## **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" duction), as well as other transducers. 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. ulations to calculate results that are meaningful to a micro-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 pro-

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 manipphone user. This means keeping the calculations in terms of SPL with the goal to compute the microphone noise floor in

$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	Mean coefficients for WM60A			REAL EAR [MAF ] SPL(A) ~			19.8 [ 100 to 5K]				
3.50E-11   1.10E-07   9.70E-06   33.4   [ 22 to 22K ]     A   B   C   D1   D2   D3   D4   E   F   G   H     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   15.5   40   8.85E-09   13.45   36   45   9.3   9.67   23.11   -35.0   -11.89   50   6.12E-09   10.24   56   7.1   14.6   11.64   22.48   -20.0   -4.32   4.30   -7.52   2.00   -3.0   -7.52   2.00   -3.0   -7.52   2.00   -3.0   -7.69   1.68   17.1   90   18.5   12.68   21.32   -2.3.0   -1.68   17.1   160   1.00E-0   4.40   14.3   180   3.1   7.09   15.3   2.08   6.10   1.43	b0	b1	b2		MIC NOIS	SE FLOOR	SPL(A) =	31.9	[ 100 to 5	K]	
A   B   C   D1   D2   D3   D4   E   F   G   H     freq   Pa^2/Hz   SPL/Hz   FcoLF   FcoHF   BW   L0G(BW)   LEVEL   SCALE   NOISE   EAR     25   200E-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   2.85   -30.4   -15.55     40   8.85E-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   -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.     120   8.28E-10   3.16	3.50E-11	1.10E-07	9.70E-06					33.4	[ 22 to 22	2K]	
A   B   C   D1   D2   D3   D4   E   F   G   H     freq   Pa^2/Hz   SPL/Hz   SPL/Hz   SOCave Calculations:   10   BAND   A   BPL(A)   REAL     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   11.44   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   2.33E-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   20.46   -16.1   4.36   17.     120   8.28E+10   3.16											
freq   Pa^2/I/z   SPL(A) SPL/Az   FCoLF FCOLF FCOLF   FCOLF FCOLF FCOLF   BW LOG(BW)   LEVEL LEVEL   SCALE SCALE   NOISE NOISE   EAR     25   2.000-08   16.98   22   28   5.8   7.63   24.61   45.0   -20.39     40   8.85E-09   13.45   36   45   9.3   9.67   23.11   -35.0   -11.89     60   6.12E-09   11.84   45   56   11.6   10.64   22.48   -30.0   -7.52     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   19.7     125   1.54E-09   5.84   111   140   28.9   14.62   20.46   -16.1   4.36   17.0     200   8.28E-10   3.16   178   22.4   46.3   16.66   19.81   -11.0   8.81   1	A	в	С	D1	D2	D3	D4	E	F	G	н
freq   Pa^2/Hz   SPL/Hz   FcoLF   FcoHF   BW   LOG(BW)   LEVEL   SCALE   NOISE   EAR     25   208-08   16.98   22   28   5.8   7.33   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   12.08   21.32   -23.0   -1.68     100   2.11E-09   7.21   89   112   23.2   13.65   20.86   -19.0   1.86   17.     120   8.28E-10   3.16   178   224   46.3   16.66   19.81   13.0   7.09   15.3 <t< th=""><th></th><th></th><th>dB</th><th>1/3 Octav</th><th>e Calculatio</th><th>ons:</th><th>10*</th><th>BAND</th><th>Α</th><th>BPL(A)</th><th>REAL</th></t<>			dB	1/3 Octav	e Calculatio	ons:	10*	BAND	Α	BPL(A)	REAL
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 -20.20 -4.32   80 2.93E-09 8.64 71 90 18.5 12.68 21.32 -23.0 -16.81   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.   160 1.10E-09 4.40 143 180 37.1 15.69 20.09 -13.0 7.09 15.   200 8.28E-10 3.16 17.8 22.4 46.3 16.66 19.31 -10.0	freq	Pa^2/Hz	SPL/Hz	FcoLF	FcoHF	BW	LOG(BW)	LEVEL	SCALE	NOISE	EAR
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.   125 1.54E-09 5.84 111 140 28.9 14.62 20.46 -16.1 4.36 17.   160 1.0E-09 4.40 143 180 37.1 15.69 20.09 -13.0 7.09 15.   200 8.28E-10 0.81 281 354 72.9 18.63 19.44 -6.5 <td< th=""><th>25</th><th>2.00E-08</th><th>16.98</th><th>22</th><th>28</th><th>5.8</th><th>7.63</th><th>24.61</th><th>-45.0</th><th>-20.39</th><th></th></td<>	25	2.00E-08	16.98	22	28	5.8	7.63	24.61	-45.0	-20.39	
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.   125 1.54E-09 5.84 111 140 28.9 14.62 20.46 -16.1 4.36 17.   160 1.10E-09 4.40 143 180 37.1 15.69 20.09 -3.10 7.09 15.   200 8.28E-10 3.16 178 224 46.3 16.66 19.81 -11.0 8.81 13.   250 6.30E-10 0.81 281 354 72.9 18.63 19.44 <td< th=""><th>31.5</th><th>1.33E-08</th><th>15.22</th><th>28</th><th>35</th><th>7.3</th><th>8.63</th><th>23.85</th><th>-39.4</th><th>-15.55</th><th></th></td<>	31.5	1.33E-08	15.22	28	35	7.3	8.63	23.85	-39.4	-15.55	
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.   125 1.54E-09 5.84 111 140 28.9 14.62 20.46 -16.1 4.36 17.   160 1.10E-09 4.40 143 180 37.1 15.69 20.09 -13.0 7.09 15.   200 8.28E-10 3.16 178 224 46.3 16.66 19.81 -11.0 8.81 13.   250 6.30E-10 1.97 223 281 57.9 17.63 19.60 -8.6 11.00 11.   315 4.82E-10 0.81 281 354 72.9 18.63 <td< th=""><th>40</th><th>8.85E-09</th><th>13.45</th><th>36</th><th>45</th><th>9.3</th><th>9.67</th><th>23.11</th><th>-35.0</th><th>-11.89</th><th></th></td<>	40	8.85E-09	13.45	36	45	9.3	9.67	23.11	-35.0	-11.89	
63   4.22E-09   10.24   56   /1   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   19.1     125   1.54E-09   5.84   111   140   28.9   14.62   20.46   -16.1   4.36   17.1     160   1.0E-09   4.40   143   180   37.1   15.69   20.09   -13.0   7.09   15.1     200   8.28E-10   3.16   178   224   46.3   16.66   19.81   -11.0   8.81   13.     1315   4.82E-10   0.81   281   354   72.9   18.63   19.44   -6.5   12.94   10.     400   3.71E-10   -0.33   561   707   145.9   21.64   19.30   -3.2   16.10	50	6.12E-09	11.84	45	56	11.6	10.64	22.48	-30.0	-7.52	
80   2.93E-09   8.64   7.1   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.     125   1.54E-09   5.84   111   140   28.9   14.62   20.46   -16.1   4.36   17.     160   1.10E-09   4.40   143   180   37.1   15.69   20.09   -13.0   7.09   15.     200   8.28E-10   3.16   178   224   46.3   16.66   19.81   -11.0   8.81   13.     250   6.30E-10   1.97   223   281   57.9   17.63   19.60   -8.6   11.00   11.     315   4.82E-10   0.81   281   354   72.9   18.63   19.44   -6.5   12.94   10.     400   3.71E-10   -0.33   356   145.9   21.64   19.31   -2.0   17.31	63	4.22E-09	10.24	56	/1	14.6	11.64	21.88	-26.2	-4.32	
100 2.11E-09 7.21 89 112 23.2 13.65 20.86 -19.0 1.86 19.   125 1.54E-09 5.84 111 140 28.9 14.62 20.46 -16.1 4.36 17.   160 1.10E-09 4.40 143 180 37.1 15.69 20.09 -13.0 7.09 15.   200 8.28E-10 3.16 178 224 46.3 16.66 19.81 -11.0 8.81 13.   250 6.30E-10 1.97 223 281 57.9 17.63 19.60 -8.6 11.00 11.1   315 4.82E-10 0.81 281 354 72.9 18.63 19.44 -6.5 12.94 10.   400 3.71E-10 -0.33 356 449 92.6 19.67 19.34 -5.0 14.34 9.   500 2.94E-10 -1.34 445 561 115.8 20.64 19.30 -3.2 16.10 8.   630 2.34E-10 -2.33 561	80	2.93E-09	8.64	71	90	18.5	12.68	21.32	-23.0	-1.68	10.0
125 1.54E-09 5.84 111 140 28.9 14.62 20.46 -16.1 4.36 17.1   160 1.10E-09 4.40 143 180 37.1 15.69 20.09 -13.0 7.09 15.   200 8.28E-10 3.16 178 224 46.3 16.66 19.81 -11.0 8.81 13.1   250 6.30E-10 1.97 223 281 57.9 17.63 19.60 -8.6 11.00 11.1   315 4.82E-10 0.81 281 354 72.9 18.63 19.44 -6.5 12.94 10.1   400 3.71E-10 -0.33 356 449 92.6 19.67 19.34 -5.0 14.34 9.   500 2.94E-10 -1.34 445 561 115.8 20.64 19.30 -3.2 16.10 8.   630 2.34E-10 -2.33 561 707 145.9 21.64 19.31 -2.0 17.31 8.   800 1.88E-10 -3.29 713	100	2.11E-09	7.21	89	112	23.2	13.65	20.86	-19.0	1.86	19.0
160 1.10E-09 4.40 143 180 37.1 15.69 20.09 -13.0 7.09 15.   200 8.28E-10 3.16 178 224 46.3 16.66 19.81 -11.0 8.81 13.   250 6.30E-10 1.97 223 281 57.9 17.63 19.60 -8.6 11.00 11.   315 4.82E-10 0.81 281 354 72.9 18.63 19.44 -6.5 12.94 10.   400 3.71E-10 -0.33 356 449 92.6 19.67 19.34 -5.0 14.34 9.   500 2.94E-10 -1.34 445 561 115.8 20.64 19.30 -3.2 16.10 8.   630 2.34E-10 -2.33 561 707 145.9 21.64 19.31 -2.0 17.31 8.   800 1.88E-10 -3.29 713 898 185.3 22.66 19.52 0.0 19.52 9.   1250 1.29E-10 -4.91 1114	125	1.54E-09	5.84	111	140	28.9	14.62	20.46	-16.1	4.30	17.0
200 8.28E-10 3.16 178 224 46.3 10.66 19.81 -11.0 8.81 13.   250 6.30E-10 1.97 223 281 57.9 17.63 19.60 -8.6 11.00 11.   315 4.82E-10 0.81 281 354 72.9 18.63 19.44 -6.5 12.94 10.   400 3.71E-10 -0.33 356 449 92.6 19.67 19.34 -5.0 14.34 9.   500 2.94E-10 -1.34 445 561 115.8 20.64 19.30 -3.2 16.10 8.   630 2.34E-10 -2.33 561 707 145.9 21.64 19.31 -2.0 17.31 8.   800 1.88E-10 -3.29 713 898 185.3 22.68 19.39 -1.0 18.39 9.   1000 1.55E-10 -4.13 891 1122 231.6 23.65 19.52 0.0 19.52 9.   1250 1.29E-10 -4.91 1114	160	1.10E-09	4.40	143	180	37.1	15.69	20.09	-13.0	7.09	15.0
250 6.30E-10 1.97 223 281 57.9 17.63 19.60 -8.6 11.00 11.   315 4.82E-10 0.81 281 354 72.9 18.63 19.44 -6.5 12.94 10.   400 3.71E-10 -0.33 356 449 92.6 19.67 19.34 -5.0 14.34 9.   500 2.94E-10 -1.34 445 561 115.8 20.64 19.30 -3.2 16.10 8.   630 2.34E-10 -2.33 561 707 145.9 21.64 19.31 -2.0 17.31 8.   800 1.88E-10 -3.29 713 898 185.3 22.68 19.39 -1.0 18.39 9.   1000 1.55E-10 -4.13 891 1122 231.6 23.65 19.52 0.0 19.52 9.   1250 1.29E-10 -4.91 1114 1403 289.5 24.62 19.71 0.5 20.21 10.   1600 1.08E-10 -5.70 1425<	200	8.28E-10	3.16	178	224	46.3	16.66	19.81	-11.0	8.81	13.0
315 4.82E-10 0.81 281 354 72.9 18.63 19.44 -0.5 12.94 10.   400 3.71E-10 -0.33 356 449 92.6 19.67 19.34 -5.0 14.34 9.   500 2.94E-10 -1.34 445 561 115.8 20.64 19.30 -3.2 16.10 8.   630 2.34E-10 -2.33 561 707 145.9 21.64 19.31 -2.0 17.31 8.   800 1.88E-10 -3.29 713 898 185.3 22.68 19.39 -1.0 18.39 9.   1000 1.55E-10 -4.13 891 1122 231.6 23.65 19.52 0.0 19.52 9.   1250 1.29E-10 -4.91 1114 1403 289.5 24.62 19.71 0.5 20.21 10.   1600 1.08E-10 -5.70 1425 1796 370.5 25.69 19.98 1.0 20.98 9.   2000 9.24E-11 -6.36 17	250	6.30E-10	1.97	223	281	57.9	17.03	19.60	-8.0	11.00	11.0
400 3.71E-10 -0.33 330 449 92.0 19.07 19.34 -5.0 14.34 9.   500 2.94E-10 -1.34 445 561 115.8 20.64 19.30 -3.2 16.10 8.   630 2.34E-10 -2.33 561 707 145.9 21.64 19.31 -2.0 17.31 8.   800 1.88E-10 -3.29 713 898 185.3 22.68 19.39 -1.0 18.39 9.   1000 1.55E-10 -4.13 891 1122 231.6 23.65 19.52 0.0 19.52 9.   1250 1.29E-10 -4.91 1114 1403 289.5 24.62 19.71 0.5 20.21 10.   1600 1.08E-10 -5.70 1425 1796 370.5 25.69 19.98 1.0 20.98 9.   2000 9.24E-11 -6.36 1782 2245 463.1 26.66 20.29 1.2 21.49 7.   2500 8.06E-11 -5.96 <td< th=""><th>315</th><th>4.82E-10</th><th>0.81</th><th>281</th><th>354</th><th>12.9</th><th>18.63</th><th>19.44</th><th>-0.5</th><th>12.94</th><th>10.0</th></td<>	315	4.82E-10	0.81	281	354	12.9	18.63	19.44	-0.5	12.94	10.0
500 2.94E-10 -1.34 445 561 115.8 20.04 19.30 -3.2 16.10 8.   630 2.34E-10 -2.33 561 707 145.9 21.64 19.31 -2.0 17.31 8.   800 1.88E-10 -3.29 713 898 185.3 22.68 19.39 -1.0 18.39 9.   1000 1.55E-10 -4.13 891 1122 231.6 23.65 19.52 0.0 19.52 9.   1250 1.29E-10 -4.91 1114 1403 289.5 24.62 19.71 0.5 20.21 10.   1600 1.08E-10 -5.70 1425 1796 370.5 25.69 19.98 1.0 20.98 9.   2000 9.24E-11 -6.36 1782 2245 463.1 26.66 20.29 1.2 21.49 7.   2500 8.06E-11 -6.96 2227 2806 578.9 27.63 20.67 1.2 21.87 5.   3150 7.09E-11 -7.51	400	3.71E-10	-0.33	300	449	92.0	19.07	19.34	-5.0	14.34	9.0
630 2.34E-10 -2.33 301 707 143.9 21.04 19.31 -2.0 17.31 6.   800 1.88E-10 -3.29 713 898 185.3 22.68 19.39 -1.0 18.39 9.   1000 1.55E-10 -4.13 891 1122 231.6 23.65 19.52 0.0 19.52 9.   1250 1.29E-10 -4.91 1114 1403 289.5 24.62 19.71 0.5 20.21 10.   1600 1.08E-10 -5.70 1425 1796 370.5 25.69 19.98 1.0 20.98 9.   2000 9.24E-11 -6.36 1782 2245 463.1 26.66 20.29 1.2 21.49 7.   2500 8.06E-11 -6.96 2227 2806 578.9 27.63 20.67 1.2 21.87 5.   3150 7.09E-11 -7.51 2806 3536 729.4 28.63 21.12 1.1 22.22 4.   4000 6.31E-11 -8.02	500	2.94E-10	-1.34	445	207	115.8	20.64	19.30	-3.2	10.10	8.0
000   1.55E-10   -3.29   713   036   103.3   22.06   19.39   -1.0   10.38   3.     1000   1.55E-10   -4.13   891   1122   231.6   23.65   19.52   0.0   19.52   9.     1250   1.29E-10   -4.91   1114   1403   289.5   24.62   19.71   0.5   20.21   10.     1600   1.08E-10   -5.70   1425   1796   370.5   25.69   19.98   1.0   20.98   9.     2000   9.24E-11   -6.36   1782   2245   463.1   26.66   20.29   1.2   21.49   7.     2500   8.06E-11   -6.96   2227   2806   578.9   27.63   20.67   1.2   21.87   5.     3150   7.09E-11   -7.51   2806   3536   729.4   28.63   21.12   1.1   22.22   4.     4000   6.31E-11   -8.02   3564   4490   926.3   29.67	830	2.34E-10	-2.33	201 712	000	140.9	21.04	19.31	-2.0	10.20	0.0
1000 1.55E-10 -4.13 0.91 1122 -23.10 23.03 19.32 0.0 19.32 9.   1250 1.29E-10 -4.91 1114 1403 289.5 24.62 19.71 0.5 20.21 10.   1600 1.08E-10 -5.70 11425 1796 370.5 25.69 19.98 1.0 20.98 9.   2000 9.24E-11 -6.36 1782 2245 463.1 26.66 20.29 1.2 21.49 7.   2500 8.06E-11 -6.96 2227 2806 578.9 27.63 20.67 1.2 21.87 5.   3150 7.09E-11 -7.51 2806 3536 729.4 28.63 21.12 1.1 22.22 4.   4000 6.31E-11 -8.02 3564 4490 926.3 29.67 21.65 1.0 22.65 3.   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<	1000	1.66E-10	-3.29	004	1400	100.0	22.00	19.59	-1.0	10.59	9.0
1250 1.29E-10 -4.91 1114 1403 229.3 24.02 19.71 0.3 20.21 10.   1600 1.08E-10 -5.70 1425 1796 370.5 25.69 19.98 1.0 20.98 9.   2000 9.24E-11 -6.36 1782 2245 463.1 26.66 20.29 1.2 21.49 7.   2500 8.06E-11 -6.96 2227 2806 578.9 27.63 20.67 1.2 21.87 5.   3150 7.09E-11 -7.51 2806 3536 729.4 28.63 21.12 1.1 22.22 4.   4000 6.31E-11 -8.02 3564 4490 926.3 29.67 21.65 1.0 22.65 3.   5000 5.74E-11 -8.43 4454 5612 1157.8 30.64 22.20 0.5 22.70 4.2   6300 5.27E-11 -8.43 4454 5612 1157.8 30.64 22.84 -0.5 22.34 11.0   8000 4.89E-11 -9.1	1000	1.55E-10	-4.13	1114	1122	201.0	23.00	19.02	0.0	19.02	9.5
1000 1.001 1.001 1120 1130 5010 12.00 12.000 12.000 12.000 10 <th>1200</th> <th>1.29E-10</th> <th>-4.91</th> <th>1/14</th> <th>1706</th> <th>370.5</th> <th>24.02</th> <th>10.08</th> <th>1.0</th> <th>20.21</th> <th>0.0</th>	1200	1.29E-10	-4.91	1/14	1706	370.5	24.02	10.08	1.0	20.21	0.0
2000 3.242-11 -0.30 1102 2240 -403.1 20.067 20.23 1.2 21.45 1.   2500 8.06E-11 -6.96 2227 2806 578.9 27.63 20.67 1.2 21.87 5.   3150 7.09E-11 -7.51 2806 3564 79.4 28.63 21.12 1.1 22.22 4.   4000 6.31E-11 -8.02 3564 4490 926.3 29.67 21.65 1.0 22.65 3.   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 5612 1157.8 30.64 22.20 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 20.1   12500 4.39E-11 -9.60	2000	9 24E-11	-6.36	1782	22/5	463.1	20.00	20.20	1.0	20.30	7.5
3150   7.09E-11   -7.51   2806   3536   729.4   28.63   21.12   1.1   22.22   4.     4000   6.31E-11   -8.02   3564   4490   926.3   29.67   21.65   1.0   22.65   3.     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   20.30     12500   4.39E-11   -9.60   11136   14031   2894.5   34.62   25.02   -4.0   21.02   13.3     16000   4.39E-11   -9.60   14254   17959   3705.0	2500	8.06E-11	-6.96	2227	2806	578.9	27.63	20.20	12	21.40	5.5
4000   6.31E-11   -8.02   3564   4490   926.3   29.67   21.65   1.0   22.65   3.     5000   5.74E-11   -8.43   4454   5612   1157.8   30.64   22.20   0.5   22.70   4.1     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   20.30     12500   4.39E-11   -9.60   11136   14031   2894.5   34.62   25.02   -4.0   21.02   13.3     16000   4.19E-11   -9.80   14254   17959   3705   0   35.69   25.89   -6   0   21.02   13.3	3150	7.09E-11	-7.51	2806	3536	729.4	28.63	21.12	11	22.22	4.5
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     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	4000	6.31E-11	-8.02	3564	4490	926.3	29.67	21.65	1.0	22.65	3.1
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	5000	5.74E-11	-8,43	4454	5612	1157.8	30.64	22.20	0.5	22,70	4.2
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   35.69   25.89   -6.0   19.89   25.0	6300	5.27E-11	-8.80	5613	7072	1458.8	31.64	22.84	-0.5	22.34	11.0
<b>10000 4.61E-11</b> -9.38 8909 11225 2315.6 33.65 24.26 -2.5 21.76 20.0 <b>12500 4.39E-11</b> -9.60 11136 14031 2894.5 34.62 25.02 -4.0 21.02 13.0 <b>16000 4.19E-11</b> -9.80 14254 17959 3705 0 35.69 25.89 -6.0 19.89 25.0	8000	4.89E-11	-9,13	7127	8980	1852.5	32,68	23,55	-1.1	22.45	19.0
<b>12500 4.39E-11</b> -9.60 11136 14031 2894.5 34.62 25.02 -4.0 21.02 13.0 <b>16000 4 19E-11</b> -9.80 14254 17959 3705.0 35.69 25.89 -6.0 19.89 25.0	10000	4.61E-11	-9.38	8909	11225	2315.6	33.65	24.26	-2.5	21.76	20.0
<b>16000 4 19E-11</b> -9.80 14254 17959 3705.0 35.69 25.89 -6.0 19.89 25.0	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	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 realear 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,  $\mathbb{A}$ , is the center frequency of the thirdoctave band. The second,  $\mathbb{B}$ , is the "power spectral density" The 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  $\mathbb{C}$  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  $\mathbb{E}$ . **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  $\sim$ 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  $\blacktriangleright$ , 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 <u>Here</u>

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 1/3octaves 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.

