January 1996, Rev. 2

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Microphone Study and White Paper
Prepared for
Andrea Electronics Corporation

Andrea Active Noise Cancellation (ANC) Microphone Technology

An immediate need exists in personal computer Automatic Speech Recognition (ASR) and Internet Protocol Telephony (IPT) applications for an affordably priced high performance microphone where audio input is not corrupted by background noise. To address these needs, Andrea Electronics Corporation has developed a revolutionary new microphone technology called *Andrea ANC* that greatly improves microphone performance in the presence of noise. Particularly noteworthy is the ability to reduce error rates of ASR and IPT systems.

Andrea Electronics Corporation's patented and patent pending *ANC* technologies increase the intelligibility of voice input by greatly reducing background noise in the frequency band between 150 and 3,500 Hz where most voice energy relevant to ASR and IPT systems resides. *Andrea ANC* microphones are designed for high fidelity sound pickup with a flat frequency response between 100 and 15,000 Hz.

Where desired, the shape of the *Andrea ANC* microphone frequency response curve can be tailored for optimum performance to match the special requirements of a particular application. Additionally, microphone output levels can be set to match the unique input requirements of any computer or telephony equipment. *Andrea ANC* technology uses active circuitry, trimming elements, and proprietary processes to achieve this flexibility while maintaining close tolerances and consistent high quality performance.

Applications claimed to benefit by *Andrea ANC* include:

Multimedia/Games	Internet Protocol Telephony
Automatic Speech Recognition	Education/Entertainment Software
Voice Command and Control	Video Teleconferencing
Computer Telephony	

As the range of speech applications broaden and their popularity increases, developers are recognizing the need to use high performance noise-canceling headsets that perform well with voice recognition speech engines and voice compression codecs. *Andrea ANC* technology claims to offer the following benefits to the providers of these products and systems:

Superior Noise Cancellation	Higher Speech Recognition Accuracy
Highest Performance/Cost Ratio	Improved Intelligibility
Frequency Shaping	Minimal Frequency Distortion
Input Level Matching	Low Power Consumption

As will be seen, these claims are well justified and derive in large measure from *Andrea ANC's* use of dual matched omni-directional microphone elements and a bi-directional polar response.

Test Proven Superior Performance

At the heart of the *Andrea ANC* technology is a pair of matched omni-directional microphone elements positioned to optimize noise cancellation and capitalize upon their directional frequency independent characteristics. Controlled bandwidth and flat frequency response result from *Andrea's ANC* active circuitry and dual matched omni-directional element design that subtracts noise with less directional frequency distortion than is possible with mechanical/acoustic noise-canceling uni-directional pressure gradient microphone designs. Reduced frequency distortion means ASR and IPT systems achieve higher speech intelligibility and lower error rates using *Andrea ANC* headsets as shown in Table 1.

Microphone	Description	Speech Intelligibility (AI)	Speech Accuracy (Percent)	Error Rate (per 100 words)
1	*Andrea ANC*	0.432	95	5
2	Dynamic Pressure Gradient	0.309	82	18
3	Electret Pressure Gradient	0.310	82	18

Table 1—Speech Intelligibility and Error Rate Comparison

The remaining pages of this study describe test procedures and results and examine how *Andrea ANC* is able to achieve these superior results. It will be seen that *Andrea ANC* technology derives many benefits from its actively summed dual omni-directional microphone elements, an overall bi-directional polar response, and an electro/acoustic design flexibility that allows optimization and customization.

Dual Omni-directional Microphone Elements Superiority

Directional microphones obtain their directional properties by sensing the pressure gradient between two points in space. This is in contrast to omni-directional microphones that measure a soundwave produced pressure change referenced to a closed volume of air and hence have no directional characteristic.

Uni-directional microphones have their greatest gain in one direction, usually taken to be along the 0 degree axis as depicted in polar plots of microphone gain. Cardioid and hypercardioid microphones are popular examples of uni-directional microphones. In contrast, *Andrea ANC* microphones are bi-directional and have their greatest gain in two directions along the 0 degree axis and the 180 degree axis. Figure 1 shows the polar plot for a typical uni-directional cardioid microphone showing how its sensitivity is significantly affected by frequency—a problem of all mechanical/acoustic uni-directional microphones.

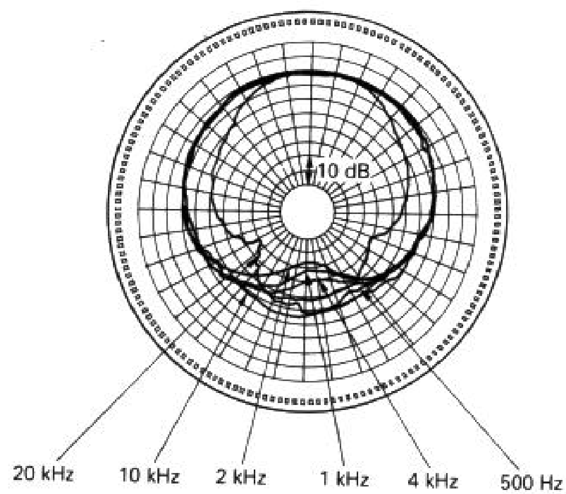

Figure 1—Uni-directional Cardioid Microphone Polar Plot

Whereas uni-directional microphone elements exhibit detrimental directional frequency selectivity, an omni-directional microphone element responds to all frequencies from all directions equally. This leads to the first of *Andrea ANC* technology's fundamental advantages; which is, *Andrea ANC* headsets inherently have less directional frequency distortion. The second fundamental advantage is that *Andrea ANC's* proprietary use of two separate microphone elements provides design flexibility in acoustic porting and packaging that is not possible with a single element uni-directional microphone—an advantage that Andrea has capitalized on through years of perfecting microphone performance in a wide range of military and commercial applications.

Andrea ANC headsets achieve bi-directional characteristics by virtue of proprietary active circuitry and manufacturing processes which take advantage of the frequency independent omni-directional nature of its two microphone elements. Particularly noteworthy of the *Andrea ANC* directional response is the deep side nulls providing separation between the front and rear lobes. It will be seen later in this study when examining articulation index effects that these deep side nulls coupled with diminished directional frequency effects result in significantly improved speech intelligibility.

Near-Field/Far-Field Signal-to-Noise Response

The directional qualities of *Andrea ANC* microphones can be visualized by considering the way in which the microphone elements respond differently to close-speaking voice than they do to far-field background noise. Far-field noise received by the two omni-directional microphone elements arrives at the microphone elements at the same time and from opposite directions because the microphone elements are oriented in precisely opposite directions to each other. In response to far-field noise, the *Andrea ANC* active circuitry senses very little difference between the two microphone element signals and thus substantially subtracts the background noise by summing the two signals. On the other hand, the way the microphone elements are positioned with respect to each other causes the element facing the close-talking speaker to generate a significantly higher output than the element facing away from the speaker due to the inverse square law of sound propagation.

An important measure of microphone performance in the presence of noise is its near-field/far-field signal-to-noise response which is the difference between the response of the microphone to a near-field sound source and a far-field sound source. Test results will be presented comparing signal-to-noise responses of an ANC-100 microphone to both noise-canceling dynamic pressure gradient microphones and cardioid electret pressure gradient microphones.

Near-field tests were performed with pink noise from an artificial mouth and a sound pressure level of 96 dB at the microphone under test. Each microphone tested was placed in a holding fixture located coaxial with and positioned one half inch from the center of the artificial mouth. The output of the microphone under test was analyzed with a spectrum analyzer using one-third octave scans over the frequency range from 200-4,000 Hz.

Far-field tests were performed using two non-correlated pink noise generators and four loudspeakers positioned to create a random sound field at the location of the microphone being tested. Non-correlated pink noise generators were used in order to simulate a reverberant chamber. Similar to the near-field test an identical sound pressure level of 96 dB was maintained at the microphone and the output of the microphone under test was analyzed with a spectrum analyzer using one-third octave scans over the frequency range from 200-5,000 Hz. The noise floor tests were performed with all sound sources in the test chamber turned off.

The differences between the near-field and far-field responses for the three microphones are tabulated and plotted in Figure 2.

1/3 Octave Band Center Frequency (Hz)	#1 *Andrea ANC* Microphone Signal-to-noise Difference(dB)	#2 Dynamic Microphone Signal-to-noise Difference (dB)	#3 Cardioid Microphone Signal-to-noise Difference (dB)
200	19	28	25
250	23	23	21
315	23	21	19
400	24	14	19
500	22	16	16
630	23	15	12
800	19	11	13
1000	18	12	10
1250	13	8	6
1600	8	9	6
2000	9	6	6
2500	6	2	5
3150	1	0	4

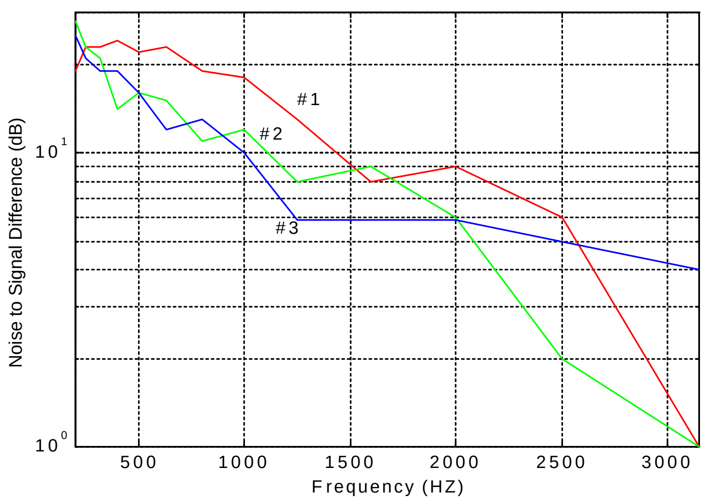

Figure 2—Comparison of Signal-to-Noise Responses

The significance of the signal-to-noise curves in Figure 2 on speech intelligibility and how they relate to the *Andrea ANC* technology is addressed in the following section on articulation index and speech intelligibility. It should be noted that microphones used for ASR and IPT applications should have at least 60 dB of separation between their near-field response and their noise floor.

The near-field/far-field signal-to-noise responses of the individual microphones are plotted in Figures 3, 4, and 5. In each plot, the near-field response is above the far-field response and the difference between the two indicates the amount of noise cancellation.

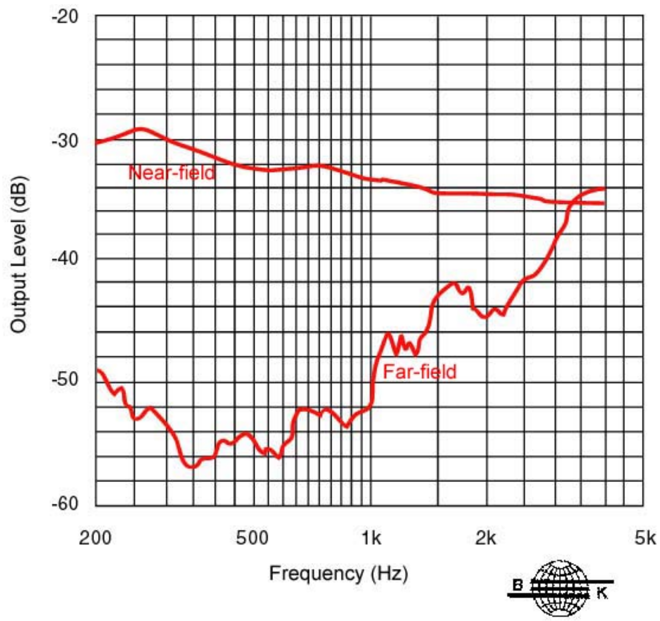

Figure 3—*Andrea ANC* (Microphone #1)
Near-Field vs. Far-Field Sensitivity

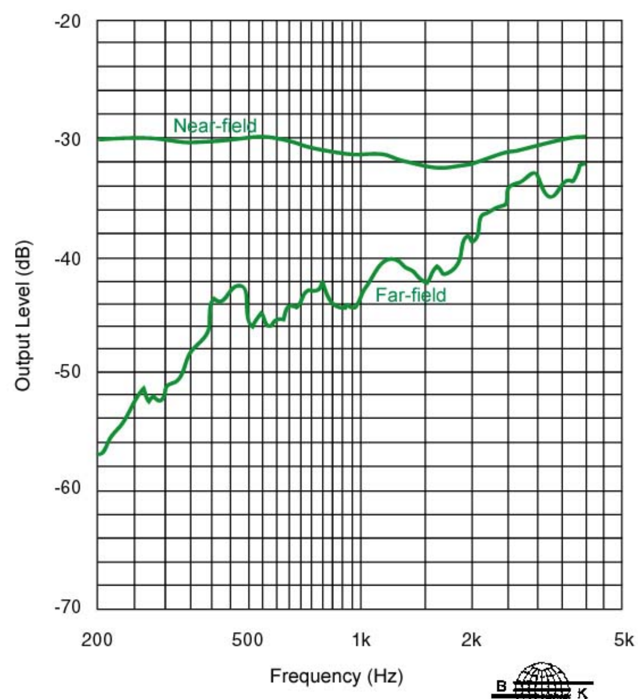

Figure 4—Dynamic Pressure Gradient (Microphone #2)
Near-Field vs. Far-Field Sensitivity

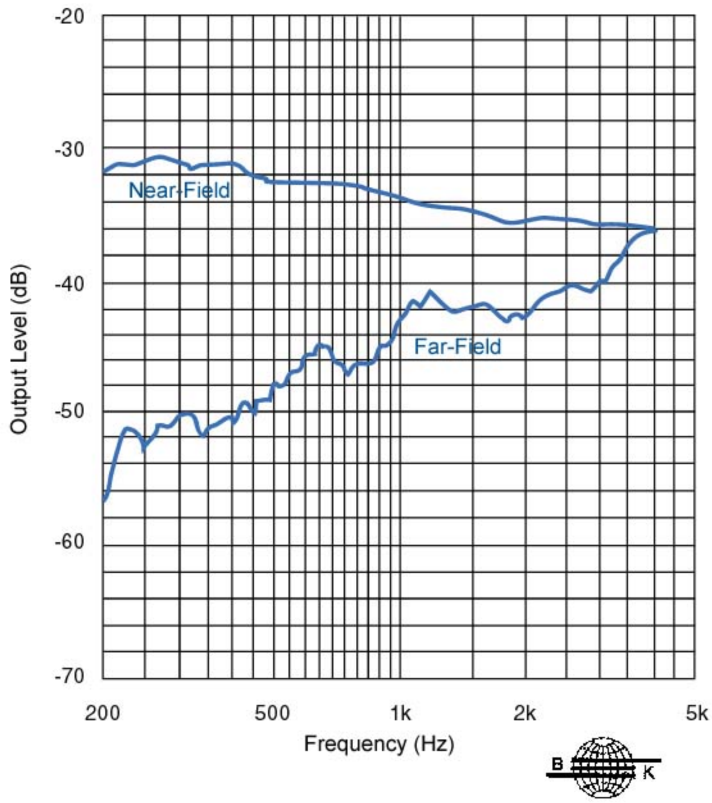

Figure 5—Cardioid Electret Pressure Gradient (Microphone #3)
Near-Field vs. Far-field Sensitivity

Articulation Index and Speech Intelligibility

Important to the real world performance of ASR and IPT voice applications are the concepts of articulation index and speech intelligibility. The articulation index weighting factors shown in the middle column of Table 2 and the method of calculation of speech intelligibility have been performed in accordance with ANSI S3.5-1969. The particular ANSI curve selected for the weighting factors was the one which most closely represents actual use, *Sentences First Presentation to Listeners*. The weighting factors in the right most column of Table 2 have been corrected for the crossover frequency of 3500 Hz where near-field and far-field response curves meet. These bandwidth corrected weighting factors perform an accurate comparison of noise cancellation microphones and were therefore used in the speech intelligibility calculations.

From Tables 3a, b, and c and the equation $AI = \sum_{F_0}^{f_{\max}} W$, speech intelligibility is calculated to be 0.432, 0.309, and 0.310 respectively for the *Andrea ANC*, noise-canceling dynamic pressure gradient, and noise-canceling cardioid electret pressure gradient microphones. *Andrea ANC* microphones realized a score of 95% (5 errors per 100 words) compared to 82% (18 errors) for the dynamic pressure gradient microphone and 82% (18 errors) for the cardioid electret pressure gradient microphone.

1/3 Octave Band Center Frequency (Hz)	Weighting Factor (ANSI S3.5-1969)	Weighting Factor (Adapted for near-field/far-field crossover point)
200	0.0004	0.0005
250	0.0010	0.0012
315	0.0010	0.0012
400	0.0014	0.0016
500	0.0014	0.0016
630	0.0020	0.0023
800	0.0020	0.0023
1000	0.0024	0.0028
1250	0.0030	0.0035
1600	0.0037	0.0043
2000	0.0038	0.0044
2500	0.0034	0.0039
3150	0.0034	0.0039

Table 2—Articulation Index Weighting Factors

1/3 Octave Band Center Frequency (Hz)	Signal-to-noise Difference Between Near-field and Far-field (dB)	Bandwidth Corrected Weight Factor	Articulation Weight (W)
200	19	0.0005	0.0095
250	23	0.0012	0.0276
315	23	0.0012	0.0276
400	24	0.0016	0.0384
500	22	0.0016	0.0352
630	23	0.0023	0.0529
800	19	0.0023	0.0437
1000	18	0.0028	0.0504
1250	13	0.0035	0.0455
1600	8	0.0043	0.0344
2000	9	0.0044	0.0396
2500	6	0.0039	0.0234
3150	1	0.0039	0.0039

Table 3a—*Andrea ANC* Microphone Speech Intelligibility Data

1/3 Octave Band Center Frequency (Hz)	Signal-to-noise Difference Between Near-field and Far-field (dB)	Bandwidth Corrected Weight Factor	Articulation Weight (W)
200	28	0.0005	0.0140
250	23	0.0012	0.0276
315	21	0.0012	0.0252
400	14	0.0016	0.0224
500	16	0.0016	0.0256
630	15	0.0023	0.0345
800	11	0.0023	0.0253
1000	12	0.0028	0.0336
1250	8	0.0035	0.0280
1600	9	0.0043	0.0387
2000	6	0.0044	0.0264
2500	2	0.0039	0.0078
3150	0	0.0039	0.0000

Table 3b—Dynamic Pressure Gradient Microphone Speech Intelligibility Data

1/3 Octave Band Center Frequency (Hz)	Signal-to-noise Difference Between Near-field and Far-field (dB)	Bandwidth Corrected Weight Factor	Articulation Weight (W)
200	25	0.0005	0.0125
250	21	0.0012	0.0252
315	19	0.0012	0.0228
400	19	0.0016	0.0304
500	16	0.0016	0.0256
630	12	0.0023	0.0276
800	13	0.0023	0.0299
1000	10	0.0028	0.0280
1250	6	0.0035	0.0210
1600	6	0.0043	0.0258
2000	6	0.0044	0.0264
2500	5	0.0039	0.0195
3150	4	0.0039	0.0156

Table 3c—Cardioid Electret Pressure Gradient Microphone Speech Intelligibility Data

Rigorous Test Procedures

The foregoing analysis has been based upon straight forward comparisons of the microphones' response curves and audio performance measured by tests conducted according to industry standard procedures adopted by the U. S. Department of Defense, and performed under identical circumstances for each microphone.

A sound pressure level of 96 dB re 20µPa was used at the mouth reference point for all near-field and far-field measurements. The microphone under test and the artificial mouth were separated one half inch and aligned on their mutual polar axes. Great care was taken to guarantee accurate positioning because measurements of noise-canceling efficiency can be greatly influenced by the position of the microphone relative to the sound source. The near-field frequency response and output gain level of *Andrea ANC* microphone was adjusted to -30 dB to be similar to that of a standard noise-canceling electret pressure gradient microphone. For testing purposes the dynamic microphone had its output amplified by a low noise preamplifier to guarantee a consistent comparison with the other two microphones. Four noise sources were used to simulate typical background noise, consisting of two pink noise generators, two power amplifiers, and four loudspeakers. The microphone under test was positioned near the center of the test chamber.

The methods used to measure noise cancellation were in conformance with *IEEE Standard Methods for Measuring Transmission performance of Telephone Handsets and Headsets*, draft 13, page 1206 and IEEE Std 269-1992 *Standard Method for Measuring Transmission Performance of Analog and Digital Telephone Sets*. CCITT recommendation on page 64 regarding the measurement of room noise side tone sensitivity was used for the unpowered artificial mouth far-field measurements. Although the artificial mouth was not powered during far-field testing, its presence was important to simulate reflections which occur between talker and the microphone.

The ANC-100 and cardioid electret pressure gradient microphones were tested with power derived the same way as in normal use, from phantom power supplied through a standard microphone interface drawing less than one milliampere of current using a bias voltage with a 2200 ohm pull-up resistor. The dynamic pressure gradient microphone tested was a Shure SM-10A and the cardioid electret pressure gradient microphone tested was a Telex Nomad.

Test Setup:

Bruel & Kjaer Audio Analyzer, Type 2012/7661
Bruel & Kjaer Head and Torso Simulator, Type 4128
Bruel & Kjaer Telephone Test Head, Type 4602
Bruel & Kjaer Artificial Mouth, Type 4227
Bruel & Kjaer Acoustic Calibrator, Type 4230

Goldline PN2 Pink Noise Generators (2)
Loudspeakers (4)
Audio Amplifiers (2)
Acoustic Chamber, 12’ x 12’ x 8’