific preference over time. Figure 6 shows DBT images of the same patient scanned on the MAMMOMAT Revelation using EMPIRE and on the MAMMOMAT B.brilliant using the new PREMIA reconstruction with less (flavor 0) and more (flavor 1) contrast.

Second, PREMIA features an advanced artifact reduction as illustrated in figure 6. Highly attenuating larger objects (like biopsy markers, surgical clips, wires, macrocalcifications, and needles) produce two different kinds of artifacts in DBT reconstructions. First, in-plane artifacts result in dark shadows in slices where the object is in focus. Second, out-of-plane artifacts result in bright traces of the object in adjacent slices where the object is out of focus. The high attenuating object overlaps the tissue inside the shadow for some of the acquired projections, which leads to areas with inconsistent object and non-object pixels in the different projection angles. Both artifacts are reduced by precisely segmenting these objects from the projection views followed by a special treatment of these objects within the reconstruction process [13].

As third component, a domain-specific noise filter is implemented in PREMIA to generate a more natural noise pattern, while maintaining visibility of microcalcifications in the DBT reconstruction.

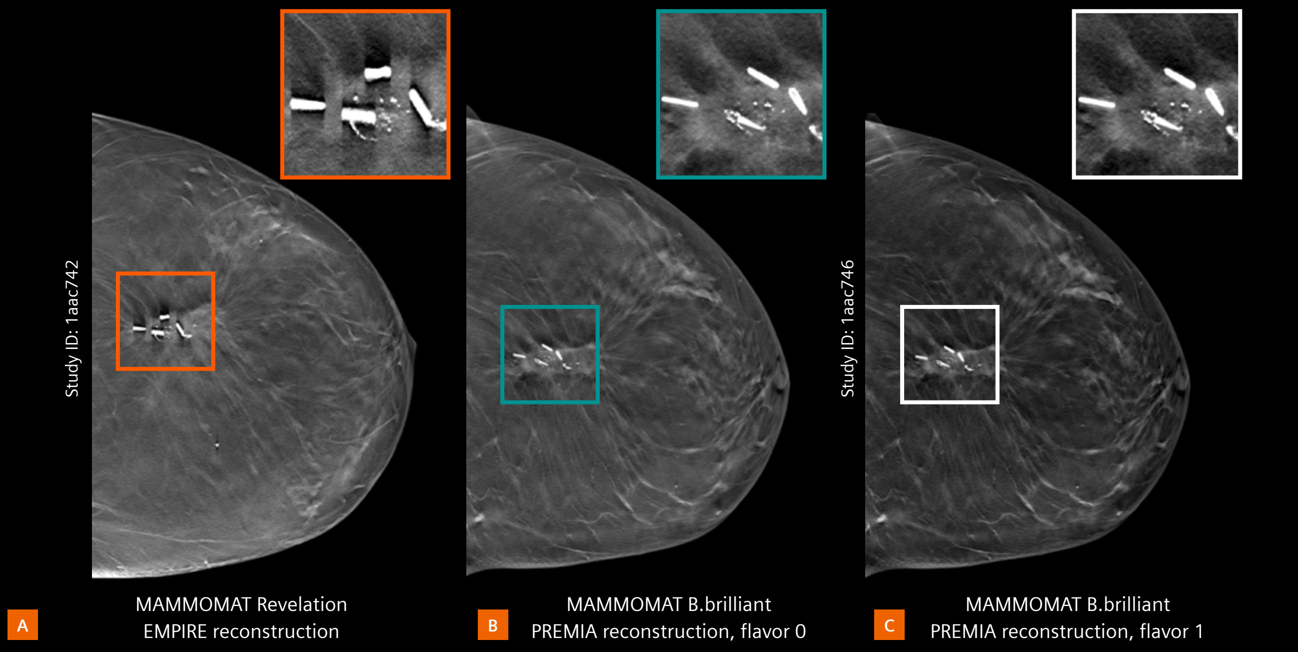

Figure 6: Woman with multiple clips in left breast after surgery had a DBT scan on the MAMMOMAT Revelation with the EMPIRE reconstruction algorithm (A). Two years later, the woman had a DBT scan on the MAMMOMAT B.brilliant with the PREMIA reconstruction. The metal artifacts (caused by the four clips) are significantly reduced in the DBT slices thanks to the advanced artifact reduction algorithm. The PREMIA algorithm also allows image parameters to be adjusted, including "contrast and brightness". The same DBT image is displayed with a lower "contrast and brightness" setting (flavor 0, B) and a higher "contrast and brightness" setting (flavor 1, C).

Improvements in the synthetic mammogram (Insight 2D)

Similar to DBT, Insight 2D also benefits from the unique X-ray tube with a flying focal spot and advanced artifact reduction. The use of the domain-specific noise filter in Insight 2D is a further measure to improve the visibility of microcalcifications. In addition, an AI-based denoising algorithm is implemented in Insight 2D to achieve a more natural image background [14]. A breast specimen was scanned to illustrate the improvements in image quality of Insight 2D with all these innovative components combined (Fig. 7). Figure 8 shows microcalcifications as seen in FFDM and Insight 2D from the same clinical case.

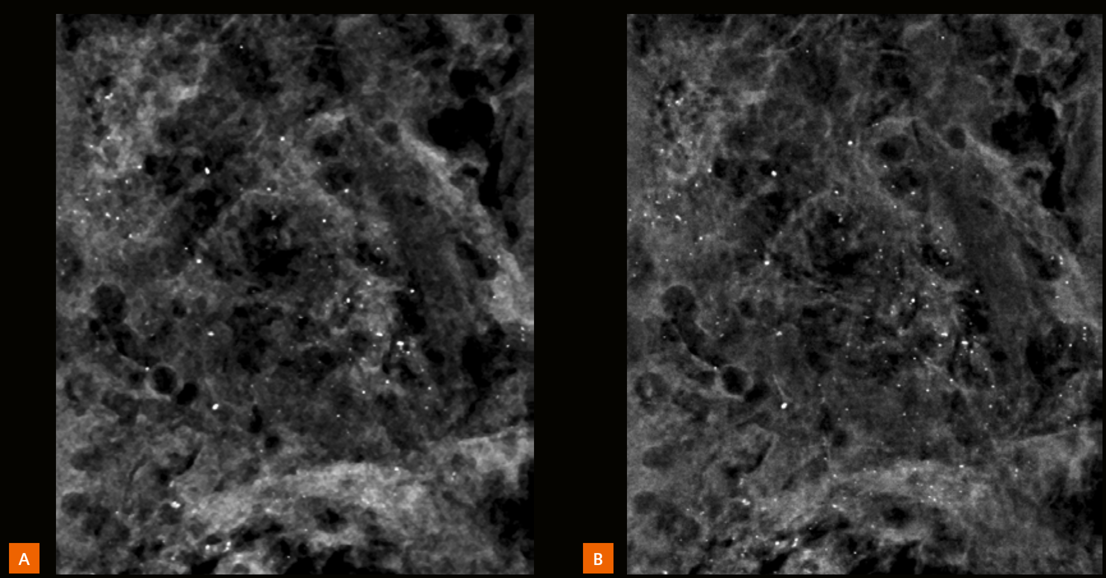

Figure 7: Synthetic mammogram images (Insight 2D) acquired using a 56-mm-thick breast specimen, with calcifications distributed at a 25 to 40-mm height above the breast support table, on both the MAMMOMAT Revelation (A) and the MAMMOMAT B.brilliant system (B). The new Insight 2D (B) visualizes the microcalcifications with greater conspicuity, with similar glandular dose, than the former Insight 2D (A).

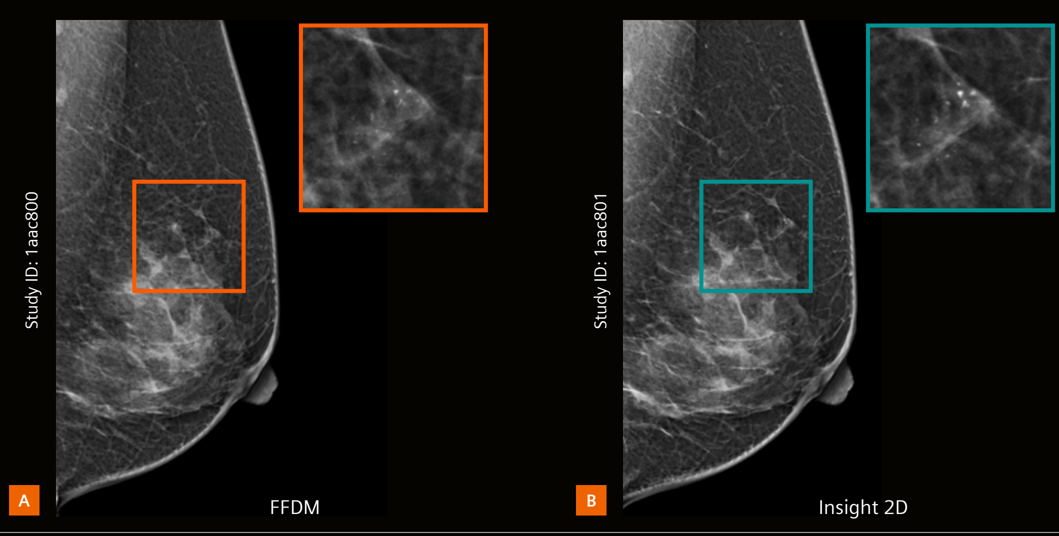

Figure 8: Clinical case with benign dystrophic microcalcifications seen on FFDM (A) and Insight 2D (B).

Summary

This white paper describes the design goals and technical solutions of Siemens Healthineers' next-generation DBT system, MAMMOMAT B.brilliant (Table 2). MAMMOMAT B.brilliant is a fast, high-resolution 50° wide-angle digital breast tomosynthesis system. Although the DBT acquisition consists of 25 projections, MAMMOMAT B.brilliant enables an acquisition time of as low as 4.85 seconds [10]. The focal spot size is also held effectively stable with respect to the intrinsic focal spot size of the tube thanks to the unique X-ray tube with a flying focal spot. This innovation leads to a higher image sharpness to improve the visibility of microcalcifications. To conclude, the new PREMIA reconstruction pipeline provides customizable DBT image impression configurations to match the image impression to the preference of the radiologist.

Design goals	Technical solution in MAMMOMAT B.brilliant
Maintaining the wide-angle DBT design that overcomes the main limitation of FFDM, tissue superimposition, for optimal soft-tissue lesion visibility	50° wide-angle DBT with 25 projections
Improving microcalcification visibility in DBT and Insight 2D in order to bring the diagnostic performance for detecting microcalcifications close to the performance of FFDM	New X-ray tube with a flying focal spot for very high in-plane resolution New reconstruction pipeline (PREMIA) for optimal microcalcification visibility
Reducing acquisition and breast compression time to reduce the risk of patient movement and improve patient comfort	A fast continuous X-ray tube motion with a flying focal spot enabling DBT acquisitions as low as 4.85 seconds [10]
Further reducing artifacts in DBT and Insight 2D to minimize the probability of missing information in the areas that are overlapped by artifacts	New reconstruction pipeline (PREMIA) with an advanced artifact reduction algorithm
Providing a customizable DBT image impression to even better meet the radiologist's preference	New reconstruction pipeline (PREMIA) with sharpness, contrast and brightness and suppression of dark-overshoot artifacts as adjustable parameters

Table 2: MAMMOMAT B.brilliant design goals with corresponding technical solutions

Glossary

CT	Computed Tomography
DBT	Digital Breast Tomosynthesis
eMTF	Effective Modulation Transfer Function
FFDM	Full-Field Digital Mammography
IEC	International Electrotechnical Commission
Insight 2D	Synthetic mammogram

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