Status report of KRISS AUV for the 12th CCAUV meeting

September 2019

Korea Research Institute of Standards and Science (KRISS)
267 Gajeong-ro, Yuseong-gu, Daejeon 34113, Republic of Korea
e-mail: chowanho@kriss.re.kr

1. Organization

The Korea Research Institute of Standards and Science (KRISS) is the National Metrology Institute of the Republic of Korea and a signatory to the CIPM MRA. KRISS has chosen to self-declare the state of its quality system for calibration and measurement services without third-party accreditation.

Currently, each part of AUV group is involved as follows:

- Acoustics in Air: Center for Optical Metrology, Div. of Physical Metrology
  Contact: Dr. Wan-Ho Cho, chowanho@kriss.re.kr

- Ultrasound: Center for Medical Convergence Metrology, Div. of Chemical and Medical Metrology
  Contact: Dr. Yong-Tae Kim, ytkim@kriss.re.kr

- Vibration: Center for Mechanical Metrology, Div. of Physical Metrology
  Contact: Dr. Yong-Bong Lee, lyblyb2@naver.com, lyb@kriss.re.kr

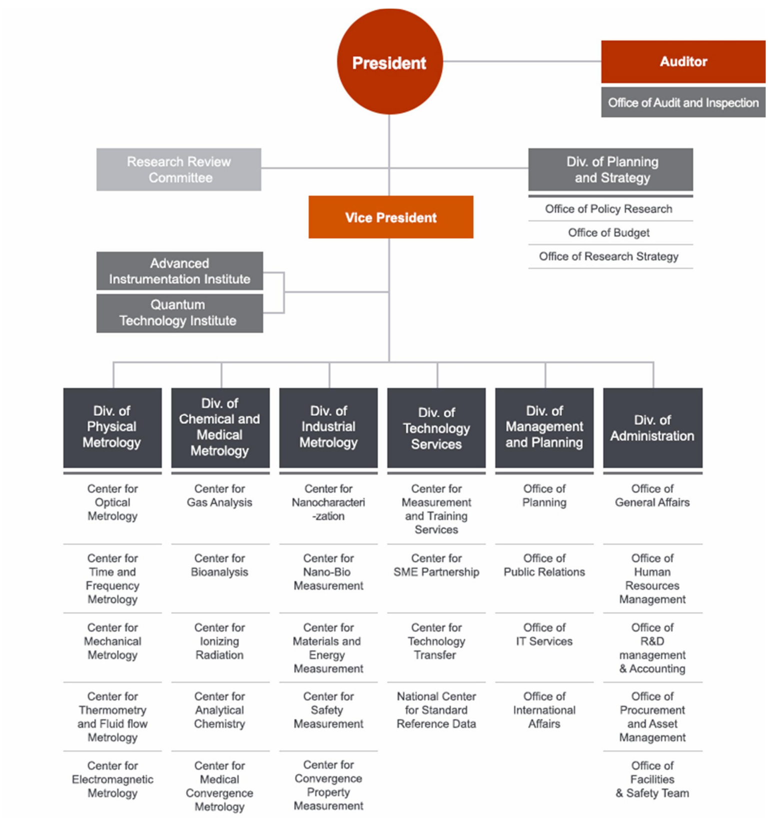

Figure 1 - Organization of KRISS.

2. Activities on the Standards

Key Comparisons

- CCAUV.A-K6

The measurement in KRISS was completed and transferred to the pilot laboratory. The modulus and phase data from 2 Hz to 25 kHz was reported.

- CCAUV.V-K4

The measurement data of KRISS was reported and Draft A was published.

- APMP.AUV.U-K3

KRISS organized the comparison as a pilot laboratory. The measurement data from whole attendances were collected.

3. Research Activities on the Metrology

Acoustics

- Research on the sound measurement by optical method for the future primary standard

Setup of the calibration system based on the optical method for the free-field sound-in-air is conducted as a reference system for research on the new primary standard of sound pressure. For the purpose of comparison with the reciprocity calibration, the system was installed in the small anechoic chamber which is capable to be used as the primary standard system of free-field calibration. The preliminary measurement with the gated-photon correlation method was conducted and the feasibility of system was checked in 2017. The measurement system and signal processing procedure to measure the 0.8 – 16 kHz range were established and the uncertainty evaluation is now on-going. This works was conducted by collaborating with Dr. T. Koukoulas a former principal research scientist at NPL. He joined at KRISS from November 2016 to April 2017 and join again from May 2018.

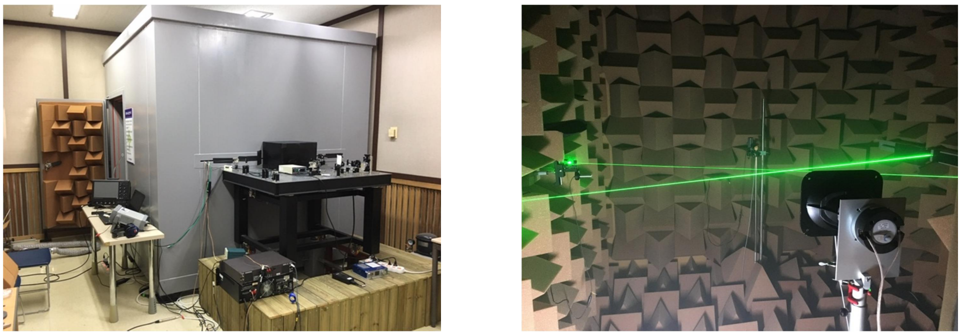

Figure 2 - System for the sound measurement by optical method: (LEFT) anechoic chamber with a light slit, (RIGHT) Optical parts.

- Establishment of the ear simulator calibration system

The system to calibrate the acoustical transfer impedance of ear simulators based on the IEC 60318-1 was established. The basic configuration of system is using the B&K 5998 reciprocity apparatus as shown in Fig. 3. The frequency range is 125 Hz to 8 kHz and the expanded uncertainty was evaluated about 0.3 dB.

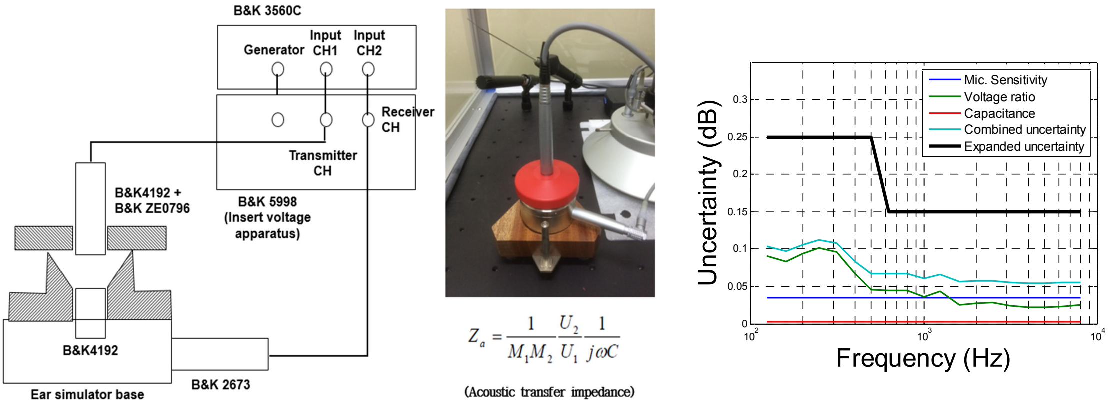

Figure 3 – System for calibrating the 60318-1 ear simulator and its briefly evaluated uncertainty.

- Development of the sensitivity measurement system for LS microphone by measuring the diaphragm vibration

To overcome the existing drawbacks of the reciprocity method, an alternative method based on the measurement of vibration on the surface of a microphone with a laser Doppler vibrometer is proposed to obtain the sensitivity of laboratory-standard microphones. The relationship between the surface velocity of the diaphragm centre and acoustic volume velocity induced by vibration of the diaphragm surface is investigated, and an empirical model is developed by measuring the distribution of the surface velocity. In this work, the empirical model for 1-in laboratory standard microphones is estimated using 6 samples, and the cross validation method based on the leave-one-out scheme revealed that the estimated sensitivity achieved using this model has a difference of about 0.1 dB from the results of the reciprocity.

Figure 4 – System for sensitivity measurement system for LS microphone by measuring the diaphragm vibration.

Ultrasound

The **speed of sound** is an important quantity for ultrasound imaging, and the demand for its traceability is increased in the field of medical imaging. We developed the procedure for the precise measurement of phase speed in medium and established the system which can cover various dimensions of specimen. The frequency range of measurement is 1 MHz – 15 MHz and the expanded uncertainty is 2 % - 4 %. By using the developed system and procedure, we successfully evaluated the phase speeds of commercialized phantom materials along the frequency.

We are also now developing the measurement system for attenuation, which is one of the important quantity to characterize reference materials, such as tissue-mimicking phantoms. We adopted the previous measurement method, which determines the phase speed and thickness of a specimen by calculating the phase spectra of measured signals and evaluate the attenuation by calculating the amplitude spectra. For precise measurement of attenuation, we also considered the corrections for diffraction effects, which are known to induce significant errors in attenuation measurement.

- Thin-film resistance temperature detector (RTD) array

A **thin-film resistance temperature detector (RTD) array** is proposed to measure the temperature distribution inside a phantom. HIFU (high-intensity focused ultrasound) is a non-invasive treatment method using focused ultrasound to heat up a localized region, so it is important to measure the temperature distribution without affecting the ultrasonic field and heat conduction. The present 25 μm thick PI (polyimide) film is transparent not only to an ultrasonic field, because its thickness is much smaller than the wavelength of ultrasound, but also to heat conduction, owing to its negligible thermal mass compared to the phantom. A total of 33 RTDs consisting of Pt resistors and interconnection lines were patterned on a PI substrate using MEMS (microelectromechanical systems) technology, and a polymer phantom was fabricated with the film at the center. The expanded uncertainty of the RTDs was 0.8 K. In the experimental study using a 1 MHz HIFU transducer, the maximum temperature inside the phantom was measured as 70.1 °C just after a HIFU excitation of 6.4 W for 180 s. The time responses of the RTDs at different positions also showed the residual heat transfer inside the phantom after HIFU excitation. HIFU results with the phantom showed that a thin-film RTD array can measure the temperature distribution inside a phantom.

- Acoustic lens

In this study, we report the first experimental realization of an ultrathin (0.14λ, λ = 1.482 mm means wavelength at 1 MHz in the water medium) subwavelength focusing acoustic lens that can surpass the Rayleigh diffraction limit (0.61λ/NA, NA means numerical aperture). It is termed a Super-Oscillatory Acoustic Lens (SOAL), and it operates in the megasonic range. The SOAL represents an interesting feature allowing the achievement of subwavelength focusing without the need to operate in close proximity to the object to be imaged. The optimal layout of the SOAL is obtained by utilizing a systematic design approach, referred to here as topology optimization. To this end, the optimization formulation is newly defined. The optimized SOAL is fabricated using a photo-etching process and its subwavelength focusing performance is verified experimentally via an acoustic intensity measurement system. From these measurements, we found that the proposed optimized SOAL can achieve superior focusing features with a Full Width at Half Maximum (FWHM) of ~0.40λ/NA $\simeq$ 0.84 mm (for our SOAL, NA = 0.707) with the transmission efficiency of 26.5%.

- **Tissue-Mimicking Phantom**

Physiologically relevant phantoms with high reliability are essential for extending the therapeutic applications of high-intensity therapeutic ultrasound. Here we describe a tissue-mimicking phantom capable of quantifying temperature changes and observing non-thermal phenomena by high-intensity therapeutic ultrasound. Using polydiacetylene liposomes, we fabricated agar-based polydiacetylene hydrogel phantoms (PHPs) that not only respond to temperature, but also have acoustic properties similar to those of human liver tissue. The color of PHPs changed from blue to red depending on the temperature in the range 40°C–70°C, where the red/blue ratio of PHP had a good linearity of 99.06% for the temperature changes. Furthermore, repeated high intensity focused ultrasound led to histotripsy on the PHP with liquefied and damaged areas measuring 0.7 and 4.0 cm2, respectively, at the signal generator amplitude setting voltage of 80 mV. Our results indicate not only the usability of the thermochromic phantom, but also its potential for evaluating non-thermal phenomena in various high-intensity focused ultrasound therapies.

- **Lens Performance evaluation**

High frequency ultrasonic focusing transducers have been developed for enhancement of image resolution. Acoustic lenses attaching to an unfocused transducer also have been studied for a long time. Among the various performance parameters of the acoustic lens, focal length is an important performance parameter used in its design together with the refractive index of the lens material. Another important parameter “beam width” at the focal point of the fabricated lens also affects the resolution of the ultrasound image. The spatial distribution of the ultrasound radiation transmitted through the lens plays an important role in determining the possibility of a false image depending on the relative intensity of the side lobe to the main lobe. In this study, we propose the parabolic type polydimethylsiloxane (PDMS) acoustic lenses based on derivation from ray tracing theory of plano-convex spherical lens. The spatial resolution of these lenses were demonstrated by finite element method (simulation using COMSOL Multiphysics software. We examine the focusing performance evaluation of PDMS lenses at 15 MHz ultrasound range using AIMS (Acoustic Intensity Measurement System). From this investigation, some parabolic lenses have been fabricated and tested experimentally by measuring the beam width. Finally, the simulated and measured results were compared.

- **Scanning Ultrasonic Microscopy using Acoustic lens**

Ultrasonic microscopy is a well well-established, and provide provides useful micro scale image or flaw information inside material. It has been used for visualization inside a non-biological and biological material as a non-destructive (NDT) manner. It uses high frequency ultrasound to produce images at near microscopic resolution [1]. Some promising approaches for enhancement of contrast ratio and image quality, i.e. resolution of the scanning acoustic microscopy (SAM) SAM), have been proposed by using the appropriate immersion liquids, particularly, those having the lowest values of the speed of sound and transmission coefficient. A single concave element ultrasonic transducer was currently commercially available for SAM. However, the concave transducer is inconvenient as it requires exchange of transducers according to the focal length. In this study, we developed house-built SAM to evaluate focusing performance of lens. Two different shapes (spherical- and parabolic

parabolic-geometrical form forms) of acoustic lens lenses were designed and fabricated by using polydimethylsiloxane (PDMS). We used a commercial flat circular transducer and commercial concave type focusing transducer, whose nominal frequencies are both 15 MHz. The results showed that the parabolic-geometrical shaped lens has better image of target as compared to the spherical one. As a result, we can acquire a major advantage of the exchangeable lens as the focal length and resolution can easily be controlled with low cost.

- **Measurement of the complex sensitivity of ultrasonic hydrophone using optical method for the primary calibration of membrane hydrophone**

Since the current primary standard for the measurement of the complex sensitivity of the hydrophone only covers the frequency range up to 1 MHz and is hard to be applied to the membrane ultrasonic hydrophone, optical method using interferometry was proposed, which can be extended up to ~ 100 MHz [M. Weber and V. Wilkens, Metrologia **54**(2017), 432-444]. This method measures the displacement induced by the acoustic pressure directly from the optical interferometry and the sensitivity is obtained by the ratio of the recorded voltage by the hydrophone located at the spot where the displacement was measured to the applied acoustic pressure. The detailed equation to determine the complex sensitivity, $\widetilde{M}(f)$, is displayed below. KRISS is now setting up such system for the estimation of the uncertainty in the measurement of the complex sensitivity and, ultimately, for the future primary calibration system of the ultrasonic hydrophone.

$$M(f) = \frac{\widetilde{U}(f)\tilde{F}_{sp}(f)}{\tilde{G}_{scope}(f)} \frac{Z_H(f) + Z_L(f)}{Z_L(f)} \cdot \frac{\tilde{T}(f)\tilde{G}_{vb}\,\tilde{G}_{opt}}{2\pi f\ \tilde{\xi}(f)\rho_w c_w} \cdot V_{rep} \cdot V_z$$

Equation to determine the complex sensitivity where $\tilde{G}_{scope}(f)$ is amplitude response of oscilloscope (or digitizer), $\tilde{F}_{sp}(f)$ is spatial correction factor due to the finite size of the hydrophone, $Z_H(f)$ is source impedance of hydrophone, $Z_L(f)$ is input impedance of the oscilloscope (or digitizer), $\tilde{T}(f)$ is acoustic transmission factor of the pellicle, $\tilde{G}_{vb}$ is frequency response of the interferometry, $\tilde{G}_{opt}$ is influence factor of focusing lens in the interferometry, V_{rep} is the repeatability of the acoustic field between the hydrophone measurement and the interferometry system, and V_z is the change of the acoustic field caused by changing the distance.

Vibration

- **Research on the seismic monitoring system to make it traceable to the national standard system**

Recently, the number of relatively large scale of earthquake higher than magnitude 4.0 has been increased in Korea. From this reason, the interest on the reliability of the seismic monitoring system is also increasing. As a part of the activity to improve the reliability of national monitoring system, KRISS start the project funded by Korea Metrological Administration to make the seismic monitoring system traceable to the national standard system. The detailed objectives of project are like below:

- ✓ Development of very low frequency vibration standard system

- ✓ Selection of essential items for all inspection before installation at monitoring site
- ✓ Development of the calibration process for seismic sensor and data recorder concerning the traceability
- ✓ Revision of the related regulations
- ✓ Suggestion of the education and management plan of secondary calibration laboratory
- ✓ Planning for establishing the national standard system to cover the whole required range for seismic monitoring system

Long stroke shaker is developed. Design stroke is 1,400 mm peak to peak. It can sustain transducer of at least 30 kg. Operating frequency range is 0.01 Hz ~ 50 Hz and the direction of motion is horizontal. Distortion of motion was designed below 0.1 %. Double rail system was adopted to ensure linear motion.

It will be a part of very low frequency vibration standard system with the laser interferometer system later. Laser interferometer system is setting up.

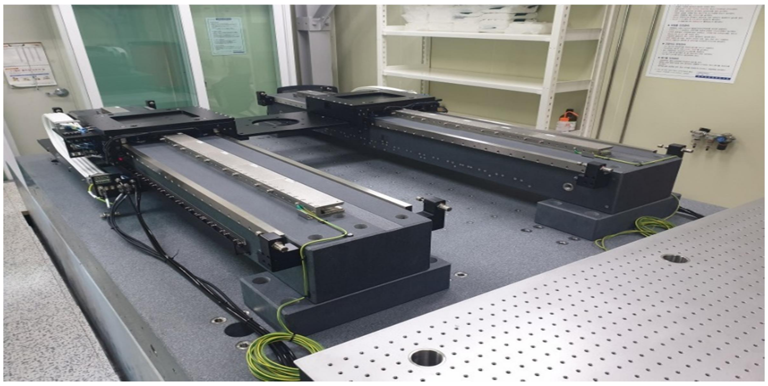

Figure 5 - Long stroke shaker system.

4. Recent Selected Publications (2017-2019)

Journal Papers:

- ✓ W.-H. Cho, T. Koukoulas, "Signal Processing Considerations on the Optical Measuremen t of Acoustic Particle Velocities in Free-field Conditions," Accepted to IEEE Trans. Inst rumentation and Mea., 2019.
- ✓ J.-G. Suh, W.-H. Cho, H.-Y. Kim, Z. Cui, Y. Suzuki, "Sensitivity measurement of a laboratory standard microphone by measuring the diaphragm vibration," App. Acoust., Vol. 143, pp. 38-47, 2019.
- ✓ Y.-B. Lee, W.-H. Cho, B.-S. Jeon, S.-S. Jung, "Evaluation of seismic sensors based on the international standard", KSNVE, 29(1), pp.114-119, 2019.
- ✓ W.-H. Cho, C.-H. Jeong, J.-H. Chang, S.-H. Lee, M.-K. Park, M.-H. Suh, J.-J. Han, "Noise and Room Acoustic Conditions in a Tertiary Referral Hospital, Seoul National University Hospital," J. Audiology Otology, Vol. 23, pp.76-82, 2019.
- ✓ Yong Tae Kim, Donghee Ma, Jai Kyoung Sim, and Se-Hwa Kim, 'Simultaneous Evaluation of Thermal and Non-Thermal Effects of High-Intensity Focused Ultrasound on a tissue-Mimicking Phantom," Ultrasound in Med. & Biol., Vol. 44, No. 8, pp. 1799–1809, 2018.
- ✓ Jaeyub Hyun, Yong Tae Kim, Il Doh, Bongyoung Ahn, Kyungmin Baik & Se-Hwa Kim, "Realization of an ultrathin acoustic lens for subwavelength focusing in the megasonic range," Scientific reports. 8:1, pp. 1-12, 2018.
- ✓ Hunki Lee, Myungki Jung, Minsoo Kim, Ryung Shin, Shinill Kang, Won-Suk Ohm, and, Yong Tae Kim, "Acoustically sticky topographic metasurfaces for underwater sound absorption," J. Acoust. Soc. Am. 143 (3), pp. 1534-1547, 2018.
- ✓ Jai Kyoung Sim, Jaeyub Hyun, Il Doh, Bongyoung Ahn and Yong Tae Kim, "Thin-film resistance temperature detector array for the measurement of temperature distribution inside a phantom," Metrologia, Vol. 55, pp. L5-L11, 2018.
- ✓ J.-W. Lee, W.-S. Ohm, and Y.-T. Kim, "Development of disposable membrane hydrophones for a frequency range from 1 MHz to 10 MHz," Ultrasonics, Vol. 81, pp. 50-58, 2017.
- ✓ S. Chun, J. Jin, and W.-H. Cho, "Construction of the prediction model between pressure and flow rate for pulsating flows based on the Greenfield-Fry model concerning wave dispersion," Experiments in Fluids, Vol. 58:37, 2017.

Conference Papers:

- ✓ T. Koukoulas, W.-H. Cho, "Acoustical metrology in the new SI framework," Proc. of Fall Meeting of Acoust. Soc. Japan, September 2019, Shiga, Japan.
- ✓ W.-H. Cho, T. Koukoulas, "Development of the calibration system for sound-in-air by the photon correlation," Proc. of Fall Meeting of Acoust. Soc. Japan, September 2019, Shiga, Japan.
- ✓ T. Koukoulas, W.-H. Cho, "Signal processing and environmental considerations in the de finition of the acoustic pascal using optics," Proc. of ICSV 26, July 2019, Montreal, Cana da.

- ✓ T. Koukoulas, W.-H. Cho, L. He, P. Yang, “Review of optical methods and the transitio n from a classical to quantum framework in acoustics,” Proc. of ICSV 26, July 2019, Montreal, Canada.
- ✓ Jaeyub Hyun, Hyungjin Lee. Il DOh, Kyungmin Baik, Sehwa Kim , and Yong Tae Kim, “Megasonic super-focusing based on the piezoelectric transducer with optimized electrode pattern,” Proc. of Acoust. Soc. Korea , April 2018, Jeju, Korea
- ✓ Jaeyub Hyun , Yong Tae Kim, Il Doh , Hyungjin Lee, Kyungmin Baik and Sehwa Kim, “Optimization of Electrode Pattern of Piezoelectric Transducer for Super Focusing in the Megasonic Range,” Proc. of Acoust. Soc. Korea , April 2018, Jeju, Korea
- ✓ Kyungmin BAIK, Yong Tae KIM, Hyung-Jin LEE , Se-Hwa KIM , Jaeyub HYUN, “Design of Subsonic Soft Material Ultrasonic Lens Using Ray Approach,” Proc. of Acoust. Soc. Korea , Nov. 2018, Gangneung, Korea
- ✓ Jaeyub Hyun, Hyungjin Lee, Il DOh, Kyungmin Baik, and Sehwa Kim, Yong Tae Kim Kim, “Systematic design of a high-frequency planar acoustic lens for subwavelength focusing based on the hybrid finite element-boundary integral approach,” Proc. of Acoust. Soc. Korea , Nov. 2018, Gangneung, Korea
- ✓ Nurhalawa Md YUSOF, Jaeyub HYUN, and Yong Tae KIM, “Focusing Performance Evaluation of PDMS Acoustic Lenses By Aims (Acoustic Intensity Measurement System),” Proc. of Acoust. Soc. Korea , Nov. 2018, Gangneung, Korea
- ✓ Nurhalawa Md YUSOF, Jaeyub HYUN, and Yong Tae KIM, “Acoustic Property Measurement of PDMS Materials For Acoustic Lenses,” Proc. of Acoust. Soc. Korea , Nov. 2018, Gangneung, Korea
- ✓ Nafra Mohamad Samiudin, Il Doh, and Yong Tae KIM, “Image Scanning by Using Acoustic Lens,” Proc. of Acoust. Soc. Korea , Nov. 2018, Gangneung, Korea
- ✓ W.-H. Cho, H.-S. Kwon, and J.-H. Chang, “Comparison of the methods to calibrate the diffuse field sensitivity of laboratory standard microphone,” Proc. of the 24th International Congress on Sound and Vibration, July 2017, London, UK.
- ✓ J. K. Sim, I. Doh, and Y. T. Kim, “A Wearable Force Regulator for Reducing the Contact Force Effect on Photoplethysmographic Signals”, EMBC2017, Jeju, Korea, 2017
- ✓ J. Hyun, Y. T. Kim, I. Doh, B. Ahn, “Finite element analysis of temperature rise induced by the high-intensity focused ultrasound (HIFU)”, 2017 Joint Conference by KSNVE, ASK, and KSME (DC).
- ✓ Y. T. Kim and B. Ahn, “Measurement of High Ultrasound Power by Radiation Force Balance Method”, 2017 Joint Conference by KSNVE, ASK, and KSME (DC).
- ✓ J. Hyun, Y. T. Kim, I. Doh, B. Ahn, K. Baik, and S. Kim, “Topological optimization of the planar ultrasonic acoustic lens for focusing acoustic energy”, 2017 Joint Conference by KSNVE, ASK, and KSME (DC)
- ✓ D. Ma, Y. T. Kim and S.-W. Kim, “Temperature-Responsive Tissue Mimicking Phantom for High Intensity Focused Ultrasound Therapy”, KSUM (Korean Society of Ultrasound in Medicine) open 2017