A portable infrasound generator

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Abstract: The rotary subwoofer is a novel low frequency transducer capable of efficiently generating infrasound from a compact source. A field-deployable version of this device may find application as a calibration source for infrasound arrays of the International Monitoring System (IMS) [(2001). *The Global Verification Regime and the International Monitoring System* (CTBTO Preparatory Commission Vienna International Centre, Vienna, Austria)]. A prototype tested at the IMS infrasound array I59US demonstrated the ability to insonify all elements of the array from a standoff distance of 3.8 km. Signal-to-noise ratios of continuous wave signals ranged from 5 to 15 dB, indicating the utility of this source to transmit controllable infrasound signals over distances of 5 km.

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1. Introduction

The ability to generate controllable infrasound has presented a technical challenge (Bedard and Georges, 2000); one reason is the mass-dominated radiation impedance found in conventional transduction technologies at very low frequencies. For example, the University of Mississippi designed and built a large horncoupled electropneumatic loudspeaker for the U.S. Army Research Laboratory known as the mobile acoustic source (Neill, 1993). The MOAS is frequently referred to as the "mother of all speakers" and was capable of projecting high intensity sound to frequencies as low as 10 Hz, though it was a large, complex system. Use of conventional loudspeaker technology in an array has demonstrated the ability to project acoustic signals down to frequencies of 8 Hz (Walker *et al.*, 2008), though likely not with sufficient sound pressure levels to be detected over ranges on the order of several kilometers.

Availability of a portable device that could project controllable infrasound detectable at ranges of several or tens of kilometers could find immediate use within the infrasound community. For example, the International Monitoring System (IMS) of the Comprehensive Test Ban Treaty Organization (CTBTO) (2001) operates a world-wide network of infrasound monitoring arrays. A portable, controllable source could enable field calibration and verification of operational arrays. Another important issue to the infrasound community is the evaluation of new sensors and the characterization of noise reduction systems, both of which could benefit from a controllable source. Other potential uses might include a surrogate for explosives that are currently employed to generate signals for testing of tactical explosion localization systems, or as a probe for atmospheric propagation studies.

The Thigpen rotary woofer (TRW) (Eminent Technologies, 2008) is a novel low frequency acoustic transducer capable of projecting controllable infrasound from a compact, energy efficient source (Garcés and Park, 2007). The TRW is essentially a baffled fan with blades that have dynamically controlled pitch. An electric motor rotates the hub at constant frequency while blade pitch is dynamically modulated by a control signal. The pitch control mechanism uses a conventional electromagnetic voice coil assembly driven by an audio amplifier to actuate the blades in response to the applied signal. The voice coil longitudinal oscillations are converted to blade axis rotary motion within the hub. Rotation of the blades about their axis changes the angle of attack of the blades as they move through the air creating uneven pressure distributions. It is believed that the TRW changes the radiation impedance from mass-

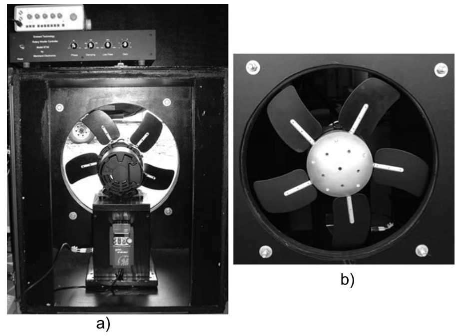

Fig. 1. Photograph of the TRW in a fixed installation. (a) View from inside the building showing the function generator, amplifier, motor controller, and motor, (b) view from the exterior showing the main rotor hub and blades.

dominated to fluid-displacement controlled by creating relatively high particle velocities at the blades of the projector thereby overcoming the canonical difficulty of mass-dominated radiation impedance at low frequencies.

The tested configuration consisted of five equally spaced blades, each approximately $B_w = 10.2$ cm (4 in.) in width by $B_L = 15.3$ cm (6 in.) in length. The outer diameter of the hub is approximately 20.4 cm (8 in.) so that the annular region of radiation has inner and outer radii of $R_i = 10.16$ cm (4 in.) and $R_o = 25.40$ cm (10 in.). Figure 1 shows a photograph of the TRW installed in a fixed laboratory.

Sections 2 and 3 outline portable deployment of the TRW, and demonstrate capability to transmit coherent infrasound signals detectable at ranges of 5 km.

2. Field deployment

To provide a field-deployable mobile prototype, the TRW was installed in a standard 17 ft U-Haul moving van. The installation was achieved by fashioning a baffle for the fan from 1.91 cm (3/4 in.) thick plywood. The fan housing is bolted to the baffle, and the baffle is clamped to the frame of the truck body. A portable generator and power-line filter were used to provide electric power.

On September 26, 2008 this portable system was deployed approximately 3.8 km from the central element ($H1$) of IMS array I59US on the western flank of Hualalai volcano, HI. A photograph of the portable system at the deployment site (19°34′38.32″N, 155°55′35.33″W) is shown in Fig. 2. An aerial view of the deployment layout is shown in Fig. 3. Table 1 lists the approximate distance from the source to each element of the I59US array. The array sensors are

Fig. 2. (Color online) The TRW in its portable configuration, located approximately 3.8 km from the central element of I59US.

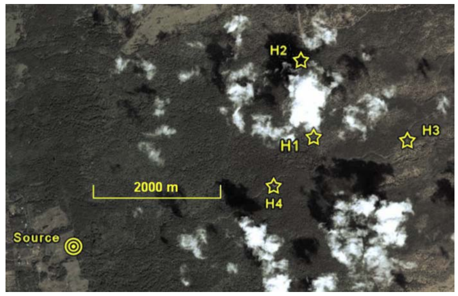

Fig. 3. (Color online) An aerial view of the deployment layout. The source was lcoated at approximately 19°34′38.32″N, 155°55′35.33″W.

Chaparral Physics (2008) Model 2.2A infrasound microphones. The data are digitized at a sample frequency of 20 Hz and recorded with GPS timestamps.

3. Results

A series of continuous wave (cw), constant frequency, and amplitude sine waves were broadcast according to the schedule listed in Table 2. The fan hub rotational speed for all transmissions was 12 Hz (720 rpm). Figure 4 plots the pressure power spectral density (PSD) recorded at the array sensors for broadcast numbers 2, 3, 8, and 9 of Table 2. These transmissions correspond to frequencies of 8, 6, 5, and 7 Hz, respectively. The three sensors, which are closer than 4.2 km (*H*1, *H*2, and *H*4), exhibit signal-to-noise ratios (SNRs) on the order of 15 dB at all transmission frequencies. Sensor *H*3 has noticeably reduced signal power at the range of 4.9 km. Even with the reduced SNR of approximately 5 dB at 4.9 km, the signal energy is clearly distinct from the noise.

Table 1. Approximate distance from the infrasound source to each of the array elements of I59US.

Array element	Distance (km)
*H*1	3.77
*H*2	4.16
*H*3	4.90
*H*4	3.02

Table 2. Schedule of signals broadcast during the test. All signals were constant amplitude and frequency sine waves. V_{in} is the rms voltage of the blade modulation signal.

No.	Broadcast time (UTC)	Frequency (Hz)	V_{in} (V_{rms})
1	9/29/08 23:53–23:56	8	6.8
2	9/29/08 23:56–23:58	8	10.5
3	9/29/08 23:59–24:03	6	13.1
4	9/30/08 00:03–00:07	4	11.9
5	9/30/08 00:10–00:15	3	18.0
6	9/30/08 00:15–00:20	1	25.6
7	9/30/08 00:20–00:24	3	13.2
8	9/30/08 00:24–00:29	5	16.4
9	9/30/08 00:29–00:34	7	16.0
10	9/30/08 00:34–00:39	8	17.6

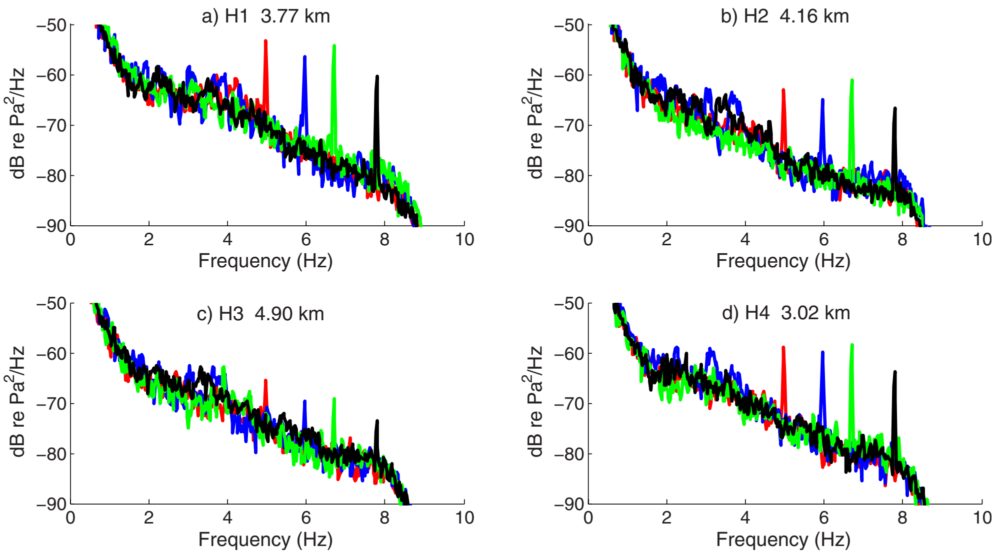

Fig. 4. (Color online) PSD of the recorded pressure at the four sensors from signal transmissions of 5, 6, 7, and 8 Hz. (a) Sensor *H*1, range 3.77 km; (b) sensor *H*2, range 4.16 km; (c) sensor *H*3, range 4.90 km; and (d) sensor *H*4, range 3.02 km.

The broadcast frequencies of 1, 3, and 4 Hz did not exhibit noticeable spectral peaks in the PSD. There are several possible reasons for this. One is the increase in noise levels below 5 Hz that could serve to mask the signals; another is that the output power of the source may attenuate at low frequencies due to the limited backvolume.

4. Conclusion

A prototype of the TRW modified for field deployment has demonstrated the ability to insonify an operational IMS infrasound array with cw signals from a stand-off distance of approximately 3.8 km. This may be the first controlled insonification of an operational IMS infrasound array from a portable device. SNRs in the range 5–15 dB indicate that this technology has merit as a field-deployable infrasound generator.

The development of a controllable infrasound generator will likely find utility in several acoustic applications. For example, the field calibration of infrasound arrays operated by the IMS of the CTBTO (2001), or as a tool for assessing atmospheric propagation studies. Other applications might include the field simulation of geophysical or anthropogenic infrasound sources to assist in the development of infrasound sensors and detection algorithms.

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