Sirens Comparison

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Abstract

This discussion compares two common siren types. They are the diaphragm driven horn based upon an improvement to Edison's original gramophone, referred to as an electronic siren, and the rotary air-shock siren based upon an improvement to the Carter type WW2 air raid siren, referred to as a rotary siren. Differences in performance, practicality and economic viability between the two are identified, with emphasis on how a spherical atmospheric wave-front dispersal influences cost escalation for electronic sirens. The validity of a new National Standard for sirens promulgated by the New Zealand Ministry of Civil defence and Emergency Management (MCDEM) is questioned.

An Original Technical Note

1. Background

Low frequency rotary sirens are the type most widely heard and recognised, requiring very few of them to cover large areas. Cycling up and down between 200 and 600 Hz, they have an enduring reputation for penetrating structures extraordinarily well [1]. Penetrating houses in wartime England, they awakened the community, prompting Prime Minister Winston Churchill's "Siren Controversy" speech in parliament [2]. These days there is controversy where electronic sirens are replacing rotary sirens, with correspondents demanding a return to rotary sirens [3]. When electronic sirens replaced rotary sirens on New Zealand (NZ) fire appliances in the 1970's, proving to be less effective, low frequency locomotive type air horns were retro-fitted to those vehicles and are still in use today. Modern rotary sirens are being heard indoors from a substantial distance in gale force winds, over the top of television programmes, with windows closed [4].

2. Siren Function

2.1 Electronic siren function

The expansion horn on Edison's original gramophone was driven by a low density paper diaphragm excited by a vibrating needle, mechanically transferring musical vibrations to the diaphragm. Modern electronic sirens use the same mechanism, except with a high density metallic diaphragm driven by magnetostrictive force from a coil with iron core, or by Piezostrictive force from a crystal or ceramic slab. Both methods convert electrical force into mechanical force, - a form of electric motor whose power supply voltage is varied by a simple electronic timing circuit.

Due to the high density of the diaphragm, electronic sirens cannot produce non-sinusoidal waves with sharp turning points. Because the diaphragm cannot accelerate quickly enough, it produces a rounded wave.

Figure 1: Chinese Internet advertisement for a typical electronic siren

2.2. Rotary siren function

Rotary sirens are often referred to as mechanical sirens, but both rotary and electronic sirens are mechanical, each featuring a single moving component to cause air displacement but producing different atmospheric effects in the near field.

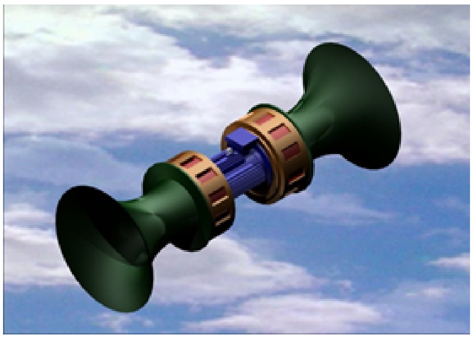

Figure 2: Solidworks image of a 150 dB New Zealand made rotary siren with 45 degree internal reflectors and impedance transformer horns

The difference between the two types is that in one siren the moving part rotates and is visible, and in the other type the moving part moves back and forth inside a housing.

The rotary siren operates on a momentary cavity with an air valve that opens and closes at high speed. Because the valve is continuously moving, there are no acceleration forces involved, so the rotary siren is able to produce atmospheric pressure pulses with very sharp turning points, thus exhibiting rich harmonics.

2.3 Using electronic sirens to mimic rotary sirens

Electronic sirens can, to a degree, mimic rotary sirens by synthesising a triangular wave by summing sinewaves that copy the Fourier transform for a triangular wave. However, it's not the same because the approximated waves will have rounded peaks and lumpy profiles, with undershoot and overshoot. Similarly, electronic sirens that attempt to mimic a triangular wave by ramping a voltage up and down, will produce a distorted version of a triangular wave with a rounded peak instead of a sharp peak, resulting in harmonic deficiency.

2.4 Sirens used as public loudspeakers (Loudhailers)

Without complex installations, outdoor loudspeakers are often unintelligible due to long reverberation times Cancellations occur at frequencies that arrive at the receiver out of phase with each other due to reflections. It can be a serious liability when a receiver's interpretation of a garbled message or its context is compromised, and the wrong action taken.

It's worse when a speaker is moving on a vehicle or aircraft, because the path lengths are varying. Helicopters are inhibited due to the presence of a doughnut shaped refractive index below the aircraft, inside which the loudspeaker is positioned, limiting reliable intelligibility to a narrow vertical field at best.

It's safer to promulgate information via broadcast radio and television and educate the community to listen to a radio broadcast whenever the sirens are heard. Libraries of pre-recorded messages are remotely selected, or changed via text to speech software to automatically over-ride radio broadcast programmes when sirens are triggered. Electronic highway billboards and community hoardings can also be networked to operate synchronously with sirens.

There has been legal action over an ineffective loudspeaker system, that has culpability implications [5]. There has also been an incident in New Zealand where people misinterpreted garbled police loudhailer instructions and fled in a wrong direction towards potential danger [6]. During the Washington navy yard shooting, witnesses described messages from police car loudhailers as "garbled," causing confusion [7]. The bedfellows of outdoor loudhailers; ambiguity and confusion, are toxic ingredients in critical situations where events are unfolding rapidly.

3. Correct coupling of sirens to the atmosphere

Sirens must be correctly impedance coupled to the atmosphere to minimise power loss by reverse reflection due to a pressure gradient at the siren mouth, analogous to a tennis ball hitting a wall and bouncing back. A coupling transformer is normally used in the form of a horn, critically shaped to convert high acoustic impedance (high pressure, small displacement) at the throat, to low impedance (low pressure, large displacement) at the mouth.

The first principles for designing acoustic radiators are similar to those for radio antennae because the distance between maxima and minima on a periodic wave, is a quarter wavelength, so the horn must be at least a quarter wavelength long at the lowest (cut-off) frequency. Practically the circumference of the horn at the mouth should be at least 1 wavelength at the lowest (cut-off) frequency.

Horns can get very large at low frequencies. Some marine fog horns are enormous and project eerie sounds over huge distances with frequencies of 200 to 400 Hz often followed by a 10 to 20 Hz grunt at the end of each duty cycle. (Turn volume up - www.sounddogs.com/previews/2742/mp3/456706_SOUNDDOGS__fo.mp3)

4. The crude nature of cheap mass-produced horns

Commercially available horns used on most electronic sirens appear to be of no particular design, perhaps profiled for consumer fashion rather than to any engineering parameter. Most electronic siren suppliers ignore horn parameters in published specifications, and seldom, mention waveforms. Some suppliers worldwide appear to be importing the Chinese siren shown in Figure 1 and replacing the brand label with their own.

The inside profile of a siren horn is critical because in addition to impedance matching, it must also be able to convert a breathing cylinder plane wave into a breathing sphere atmospheric wave. The folded horn in figure 1 is a typical example of a tendency to fold horns back inside themselves to minimise the cost of tooling dies, ostensibly proffered as a space saving measure.

The New Zealand designed rotary siren horns in Figure 2 require several stages of heat annealing during the metal spinning process over a large and complex tooling die where the metal is required to migrate across the die at compound angles without cracking. This expensive process is justified by superior horn performance. There is no need to conserve space at the top of a pole. Because world markets are saturated with cheap folded horns, their crude configuration is seldom questioned, but they are rarely seen in critical applications like low frequency marine fog horns on big ships, or serious locomotive air horns where safety is of the essence.

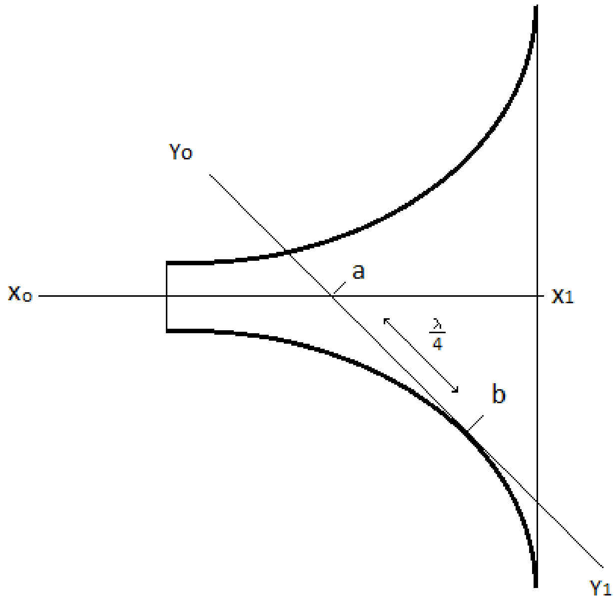

Figure 3: Visualisation of an internal folded section of horn interfere with the quarter wave dimension (a-b) along the horn profile.

Figure 3 visualises how an internal folded section of horn would interfere with the quarter wave dimension (a-b) along the horn profile. An imaginary line from X_0 to X_1 defines pressure maxima at any interval along it. If we slide a tangent (Y_0 – Y_1) along that line, the tangent will always intercept (X_0 –X_1) and the surface of the horn, at b in a correctly profiled horn. Points (a–b) being a quarter wavelength apart.

5. Unforeseen cost escalation

If you want to double the propagation distance of a siren, (an increase of 6 dB SPL) you must increase power output by 4 times because the wavefront dispersal is spherical. Numbers of installations of electronic sirens will continue to require more sirens to be added as communities complain about not hearing them, accompanied by burgeoning costs. The increase in siren numbers, batteries, and maintenance, is according to square-cube law because the acoustic wavefront dispersal is spherical. For example, consider for a moment, electronic sirens of the type shown in Figure 1, mounted on a pole. To achieve a power increase of 3 dB, you must double the number of sirens. So if you have 4 sirens on a pole and you wish to increase the power output by 3 dB, you must add another 4 sirens. To realise 9 dB gain, you must therefore have 32 sirens on the pole that originally had 4. Put simply, you need large amounts of money, increasing by square-cube law, to make a big difference at the receiver. In contrast to that, in 2012, tangential expansion horns with 45 degree centre reflectors, were fitted to a New Zealand made PSL Firemaster rotary siren and independently measured at

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150 dB power output on axis [8]. This is a power increase of 13 dB over the published Firemaster siren specification (20 times power output), which is theoretically nearly 4.5 times the propagation distance, so the published specification of 8 km working distance for the Firemaster siren was theoretically increased to 36 km. In practice it will be less due to ground and air effects, but nevertheless a significant gain at modest cost.

6. Sound character

At a measured power output of 150 dB with a richness in odd-order harmonics, the rotary siren in Figure 4 produces around 20 times more power output than electronic sirens in current use, whilst also satisfying noise compliance when installed on a 10 metre pole. The rotary siren gets its haunting sound character from two valve sets synchronised on a common shaft typically with 10 ports in one valve, and 12 ports in the other So there are two triangular waves about 100 Hz apart with a phase offset of 6 degrees.

Because the sound character of the rotary siren is unique, it is readily recognisable over wide areas despite competition from local noise. Conversely, the electronic siren is perceived as "just another alarm we hear daily". The effectiveness of electronic sirens has been progressively eroded by the introduction of similar sounds that desensitise the community by over exposure to the sound.

There is now an emerging realisation that electronic siren potency has been diminished by desensitisation due to over-exposure [9]. Meanwhile, the potency of rotary sirens has improved because the sound character continues to escape contamination by other diurnal sounds.

7. Fire stations sirens

A similarity in sound character between fire brigade station sirens and rotary emergency sirens, is coming to an end as the New Zealand Fire service (NZFS) gradually phases brigade station sirens out in favour of telecommunications media for callout alarms. That initiative has reportedly already yielded a higher volunteer turnout to alarms [15]. The phasing out trend currently being observed, and acknowledged by NZFS, [16], is being accelerated by public pressure for fire station sirens to be silenced, making their eventual demise inevitable. A few examples can be found in [17, 18, 19, 20, 21, 22, 23, 24]. It will render rotary emergency sirens free of competition, preserving their potency for civil defence use. A vital ingredient of that potency being penetration into houses, especially in communities potentially exposed to flooding that could occur suddenly at night. To include competition from fire station sirens among main reasons for rejecting rotary sirens, as some reports have [25, 26, 27] is not entirely accurate.

8. The new National Standard for sirens in New Zealand

In August 2014, a new national standard [25, 26] for sirens was promulgated by the Ministry of Civil Defence and Emergency Management (MCDEM), featuring a sound format with a disturbing similarity to other diurnal sounds, effectively compounding public desensitisation to electronic sirens. See: www.civildefence.govt.nz/assets/Uploads/publications/Tsunami-Sirens-Standard-signal-multiple-tone-repeated-rise.wav

A supporting science document [27] for the new standard is enigmatic, one example being that it is the origin of the new sound format, but contradicts its own stated requirement that "[the signal shall be distinct from all other sounds and any other signals]" The development process for the standard was irregular, bypassing all the normal transparency protocols for the formation of standards [28, 29]. An unfortunate consequence is that although there was some academic science input to the development of the standard, it was devoid of non-selective opportunity for industry-based engineering input via the normal public draft comment process. Consultation was therefore highly selective, exposing the standard to a stigma of appearing to have been tailored towards a particular type of siren. It was unfortunately not possible to influence any moderation to that outcome, due to attempts to make submissions being unsuccessful. Rotary sirens have a proven track record that is hard to ignore. Lower Hutt city have 13 that are widely heard both indoors and out except for a couple of sites where installation adjustments are needed. Their house penetrating ability is a particularly important ingredient where there is risk of sudden flooding, especially at night. It would be an imprudent waste of resources to replace them with disproportionately large numbers of electronic sirens, solely to satisfy a questionable technical standard that is not supported by empirical evidence.

In surprise at the new sound format, a brief survey of nine randomly selected receivers [34] and one eminent recently retired acoustician [8] was conducted. The sound clip was played to them individually, and each was asked to describe the sound they heard. Without exception, the nine receivers described it as either a house burglar alarm, or a car security alarm. Two added that it might be a commercial building fire alarm. Respondents were unanimous that it was a common everyday kind of sound that would likely be ignored. The acoustician was surveyed differently. He was told before listening, that it was the newly required sound format for sirens, and was invited to comment on it. With his permission, his

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response is quoted verbatim:- "It sounds like a car alarm. For a siren that is meant to be distinctive it fails". Other independent surveys will likely yield a similar result, and that has public safety implications that cannot responsibly be ignored. On the contrary, public reaction to rotary sirens has been consistently positive because they exhibit a unique timbre that has been described by receivers as "intimidating and haunting" [30]. "Melancholy and depressing in the dead of night" [31]. Fortuitously, due to a random observer during a 2012 rotary siren test, an amateur audio/video clip (below), of the 150 dB rotary siren in Figure 4, provides a remarkable appreciation of both the sound character and the propagation distance. The wind gusts in the area averaged 42.6 kph from the west, blowing the vibrating air out to sea, so the recording site was seriously handicapped, as demonstrated by two tugboats in high wind and spray at the end of the video clip. Despite those adverse conditions, the siren excelled by being impressively loud and clear at the remarkably long distance. (Turn volume up - www.youtube.com/watch?v=DQUlENpwLNU)

9. Durability

Electronic sirens in large communities invite exceptionally high costs because large numbers of them are required to do the same job as fewer rotary sirens that are known to last for up to 70 years. Sirens need to be mains power independent because a distant knockout can effect local supply. This means small auto-start diesel generators are ideal for powering rotary sirens, but not practical for electronic sirens in such large numbers. Each electronic siren site must therefore be battery dependent involving daunting maintenance costs after the initial period of grace for new installations.

Diesel power can reduce a remote site to a super capacitor for the SCADA (Supervisory Control and Data Access) RTU (Remote Terminal Unit) with combination solar/wind replenishment, requiring no mains power and minimal battery. Diesel engine starting by compressed air is elementary. SCUBA (self-contained underwater breathing apparatus) tanks are a reliable energy storage medium and the amount of air used per engine start is small. Batteries present problems in many industries. Single batteries have a lower failure risk than batteries in banks where one sick cell can knock the whole bank out. Any type of chemical battery is the weakest component in an installation. Battery failure can be insidious and most likely to present during extreme cold or heat. It can be difficult to detect remotely because a sick battery terminal voltage can appear normal on test when the battery is incapable of delivering the required amount of energy during an alert. Remotely monitoring the terminal voltage of a battery is inconclusive.

NASA have now deemed conventional batteries an unacceptable risk for aerospace applications, and commissioned the University of Texas to develop an alternative. The result is a rotary flywheel battery that outperforms conventional batteries in all respects [32].

10. Siren testing

10.1 Electronic siren testing

Regular testing is essential, but presents daunting issues for electronic sirens because whilst battery performance might appear normal when sirens are tested at reduced power, they could fail when operated at full power in a real emergency. Proper testing of electronic sirens with battery backup should therefore only be done at full power with the mains electricity disconnected, and needs to be regular. There is then the dilemma of trading off regular testing against community desensitisation to the sound. The absence of regular testing of electronic sirens potentially exposes them to failure.

10.2 Rotary siren testing

Growl testing of rotary sirens, widely practised in the USA, only requires the siren to be rolled over a few revolutions without winding up to speed. The test and its remote measurement are automated to be performed at programmed intervals without public notification or human input. Growl testing does not generate the normal siren sound heard on alert, thereby posing no risk of community disturbance.

Some jurisdictions run their rotary sirens up to full speed for a few minutes annually to remind the community what the real thing sounds like without overexposure to the sound, and to remind them to listen to the radio when the sirens are heard.

11. Optimising installations

It is better to mount a siren on a high pole in the bottom of a valley than on a hilltop, to optimise reflections and direct the sound into the community rather than over it.. Due to their low frequencies and rich harmonics, rotary sirens will penetrate buildings and reflect readily off both hard and soft surfaces including bush covered hills.

It is better to mount a siren on a 10 metre pole than on a building because high power sirens feature a large near-field. A near-field can be visualised as a large imaginary sphere around the siren, that is populated with standing waves as opposed to travelling waves, a bit like waves on a disturbed pool of water that appear stationary when they collide with each other. The rotary siren in Figure 3 has a measured near-field of 8 metres radius, so the imaginary sphere is 16 metres in diameter. That siren should therefore be mounted on a 10 metre pole to avoid

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ground effects, rather than on or too near a building. A pole height of 10 metres also renders the 150 dB siren in Figure 3 noise compliant in New Zealand [8].

A common mistake is to locate siren installations on coastal waterfronts. It is much better to install them a suitable distance inland, where they can still be heard on the coast, thus creating a wider coverage area at no extra cost. It is a waste of power to propagate sound waves out to sea by installing sirens along beach-fronts unless there is a special need for it. Even the most directional sirens will have a cardioid polar emission profile that projects considerable sound to the rear, so this ought to be exploited rather than wasted.

12. Sirens for local source Tsunami

Sirens are not considered by Civil Defence (CD) authorities to be suitable for local source tsunami, but there are exceptions that ought to be acknowledged. For example, Wellington city, surrounded by hills for people to flee to on foot, could potentially see thousands of lives saved with a warning as short as 15 minutes. The Japan amateur video below is surprisingly unique, having been recorded well up an estuary. It shows three quarters of the period of a first wave whose full period is 36 minutes, extrapolated from an observed half-wave distance between maxima of 18 minutes. This provides an estimated warning opportunity of around 20 minutes – enough time to walk to high ground instead of standing around wondering what's happening, as this remarkable video sadly attests. The footage is a compelling illustration that some estuaries could be protected against local source tsunami. Wellington city is just one example of where a small number of high power sirens could save many lives regardless of whether a tsunami is of local, regional, or distant source. (Ignore the wildcat insert between clock 17 and 24 secs - www.youtube.com/watch?v=ldsWIf2OSYQ)

13. Cogent analogies

Traditional marine whistle buoys use a very low frequency surge powered generator basically a Helmholtz cavity that "moans" to alert mariners to a reef (turn volume up - www.youtube.com/watch?v=v5w4EHlTt_0). Additionally, on top of some buoys, is a high frequency bell that rings as the buoy sways, to provide direction for receivers (www.youtube.com/watch?v=GXIhmlR7Qss).

The bell is designed to be heard only at a short distance whilst providing good direction. If you can hear the bell, you know you are close, and you know which direction it is in because its wavelength is short, unlike the low frequency moan which gives no directional sense due to its long wavelength, but can be heard at a remarkably long distance.

Moral 1: We don't need directional information for sirens, so very high frequencies without low frequencies, are a waste of power.

13.1 Car stereo

Loud car audios remind us daily of the remarkable ability of long wavelengths at low frequencies, to penetrate houses, and propagate much better than high frequencies. Sometimes we can hear from indoors, the obnoxious thump of the bass hundreds of metres away, but more often than not, the treble music is not heard indoors at all as the vehicle passes by, rattling windows, double-glazed or not. There is no directional sense to those long wavelengths, so the bass thump sounds as if it is all around us indoors and out, rather than coming from any particular direction.

Moral 2: Receivers inside their houses could understandably wonder why electronic sirens do not work as well as car stereos, but rotary sirens do. Arguably then, it is a flawed concept to design a siren to maximise the peak frequencies of human hearing at the expense of the low frequencies if we want to successfully propagate sound waves to distant receivers and into houses.

13.2 Twin-wing helicopters

Helicopters with 2 main rotor blades, like the Bell 212 Iroquoi or Huey, propagate a main rotor beat frequency of 5.5 Hz in a forward direction. It is normally impossible for receivers to determine which direction the machine is approaching from, due to the extremely long wavelengths of the sound at 64 metres, with an impressive distance between maxima and minima along the wave, of about 16 metres. These machines can be heard 20 km away when approaching a receiver in still weather. The 5.5 Hz main rotor slap is "all around" us rather than coming from any particular direction.

Moral 3: We want sirens to sound as if they are "all around" us, so the low frequencies and their harmonics are an essential part of the sound character exhibited by a rotary siren.

14. An example of how we hear sounds differently as distance changes

Using the example of a combined whistle and bell buoy, if we sail close to the buoy in a good swell so that both bell and whistle are sounding at full power, we will perceive the bell to be the loudest, being nearer to the peak frequency of human hearing. If we then sail away until the bell loses its higher frequencies and becomes faint, we will perceive the moan of the whistle to be the loudest because its low frequency is propagated much further. Eventually, the bell will become inaudible as we sail further away, but the moan will endure for a remarkable distance. By analogy, we have compared electronic sirens (the bell) with rotary sirens (the moan), and demonstrated that electronic sirens would only be a viable option if we had many of them spaced at close intervals throughout a community.

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