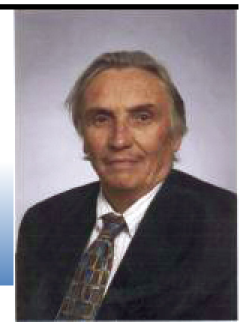


Modeling Microphone Noise

It's time to go a little 'upscale' and get a close look at a different kind of modeling – electret microphones. Some manufacturers call them 'pre-charged' or "pre-polarized" condensers. Originally they were called 'capacitor' mics, and so it is logical to model this type of mic as an electrical capacitor. Of course, there are other elements to model because there is no such thing as a 'perfect' capacitor in the real world, and whatever gets designed has to be packaged, amplified, and analyzed acoustically. So, the 'perfect' capacitor is surrounded by stuff and it all has to go into the model to predict real-world behavior.

There are many papers written on microphone background noise with some of these frightfully complicated. However, one paper stands out in my collection, appearing in **JASA**, June 2003 [1]. This paper presents a rather simple model that predicts quite close to reality for the venerable Panasonic WM60A microphone capsule (no longer in production), as well as other transducers.

Measuring mic noise is a real project. It requires some elaborate equipment to create a chamber for the mic that has ambient acoustic noise at least 10dB below that of the capsule. It is usually a can within a can within a can, each of thick metal and the whole arrangement mounted on springs. Obviously, wiring isolation is critical, and in the case of [1] the WM60A internal FET was powered by batteries inside the test chamber.

One result of this exercise is to use standard band manipulations to calculate results that are meaningful to a microphone user. This means keeping the calculations in terms of SPL with the goal to compute the microphone noise floor in

Mean coefficients for WM60A		
b0	b1	b2
3.50E-11	1.10E-07	9.70E-06

REAL EAR [MAF] SPL(A) ~	19.8	[100 to 5K]
MIC NOISE FLOOR SPL(A) =	31.9	[100 to 5K]
	33.4	[22 to 22K]

A	*B*	*C*	*D1*	*D2*	*D3*	*D4*	*E*	*F*	*G*	*H*
		dB	1/3 Octave Calculations:			10*	BAND	A	BPL(A)	REAL
freq	Pa^2/Hz	SPL/Hz	FcoLF	FcoHF	BW	LOG(BW)	LEVEL	SCALE	NOISE	EAR
25	2.00E-08	16.98	22	28	5.8	7.63	24.61	-45.0	-20.39	
31.5	1.33E-08	15.22	28	35	7.3	8.63	23.85	-39.4	-15.55	
40	8.85E-09	13.45	36	45	9.3	9.67	23.11	-35.0	-11.89	
50	6.12E-09	11.84	45	56	11.6	10.64	22.48	-30.0	-7.52	
63	4.22E-09	10.24	56	71	14.6	11.64	21.88	-26.2	-4.32	
80	2.93E-09	8.64	71	90	18.5	12.68	21.32	-23.0	-1.68	
100	2.11E-09	7.21	89	112	23.2	13.65	20.86	-19.0	1.86	19.0
125	1.54E-09	5.84	111	140	28.9	14.62	20.46	-16.1	4.36	17.0
160	1.10E-09	4.40	143	180	37.1	15.69	20.09	-13.0	7.09	15.0
200	8.28E-10	3.16	178	224	46.3	16.66	19.81	-11.0	8.81	13.0
250	6.30E-10	1.97	223	281	57.9	17.63	19.60	-8.6	11.00	11.0
315	4.82E-10	0.81	281	354	72.9	18.63	19.44	-6.5	12.94	10.0
400	3.71E-10	-0.33	356	449	92.6	19.67	19.34	-5.0	14.34	9.0
500	2.94E-10	-1.34	445	561	115.8	20.64	19.30	-3.2	16.10	8.0
630	2.34E-10	-2.33	561	707	145.9	21.64	19.31	-2.0	17.31	8.0
800	1.88E-10	-3.29	713	898	185.3	22.68	19.39	-1.0	18.39	9.0
1000	1.55E-10	-4.13	891	1122	231.6	23.65	19.52	0.0	19.52	9.5
1250	1.29E-10	-4.91	1114	1403	289.5	24.62	19.71	0.5	20.21	10.0
1600	1.08E-10	-5.70	1425	1796	370.5	25.69	19.98	1.0	20.98	9.0
2000	9.24E-11	-6.36	1782	2245	463.1	26.66	20.29	1.2	21.49	7.5
2500	8.06E-11	-6.96	2227	2806	578.9	27.63	20.67	1.2	21.87	5.5
3150	7.09E-11	-7.51	2806	3536	729.4	28.63	21.12	1.1	22.22	4.5
4000	6.31E-11	-8.02	3564	4490	926.3	29.67	21.65	1.0	22.65	3.1
5000	5.74E-11	-8.43	4454	5612	1157.8	30.64	22.20	0.5	22.70	*4.2*
6300	5.27E-11	-8.80	5613	7072	1458.8	31.64	22.84	-0.5	22.34	*11.0*
8000	4.89E-11	-9.13	7127	8980	1852.5	32.68	23.55	-1.1	22.45	*19.0*
10000	4.61E-11	-9.38	8909	11225	2315.6	33.65	24.26	-2.5	21.76	*20.0*
12500	4.39E-11	-9.60	11136	14031	2894.5	34.62	25.02	-4.0	21.02	*13.0*
16000	4.19E-11	-9.80	14254	17959	3705.0	35.69	25.89	-6.0	19.89	*25.0*
20000	4.05E-11	-9.94	17818	22449	4631.3	36.66	26.71	-8.0	18.71	

Table 1. Spreadsheet of data for microphone noise prediction. [1]. Note that there are two bandwidths calculated for the microphone A-weighted noise floor. The lower bandwidth, 100 to 5k, is for comparison to the real-ear minimum audible field data [2].

dB(A). The spreadsheet printout in Table 1 shows all of the calculations spaced in 1/3 octave bands encompassing 25Hz to 20kHz. The columns are labeled **A** through **H** with **D** occupying the four tan-colored columns.

The first one, A, is the center frequency of the third-octave band. The second, B, is the "power spectral density" in Pascals-squared per Hertz from the equivalent circuit model in [1]. The referenced paper has a graph that shows how astonishingly close the model is to reality through 30 kHz. That is because of the three coefficients shown above column A that are polynomials fitted to measured data. Each coefficient has a physical connection to some part of the microphone assembly.

Column C is a representation of column **B** but expressed in SPL, by taking $10*\log((A)/(P_0^2))$ where P_0 is 20 µPa (standard reference pressure).

Now we shift gears to mess with 1/3 octave bands in D1-D4. Since spectral density numbers are per Hertz, we have to know the number of cycles in each band to see how they combine to get Band Pressure Level (BPL) for each band. **D1** is the low frequency -3dB point, and **D2** is the high. **D3** is simply **D2-D1**. **D4** is 10*log (**D3**) that corrects the spectrum level to BPL.

Therefore, adding **D4** and **C** yields the BPL, shown in E. F is the A-scale weighting and G is the sum of **E** and **F.** The last step of combining all the numbers in **G** in dB(A) requires that we convert back to pressure using the anti-log , then take all the numbers, then back to dB(A). Whew!

The final answer is 33.4 dB(A) for the WM60A over a 22Hz to 22kHz bandwidth. This level is about 60dB below 1Pa and is equivalent to about NC 27 (in terms of auditorium background noise) – perhaps 1000 people breathing? Not too bad for a 75-cent transducer that could get to 115dB with 1% THD. If the bandwidth is reduced to 100Hz to 5kHz (to match the real-ear data that follows) the noise drops only ~1.3dB.

The solid blue BPL curve has some interesting features. If the noise were pink then the curve would be flat. But the only 'flat' portion is at mid frequencies. The upper end appears to be white noise. The lower end appears to be $1/f^2$ and is caused by the gate shot noise in the FET. Aside from this, the rest of the noise is mainly from Brownian motion of air on the diaphragm. The equivalent resistor value to generate this noise is 737k.

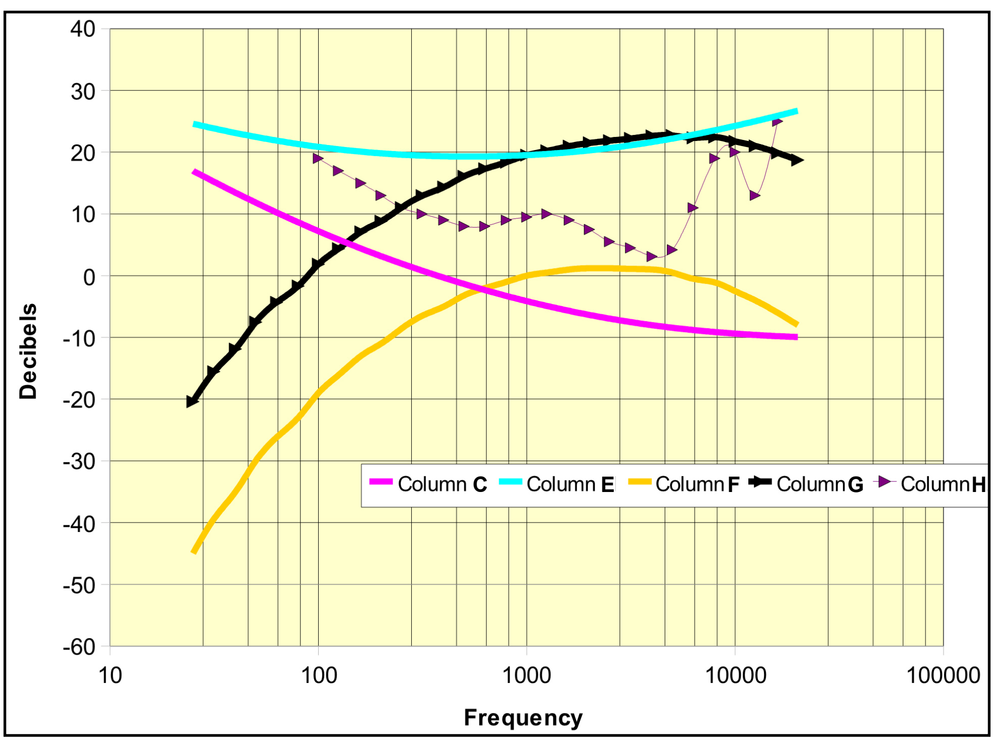
A quickie review through the curves in Fig. 1: we start with magenta, transform it using bandwidths to blue, subtract the A-weighting tan curve, and plot the result in black. Finally do a power sum of black to get the overall noise in dB SPL(A).

One important comparison is to include the human ear on the same scale, column H , from an estimate by Mead Killion in **JASA**, 1976 [2] with human subjects in a free field. This curve, marked with ► , is compared with the solid blue one, and shows the WM60A to be 10-12 dB more noisy than 1976 ears (what might we say about 2008 I-Pod ears?).

References:

[1] "Background noise in piezoresistive, electret condenser, and ceramic microphones", Alan Zuckerwar and Theodore Kuhn, **JASA** 113 (6), June 2003

[2] "Noise of ears and microphones", Mead C. Killion, **JASA** 59 (2), 1976



Download the Spreadsheet [Here]

Figure 1. Curves based upon column data from Table 1. The real-ear data above 5kHz is considered unreliable and is not used in the comparison calculation in Table 1. Curve C is the noise spectrum resulting from the equivalent circuit model in [1]. Curve E is the band pressure level in 1/3 octaves of Curve C. Curve F is the standard A-weighting filter in 1/3 octaves. Curve G is the result of applying Curve F to Curve E. Curves E and H should be compared in the final analysis. Note that at 100 the ear is almost as noisy as the microphone. In the most sensitive part of the hearing curve, the Wm60A microphone is ~20dB noisier than the ear.