APPLICATION NOTE AN-26

PHASE SEQUENCED MEMS MICROPHONES FOR BEAM-FORMING APPLICATIONS

Omni-directional microphones are commonly utilized in arrays of two or more. Microphone arrays detect differences in arrival time to focus on sounds originating from a preferred direction, while canceling sounds from unwanted directions. When physical space constraints limit array size, phase-matching sets the low frequency limit for directional performance.

Manufacturers may choose to perform an initialization measurement and apply a correction in software to align microphone phase. This process requirement contributes cost and complexity that could be saved by instead using microphone elements with matched phase. Some of the newest MEMS microphone introductions are trimmable for amplitude and phase, and feature an absolute tolerance. Phase sequencing facilitates array implementation for other common microphone series.

WHY PHASE SEQUENCING?

Matched pair and matched triplet electret microphones have been used for decades in hearing aids to enable omni-directional microphones for uni-directional beam-forming functionality in the voice band. Microphones can be switched between omni-directional pick-up to uni-directional pickup, increasing the utility of a hearing instrument. More recently, MEMS microphones for hearing aids have also been provided in tray packaging as matched pairs. If trimming is not an option, matching becomes logistically challenging to migrate to a tape-and-reel format. While tape-and-reel automates handling, matched pairs are not practical to implement. If a pick-and-place machine drops a microphone, or an array assembly otherwise cannot support installation of specific microphone pairs, manual intervention may be needed. Phase sequencing removes practical obstacles, enabling convenient manufacture of arrays for both hearing aids and consumer earphones.

PHASE AND SPACING

Consider a simple two-microphone array situated within the concha of the ear:

Sound travels at an approximate speed of 343 meters/second in air. Assume a typical spacing between microphone port openings is 15mm for a device worn in-ear or for a small behind-the ear device housing. The time required for sound to travel 15mm is approximately 44μs. For the low end of the telephone bandwidth (400Hz to 3.4 kHz), 400Hz, wavelength is 0.858m. 15mm spacing represents about 1.7% of the wavelength. 1.7% of a full 360 degrees of phase is approximately 6.3 degrees.

To accurately resolve time of arrival, phase matching error befween microphones must constitute a relatively small fraction of the phase difference at the lowest frequency of interest for the microphone port spacing.

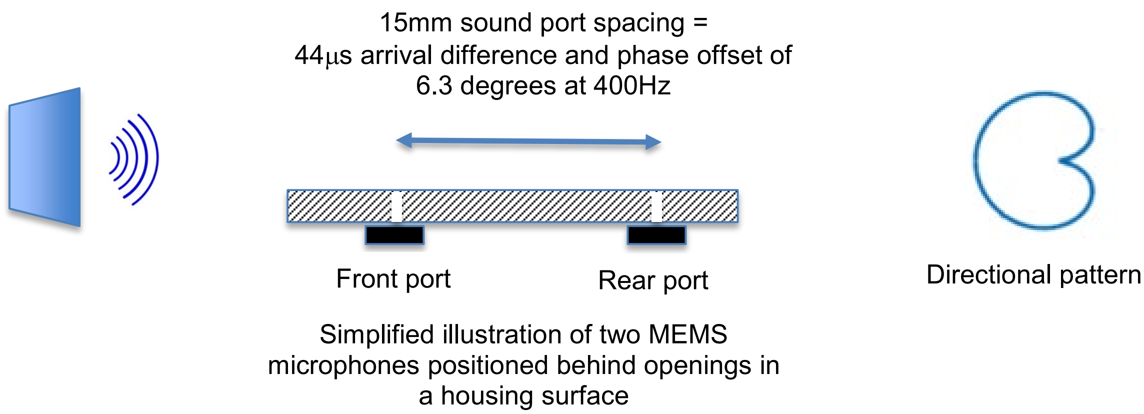

Figure 1

Figure 1 illustrates a simplified representation of sound traveling past a housing surface, noting the spacing, time of arrival, and change in phase for a 400 Hz tone. For an actual device, the effective port spacing depends on the contour of the housing surface and sound diffraction due to the head of the wearer.

DIRECTIVITY

To create a cardioid polar response, an electronic delay is applied to sound entering the rear port of the microphone. If the electronic delay is set to match the speed of sound delay for sound traveling in a line from rear port to front port, the microphone signals will cancel if subtracted. Other ratios of the electronic delay of the phase shift network to the external delay of the port separation will produce different polar response patterns. All of the response patterns shown in Figure 2 are members of a limaçon curve family derived from the equation $f(0) = (1 - k) + k \cdot \cos(0)$ where $k = e / (e + I)$, where e is the external phase shift and I is the internal phase shift. The table below shows a comparison of some of the more important features of common polar patterns.

The shape of the pattern describes the sensitivity for sounds arriving from specific directions. Reduction in sensitivity for non-directional sound is listed in the Directivity Index. Delay ratios between 0 and 0.5 yield a pre-cardioid or sub-cardiod polar pattern as illustrated in Figure 3. If the microphones used are perfectly phase matched (or calibrated), the intended polar pattern design will be repeatable. Phase error will cause some deviation from the intended directional pattern. As a simplified example, a two microphone array in an idealized setup designed to achieve a cardioid pattern would change toward pre-cardioid (reduced null at 180 degrees) or post-cardioid (formation of back lobe).

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	Omni	Cardioid	Supercardioid	Hypercardioid	Figure-8
Polar Pattern					
Delay Ratio, K	0	0.5	0.63	0.75	1.0
Null Angle(s)	--	180°	± 125°	± 110°	±90°
Directivity Index, DI	0 dB	4.8 dB	5.7 dB	6.0 dB	4.8 dB

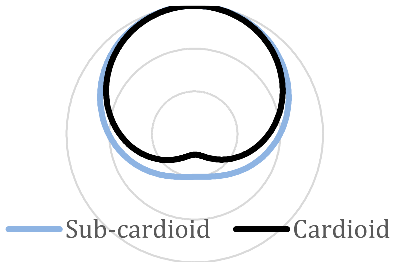

Figure 3

PHASE SEQUENCED MEMS REELS

Sequenced phase reels offer an alternative to two other phase matching options, reels with specificed phase, and MEMS models packaged as matched pairs/triplets. To facilitate design and manufacture of ear-scale arrays, Knowles offers MEMS microphones arranged in sequencial order of phase, and also within a specified maximum phase and sensitivity difference. Matching may be specificed for a window of 100 microphones or for any pair of microphones.

Microphones are 100 percent measured for 1kHz sensitivity and 200 Hz phase, and arranged on tape and reel. Reel sizes of 1200, 3200, and 5000 are standard. The microphone with the largest phase is located at the start of the reel – the first portion of tape that unwinds from the reel.

Reels that specify phase for a 100 microphone window allow population of an PCB array populated such that up to 100 microphones are placed in no specific order. Reels that specify phase matching of pairs are intended for use where single PCBs receive sequential pairs (or triples, etc.) in known arrangement.

Take for example Knowles model MM20-33639-B116:

Phase for a 100 microphone window must be within 1.5 degrees maximum at 200Hz. From the earlier example of 6.3 degrees at 400Hz, the maximum error is less than 24%, as phase difference will be smaller at 400Hz compared to 200Hz. Looking at the Delay Ratio K, the difference in K that would change directionality from cardioid to super-cardiod is 26%. Hence an array using MM20-33639-B116 designed for cardioid directionality might, in the extreme, display close to super-cardioid directionality (or its equivalent toward a pre-cardioid pattern).

While even the maximum variation in directional pattern would be extremely challenging to detect in use, typical phase distribution is also likely to be tighter than specified. Phase data for a random window of MM20-33639-B116 is presented in the Appendix.

SUMMARY

Phase sequenced reels provide an alternative to initialization/calibration of microphone arrays for earphones and hearing aids. The phase tolerance is small enough to ensure that differences in directional pattern are minor. Phase sequenced reels cost more than non-sequenced reels, but can reduce overall device process cost. Available models as of the issue date of this note:

Model	Size
MM20-33366-B116	1200
MM20-33639-B116	1200
MM20-33601-B118	3200
MM25-33663-B141	5000

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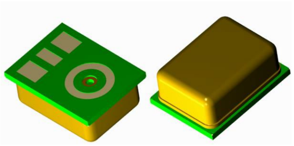
APPENDIX

MM20-33639-B116 – arbitrary data example for window of 100 adjacent microphones.

Note: The data below is not necessarily typical, nor nominal. However, while the designer should account for phase differences up to the specified maximum, actual phase variance will vary within the allowed range.

Delta Maximum 1.5 degrees



Microphone	Phase (degrees)	Delta (degrees)									
1	15.51	0	26	15.64	0.13	51	15.75	0.24	76	15.84	0.33
2	15.52	0.01	27	15.65	0.14	52	15.75	0.24	77	15.84	0.33
3	15.53	0.02	28	15.66	0.15	53	15.75	0.24	78	15.84	0.33
4	15.54	0.03	29	15.66	0.15	54	15.76	0.25	79	15.85	0.34
5	15.54	0.03	30	15.66	0.15	55	15.76	0.25	80	15.85	0.34
6	15.54	0.03	31	15.66	0.15	56	15.76	0.25	81	15.85	0.34
7	15.54	0.03	32	15.67	0.16	57	15.77	0.26	82	15.86	0.35
8	15.55	0.04	33	15.67	0.16	58	15.78	0.27	83	15.86	0.35
9	15.56	0.05	34	15.68	0.17	59	15.78	0.27	84	15.86	0.35
10	15.56	0.05	35	15.68	0.17	60	15.79	0.28	85	15.86	0.35
11	15.56	0.05	36	15.69	0.18	61	15.79	0.28	86	15.87	0.36
12	15.58	0.07	37	15.69	0.18	62	15.79	0.28	87	15.87	0.36
13	15.59	0.08	38	15.69	0.18	63	15.8	0.29	88	15.87	0.36
14	15.59	0.08	39	15.7	0.19	64	15.8	0.29	89	15.87	0.36
15	15.6	0.09	40	15.71	0.2	65	15.8	0.29	90	15.87	0.36
16	15.6	0.09	41	15.71	0.2	66	15.8	0.29	91	15.87	0.36
17	15.61	0.1	42	15.71	0.2	67	15.81	0.3	92	15.87	0.36
18	15.62	0.11	43	15.72	0.21	68	15.81	0.3	93	15.87	0.36
19	15.62	0.11	44	15.72	0.21	69	15.81	0.3	94	15.87	0.36
20	15.62	0.11	45	15.72	0.21	70	15.81	0.3	95	15.88	0.37
21	15.63	0.12	46	15.73	0.22	71	15.82	0.31	96	15.88	0.37
22	15.63	0.12	47	15.73	0.22	72	15.82	0.31	97	15.88	0.37
23	15.64	0.13	48	15.74	0.23	73	15.83	0.32	98	15.89	0.38
24	15.64	0.13	49	15.74	0.23	74	15.83	0.32	99	15.89	0.38
25	15.64	0.13	50	15.75	0.24	75	15.84	0.33	100	15.89	0.38

REFERENCES

[1] Knowles Application Note AN-04 Directional Microphone Applications (Knowles web site)

[2] Knowles Technical Bulletin TB-21 Application of EL Directional Microhphones (Knowles web site)

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