Acoustic Building Infiltration Measurement System (ABIMS)

2017 Building Technologies Office Peer Review

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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Project Summary

Timeline:

Start date: 10/1/2014

Planned end date: 9/30.2017

Key Milestones

1. Full Computer Simulations: 9/30/2015
2. First Lab Prototype: 8/1/2015
3. DOE Lab Corps: 11/2/2015 – Rename of Technology to SonicLQ for commercialization
4. First Field Prototype 4/1/2017

Budget:

Total Project $ to Date:

- DOE: $925K
- Cost Share: $65K

Total Project $:

- DOE: $925K
- Cost Share: $125K

Key Partners:

Illinois Institute of Technology
SonicLQ LLC

Project Outcome:

Develop a new building infiltration measurement system using acoustics to replace blower door IR camera testing.

The new system will be capable of measuring infiltration rates on buildings of all sizes and at all stages of construction completion. This will enable changes to building code resulting in potential energy savings of upwards of 0.6 quad per year

Purpose and Objectives

Problem Statement:

- Infiltration through envelopes represents a significant portion of a buildings heating and cooling loads, especially in heating climates.
- Infiltration measurement of commercial buildings is difficult so building energy code does not require infiltration measurement to show compliance.
- Weatherization of existing commercial buildings is made more difficult because of the inability to quantitatively measure infiltration to quantify savings and prioritize sealing

Target Market and Audience:

- Full target market is the entire commercial and residential building market which waste over 3 quad of energy annually due to infiltration (BTO Scout)
- The specific target audience is firms that provide infiltration measurement, building commissioning, and building weatherization
  - The initial target markets are commercial building envelope commissioning agents and military bases

Purpose and Objectives

Impact of Project:

- The main outcome of this project is a new technique for measuring building infiltration and commercialization as SonicLQ

SonicLQ will be a *disruptive technology* because it will make quantitative infiltration measurement on all commercial buildings practical for the first time. SonicLQ will

- Enable stricter infiltration rates in building energy code
- Improve compliance with code
- Allow quantitative assessment of energy savings from weatherization and infiltration reduction of existing buildings which is required to justify and finance such retrofits

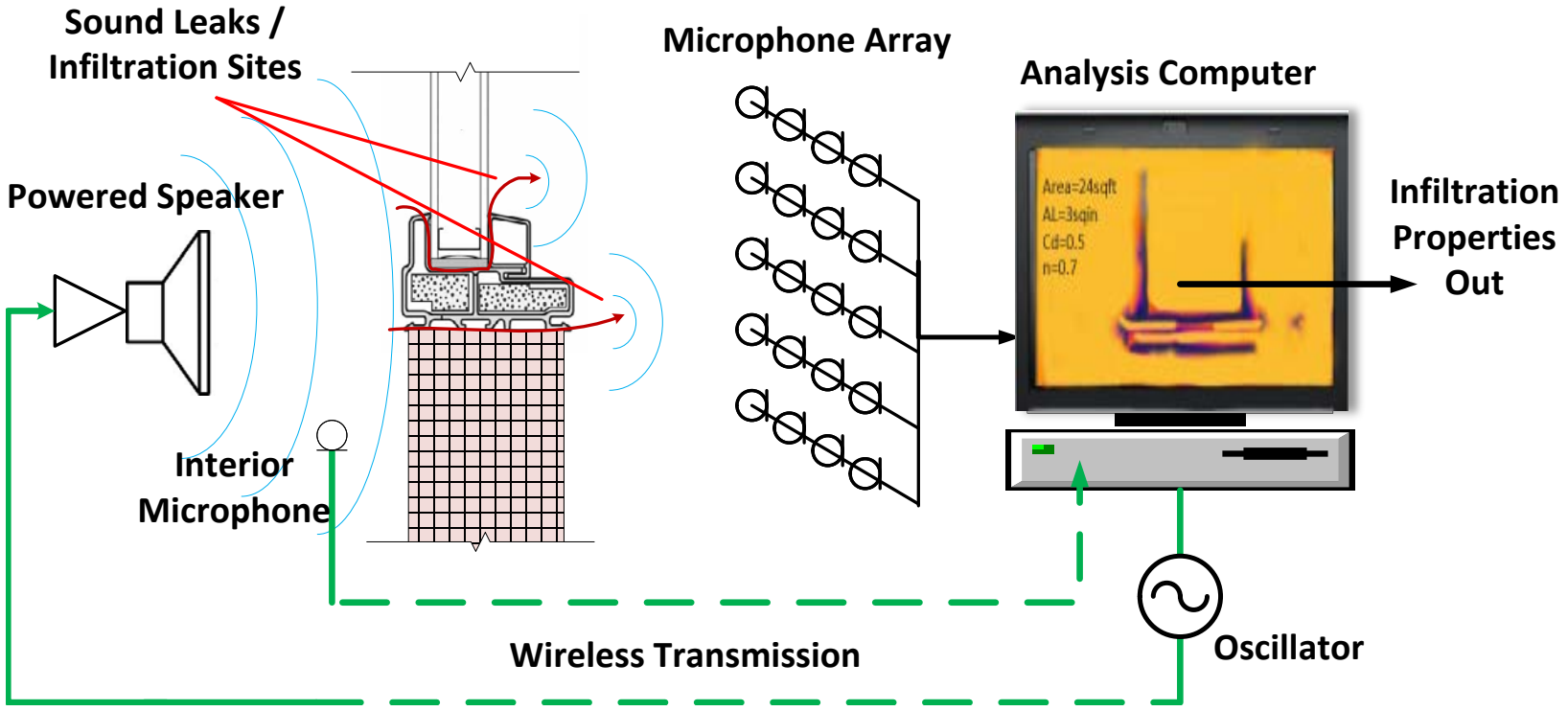
Achievement will be measured by

- **Near Term: Patent Application**
- **Short Term: Commercialization of the technology within 2-3 years**
- Long Term: Adoption of the technology by industry and changes to building code

Approach

Approach:

- SonicLQ ensonifies a portion of a building enclosure, measures the sound leakage using Nearfield Acoustic Holography (NAH), and uses the acoustic leakage information to estimate the infiltration properties



Approach

Key Issues:

- Need to quantitatively measure acoustic properties of leaks at a distance.
  - At a distance is necessary to make measurements practical and low cost.
- Need to be able to take measurements with other intruding sounds present
  - Want to be able to measure during construction or when occupied.
- Need to develop relations between acoustic properties and infiltration properties of an enclosure section.
  - Relations required to get infiltration information from acoustic data.
- Need to identify first customers who's problems can only be solved with SonicLQ

Distinctive Characteristics:

- We will use patent pending advanced acoustic measurement techniques to isolate and quantify the acoustic properties of the leaks, reject background noise, and convert acoustic properties to infiltration properties

Progress and Accomplishments

Selected Equivalent Source Method (ESM) for NAH inversion

- Completed systematic study of four most popular NAH inversion methods (DFT, SONAH, BEM, and ESM) and found that for this problem, ESM provides the best imaging with reasonable computational effort and **is the best NAH inversion method to use for SonicLQ**

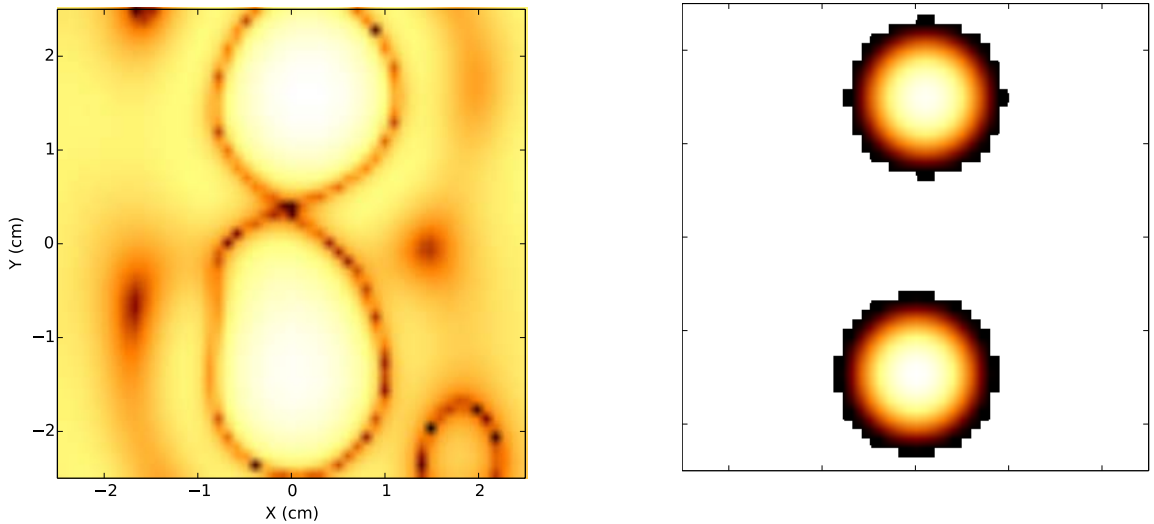
Developed new matrix regularization method for extending hologram measurement distance

- Most researchers use the extreme nearfield with the measurement distance about the spacing of the microphones. We want to make measurements at a distance of several feet if possible. This requires filtering eigenvalues of the propagation matrix (aka matrix regularization) before inversion
- We found a new NAH propagation matrix regularization method that lets us extend the distance of measurement to 16x the microphone spacing.
- We are continuing research to try extend that to 24x or 36x to allow us to have 1” microphone spacing and take measurements at a distance of 2ft or 3ft from the wall.

Progress and Accomplishments

Developed a beamforming algorithm for long distance snapshot

- Implemented a version of the CLEAN-SC beamforming algorithm that allows one to take a long distance, large aspect ratio “acoustic picture” at a long distance. This allows user to find potential leak areas and focus the close microphone array measurements only on those areas, speeding up measurement using Sonic-LQ

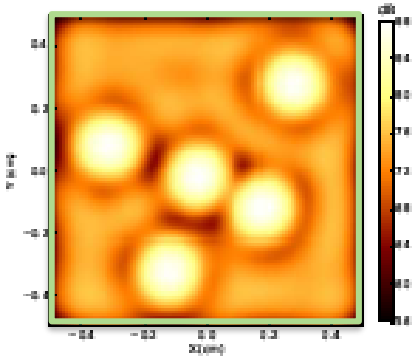


Long distance imaging of 2 cm diameter speaker sources at a distance 10m with a standard beamforming algorithm (left) and the improved CLEAN-SC algorithm (right)

Progress and Accomplishments

Began development of a "patch" algorithm for extending imaging beyond boundaries of the microphone array for the NAH measurements

- If successful will allow users to reduce number of NAH snapshots they need to take, speeding up use of SonicLQ
- Have had good imaging success shrinking array to 1/4 of area under test with acceptable imaging.
- Goal is to reach array area being able to be about 1/9 the area under test



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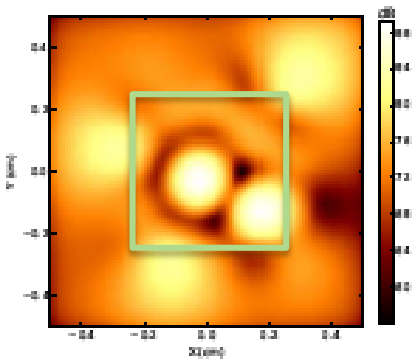

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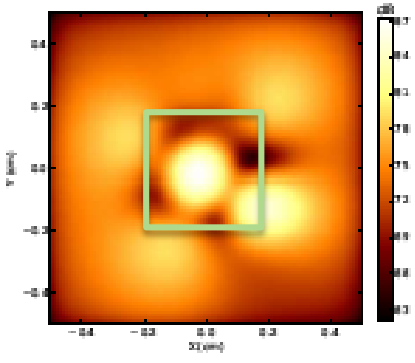

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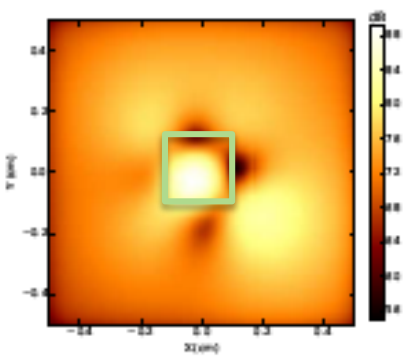

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Progress and Accomplishments

Updated Technical Potential Energy Savings from Code Changes Estimated

- Technical Potential Energy Savings from a 20% reduction in infiltration enabled by SonicLQ estimated to be over 0.6 Quads annually (BTO Scout)

Other Progress

- Creating an Acoustics Laboratory at Argonne for ongoing lab work
- Equipment and microphone array transferred to Argonne from IIT
- Field measurement will occur at Argonne

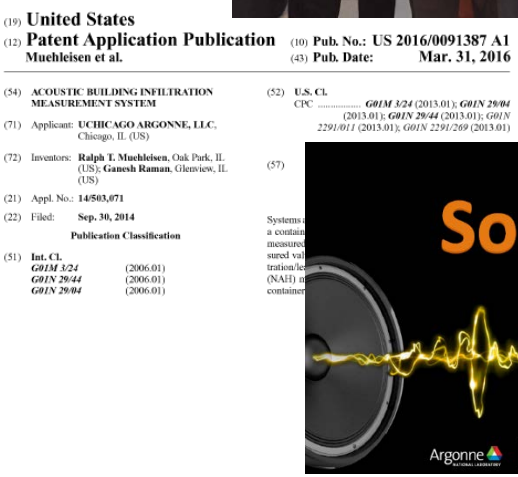
Market Impact

- SonicLQ LLC incorporated for licensing and commercialization
- Over 80+ market and potential customer interviews as part of DOE Lab-Corps
- Pitched SonicLQ at two investment competitions Clean Energy Trust Challenge and USG Demo Day

Progress and Accomplishments

Awards/Recognition:

- Fall 2015: ABIMS selected for DOE Lab-Corps Cohort 1 as SonicLQ – The Sonic Leak Quantifier
  - Won award for best video
- Spring 2016: SonicLQ selected as a finalist for Clean Energy Trust Challenge
- Patent Application Published, Muehleisen, Ralph T., and Ganesh Raman. 2016. ACOUSTIC BUILDING INFILTRATION MEASUREMENT SYSTEM. 20160091387, filed September 30, 2014, and published
- Fall 2016: SonicLQ was selected as a finalist at US Gypsum "Demo Day" pitch competition



(19) **United States**
(12) **Patent Application Publication**
Muehleisen et al.

(10) **Pub. No.: US 2016/0091387 A1**
(43) **Pub. Date: Mar. 31, 2016**

(54) **ACOUSTIC BUILDING INFILTRATION MEASUREMENT SYSTEM**

(71) Applicant: **UCHICAGO ARGONNE, LLC**, Chicago, IL (US)

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(21) Appl. No.: **14/503,071**

(22) Filed: **Sep. 30, 2014**

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G01N 29/44 (2006.01)
G01N 29/04 (2006.01)

(52) **U.S. Cl.**
CPC *G01M 3/24* (2013.01); *G01N 29/04* (2013.01); *G01N 29/44* (2013.01); *G01N 2291/011* (2013.01); *G01N 2291/269* (2013.01)

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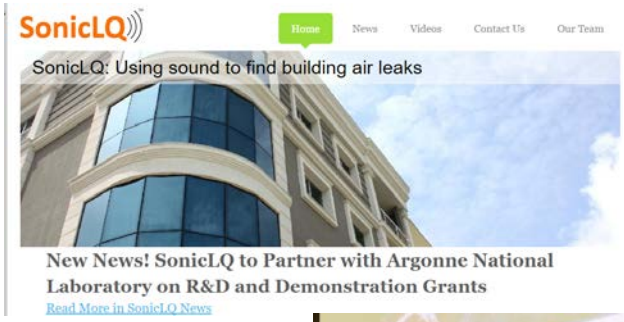
Project Integration and Collaboration

Project Integration:

SonicLQ is being introduced to industry through:

- Customer discovery interviews (80+)
- Product Web Page
- Pitch Competitions
  - Clean Energy Trust
  - USG Demo Day
- DOE Technology Showcases
  - EERE Lab Industry Day (Fall 2015)
  - EERE Lab Impact Summit (Spring 2016)
  - DOE LINKS-NYC (Summer 2016)



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Project Integration and Collaboration

Partners, Subcontractors, and Collaborators:

- New Argonne Team Member: Postdoc Kanthasamy Chelliah. Kanthasamy was previously a member of the IIT team as a grad student researcher

- New Partner for Commercialization: SonicLQ, LLC. CEO is Bill Shadid, the industrial mentor for the Lab-Corps SonicLQ team.

- Previous Partner: IIT
  Subcontract with IIT ended in June 2016. IIT PI moved to new institution as a Vice Provost and is no longer research active. All lab worked moved to the new Acoustics Lab at Argonne

SonicLQ

Project Integration and Collaboration

Communications:

Work has been presented at a number of conferences including ASME, Acoustical Society of America (ASA), Institute of Noise Control Engineering (INCE), Internoise, and Berlin Beamforming Conference

Work so far has been submitted to several archival journals

List of Journal and Conference Papers

Communications: Bibliography

Journal Papers (From 2016 and in review)

Chelliah, Kanthasamy, G. G. Raman, and R. T. Muehleisen. “An Experimental Comparison of Various Methods of Nearfield Acoustic Holography.” *Submitted to Journal of Sound and Vibration*.

Chelliah, Kanthasamy, G.G. Raman, and R. T. Muehleisen. “Conditional generalized cross validation for nearfield acoustic holography.” *Submitted to Acta Acoustica*

Chelliah, Kanthasamy, G. G. Raman, and R.T. Muehleisen. “ An experimental demonstration of the effect of sensor phase error on the nearfield acoustic holography reconstructions” Submitted to JASA-EL

Chelliah, Kanthasamy, Ganesh G. Raman, and Ralph T. Muehleisen. 2016. “Enhanced Nearfield Acoustic Holography for Larger Distances of Reconstructions Using Fixed Parameter Tikhonov Regularization.” *The Journal of the Acoustical Society of America* 140 (1): 114–20.

Conference Papers (Only from 2016)

Muehleisen, Ralph T., Kasanthamy Chelliah, Hirenkumar Patel, and Ganesh Raman. 2016. “Modifying Nearfield Acoustic Holography for Use in Building Leak Detection.” *The Journal of the Acoustical Society of America* 139 (4): 2109–2109.

Chelliah, Kanthasamy, Ganesh Raman, and Ralph Muehleisen. 2016. “On the Factors Affecting the Performance of the Generalized Cross Validation Method in the Context of Nearfield Acoustic Holography.” In *54th AIAA Aerospace Sciences Meeting*. American Institute of Aeronautics and Astronautics.

Patel, Hirenkumar J., Kanthasamy Chelliah, Ganesh Raman, Ralph T. Muehleisen, and Eric Tatara. 2015. “Detecting Building Leakages Using Nearfield Acoustic Holography Technique: A Numerical Simulation (A).” *The Journal of the Acoustical Society of America* 137 (4): 2233–2233.

Next Steps and Future Plans

Next Steps and Future Plans:

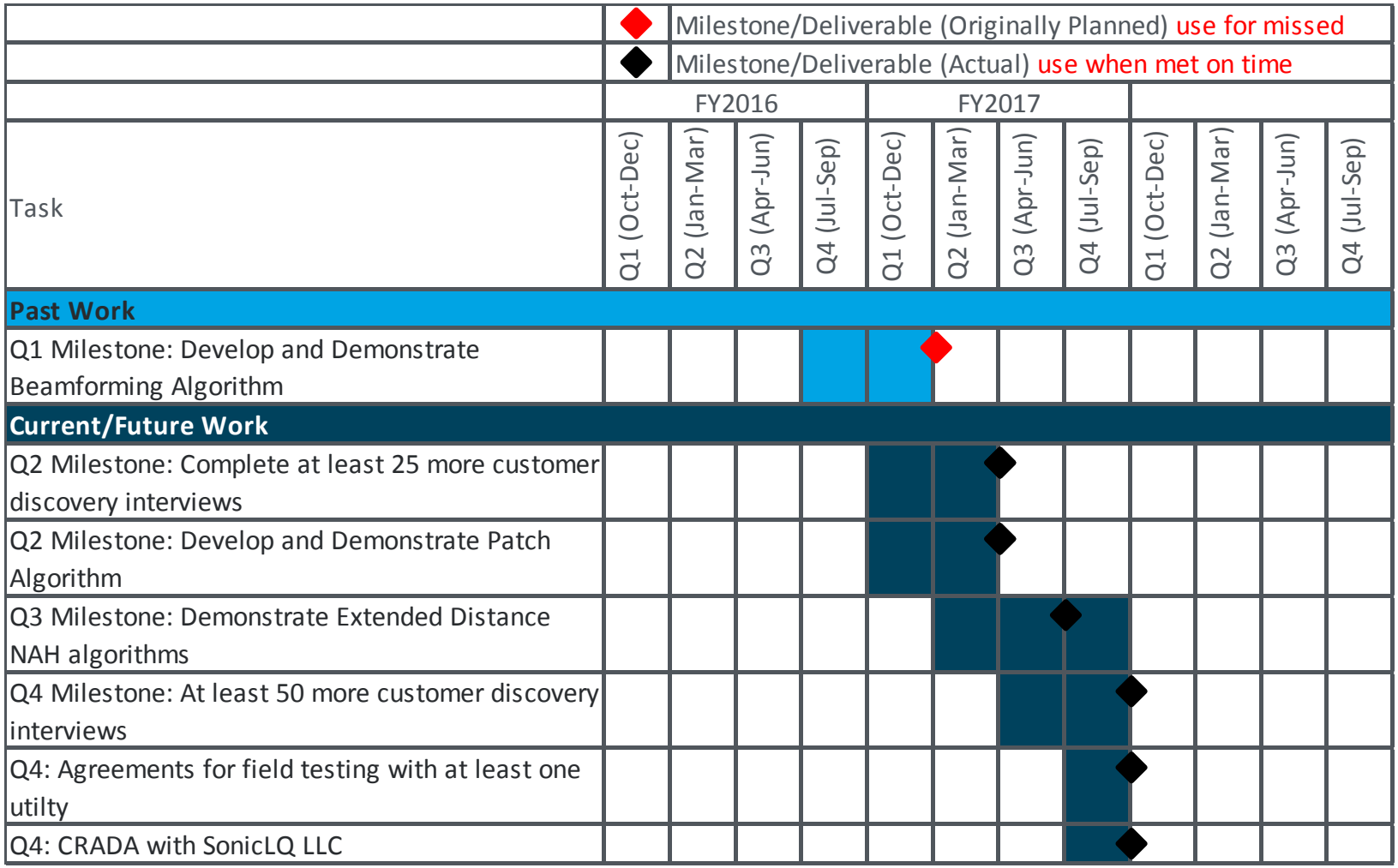
- Licensing to SonicLQ LLC and CRADA for ongoing R&D
- CRADA with USG for adaptation of SonicLQ as an internal R&D Tool
- Ongoing customer discovery by both SonicLQ LLC and Argonne
- $1M DoD ESTCP project for Argonne, SonicLQ LLC, and the CERL for comparative testing on two military bases and development of documentation and DoD standards for using SonicLQ to start in 2017
- Application to U. Chicago Innovation Fund for SonicLQ LLC in Mid 2017
- Application in 2018 for DOE TCF funds
- Nomination for R&D 100 award in 2018

REFERENCE SLIDES

Project Budget

Project Budget: $650K FY14-16, $275K FY17 with $65K Cost Share from Partner IIT
Variances: 1 year no cost extension in Q4 of FY15 for FY16 from original award
Cost to Date: $710K ($650k FY13-16 + $60K FY17)
Additional Funding: $75K of DOE funding in FY16 through DOE Lab-Corps used to investigate path to market and do customer discovery
$5K of ANL internal funds for technical assistance to SonicLQ for application to Clean Energy Trust Challenge. $1M of demonstration funding from DoD awarded through ESTCP with project to start in middle of FY17

Budget History					
Q1– FY 2016 (past)		FY 2017 (current)		FY 2018 – (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$0	$0	$275k	0	$0	$0


Milestone/Deliverable (Originally Planned) use for missed
Milestone/Deliverable (Actual) use when met on time
FY2016
FY2017
Task
Q1 (Oct-Dec)
Q2 (Jan-Mar)
Q3 (Apr-Jun)
Q4 (Jul-Sep)
Q1 (Oct-Dec)
Q2 (Jan-Mar)
Q3 (Apr-Jun)
Q4 (Jul-Sep)
Q1 (Oct-Dec)
Q2 (Jan-Mar)
Q3 (Apr-Jun)
Q4 (Jul-Sep)
Past Work
Q1 Milestone: Develop and Demonstrate Beamforming Algorithm
Current/Future Work
Q2 Milestone: Complete at least 25 more customer discovery interviews
Q2 Milestone: Develop and Demonstrate Patch Algorithm
Q3 Milestone: Demonstrate Extended Distance NAH algorithms
Q4 Milestone: At least 50 more customer discovery interviews
Q4: Agreements for field testing with at least one utilty
Q4: CRADA with SonicLQ LLC