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http://www.alternativesjournal.ca/community/blogs/ecologic/carp-fear

ASIAN CARP ACOUSTIC REPELLING SYSTEM (ACARS)

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3 DECEMBER 2019

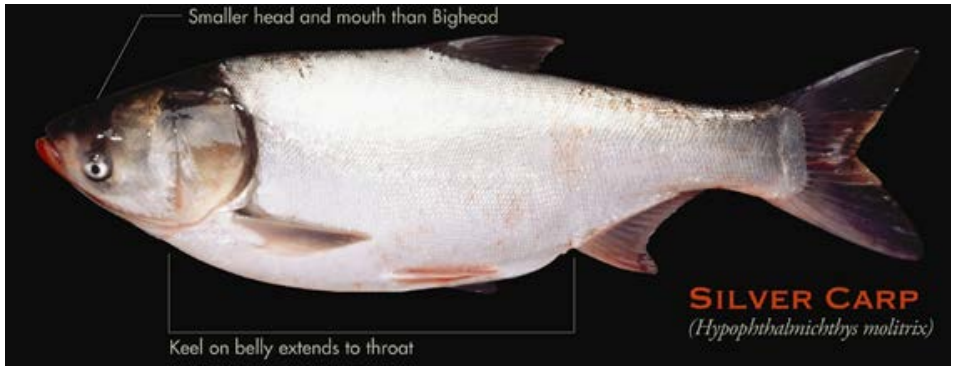
TECHNICAL & POLICY COMMITTEE MEETING

AGENDA

- OVERVIEW
- CURRENT CONTROL MEASURES
  - Electric barriers
  - Sound sensitivity
  - Shock/noise generators
- UNDERWATER-PLASMA ACOUSTIC GENERATORS
- POTENTIAL ATTACK VECTORS
- ACARS RELATED TECHNOLOGY
- SUMMARY/NEXT STEPS

OVERVIEW OF ASIAN CARP PROBLEM

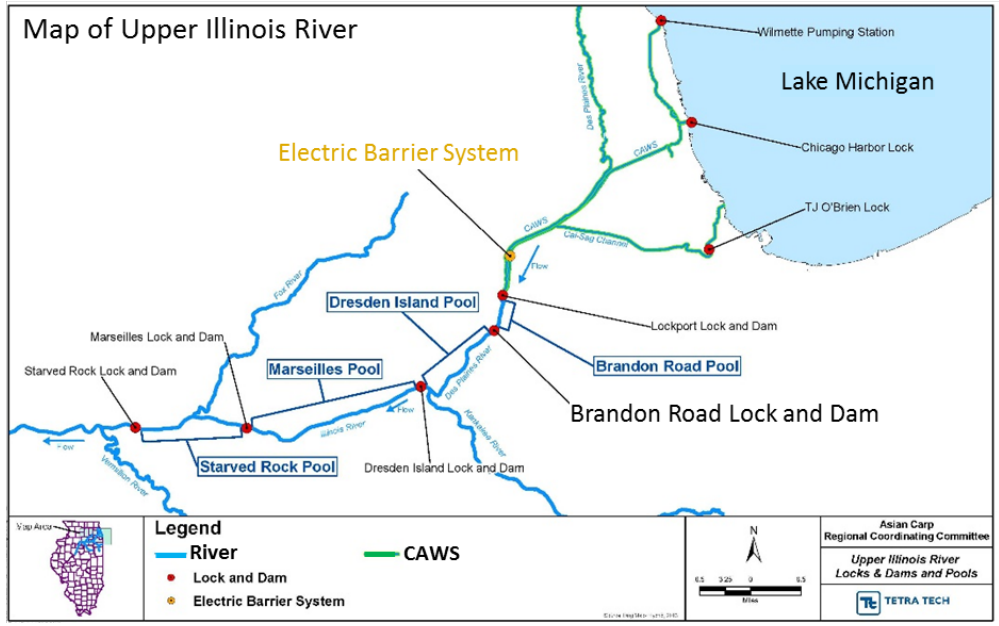
- Invasive Asian carp being considered for this effort:
  - **Bighead carp** (Aristichthys nobilis) and **Silver carp** (Hypophthalmichthys molitrix),



- Since the 1970s, they have migrated north into the U.S. Midwest, infesting the watersheds of the Mississippi, Missouri, and Illinois rivers —and are now poised to breach the Great Lakes ecosystem.
- During the summer of 2017, a commercial fisherman contracted by the Asian Carp Regional Coordinating Committee (ACRCC) caught a species of the intruding fish in Illinois, only 14 kilometers south of Lake Michigan.[1]
- U.S. Army Corps of Engineers working to stop the invasive species from infesting the Great Lakes
- Chicago Area Waterway System (CAWS) is the focus area to stop the carp

[1] https://www.scientificamerican.com/article/great-lakes-defenders-have-a-shocking-idea-to-stave-off-invasive-carp/

CHICAGO AREA WATERWAY SYSTEM (CAWS)



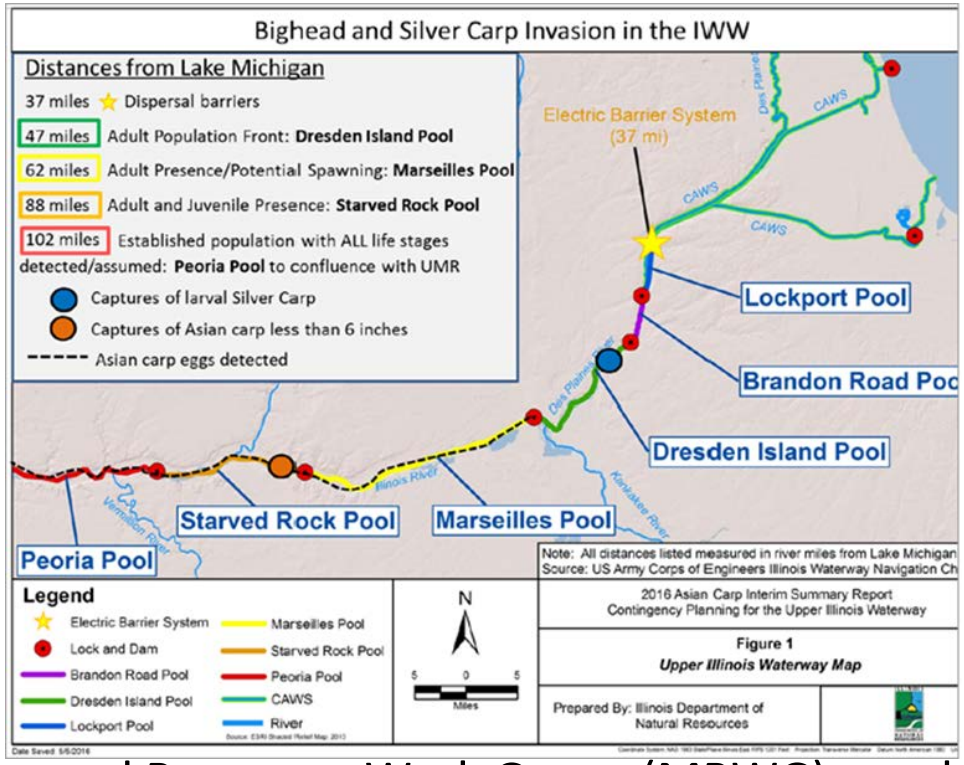
Brandon Road Lock and Dam

http://www.mvr.usace.army.mil/Missions/Navigation/Lock-and-Dam-Information/Lockport-Lock-and-Dam-Copy/

- Chicago Area Waterway System (CAWS) is a complex of natural and artificial waterways extending through much of the Chicago metropolitan area, and is the sole navigable inland link between the Great Lakes and the Mississippi River, and makes up the northern end of the Illinois Waterway (IWW)
- *Brandon Road Lock and Dam* is at the population front of bighead and silver carp

2017 ASIAN CARP ACTION PLAN, Asian Carp Regional Coordinating Committee

POPULATION FRONT OF BIGHEAD AND SILVER CARP



- As of fall 2016, Monitoring and Response Work Group (MRWG) concluded that the **adult population front of Bighead and Silver Carp** is approximately 47 miles and two lock structures from Lake Michigan **in Dresden Island Pool**, just downstream of the Brandon Road Lock and Dam
- No small fish (< 6 inches) have been detected in Dresden Island or Marseilles pools by MRWG efforts at that time

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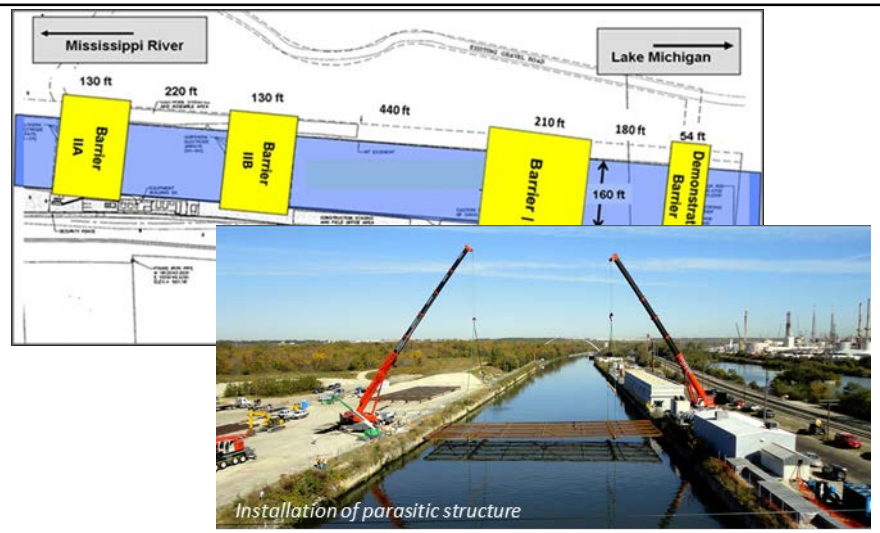
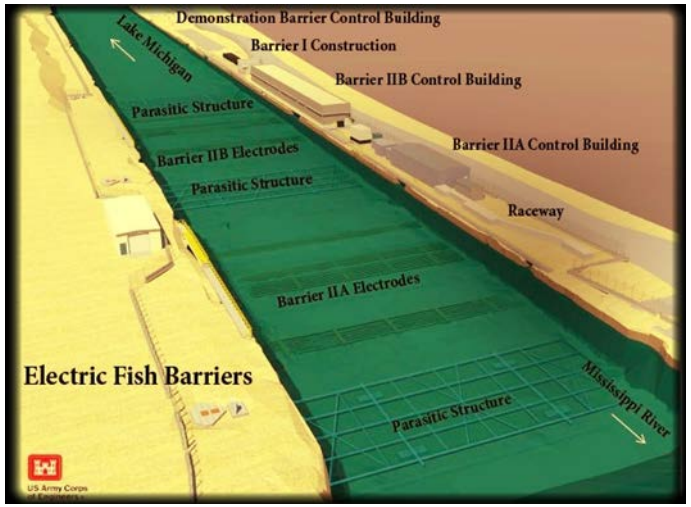
ELECTRIC BARRIER SYSTEM LOCATED NEAR ROMEOVILLE, IL, IN THE CSSC WITHIN THE CAWS





- Chicago Sanitary and Ship Canal (CSSC) is a man-made connection between the Great Lakes and Mississippi River basins to address sanitation/flooding, and accommodates increased shipping
- Three Electric Barriers deter the inter-basin establishment of Asian carp and other fish by maintaining an electric field in the water, with a fourth (Barrier I) currently under construction
  - Metallic "parasitic" structures in the barrier zone to better control the shape of the barrier electric field

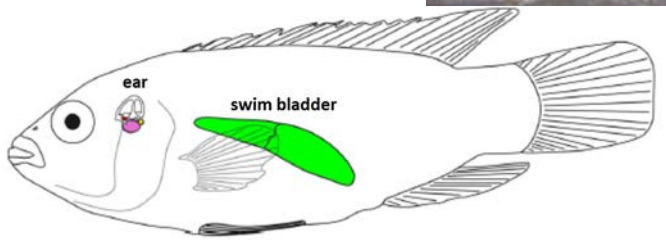
Specific water conductivity measures near the barriers (Oct 1998 – Apr 2010) [1], showed specific conductivity of water in the CSSC was 489 to 4697 µS/cm over the period

- **3049 and 4697 µS/cm from December to March (potentially due to salt run-off from roads)**
- **89 to 1940 µS/cm the rest of the year**

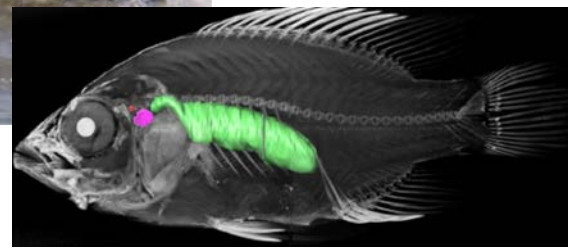
[1] Dispersal Barrier Efficacy Study, Efficacy Study Interim Report IIA, Chicago Sanitary and Ship Canal Dispersal Barriers – Optimal Operating Parameters Laboratory Research and Safety Tests , USACE, September 2011

FISH SOUND SENSITIVITY

Hearing Generalist



Hearing Specialist

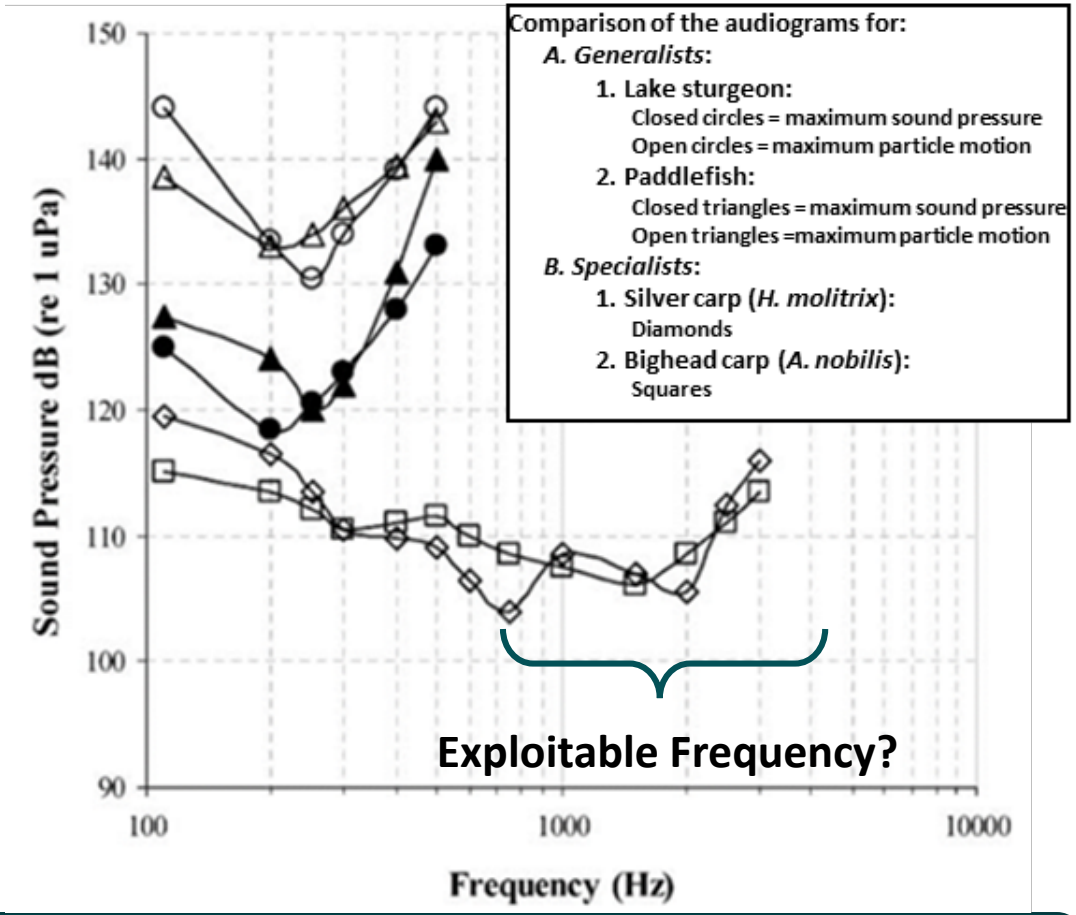


- A ***Bio-Acoustic Fish Fence (BAFF)*** is a barrier that relies on the generation of *complex noise* underwater. Speakers on the walls and bottom of an engineered concrete channel emit sounds to chase away the fish. ***Air bubble curtains*** from diffusers on bottom of channel also used.
  - Scientists studying Asian carp in the Mississippi and Missouri rivers have noted, however, that this species will consistently leap out of the water when exposed to the complicated sounds of a motorboat engine.
- Fish have been broadly categorized as either **"*hearing generalists*"** or **"*hearing specialists*"** [1]
  - **Generalists**, such as paddlefish and lake sturgeon, have a separation between the inner ear and the swim bladder, and rely on the motion of water particles in a sound field to stimulate the sensory hairs of the ear.
  - **Specialists**, such as carp and catfish, have an anatomical structure that connects the inner ear and the swim bladder to assist in transmitting sound waves to the inner ear; making these fish sensitive to the sound pressure component of an acoustic signal, measured in units of decibels [dB] (re 1 µPa).

[1] Schulz-Mirbach T, Metscher B, Ladich F (2012) Relationship between Swim Bladder Morphology and Hearing Abilities–A Case Study on Asian and African Cichlids. PLoS ONE 7(8): e42292. doi:10.1371/journal.pone.0042292

FISH SOUND SENSITIVITY

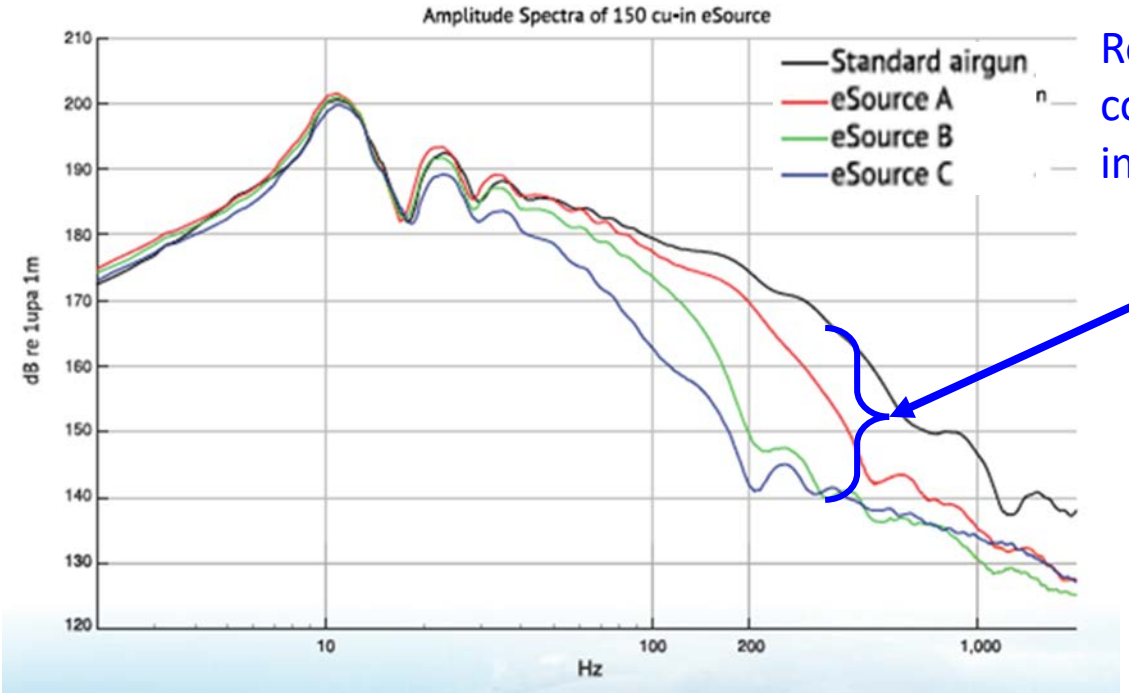
- Asian carp are more sensitive at higher sound frequencies then most indigenous fish
- Audiograms for Silver carp and Bighead carp are similar, with the lowest thresholds occurring at frequencies of between 750 Hz and 1500 Hz, with sensitivities beyond 3 kHz [1]
- Lowest threshold recorded from Silver carp was 104 dB (re. 1 µPa) at 750 Hz, and the lowest threshold from Bighead carp was 106 dB (re. 1 µPa) at 1500 Hz



Higher sensitivity of Asian Carp at higher frequencies may provide a more effective sound-pressure attack vector

[1] J.M. Lovell, et al., *The hearing abilities of the silver carp (Hypopthalmichthys molitrix) and bighead carp (Aristichthys nobilis),* Comparative Biochemistry and Physiology, Part A 143 (2006) 286 – 291

SEISMIC ACOUSTIC SOURCES: AIRGUNS



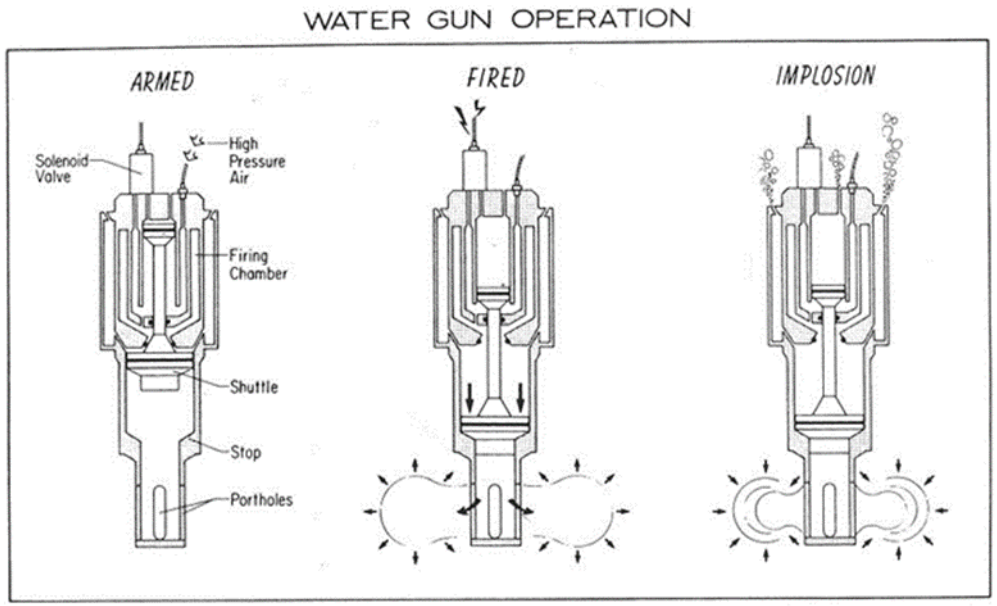
Reduced higher-frequency content to minimize impact to marine life

- Airguns, used for marine reflection and refraction surveys, consist of one or more pneumatic chambers that are pressurized at pressures from 14 to 21 MPa (2,000 to 3,000 psi). Airguns are submerged/towed behind a ship.
- Teledyne Bolt, Inc., has engineered a new type of "eSource" airgun designed to reduce the potential impact of seismic acquisition operations on marine life by reducing frequencies above 200 Hz [1]

Our approach to impacting Asian carp is trying to explore higher-frequency noise generation through underwater pulsed-power electrical discharge

[1] http://www.teledynemarine.com/Lists/Downloads/eSource_mobile_brochure1.pdf

SEISMIC ACOUSTIC SOURCES: WATER GUNS



- Water guns are pneumatic devices like airguns in that they operate on compressed air. But instead of discharging a bubble of air into the water column, they propel a jet of water.
- A 15- in^3 water gun can generate 230 dB of pressure over a frequency spectrum of 50 Hz to 1000 Hz; an 80- in^3 water gun can generate 237 dB from 20 to 500 Hz output. [1]
- As the volume of the water gun is increased, the frequency spectrum decreases, while the sound pressure increases due to the increased volume of the imploding vacuum cavity.

[1] United States Department of The Interior, St. George Basin, Final Supplemental Environmental Impact Statement. 6. 1983

SEISMIC ACOUSTIC SOURCES: WATER GUNS

- The USGS is exploring different methods to also deploy the gun from mobile locations. [1]
- Concerns over the possible damage of structures in the CSSC led the USGS to carefully study this issue using two water guns, one 343 in^3 and one 120 in^3. [2]
- Acoustic levels from the water guns are roughly an order of magnitude or greater then background energy for land and in water (i.e., barge traffic, a nearby coal plant, etc.), no structural damage detected.

USACE allowed the use of the water gun for fish clearing operations in support of electric barrier maintenance. Water guns were used to clear fish during an October 2011 fish suppression action at the barrier site near Romeoville, IL.

[1] http://glmris.anl.gov/documents/docs/anscontrol/AcousticFishDeterrents.pdf

[2] 2011 Asian Carp Monitoring and Rapid Response Plan Interim Summary Reports, Asian Carp Regional Coordinating Committee Monitoring and Rapid Response Workgroup. p. 115. April 2012

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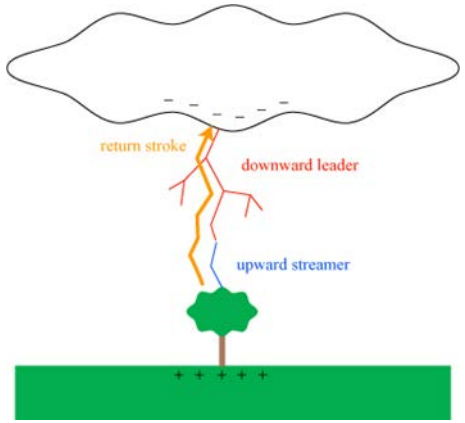
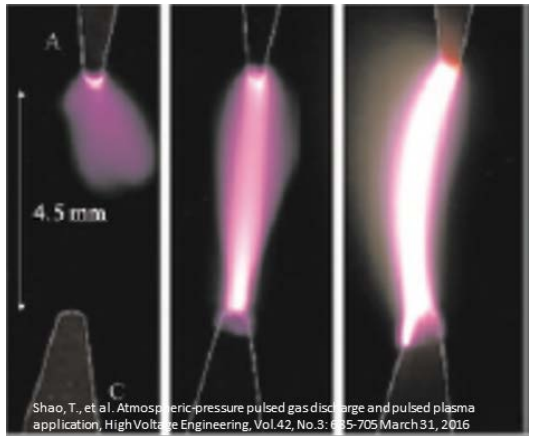
UNDERWATER-PLASMA ACOUSTIC GENERATION: ASIAN CARP ACOUSTIC REPELLING SYSTEM (ACARS)



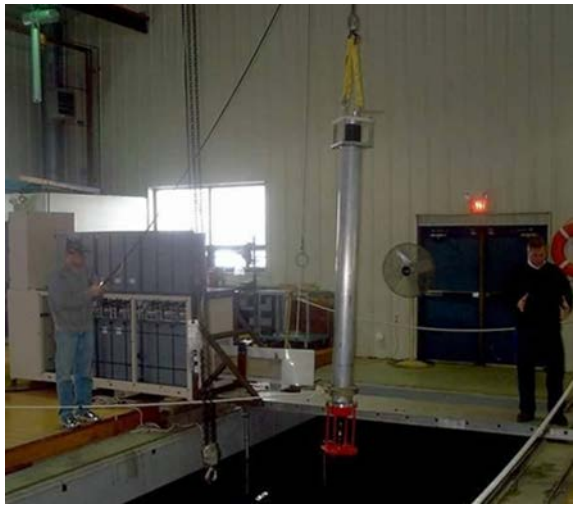


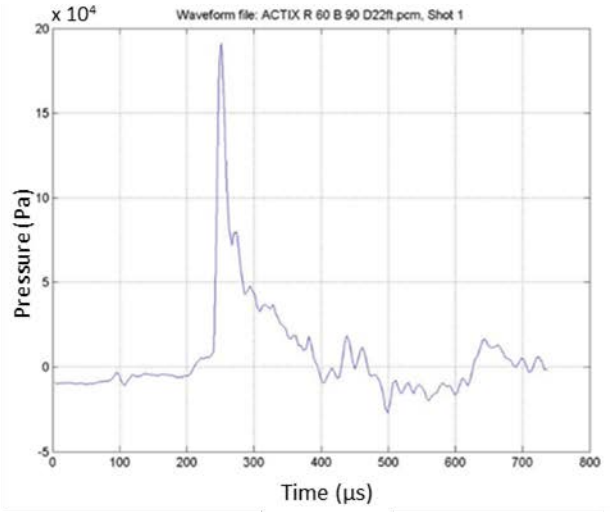
- A technique that is notably absent from all control efforts is using straightforward pulsed-power technology to generate an underwater acoustic shock to impact Asian carp
- An underwater spark discharge is formed by switching an energy storage capacitor at a high voltage to a pair of submerged electrodes (electro-acoustic efficiency of 32%). Prime power can be a battery or generator.
- An ionized plasma at high temperature and pressure forms between the electrodes. The pressure within the plasma is transmitted to the surrounding water as a wave of compression, much like the shock wave created by an underwater explosion (without the production of a large gas bubble)
- Inertia of the surrounding water exerts a rigid opposition to the expansion of the spark channel, therefore extremely high pressures result (reported channel pressures in excess of 10,000 atmospheres and temperatures greater than 40,000°C) [1]

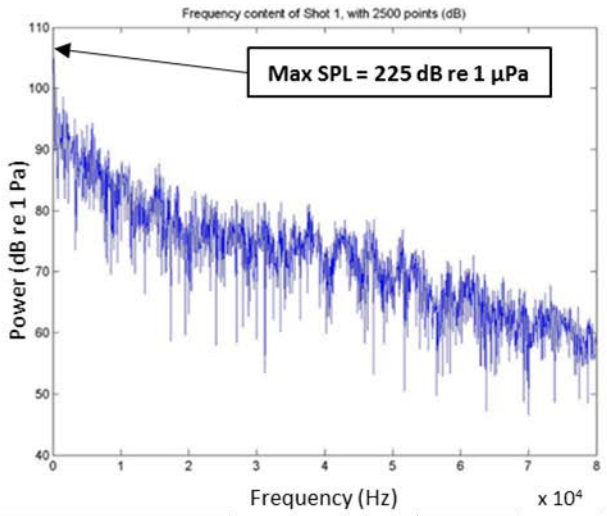
Large acoustic impedance contrast between air and water (the ratio is about 3500) and the scale of surface roughness means that the water surface behaves as an almost perfect reflector of sound, preventing significant sound transmission into the air.[2]

[1] http://www.dtic.mil/dtic/tr/fulltext/u2/259947.pdf
[2] *www.physics.mcgill.ca/~guymoore/ph224/notes/lecture18.pdf*

UNDERWATER-PLASMA ACOUSTIC GENERATION: COUNTER-SWIMMER



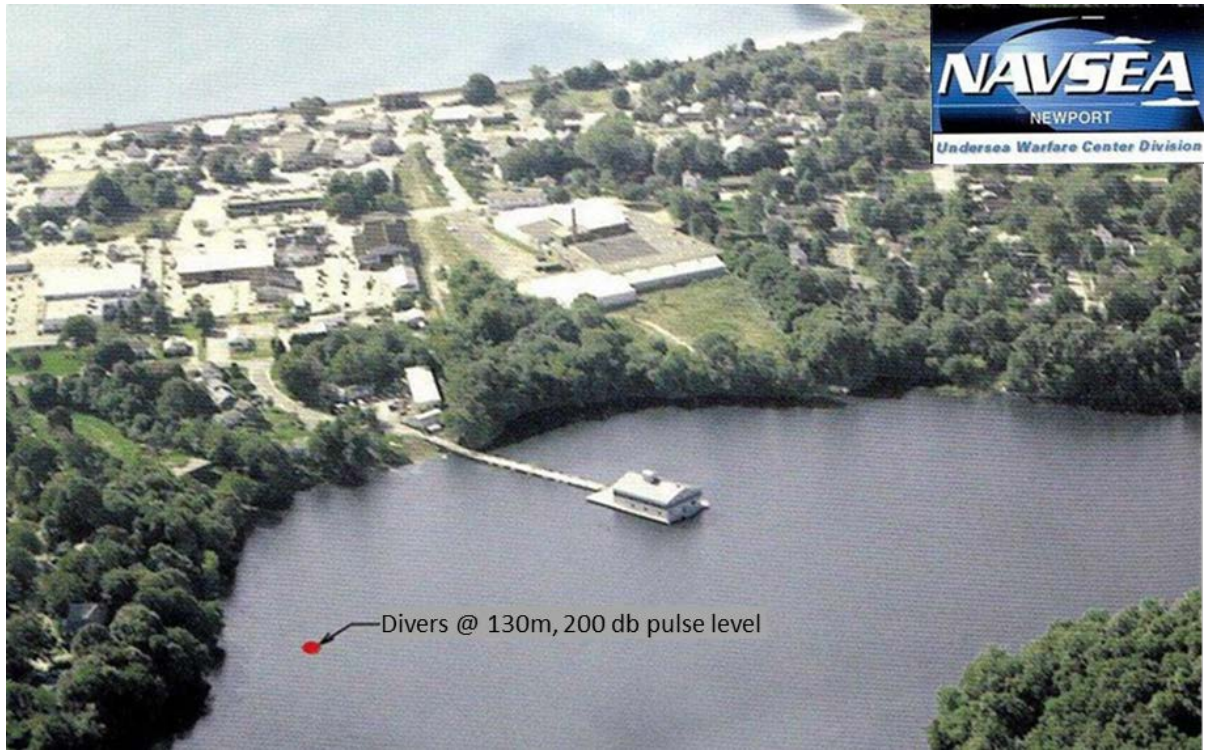




- Underwater discharges have been investigated by the U.S. Navy for many years for such applications as underwater mine clearing, counter-mammal, and as a counter-swimmer capability
- Photograph shows a 25kJ pulser unit where the pulser portion of the system weighs less than 200 pounds. The model 500B submerged-arc High-Intensity Pulsed Power (HIPP) Pulser will develop a 250dB (re 1 µPa) sound-pressure pulse of nearly 60µsec duration with a swimmer deterrent range of over 150m
- Measured output of the HIPP Pulser with 16kJ stored, measured by a hydrophone at a range of 60 yards [1]
- The faster energy release greatly increases the strength of the shock wave, produces no air bubble, and the higher frequency content of the pulse moves significant radiated energy into the 1 kHz range, where Asian carp are more sensitive

[1]ACTIX, Evaluation and Extrapolation of Measured Sound Levels from a High Intensity Pulsed Plasma (HIPP) Device, at NAVSEA – Dodge Pond Acoustic Measurement Facility, Niantic, CT. September 2003–August 2004

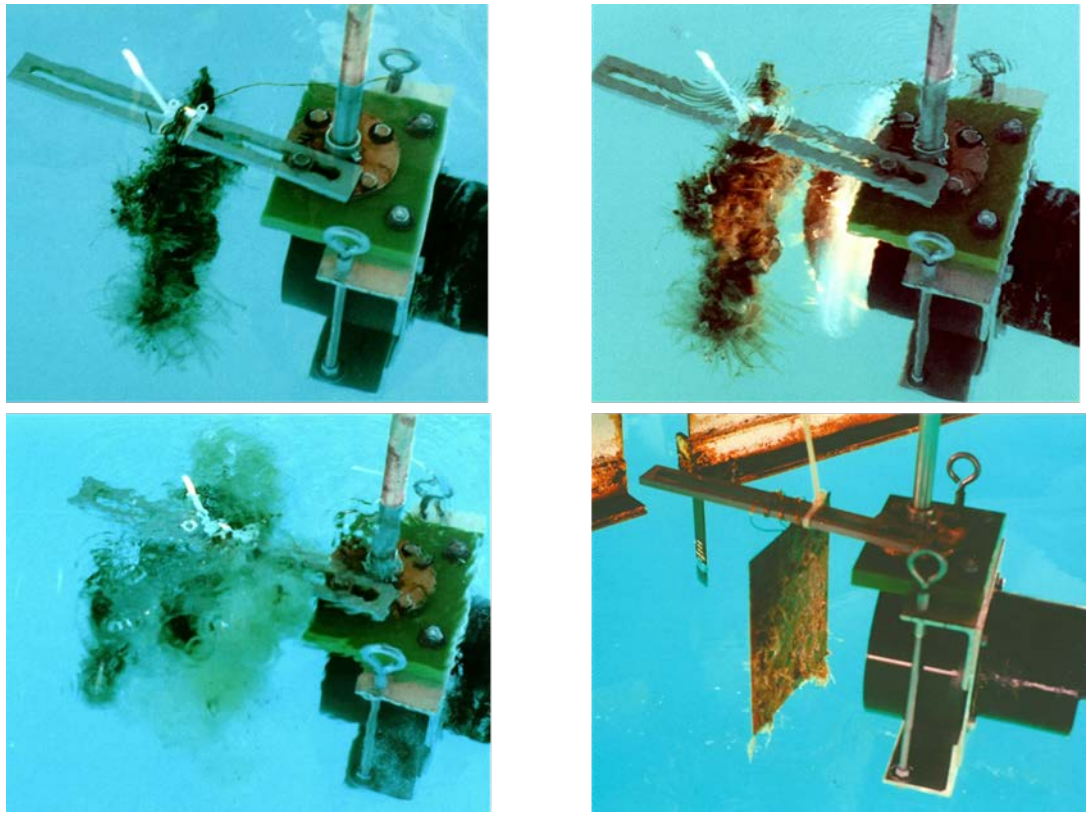
UNDERWATER-PLASMA ACOUSTIC GENERATION: DODGE POND ACOUSTIC MEASUREMENT FACILITY



- 16kJ discharge produced a sound-pressure pulse of 200db at 130m (16 kJ stored, spark head used was omni-directional)
- Pressures increasing to 245db at a one meter distance from the source
- "… due to the extremely low specific conductance of the pond water, ~50µmhos/cm, and way lower than typical drinking water. To stay within the Pond's sound limit, we found it necessary to run the 500B at 16kJ and to salt the water around the spark head." [1] **Therefore, river water should result in higher sound-pressure levels.**

[1]ACTIX, Evaluation and Extrapolation of Measured Sound Levels from a High Intensity Pulsed Plasma (HIPP) Device, at NAVSEA – Dodge Pond Acoustic Measurement Facility, Niantic, CT. September 2003–August 2004

UNDERWATER-PLASMA ACOUSTIC GENERATION: BIOFOULING REMOVAL AND PREVENTION



- The photo sequence shows the shock wave generation and moving thru the water without any steam bubble. The final photo shows plate cleaned on both sides.[1]
- Tests performed at TRANSDEC showed severe biofouling removal on painted plates submerged in the San Diego Bay for several years without damage or removal of the paint

[1]ACTIX, *Advanced Conversion Technologies, Inc.* Overview for High Intensity Pulsed Plasma (HIPP) TECHNOLOGY, briefing circa 2016

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ACARS MULTIPLE POTENTIAL ATTACK VECTORS

APPLICATION	DESCRIPTION
Deter	Unlike the current electric or sound barrier approaches, ACARS would be capable of sending disruptive pulses downriver to keep the Asian carp from approaching the CSSC.
Stun	As the Asian carp approached the ACARS, the intensity of the shock waves could stun the fish, causing them to float to the surface for collection, if desired.
Kill	At even closer ranges, the intense ACARS shock waves would cause internal damage to the Asian carp, such as rupturing their swim bladder, leading to death. This species' connection of their swim bladders to their inner ear may make them more susceptible to this attack vector. Studies have also been conducted by the USGS on the impact of water cannon on juvenile Asian carp, as well as their eggs.
Disrupt Spawning	Since the ACARS could be fired in a repetitive fashion, it may be possible to disrupt the spawning activities of the Asian carp. It would be relatively straightforward to cause them to move to a new spawning area, preferably downriver, which then can be disrupted by moving the ACARS into this new spawning area. The net effect would move the fish downriver and decrease the number of Asian carp spawn.
Herd Fish Downriver	A permanently mounted ACARS system could keep Asian carp from passing upstream, or a system mounted on a boat could herd the Asian carp back downstream. More than one system could be used together – for instance, using a mobile unit to herd fish downstream past a permanent, deenergized barrier, which would then be energized as a barrier behind them. Even if other fish are driven downstream, they can be restocked once the river is clear of Asian carp.

Note: ACARS could be used within a lock to stun/kill invasive species in a confined volume.

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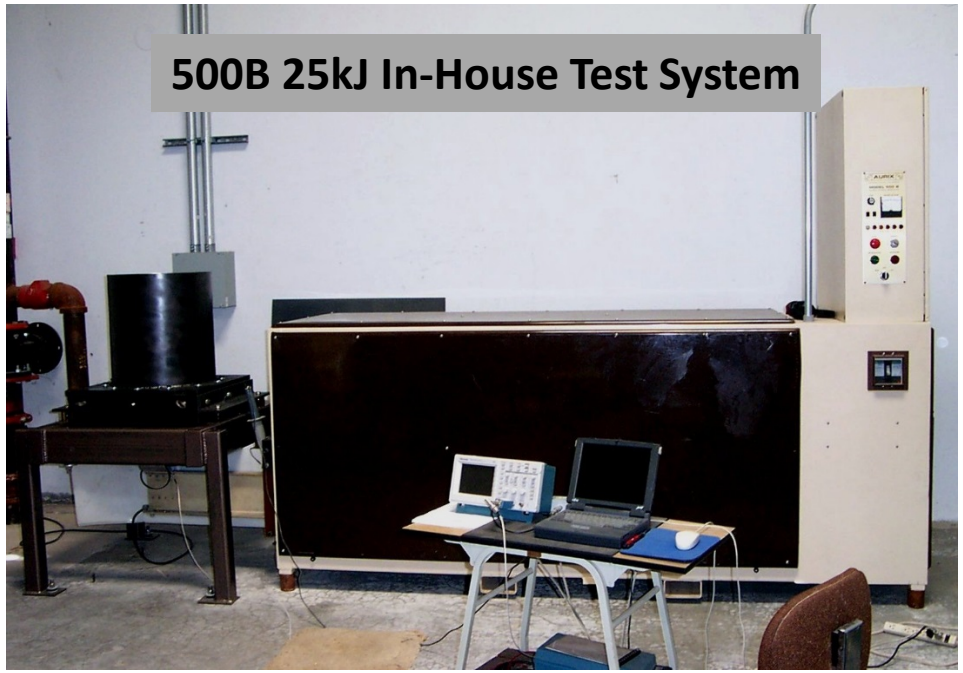
VINTAGE EXISTING HARDWARE : 500B HIPP SYSTEM

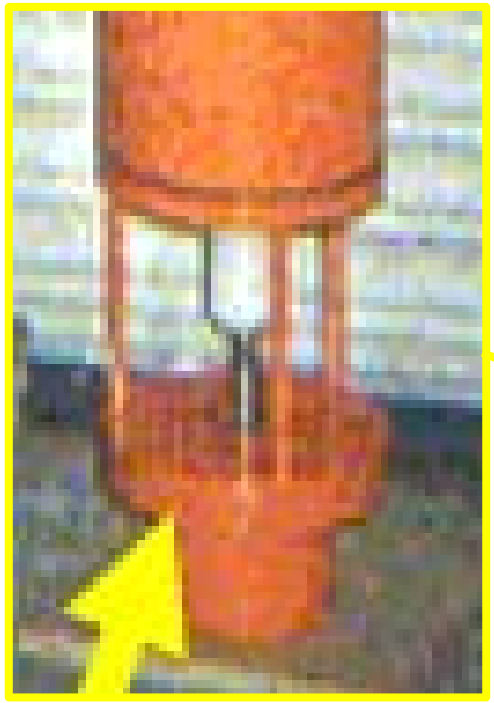


Approximate Dimensions	8’ Long, 3’ Wide, 7’ High
Weight	1500 Pounds
Line Power	240VAC, 3Ø, 25 Amps Demand
Output Peak Pulse Power	≥500MW
Pulser Capacitance	135MFD
Max Charge Voltage	20kV

- ACTIX designed and constructed the 500B 25kJ, 20kV pulser unit that transferred this energy to very low impedance loads, milliohms, in approximately 25µs with a resulting peak power of roughly a gigawatt.
- Unit has been used extensively for a wide range of customer tests; including wastewater recovery, mineral extraction, swimmer deterrence and food processing.
- Used 20-year-old pulser/spark head apparently sitting at Murphy’s Surplus with roughly a $233k price tag. (**Should develop new pulser.**) [1]

[1] Alan Murphy, Murphy's Surplus, 401 N Johnson Ave, El Cajon CA 92020

VINTAGE EXISTING HARDWARE: SEA LION DETERRENT DEVICE (SLDD)



Specifications

Input power -	208-240vac, 1Ø, 60 Hz									
Stored energy	3kJ			6kJ			12kJ			
Distance m	50	100	200	50	100	200	50	100	200	
Pressure Psi	4	1	¼	8	2	½	16	4	1	
Line power kva		3			6			9		
Duty Cycle										
Ave. sec.		5			5			5		
Burst sec.		2			2			2		

Note: Pressure scales linearly with stored energy

- ACTIX designed/constructed the SLDD 12kJ pulser unit that transferred this energy to very low impedance loads
- Stand-off Sea Lions from 50 to 200 meters
- Shown to be less effective than the HIPP system
- **Status of this pulser is unknown**

[1] Alan Murphy, Murphy's Surplus, 401 N Johnson Ave, El Cajon CA 92020

VINTAGE EXISTING HARDWARE: 750B SEA LION DETERRENT UNIT (SLDU)

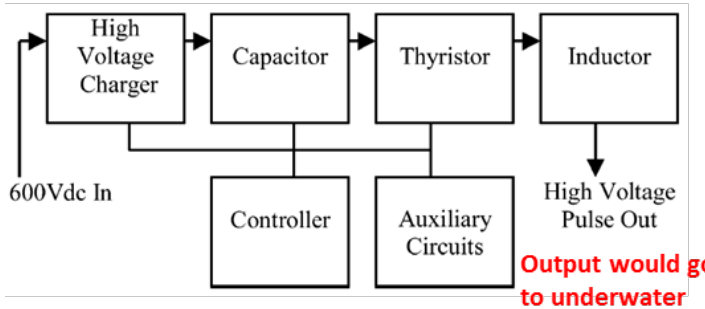
750B SEA LION DETERRENT UNIT

The 750B was deployed in Australia and demonstrated effective seal deterrence in a wide range of situations at an aquaculture installation. The 750B always drove off seals and prevented their return for over 8 hours. This was an opportunity to further develop and refine spark tip and electrodes from both mounting considerations and materials used in their construction.

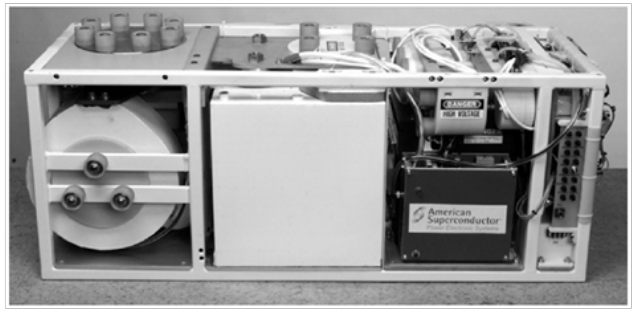
- 750B is likely in Tasmania and is owned by the Australian Government, and is thought to need refurbishment [1]
- More flexible for field testing and very effective in dealing with seals, with comparable energy and peak pressure of the 500B, but would be more difficult to obtain and restore.

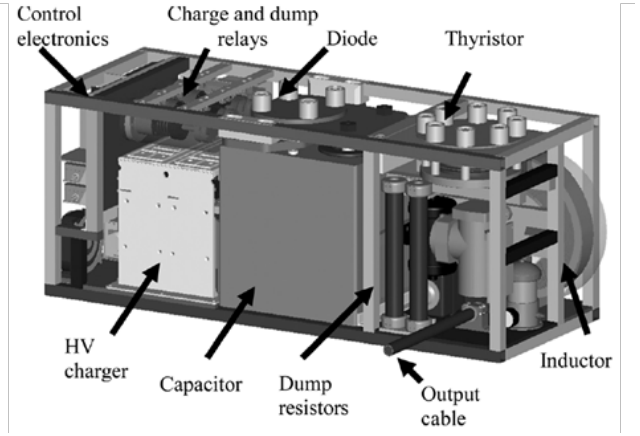
[1]ACTIX, *Advanced Conversion Technologies, Inc.*, private communication with Richard Ayers, February 2018

RELATED POSSIBLE TEST HARDWARE FOR INITIAL INVESTIGATION: BAE COMPACT ELECTROTHERMAL IGNITION PULSED POWER SUPPLY (ETIPPS)



Description	Value	Unit
Mass	219.5	kg
Length	1099	mm
Width	414	mm
Height	440	mm
Volume	0.2	m3
Energy storage at maximum voltage	114	kJ
Maximum voltage	6.5	kV
Maximum current output	47	kA



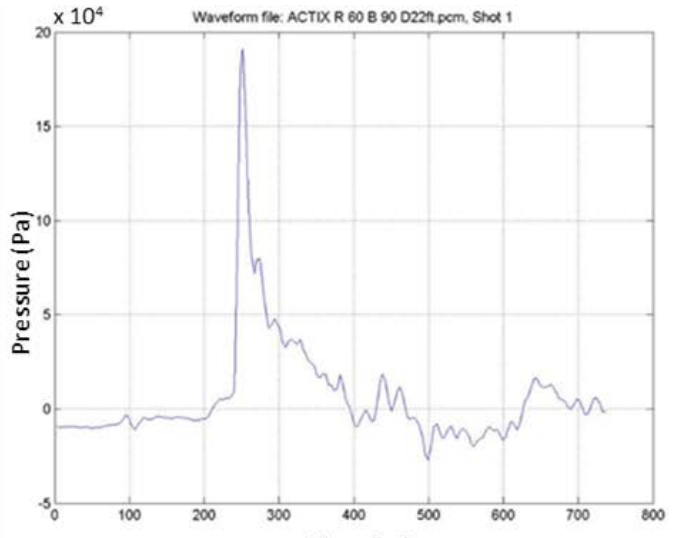


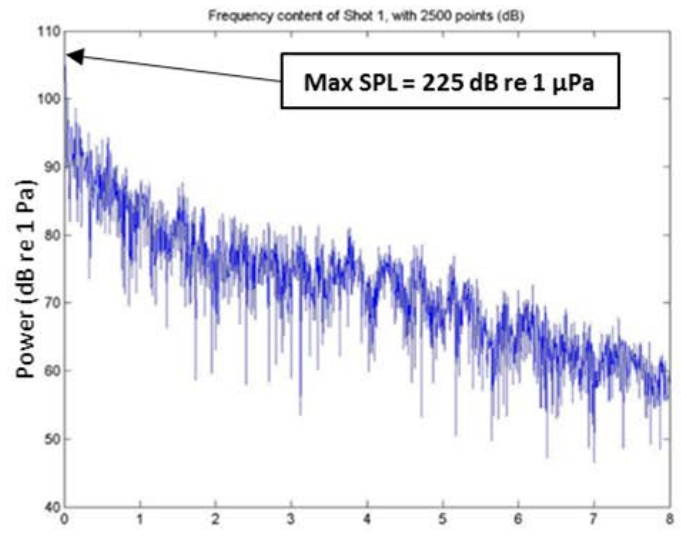
- Army electrothermal chemical (ETC) launcher program funded to advance ETC launcher technologies
- Includes development of ETC plasma injectors for 120-mm M829A2s and a 100-kJ pulsed power supply small and robust enough to be integrated into a combat vehicle
- Represents the higher end for compact high-energy-density power modulators. Can be leveraged by ACARS
- **Booz Allen has the required skills and capabilities to design/build the needed pulsed power modulator**

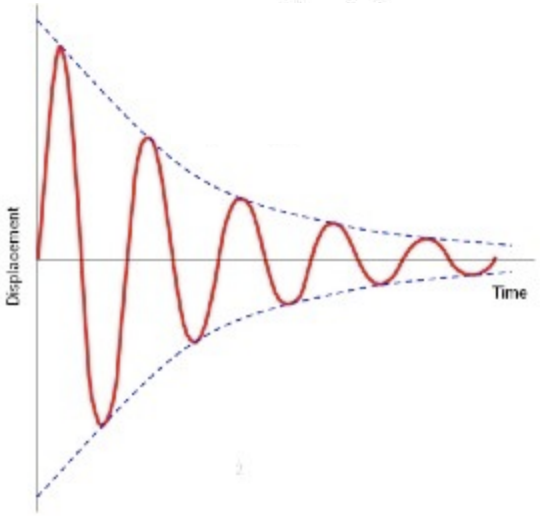
[1] Dyvik, Jahn, et al., Recent Activities in Electrothermal Chemical Launcher Technologies at BAE Systems, IEEE TRANSACTIONS ON MAGNETICS, VOL. 43, NO. 1, JANUARY 2007

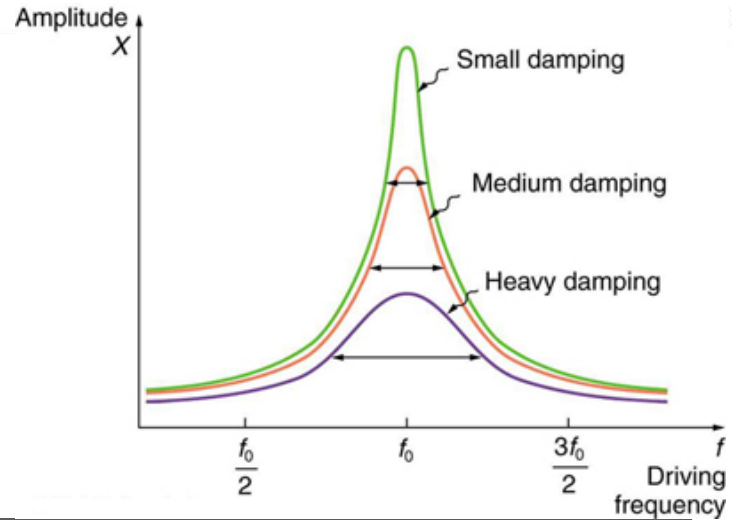
TAILORING THE GENERATED ELECTRICAL PULSE

- Basic electrical pulse parameters can be easily adjusted: risetime, falltime, energy, amplitude, etc.
- Most of the energy contained in a monopulse waveform will at low frequencies
- It should be possible to design an underwater discharge circuit that performs as a damped sinusoid rather than a monopulse
- This should have the effect of moving the radiated acoustic energy into a frequency range where the carp are more susceptible, and reduce impact to indigenous species
- Design for f_0 to be 1-3 kHz range





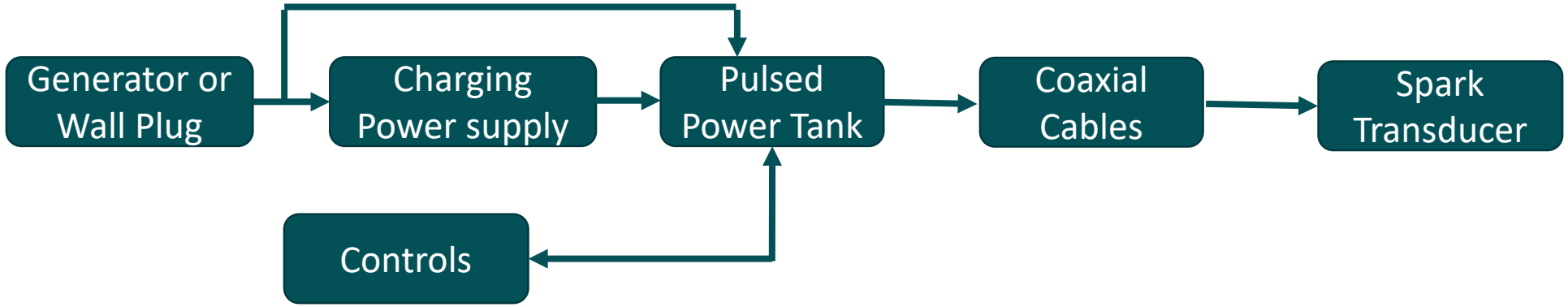




https://physics.stackexchange.com/questions/294047/non-resonant-but-efficient-frequencies

POSSIBLE PULSER OVERALL CONFIGURATION

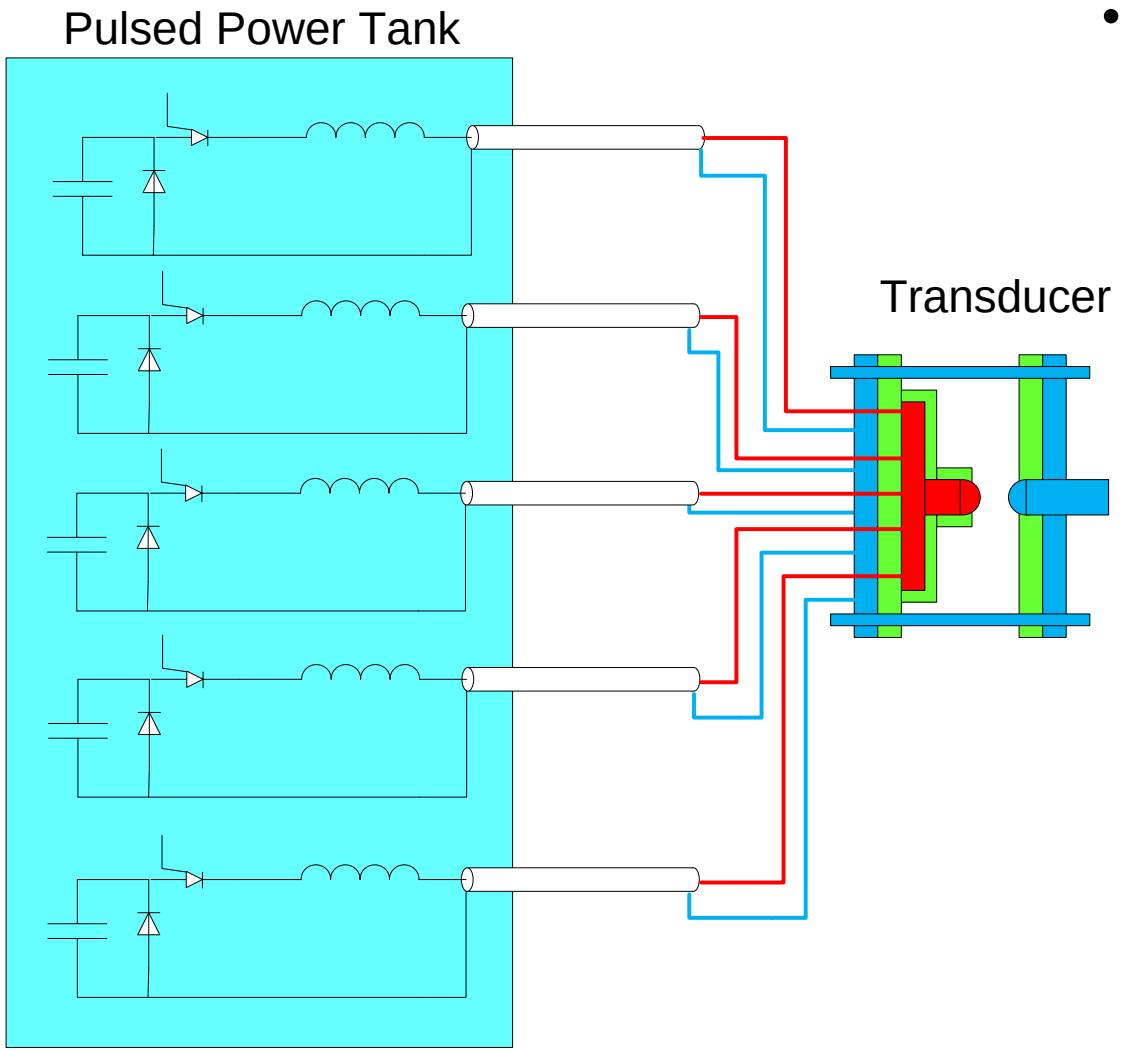
- Overall envision a metal tank housing the pulsed power and the charging power supply
  - A series of coaxial output cables connect the tank to the spark transducer
  - AC power input for Power Supply and tank controls hardware
    - Generator provides AC power (optional)
    - Could us batteries from prime power and use DC-DC conversion for charging
  - Fiber and diagnostics connection between tank and control console (laptop)



ACOUSTIC SPECTRUM VARIABILITY

- Spark transducer principles of operation
  - An underwater spark rapidly heats the water surrounding the arc, creating a gas bubble
  - Pressure pulse inside the bubble is controlled by the amount of heat dissipated in the arc by the electric circuit
    - Current amplitude and pulse duration affect the magnitude and duration of the pressure
    - Incompressibility of water propagates shock
    - After energy input ends, bubble collapses producing a negative pressure (need to verify)
- Frequency content of acoustic output may not be the same as electrical spectrum of pulse
  - Depends on the interaction of arc with water
  - An oscillating current will provide a series of heat pulses – one every half cycle
    - Current polarity does not influence polarity of pressure – unlike a speaker (Pushes but does not pull)
- A pulse train will repeat the acoustic signature of single pulse
  - Should produce a significant frequency component at the pulse repetition frequency (PRF)

POSSIBLE INITIAL CIRCUIT

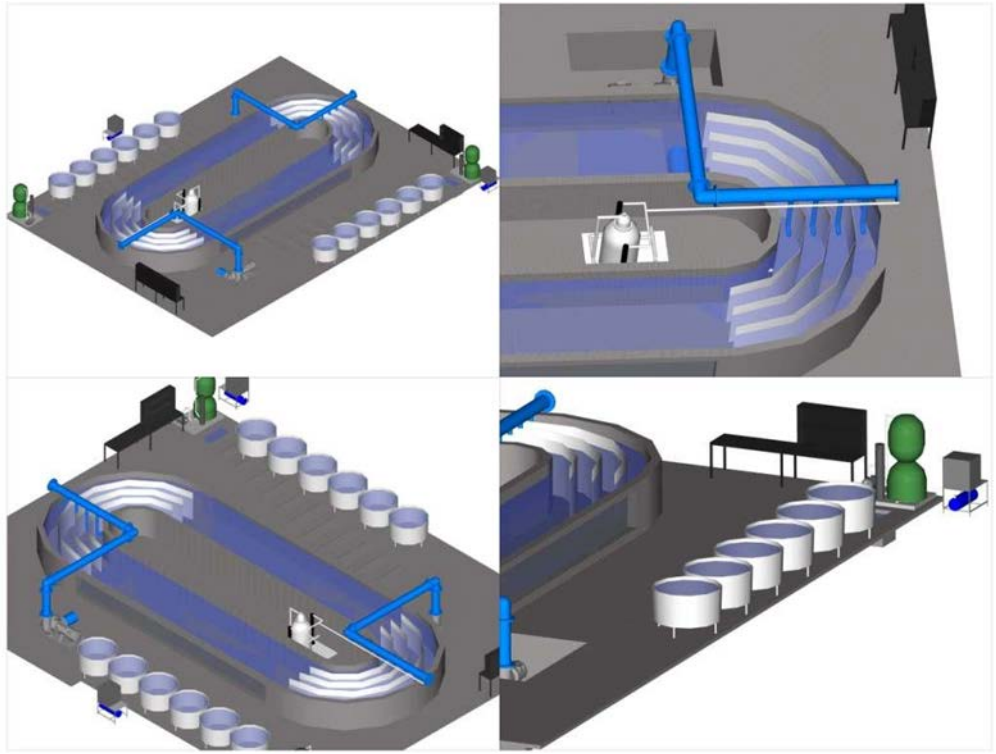


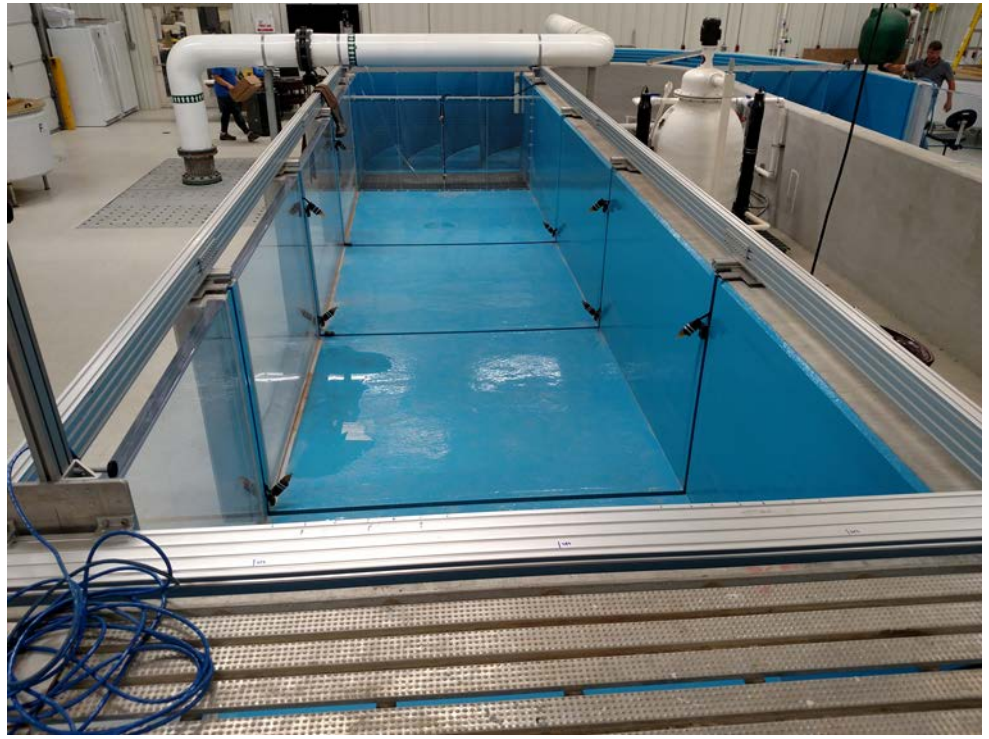
- Energy storage segmented into individually triggered modules
  - Modules produce unipolar pulse
  - Adjusting trigger times allows pulse shaping to control acoustic spectrum
    - Pulse train concentrates frequency at PRF
    - Trigger grouping controls pulse amplitude
    - Pulse shape synthesis possible
  - Allows programmed continuous variation of pulse spectrum if desired
  - Cable consolidation can be done at transducer, at tank, or a both
  - Individual cables allows use of standard smaller cables
    - Bundle maintains flexibility of transmission line
  - Allows system scalability and growth

PROPOSED HARDWARE

- Use off-the-shelf components as much as possible
  - Capacitors: Group single-winding capacitors to build bank
    - Allows flexibility in configuration
    - Need approximately 20 capacitors for 10kJ system
  - Switch/diode assembly: Stack devices in clamped assembly to achieve voltage rating
    - 6-8 devices per clamp assembly
    - Approximate total of 40 devices
  - 5 kJ/sec charging power supply
    - One pulse every 2 seconds
  - ~7kW generator
  - Controls: Leverage existing controls and interfaces

INITIAL TESTING FACILITY: ERDC LABORATORY FLUME IN VICKSBURG, MS





- ERDC Cognitive Ecology Flume provides an instrumented controlled test environment
- Electrical source will be designed with output energy variability to make it compatible with test environment physical specifications
- Additional opportunity to evaluate the fish size dependence on acoustic effects

AGENDA

- OVERVIEW
- CURRENT CONTROL MEASURES
  - Electric barriers
  - Sound sensitivity
  - Shock/noise generators
- UNDERWATER-PLASMA ACOUSTIC GENERATORS
- POTENTIAL ATTACK VECTORS
- ACARS RELATED TECHNOLOGY
- **SUMMARY/NEXT STEPS**

SUMMARY / RECOMMENDED NEXT STEPS

- Data is needed on the impact of the ACARS high-frequency shock waves on both the Asian carp and the indigenous fish species. Early efforts should address this discrepancy.
- We have the expertise needed to build the ACARS system and can team with the USACE and USGS team members to utilize their resources and expertise of the Asian carp and acoustic deterrence.
- If the ACARS is successful and approved for use, the focus would turn to producing units to support multiple placements in the Great Lakes basin, ensuring sufficient spares are on hand to keep the systems fully operational, and managing operations and maintenance of the systems in the field.
- Phased approach (PoP 12 months from Task Order kickoff):
  1. Identify suitable contract vehicle(s) for $275k level of effort
  2. Design/develop compact pulser/spark head with suitable energy storage, voltage, waveform (damped sinusoid?), and safety characteristics to support initial testing (9 months)
  3. Use prototype ACARS to conduct testing at ERDC Laboratory Flume in Vicksburg (2 months)
  4. Analyze results and determine next experimental/programmatic steps (1 month).