THE ADVANCEMENT OF CEILING ARRAY TECHNOLOGY EXPLORING THE CHALLENGES OF CREATING A MICROPHONE ARRAY WITH AN INTEGRATED LOUDSPEAKER

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1 INTRODUCTION

Flexible working has caused a rise in the demand for technology to be adaptable whilst remaining unobtrusive in design and simple for end-users. Whether at home, in small spaces, medium-sized meeting rooms or boardrooms, end-users are looking for a consistent experience in audio quality to interact with other colleagues.
Contemporary ceiling array microphones and audio 'ecosystems' are designed to capture audio throughout a room (or in the desired areas of a room) so an end-user can walk into a space and with minimal setup: join a conference call, broadcast a webinar or record a meeting.

1.1 Room Solutions Before 2005

Whether amplifying a voice, 'voice lifting' or staging a conference call, the requirement for microphone technology in the conferencing space has shaped meeting room design for the past 50 years [1]. The typical boardroom would need the integration of either multiple gooseneck or boundary microphones within a room to capture the desired participants. Integration of these microphones offered challenges of ambient noise, considerations concerning the space the technology takes up within a room and its aesthetics. Early ceiling microphones (or usually boundary microphones put into the ceiling), whilst low-profile in design, were often less preferred due to a larger pick up of ambient noise. They were not a viable solution for voice lift due to this.

1.2 Speakerphones

Triangular-shaped speakerphones sat as a centrepiece of most boardroom tables through the 1990s – early 2000s for teleconferencing calls. Whilst audio quality for speakerphone conferencing was typically low (in comparison to today's network audio systems), these systems were at a low price point, quick to deploy, and end-users could operate them with limited training/assistance. The user experience usually matched their desk telephone system, and audio quality remained consistent with their desk phone technology.

1.3 MEMs Microphones, DSP and Array Technology

In the 2010s, developments in Digital Signal Processors (DSPs) allowed leading audio brands to create audio devices with features including: beamforming audio, voice activity detectors, muted zones, noise cancellation, echo cancellation and auto-mixed microphones. With the development of Micro Electro-Mechanical System (MEMs) microphone technology, possibilities have increased to allow audio engineers to create more ergonomic microphone designs and innovate with microphone array architecture, including over 100 microphones within a single device like Shure's MXA920 [6] Ceiling Array Microphone.

A combination of DSP and beamforming audio using MEMs capsule microphones are found in some of the market-leading video bars, which arguably have replaced the teleconferencing speakerphones of the previous decade in their affordability and ease-of-deployment.

Shure popularised the use of array microphones in premium meeting spaces around the world. Their award-winning Microflex® Advance™ array microphones have set the benchmark for corporate, education, and government environments. Shure introduced its Microflex Advance array microphones in 2016. Microflex Advance array microphones combine beamforming technology with advanced digital signal processing to deliver unmatched performance for AV conferencing, camera tracking, voice lift, and sound reinforcement.

2 MXA902 CEILING ARRAY MICROPHONE AND LOUDSPEAKER

2.1 MXA902- Introduction

The MXA902 is the first ceiling array microphone with an integrated wide-dispersion loudspeaker and IntelliMix® DSP for AV conferencing in small and medium spaces. The product is connected and powered by a single CAT5/6 cable (PoE+) via Dante or AES67. It is a Microsoft Teams Certified and Zoom Certified product when paired with Shure ANIUSB-MATRIX audio interface. [4]

This product was conceptualised as a complete room audio solution at a more affordable overall installation cost than a system with a microphone array, plus standalone loudspeakers. The open question was whether a loudspeaker could be successfully integrated into a MXA910 [5] ceiling array microphone with minimal changes to the existing mechanicals while maintaining premium acoustic coverage and AEC characteristics. The next two key challenges Shure engineers faced were:

- *Designing a speaker that would fit in the designated space.*
- *Solve feedback, mechanical and acoustical vibrations, to correctly integrate the speaker.*

The MXA902, was introduced to the market on 31st May 2023.

2.2 Microphone Overview

The microphone element of the MXA902 includes Single-Zone Automatic Coverage™ technology that captures audio within a 20 by 20 foot (6.1 by 6.1 meter) area. The main support panel and frame are made from aluminium. The MEMs microphone elements are placed on a single, very large PCBA: Shure call the “megaboard”. [2] These are combined through a proprietary beamforming algorithm to create the pickup lobes. The high directivity of the lobes creates similar sonic characteristics of a ‘close mic’d’ meeting participant: similar to a gooseneck mic 12” away from a talker. There is also frequency shaping and noise reduction active that contributes to the sonic character.

MXA902 uses a similar microphone technology to Shure’s flagship MXA920 but within a reduced coverage area. Audio lobes are active within the microphone’s coverage area which are sent to the automix output when a meeting room participant talks. Internally, the automix output is derived from one or more lobes through a technology called Automatic Lobe Deployment (ALD). There is a localisation “searchlight” and when it finds sonic activity, the Voice Activity Detection (VAD) is applied to determine if it is a talker or not. If it is a talker, a lobe is deployed to that location. Multiple lobes can be deployed to capture simultaneous talkers within the coverage area. The Autofocus algorithm will adjust the lobe to account for small changes in the talker location (within a specific area). If additional lobes are needed, lobes can be ‘recycled’ and redeployed to a new area.[2]

Alterations to the MXA902 microphone from the MXA910 and MXA920 products were focused on the inclusion of the speaker, class-D amplifier, supporting circuitry and resulting differences in the capture area.

Within the MXA910 and MXA920 products, lobes can be flexibly positioned within a 30 by 30 foot (9 by 9 meter) area to focus the audio in particular areas of the room. Within the MXA920 coverage area, both focus and muted zones can be applied.
In contrast, the MXA902 has a fixed 'Single-Zone' coverage in a smaller 20 by 20 foot area. The MXA902 is focused on the simplicity of its single coverage zone, automatically covering all talkers without any manual lobe setup or steering. This functionality helps when positioning the MXA902 more toward the display in the room for optimising the listener's sense of directionality as audio is coming from where they see the far-end video displayed.[2]

2.3 Integrating a Loudspeaker

Integrating the loudspeaker met several hurdles. Especially, since one of the key project requirements was to minimally differ from the MXA910/MXA920. It was challenging for the Shure engineers to find the correct materials, power supply, meet total weight requirements, size requirements, and deliver audio to the defined area.

The speaker design is a first-order, sealed system with a volume of about 0.4 litres. The system uses a 2.5-inch, full-range loudspeaker, which was favourable due to its high sensitivity, wide dispersion, and performance in a sealed enclosure. [2]

The project end goals guided the material selection of the loudspeaker enclosure: the height of the loudspeaker enclosure could not surpass that of the processor board housing, and the speaker itself had to fit in the corner of the array. To overcome these obstacles: a loudspeaker with a neodymium magnet was selected to minimise height. The loudspeaker enclosure had to be metal to pass certain flammability requirements and needed to be rigid enough to prevent vibration of the walls. So, an aluminium alloy was tested and selected for its construction.

Designing the isolation system was an important part of the process. The speaker vibration needed to be isolated from the PCB and the mechanical structure. The internal volume of the enclosure had to work well with the selected speaker driver, and the isolation of the enclosure had to work well with the rest of the assembly.

In an interview, [2] Shure Sr Acoustical Engineer Matthew Koschak commented:

"Many challenges were met attaching the loudspeaker to the array. It initially induced a lot of buzzing, rattling and resonances in the frame and grill structures. The SPL produced by the loudspeaker was in some cases high enough to move the grille fabric in a way that can be audible. Mitigating these issues involved treatments with damping materials and some mechanical modifications. To further isolate the speaker vibration from the PCB and mechanical structure an isolation system was developed where the speaker enclosure sits on three silicone rubber isolators.

Naturally, having a loudspeaker only inches away from a large number of microphones is going to present problems. One main problem is impact to the Acoustic Echo Cancellation (AEC) system. This required extensive tuning of the AEC system. The close proximity of the speaker to the microphones also raised the concern of exceeding the maximum sound pressure level capability of the microphones, though ultimately it was determined that increasing the Acoustic Overload Point (AOP) of the microphones had little impact."

To meet the requirements of simple deployment the MXA902 is powered over the same ethernet network cable that the audio data travels - Power Over Ethernet (PoE). There is a limit on the amount of power that can be delivered to a device over an ethernet cable and there are several versions of the standard with varying power outputs (PoE is 15.4 Watts, PoE+ is 25.5 watts). The product is designed to operate on PoE+ but, this did not come without its challenges. Shure implemented both hardware and software limiters to balance power requirements between the class D amplifier and the processing power of the onboard DSP.

The key focus of the speaker is voice reproduction for conferencing audio. Shure spent a lot of time tuning the frequency response for speech as well as for meeting the Microsoft Teams Audio Specifications. This included equalisation of the speaker response and tweaks to the Acoustic Echo Canceller, following strict limits on single and doubletalk echo performance.

2.4 DSP

The Microphone and Speaker are linked intrinsically by the Digital Signal Processor (DSP). The onboard Shure IntelliMix DSP includes Acoustic Echo Cancellation (AEC), Noise Reduction, automatic mixing, compression, Automatic Gain Control (AGC) and EQ. The optimisation of these features contributes largely towards the overall functionality of the product.

When a talker is detected, the microphones are gated on by automatic mixing. [2] Automatic gain control, automatically adjusts channel levels to ensure consistent volume for all talkers in all scenarios. For quieter voices, it increases gain. For louder voices, it attenuates the signal. Automatic gain control happens post-gate (after the automixer) and does not affect when the automixer gates on or off.

Noise reduction significantly reduces the amount of background noise in a signal caused by projectors, HVAC systems, or other environmental sources. It is a dynamic processor, which calculates the noise floor in the room and removes noise throughout the entire spectrum with maximum transparency. [3]

AEC is a DSP algorithm that gets rid of distracting echo in a microphone signal. AEC identifies the far-end signal and stops it from being captured by the near-end microphone. During a call, AEC works constantly to optimise processing as long as far-end audio is present. AEC is necessary for clear, uninterrupted calls. The MXA902 uses the built-in loudspeaker as the AEC reference signal.

In an interview, Shure Sr Acoustical Engineer Matthew Koschak [2], commented:

“The largest engineering challenge presented with the MXA902 was the loudspeaker is picked up much louder than the near-end talker which makes the AEC system’s job difficult. Many hours went into tuning the signal processing to minimise echo. As an acoustical engineer, we worked really closely with the DSP engineers to fine-tune the system.”

Multiple simultaneous talkers are able to be processed into 1 output channel by the onboard Intellimix DSP. The MXA902 has:

- 2 input channels
- 1 automix output with IntelliMix DSP

The 2 input channels are summed and sent to the loudspeaker's output. These input channels are useful to send a far-end signal and program audio to the loudspeaker. The MXA902's AEC reference is the same signal sent to the integrated loudspeaker and can't be changed. [3]

Other features, including the EQ and compressor, can be manually adjusted to control the dynamic range of the signal, improve speech intelligibility, reduce noise, and room irregularities.

2.5 Testing

Shure conducted extensive testing in the anechoic chamber to validate the frequency response and polar pattern of the microphone lobes at various steering angles.
For the speaker, a lot of time was spent testing frequency response and distortion of the speaker system to optimise the enclosure. Shure went through many iterations of the enclosure design. The initial design intent was to use a plastic speaker enclosure and prototypes were 3D printed to speed up development and allow quick iteration on the design. Problems with this method included the

material flexing and poor sealing between the two halves. The mechanical team added ribs and additional fasteners to improve the performance, but eventually, a design utilising a cast metal structure was chosen, which was ultimately necessary to pass the flammability requirements. Metal also made the enclosure heavier which helped the engineer's efforts to design the isolation mounts. To verify the isolation system design, tests included mounting accelerometers on the speaker enclosure and main support structure to look at the transmission of the speaker vibration to the rest of the assembly.

The next phase was Microsoft Teams audio testing, a series of comprehensive tests that looks at the total performance of the product when used in a conferencing application and includes frequency response of the mic, speaker, distortion, noise, and echo performance. Different DSP configurations and 'running tests' were carried out in anechoic and reverberant room environments. These tests took place during the COVID-19 pandemic, which brought additional personnel challenges to bring focus to this detailed work.

2.6 Installation Considerations

The MXA902 is an integrated microphone/speaker solution, ready for quick deployment in small to medium-sized meeting rooms. It can be mounted into a standard 24 by 24 inch (60 x 60 cm) ceiling tile grid or suspended, usually via gripple or a pole mount. The full list of mounting options are described within the user guide.

Shure recommend the following installation best practices [3]:

- Do not place the microphone behind obstructions.
- Coverage depends on room acoustics, construction, and materials. Take these into consideration when planning.
- For most rooms, Shure recommends 10 feet (3 m) as the maximum mounting height.

It is recommended to consider the quality of the room acoustics when installing the MXA902. The microphone's IntelliMix DSP and its highly directive audio capture can help improve the performance of rooms with poor acoustics. However, having a room that is not too reverberant will improve the overall experience. Having a low reverberation time and level will improve not only, the microphone performance but also the loudspeaker intelligibility and echo performance.

It is possible to offset the positioning of the 20 by 20-foot (6.1 by 6.1 meter) microphone capture coverage area up to 4 feet (1.2 m) [3] in any direction within the Shure Designer application or web browser. This allows for flexible integration across different room shapes or where the ceiling microphone may need to be offset due to other obstacles in the ceiling, such as lighting. Where the microphone is positioned in the ceiling will be where the sound source is located, so an offset location should be considered with some thought.
Offsetting the MXA902 toward a screen can be a useful consideration where an end user prefers the speaker audio to emanate from where a screen is positioned.

If the user guide is followed correctly, the microphone can be painted to match the aesthetics of a room without voiding the warranty allowing for a seamless integration. Its LED status bar is also configurable to alter its colour and brightness.

2.7 Summary

The Shure engineering, research and development teams achieved their goal of integrating a loudspeaker with minimal changes to the existing mechanicals of the MXA910/MXA920 product, overcoming both technological, acoustic engineering and COVID-19 pandemic challenges during its development.

The MXA902 meets the explored convenience requirements of simple deployment and seamlessly blends into the design of meeting spaces. It removes the requirement to integrate a speaker in small

– medium-sized meeting rooms, creating a competitive price point to other high-end meeting room audio solutions.
With this kind of product, room design consultants have further flexibility in small to medium-sized spaces to create a comfortable and adaptable meeting environment.
End-users are now able to consider audio consistency across all rooms in their building up to the standards they are used to in their executive boardrooms. This improves meeting equity as users will be comfortable to stage or join a call no matter the room, without the fear of not being heard.
With all the required audio technology compacted into a 60 cm x 60 cm tile, more room is left for lighting or ceiling design. If mounted in the ceiling and painted appropriately, visible technology becomes obsolete, leaving just the technology an end user interacts with on show - a screen, a camera, perhaps device connection for BYOD spaces, and a touch console. This is not necessarily to achieve a visually minimalist approach but to create an environment that is easy to understand and use: joining a conference call, broadcasting a webinar or recording a meeting with minimum set-up.

2.8 Final Comment from Shure Engineer Matthew Koschak

In an interview, Shure Sr Acoustical Engineer Matthew Koschak commented:

"I worked on many projects at Shure and this was one of the tougher ones. Not only because it was a challenging product to design, but also because development was largely conducted during the pandemic restrictions when suddenly most people were working from home as opposed to coming into the office and meeting in person.

Shure's array conferencing products are second to none and I'm proud of what the team accomplished in releasing a Microsoft Teams certified ceiling array with a loudspeaker. It was a massive challenge and required a lot of dedication from a large number of engineers."

3 ADDITIONAL READING / REFERENCES

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