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Airborne Doppler transceiver designs for external urodynamics study with drip proof aperture : comparison in between airborne ultrasound and millimeter wave Doppler systems

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ABSTRACT: We devised K-band (24GHz, 12.5mm) microwave and 40KHz (8mm) airborne ultrasound CW-Doppler systems to monitor and measure variety of moving target investigation in biomedical research fields. The major application, but not limited to, is measurement of urea flow running in air (external urodynamics study). The Doppler method makes an alternative new method for unconstrained, natural urodynamics study for urology. Other than urodynamics study the devices can take up interesting Doppler signals from human and small animal and natural phenomena activities such as body and limb movements, aspiration/respiration air jet, running water droplets including rain, and bicycle to ground speed, etc. Both of the devices are wearable, finger-mount style. Observation of Doppler spectrum of running urea gives diagnostic information almost compatible to conventional mess-cup type uroflow meter/recorder. Here microwave and ultrasound systems are application compatible including signal processing and measurement, except very specific case dependent to physics of each method. Unlike our old days study (3) where Gunn diode oscillator based microwave Doppler unit was so expensive and power consuming, today, they are easily devised by single transistor oscillator single diode detector, with comparable cost, size and power requirements. Some of selected Doppler signals and their analyses, out from biological activities of human and small animals will be shown.

KEYWORDS: urodynamics, microwave, airborne ultrasound, CW-Doppler, wearable device,

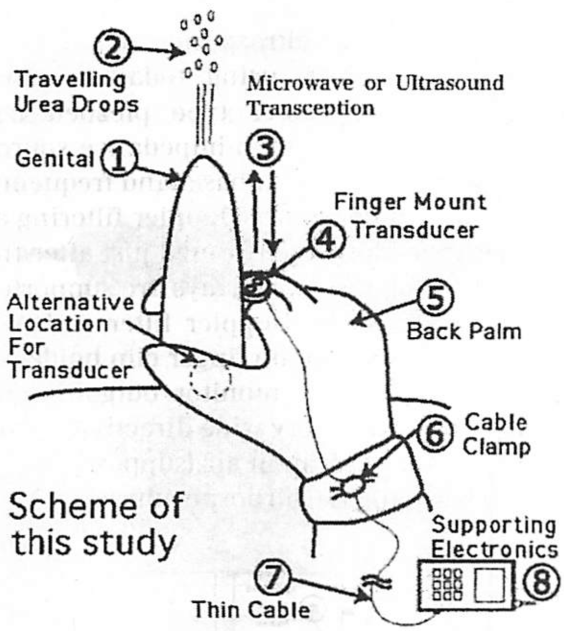


Fig.1. The scheme of our airborne ultrasound Doppler urodynamics measuring system. The mostly key feature is patient finger mounted wearable front-end system including transducer.

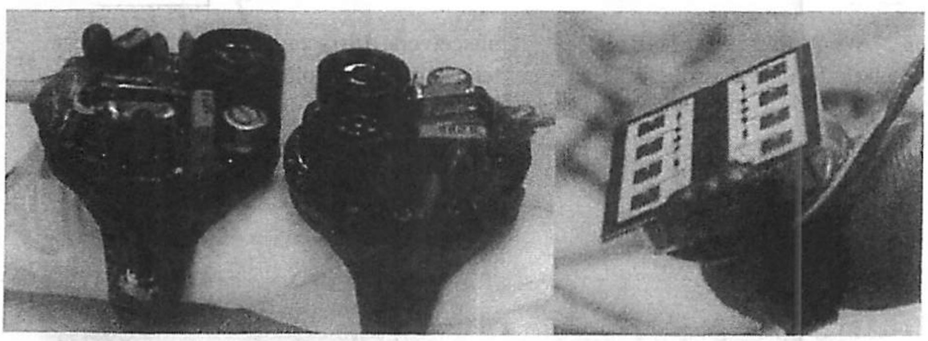


Fig.2: Our prototype finger mount Doppler units. 40KHz airborne ultrasound (left) and K-band (24GHz) version (right).

1. Background of the study

In urodynamics study (1a,b), measurements are made on storage phase, voiding reflex, vesical pressure, flow rate during voiding as time-serial flow pattern, and total voiding volume are made. As an external, non-invasive measurement of such pattern typically employs a reception cup, or some setup like a toilet device(s) together with necessary sensors coupled thereon. Unlike such toilet-borne equipment and measurement philosophy we devised a patient born, independent, light-weighted small equipment to perform such measurement at patient's own conduction. We use finger-tip mounted CW-Doppler devices to realize our concept. in 40KHz airborne ultrasound (2) and 24GHz microwave. Both of our prototype devices are application compatible and successfully yielded the Doppler spectrum of urinary flow representing its instantaneous flow rate and flow pattern. Our scheme is given in fig.1.

2. Methods and Equipments

Like our prior work (3) we again made 40KHz airborne ultrasound and 24GHz electromagnetic wave Doppler systems in comparison, hwever, using today-available state-of-art component. For airborne ultrasound resonant chamber type piezoelectric transducer (4) is used as transmitter as well as receiver, driven by high-impedance source beside detecting its terminal voltage to yield Doppler echo component at baseband frequency. A single stage low noise audiofrequency amplifier follows via necessary Doppler filtering as a smoothing (high-cut) and low-cut (dc-cut) filter. A/D conversion is performed just after the amplifier. For K-band system transmitting and receiving patch antenna arrays are supported by HEMT oscillator and homodyne diode mixer, followed also by Doppler filter and A/D converter in similar way. The antenna or transducer pair is mounted on finger clip holder as shown in fig.1. The sensing beams are normally to the finger to monitor outgoing and incoming echogenic targets dorsal to the finger. Both system have very wide directivity, -3dB cone angle more than 60 degree. Since the echogenicity of urea drop in air (supposed size 1 to 2mm) for K-band (24GHz, λ=12.5mm) microwave and 40KHz airborne ultrasound (λ

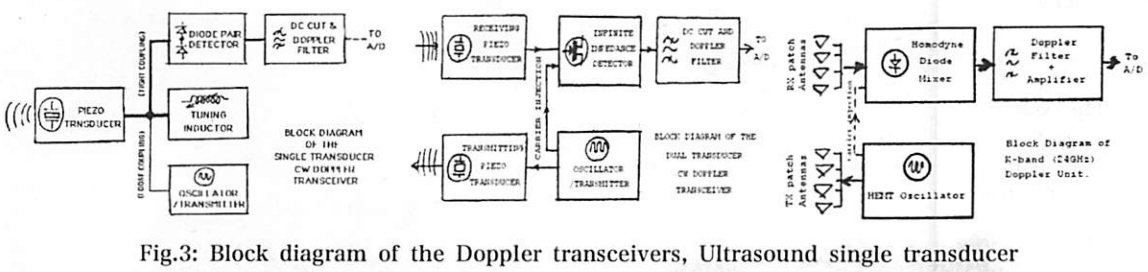


Fig.3: Block diagram of the Doppler transceivers, Ultrasound single transducer model (left), dual transducer model (center), and K-band microwave model (right).

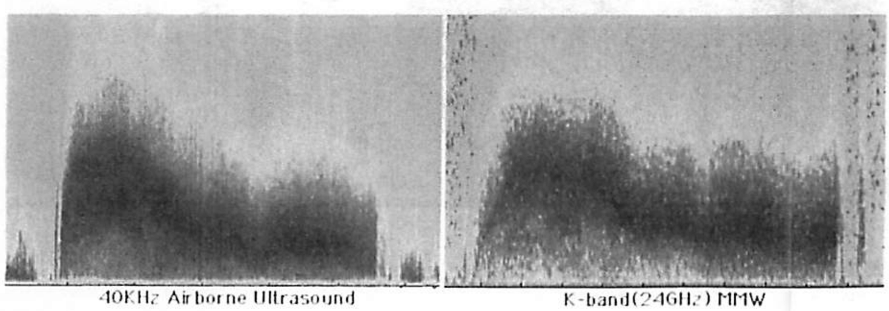


Fig.4 Scale factor matched presentation of Doppler spectrums of typical urination, 40KHz airborne ultrasound (left) and K-band microwave (right). Horizontal axis span is 30 second.

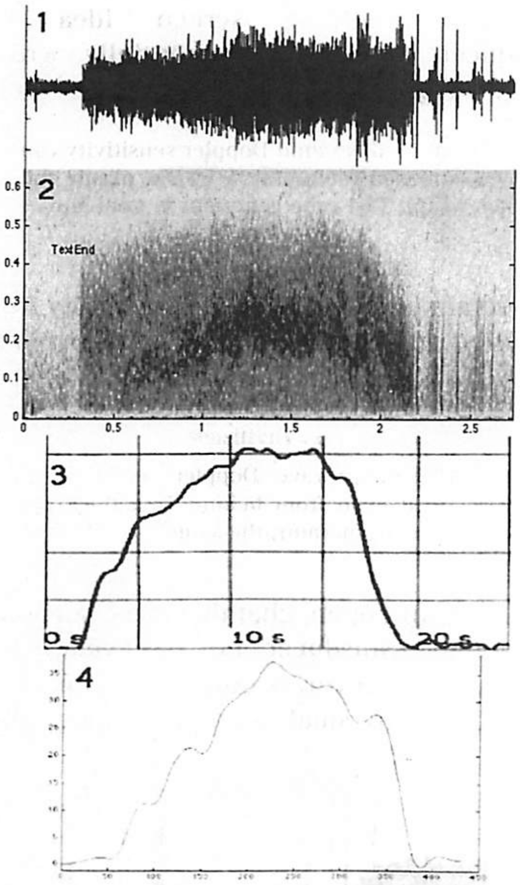
=8.5mm) is sufficiently strong, system sensitivity is quite good. The block diagrams are shown in fig.3. The receiver Doppler filter output is coupled to built-in A/D converter of audio input of a PC (Macintosh). Following stages of signal processing is performed by Matlab-5 for Macintosh final version. Fig.4 shows a typical Doppler spectrums of urination obsedved by the ultrasound and K-band, in side by side conparison. We understand that they are essentially same.

3. Physiological Observation(s)

In fig.5 an example of ultrasound Doppler observation of a 30 years old male urination, where signal waveform, its frequency spectrum and flow rate (uroflow) curve, measured simultaneously by conventional device (5), are shown. It could be said that, although observing different aspect of physics of a phenomenon, the Doppler spectrogram and flow rate curve qualitatively meet well to each other. Further more, spectrum peak (ridge tracking) trace of the Doppler spectrogrm also or even more similar look to the flow rate curve obtained by conventional uroflow device. The short-time averaging nature of flow rate curve and almost completely instantaneous nature of Doppler spectrogram seems one of major reason of discrepancy in visual impression. Fig.6 introduces the spectrum peak track-trace (ridge tracking) process of the Doppler spectrogrm, where smoothed (2D-lowpass filtered) spectrogram image is put to ridge tracking process, while tracked trace is again slightly smoothed for nit still is much noisy and zaggy due to speckle nature of the Doppler spectrogram. The track-trace software was made ad-hoc by building block method using Matlab-5.

4. Interm conclusion and addressing

In this study with device development, the mostly important point is that the sensing and signal processing are performed by patient-born mobile device, not by toilet (or ground) born immobile device. Its feasibility for new style of external urodynamic study or uroflowmetry managed by patient himself (or possibly herself), is proved. Issues left are (a) method to extract



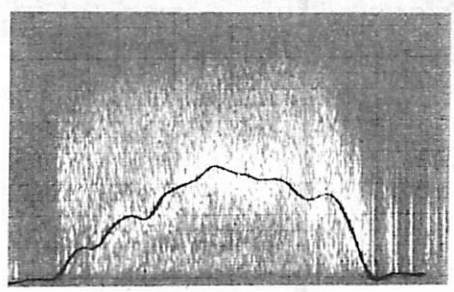


Fig.6 Ridge tracing applied to the Doppler spectrogram. This makes the "4" of fig.5

Fig,.5 An example of synchronous presentation of Doppler signal [1], Doppler spectrogram [2], flow-rate curve [3] by conventional device (5), and spectrum peak (ridge tracking) trace [4] of the Doppler spectrogram, of a voiding process. (see fig. 5 also) Horizontal full scale is 25 sec, vertical full scale of spectrogram corresponds to 700Hz Doppler shift or 2.4m/sec. line-of-sight velocity. Full scale of flow rate is 20mL/sec.

uroflow curve substitute from Doppler signal (with calibration, including transducer directivity), (b) possible noise and/or artifact in this measurement, and (c) trials with variety of patients and environments. These will be addressed in time and reported elsewhere in nearest future.

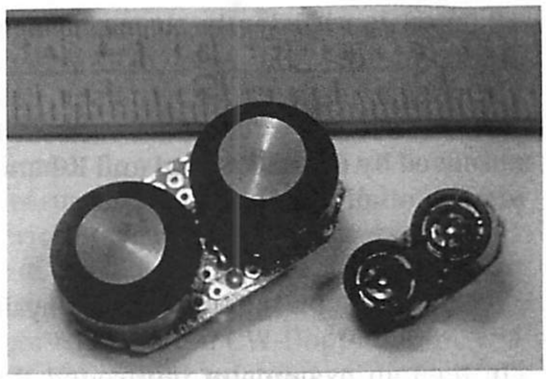


Fig.7: Transmitter-receiver assemblies using closed plastic wall radiator transducers (7) (left) and resonant openchamber transducers (5) (right).

5. Issued for clinical implementation

Since the device is to be used in water rich environment such as toilet, also for sterlization, the device should be of drip-proof design, best if washable, water immersible design. Also, it may get splash of urea when in use. There could be two standpoint of view for this. First the device must withstand splashing and water immersed washing,, and second, device operation (performance) should not be disturbed by splashing, during operation. Like shown in fig.7, we have major two options for transducers, a kind of closed plastic wall radiator transducers (7) and a kind of resonant open chamber transducers (5).

Generally, airborne ultrasound propagation is quite well interfered by very thin, even several micron of plastic (or rubber) foil. So, protective shielding screen idea for transducer assembly is essentially wrong concept. Fig.8 explains this.

Fig.8: Airborne ultrasound Doppler sensitivity can easily be blocked merely by a 10μm plastic foil (kitchen wrap). Test echo generator is mini-fan.

On the other hand, 24GHz (K-band) microwave can retain practical Doppler sensitivity from behind several or more mm thickness of plastic (acrylic) wall or bank of paper. Fig.9 explains this.

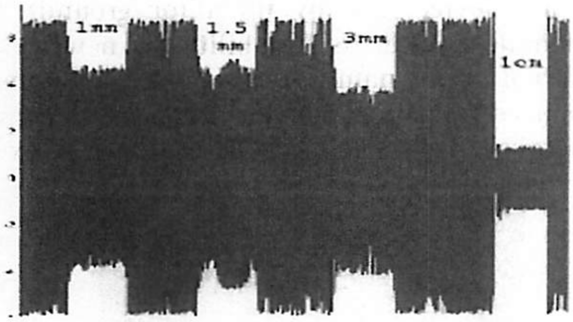


Fig.9. 24GHz microwave Doppler sensitivity can fairly retained even from behind 1cm thick paper bank. Test echo generator, the same.

The resonant open chamber type airborne ultrasound transducer (4) has very good sensitivity, however, is quite prone for water droplet, for any small amount of water stick to resonating radiator. Also, this structure is never good for immersing washing. Fig.10 explains this.

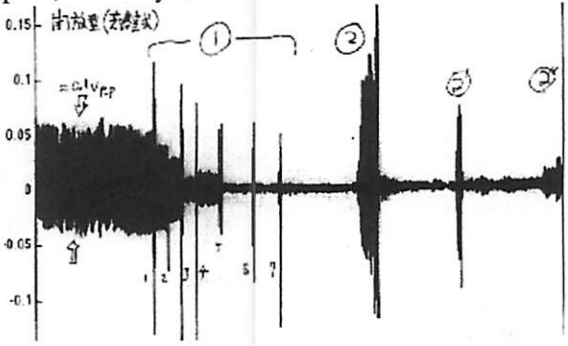


Fig.10: Spraying watery air jet to open resonator type airborne ultrasound transducer jeopardy the sensitivity almost to zero (1). It never comes back by another dry air jet injected there (2),(2'),(2").

The radiating closed-wall type transducer (6) has less optimal coupling to air, hence less (for example -10dB one way) sensitive than resonant open chamber type transducer, however, can survive splashing with reduced, but not zero sensitivity, can also durable for immersing washing. Fig.11 explains this.

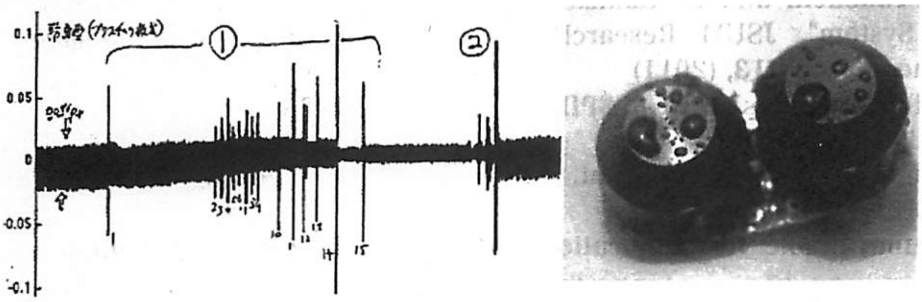


Fig.11: Spraying watery air jet to closed wall type transducer surface causes sensitivity down, but not to "almost zero". (left). Water drop sticks to the radiating surface (right) but not covers all due to hydrophobic nature of radiating wall surface.

On the other hand, mm-thickness plastic (acryl) wall and/or paper bank is well transparent for 24GHz microwave, such Doppler unit (7) can easily mounted inside plastic wall chamber without degrading sensitivity, durable for splashing as well as immersing washing. In this sense microwave or mm-wave Doppler system is definitely superior to airborne ultrasound Doppler system. Fig.12 explains this.

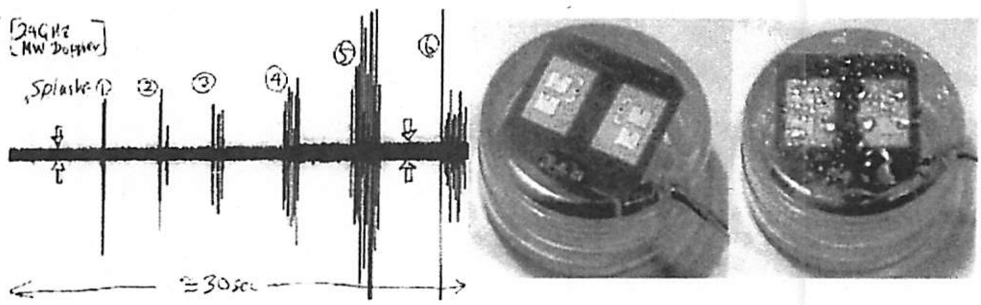


Fig.12: 24GHz microwave Doppler unit can be mounted inside plastic (acrylic, in this case, left)) container with almost no degradation of sensitivity, can also retains sensitivity even with sprayed water drops sticking to its surface (right).

6. Summary and conclusion

In this study following conclusions were obtained, with each experimental evidences.

(1) For Doppler external urodynamics instrumentation, microwave and airborne ultrasound CW-Doppler systems are application-compatible, when their wavelengths in situ are similar and matching for best echogenicity to running urea drop size.

(2) Airborne ultrasound is quite prone for very thin (10 micron) membrane shield while microwave is well transparent for medium thickness (1mm) plastic or paper wall.

(3) Drip or splashing durability of open resonating chamber type 40KHz airborne ultrasound transducer is quite poor, radiating wall type transducer is modest, while microwave (24GHz) antenna set mounted in plastic (t=1mm acrylic) enclosure is very good.

(4) For splash rich environment operation and water immersing washing (sterlization) microwave (or mm-wave) Doppler is far superior to airborne ultrasound Doppler.

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7: References

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(b) http://en.wikipedia.org/wiki/Urodynamic testing

(2) S. Matsumoto, Y. Takeuchi and H. Kakizaki, "Urodynamics Application of Airborne Ultrasound Doppler System", JSUM Research Committee on Basic Technologies in Ultrasonics in Medicine, BT2011-13, (2011)

(3) Y. Takeuchi, 13th IRMMW, session F1.8, SPIE Volume 1039, 1988

(4) Nicera AT40-10BP3 or equivalent.

(5) Medtronics URODYNE(R)-1000, or equivalent.

(6) Nicera PR/PT40-18N or equivalent.

(7) Technical detail unavailable for publication due to non-disclosure agreement with original manufacturer.