# Tunable Monochromatic Hard X-Ray CT Device by X-band Linear Accelerator and Laser

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## 1. Introduction

Compton scattering hard X-ray source for 10~80keV are under construction using the X-band (11.424GHz) electron linear accelerator and YAG laser at Nuclear Engineering Research laboratory, University of Tokyo. This work is a part of the national project on the development of advanced compact medical accelerators in Japan. National Institute for Radiological Science is the host institute and University of Tokyo and High Energy Accelerator Development Organization (KEK) are working for the X-ray source. Main advantage is to produce tunable monochromatic hard (10-80 keV) X-rays with the intensities of $10^{8\text{-}10}$ photons/s (at several stages) and the tabletop size. Second important aspect is to reduce noise radiation at the beam dump by adopting the deceleration of electrons after the Compton scattering. This realizes one beam line of a 3rd generation synchrotron radiation source at small facilities without heavy shielding. The final goal is that the linac and laser are installed on the moving gantry. This device enables the tunable monochromatic X-ray CT and the dual energy X-ray imaging to determine the 3D distributions of the electron density and equivalent atomic number. This supplies real physical information to diagnosis and curative program. The system that enables both the diagnosis and therapy is also under design. The application plans to be performed by the collaboration with the department of radiology of the University of Tokyo Hospital. Updated results of the development and application plan are presented.

## 2. Compact Hard Tunable X-ray Source

*2.1 Conceptual design of the hard X-ray source*

Compact hard X-ray source we have proposed [4, 5] is based on laser-electron collision by the X-band linac with a thermionic-cathode RF-gun and a commercial Nd:YAG laser as shown in Figure 1. The RF-gun is collimated and compressed temporally by a alpha-magnet and accelerated by an X-band accelerating structure. The electron beam is bent by achromatic bends and focused at the collision point(C. P.). About 10 ns hard X-ray is generated via Compton scattering. After the collision, the electron beam is bent and decelerated by the X-band decelerating structure. The decelerated electron beam with the energy is lower than 1 MeV is injected to a beam dump.

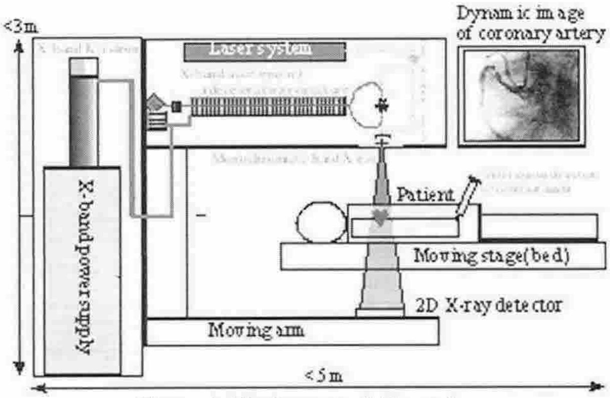


Figure 1. Final target of this study.

*2.2 X-band beam line for proof-of-principle experiment*

Proof-of-principle experiment for the X-ray source is under performing at UTNL site. The X-band beam-line for the experiment shown in Figure 2 is under construction.

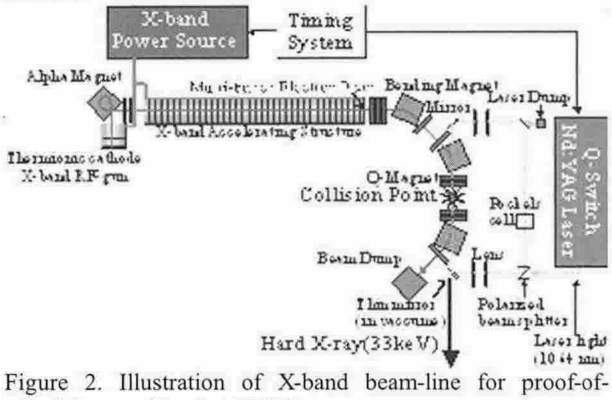


Figure 2. Illustration of X-band beam-line for proof-of-principle experiment at UTNL.

To realize such a compact system, we adopt the Q-switch Nd:YAG laser (Spectra Physics Quanta-ray PRO-350-10) with the intensity(pulse energy) 2.5 J/pulse, the repetition rate 10 pps, the pulse length 10 ns(FWHM), and the wavelength 1064 nm. Commercial Q-switch laser system we have chosen is rather reliable pulse. Multi-bunch electron beam collides with the long laser pulse. One laser pulse can collide with about 200 micro-bunches. In this case, the required timing stability is nanoseconds order. Thus, the combination of the thermionic-cathode RF-gun and Q-switch laser can generate high flux X-ray with intensity of $10^{8}$ photons/s most stably. The maximum field gradient of 40 MV/m of the X-band linac realizes remarkable compactness. The technologies of the X-band accelerating structure developed for future linear colliders[6] at KEK and Stanford Linear Accelerator Center(SLAC) are fully adopted for this development.

*2.3 X-ray characteristics.*

Total X-ray spectrum and angler distribution is shown in Figure 3. The solid line indicates spectrum calculated by the Klein-Nishina's formula and the luminosity calculation. The histogram in (a) shows the result of beam-beam interaction Monte-Carlo simulation code CAIN.9) Maximum X-ray energy is 56 keV at the beam energy 56 MeV.

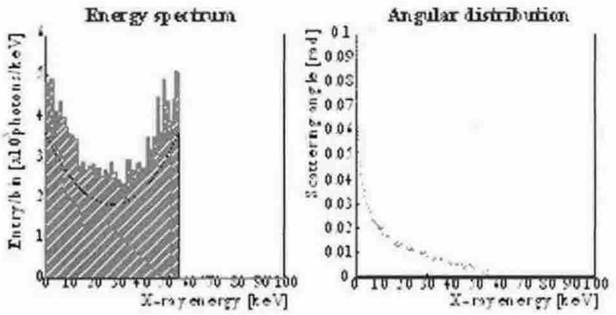


Figure 3. Total X-ray spectrum (a) and angular distribution (b) in single bunch(20 pC/bunch) collision with Q-switch Nd:YAG-laser.

*2.4 X-band RF source*

Important challenge of this study is to generate the stable high power X-band (11.424GHz) RF pulse(50 MW peak power, 1μsec pulse width) of 50 ppm at a compact commercial system. Periodic-Permanent-Magnet (PPM)-type X-band klystron (Toshiba E37681 shown in Figure 4) designed for the linear colliders is used to the RF source. Klystron modulator (power supply) shown in Figure 4 is designed to fit this X-ray source. To realize such a small size of the modulator, high turn ratio (1:32) pulse transformer and low voltage PFN in air are adopted to reduce the clearance of the PFN components with the high output voltage (Vk = 470 kV).

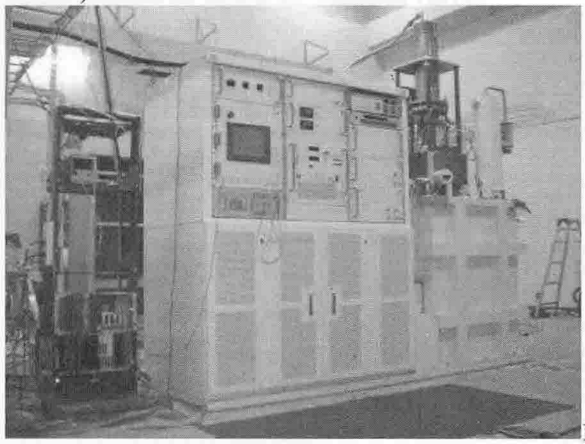

Figure 4. X-band RF source (Modulator and X-band Klystron Toshiba E3768I)

## 3. Conclusion

Compact tunable hard X-ray source based on the X-band linac is under construction. 50 MW X-band RF source for the proof-of-principle experiment is tested and measure. X-ray generation and medical application will be performed in the early next year.

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