# DESIGN OF AN ELECTRET BASED MEASUREMENT MICROPHONE

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## ABSTRACT

This paper presents the design and benchmark test results of a low cost electret based microphone. As workplaces and living spaces become “smarter” and more energy efficient there is an ever increasing demand for low cost sensors to detect human behaviour and location in order to control energy consuming devices at optimal levels. Although microphones can provide detailed “high level” information their prohibitive cost has been an obstacle to their incorporation into smart spaces. For example, although Passive Infared Sensors are commonly used to detect human proximity, microphones with sophisticated beamforming techniques can not only pinpoint human location but can also provide additional information with regard the activity, i.e. speech, and post processing Blind Source Separation Techniques can separate out the voice record from background noise.

Electret microphone capsules are now so common due to their proliferation in multi-media devices that their prices are now at an affordable level. A measurement microphone designed using an electret capsule is described in this paper. The signal conditioning, power supply and amplification of an electret output signal is detailed as well as the final product including housing and cabling. The electret microphone is benchmarked against a high quality G.R.A.S. (BF40) microphone and tested for dynamic range, frequency range, linearity as a function of frequency as well as linearity as a function of amplitude. The solution is shown to perform extremely well with a noise floor of approximately 0dB and upper threshold of 118dB with a cost per channel of around €100.

**KEYWORDS: Design, Microphone, Electret**

## 1. INTRODUCTION

Pervasive devices, sensors, and networks, provide infrastructure for context-aware smart meeting rooms and spaces that sense ongoing human or machine activities and respond to them. The information that the sensors can provide can support recognition processing research communities working in audio, video, and sensor fusions. These spaces can be office space [1, 2] or workspaces such as factory floors in manufacturing facilities. This data can be used to monitor activity and implement energy saving algorithms. Microphones are sensors which provide high level information and have been used successfully to date in power management projects [3]. Arrays of microphones can provide more complex information which can be used to optimise energy saving procedures or in other areas of engineering, such as aeroacoustics, to perform noise source identification techniques to reduce environmental noise [4]. Array techniques require large numbers of microphones to optimise spatial and frequency resolution. This paper seeks to remove the barrier of sensor cost from the implementation of energy saving algorithms.

## 2. MICROPHONE DESIGN

The assembly consists of the Electret microphone capsule, a D.C. power supply, a microphone amplifier, a stainless steel tube and an SMB cable.

### 2.1 Electret Cartridge

This is the key component of the product and although large volumes have resulted in an affordable product range, they have a high quality specification. Two cartridges were evaluated: the WM-61A and the WM-64, both manufactured by Panasonic [5] and available for purchase from Digi-key [6]. They are both omni-directional back electret condenser microphone cartridges, the first being more sensitive than the latter. This particular brand was chosen as the author had seen home-made microphones constructed with this product used by the Institute of Sound and Vibration Research (ISVR), Southampton, in European Union funded Aeroacoustic tests. These microphones performed well and were extremely economical to produce. Since the microphones in this paper were designed and assembled, the author has found a paper documenting a similar study on Electrets by NASA, Langley [7], which uses the Panasonic WM-60A - since discontinued. The electrets are compact, see figure 1, and have a reasonably flat frequency response in the audio frequency range, figure 2. The package incorporates a field-effect transistor driver on the output stage and can operate at a maximum supply voltage of 10V, with a maximum current draw of 0.5mA. The nominal sensitivities of the WM-61A and the WM-64 are 19.5mV/Pa and 6.2mV/Pa respectively. Full specifications can be found on the Panasonic or DigiKey Websites [5, 6].

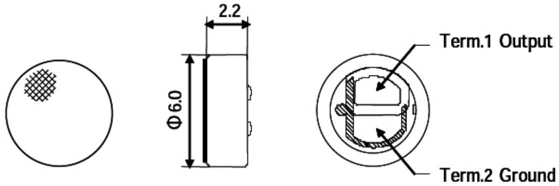

**Figure 1.** Electret Dimensional Drawing (mm)

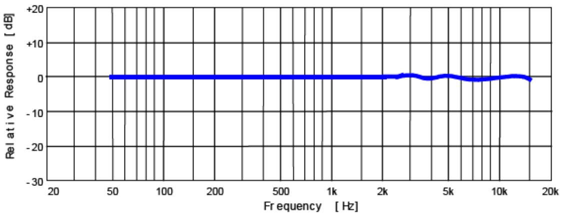

**Figure 2.** Electret Frequency Response

### 2.2 Amplifier Circuit

Typically, a microphone data acquisition channel will consist of the microphone, a cable connecting it to an amplifier, a cable from the amplifier to a data acquisition system and an A.C. power cable to the amplifier. To reduce the number of cables required per channel and to improve the signal to noise ratio, the amplifier was designed to be housed within the microphone housing. In addition, as the current-draw from the electret is extremely small, it was decided to power the electronics using a battery located locally. This would reduce the number of cables required per channel from three to one. Figure 3 shows the wiring diagram for the design. One of the components which allowed the amplifier circuitry to be contained within the microphone housing is the miniature microphone amplifier manufactured by Maxim (MAX9812H). This is an integrated circuit (i.c.) surface mount component and is indicated by U2 on the wiring diagram in figure 3 and has an op. amp. with a 20dB gain and an integrated bias. This and some other conditioning components were mounted onto a printed circuit board 4.9mm wide. A schematic of this board, which was manufactured by Beta LAYOUT, Shannon, Co. Clare, is shown in figure 4. The boards were populated by a technician in TCD, hence labour costs would have to be included in the assembly price. The other key element in the circuitry of figure 3 is the voltage regulator, U1. This serves to step down the voltage of the 9V battery to 5V as well as providing load and line regulation. It would be foreseen to use small lithium batteries for future assemblies, thus reducing the size and also eliminating the need for a regulator if correctly chosen. Further work is planned to investigate using a constant current supply from an ICP compliant Data Acquisition system. This would eliminate the need for batteries entirely, with the data cable also supplying power to the i.c. amplifier.

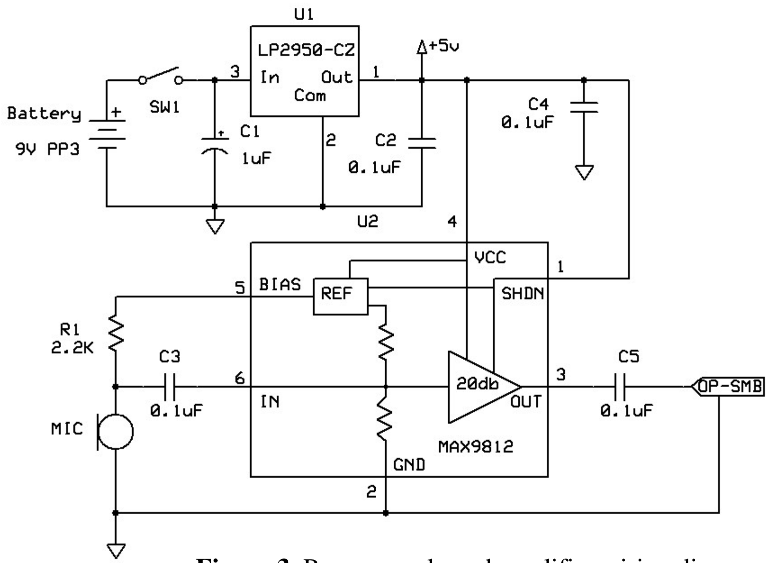

**Figure 3.** Power supply and amplifier wiring diagram

## 2.3 Microphone Assembly

A photograph of the prototype assembly is shown in figure 5. A stainless steel tube is used as a housing and also to connect the ground of the electret capsule to the SMB cable earth. The printed circuit board is contained within the tube and, in this prototype, the battery, voltage regulator, the large smoothing capacitor, C1, and the capacitor C2 are located outside the tube. To provide an idea of the componentry and of some prices, a bill of material is given in table 1.

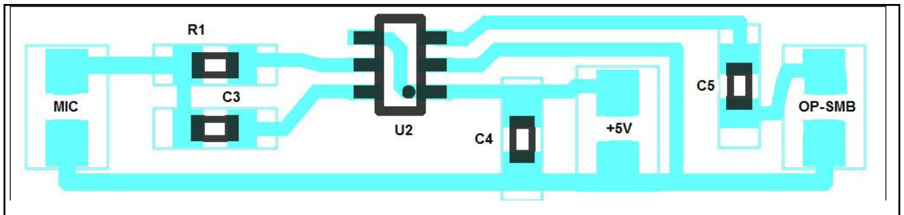

**Figure 4.** Printed Circuit Board Layout

# 3. EVALUATION

Although figure 2 presents a frequency response curve for the electret capsule, this and the stated sensitivity are only representative. Indeed, the sensitivity has a typical error of +/- 4dB (0dB=1V/Pa, 1kHz). In addition, the power/amplifier circuitry, the cable and connector as well as general handling and installation effects will all modify the sensitivity and frequency response of the entire assembly. A series of tests were performed to calculate the sensitivity of the complete channel and to assess its frequency response for magnitude and phase as well as its linear dynamic range. The general approach was to compare the electret assembly with a high cost and quality microphone which has a flat frequency response and a high dynamic range. The microphone chosen was a G.R.A.S. (BF40) measurement microphone. Two electret assemblies were tested: one with a WM-61A electret capsule coupled with the MAX9812L (3V operation); the second the WM-64 used with the MAX9812H (5V operation). These will be referred to as the E1 and E2 assemblies, with the G.R.A.S. channel being referred to as the reference assembly. The objective of assessing both the E1 and E2 assemblies was to see how the upper and lower end of the dynamic range could be extended.

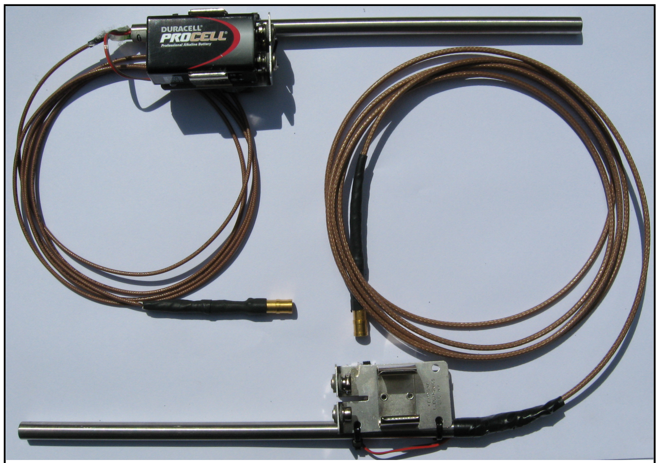

**Figure 5.** Photograph of two assemblies.

**Table 1.** Bill of Material for Microphone Assembly.

| Part | Detail | Part No. | Cost |
|---|---|---|---|
| Battery | 9V PP3 | Farnell 101-8880 | €2.01 |
| C1 | 1uF | Farnell | |
| C2 | 0.1uF | Farnell 941-1887 | €0.01 |
| C3 | 0.1uF | Farnell 128-8282 | €0.03 |
| C4 | 0.1uF | | |
| C5 | 0.1uF | | |
| R1 | 2.2K | Farnell 923-9278 | €0.04 |
| SW1 | | Farnell 120-1430 | €1.00 |
| U1 | LP2950-CZ | Farnell 948-9479 | €0.64 |
| U2 | MAX9812 | | |
| electret | | WM-61/64 | €1.38 |
| op SMB | SMB Con | Farnell 116-9648 | €2.40 |
| board | | Beta LAYOUT | 95 boards for €74 |
| cable | rg187 cable | Farnell 149-1564 | €10.35 |

## 3.1 Sensitivity at 1kHz

The sensitivity of the three microphone assemblies was measured using a Bruel & Kjaer Sound Level Calibrator Type 4231. This exposes the microphone to 1Pa or 94 dB (ref 2e-5) at 1kHz. The results were 0.213V/Pa, 0.0793V/Pa and 0.0034V/Pa for the E1, E2 and the reference assemblies respectively. As the 20dB gain of the op. amp. is equivalent to an order of magnitude increase, these results and the result from the reference assembly are consistent with the supplier's documentation.

## 3.2 Frequency Response

Calibration using the B&K 4231 device is necessary for volts to Pascal conversion but as it is a gain factor at 1kHz only, multiplication by this number assumes a flat frequency response.

Typically, this can not be assumed and so transfer functions between the reference assembly and the electret assemblies were calculated using controlled conditions. The set-up for this test is shown in figure 6.

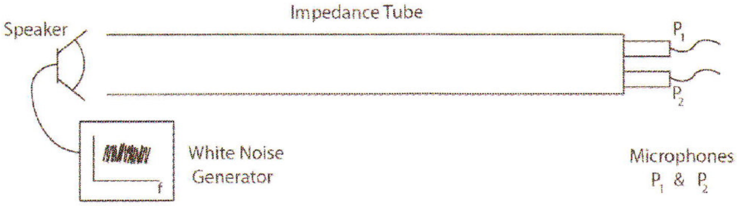

**Figure 6.** Frequency Response Experimental set-up

The objective behind this set-up is to expose both microphone assemblies to the same acoustic field. This can be achieved by flush mounting the reference microphone and each electret assembly in turn at the end of a sealed circular duct. It can be demonstrated that at frequencies below the plane wave cut-off frequency of the duct, only planes waves will propagate down the duct. The equation for this frequency is given by

$$f_{cut-off} = \frac{1.83c}{\pi D} \tag{1}$$

where c is the speed of sound, and D is the diameter of the duct. Therefore, the microphones, being located on the same plane, will see the same sound field radiated by a loudspeaker located at the open end of the duct. By choosing white noise as the sound source, a frequency response function can be calculated between the two microphones assemblies for all frequencies in the audio-range.

### 3.3 Data Acquisition and Reduction

The data was acquired from the microphone assemblies using a National Instruments A/D convertor – *viz.* NI PXI-4472B cards mounted in an NI PXI-1044 chasis. These 8 input cards can sample each channel simultaneously with 24-bit resolution and have variable anti-aliasing filters. Labview was used to control the acquisition system and to save the data to disc. Matlab was used to post-process the data and to calculate the frequency response function using equation 2 and the spectral estimate parameters of table 2.

**Table 2.** Spectral estimate parameters

| **Parameter** | **Value** |
|---|---|
| Segment length, i.e., data points per segment, $N$ | 8192 |
| Sample rate, $fsamp$, Hz | 32,768 |
| Segment length, $Td = N/fsamp$, s | 0.25 |
| Sampling interval, $\Delta t = 1/fsamp$, s | 3.05E-5 |
| Frequency step, $\Delta f = 1/Td$, Hz | 4 |
| Upper frequency limit, $f_c = 1/(2\Delta t) = f_{samp}/2$, Hz | 16,384 |
| No. of frequencies, $Ly = f_c/\Delta f = N/2$ | 4096 |
| No. of independent averages $n_d$ | 40 |
| Overlap | 0 |
| Sample length, s | 10 |

The frequency response function is calculated according to [8]

$$H(f) = \frac{\hat{G}_{xy}(f)}{\hat{G}_{xx}(f)} \tag{2}$$

where the single sided averaged cross-spectrum is defined by

$$\hat{G}_{xy}(f_k) = \frac{2}{n_d N \Delta t} \sum_{i=1}^{n_d} X_i^*(f_k) Y_i(f_k) \qquad k = 0, 1, \ldots, \frac{N}{2} \tag{3}$$

and similarly the auto spectrum is calculated using equation 4.

$$\hat{G}_{xx}(f_k) = \frac{2}{n_d N \Delta t} \sum_{i=1}^{n_d} |X_i(f_k)|^2 \qquad k = 0, 1, \ldots, \frac{N}{2} \tag{4}$$

## 4. RESULTS AND DISCUSSION

An initial test was performed to ascertain the noise floor of the microphone assemblies and thus the lower limit of the dynamic range. In condenser microphones the lower limit is affected by thermal movement of the diaphragm, or thermal noise. However, the amplifier circuitry also contributes to noise at the lower threshold and of interest here is a measure of the total noise that sets this limit. A simple procedure was to place the assemblies in the impedance tube, located in a box padded with sound absorbing material and to record a power spectrum in a quiet laboratory. This procedure while certainly not rigorous will give indicative results. Figure 7 shows the results for this test for the less sensitive E2 assembly versus the reference assembly. To be seen is the very low noise floor, 0dB, and the 15dB noise floor of the reference microphone which is in agreement with the specifications. The increase in noise at the lower frequencies is in keeping with the 1/f behaviour of electret microphones and the narrowband increases correspond to low level excitation of the duct modes of the impedance tube. The low frequency tones are most likely the blade pass frequency of the cooling fans in the data acquisition system. The noise floor of the E1 assembly was measured, using the same test set-up, to be -10dB.

Figure 8 shows a comparison between the auto-spectrum of the E2 assembly and the reference assembly when the loudspeaker radiated white noise down the impedance tube. Both microphones were calibrated according to the measured sensitivities. The peaks correspond to the longitudinal duct modes of the duct. To be seen is the very close agreement between the two assemblies. However, also to be seen is the drop in magnitude with increasing frequency. This can be best understood and compensated for by calculating the frequency response function between the two assemblies. This was carried out using equation 2 and the magnitude and phase are plotted in figures 9 and 10. As can be seen, the magnitude supports the fact that the electret assembly response drops off with increasing frequency, assuming a flat response from the G.R.A.S. microphone. The smallest tube that could accommodate the two microphones side by side was used, and a result, from equation 1, the plane wave cut-off frequency was just higher than 11kHz. Due to this fact, the electret assembly could only be frequency corrected up to this frequency. The phase plot of figure 10 also shows a frequency dependent variation and the importance of calibration is underlined if accurate measurements are to be made.

The upper end of the dynamic range was determined by increasing the magnitude of the loudspeaker signal and by looking for output distortion or non-linear behaviour. With a broadband noise input, this can be detected by plotting the rms of the input voltage to the loudspeaker against the rms voltage measured by the acquisition system. Figures 11 and 12 shows these plots for both the reference and the E2 assemblies. The output voltage from the microphones has been converted to Pascals to allow the SPL in dB to be determined. The upper limit for the E2 assembly is calculated to be approximately 118dB, whereas the reference assembly remains linear in the same input voltage range. The specifications for this high amplitude microphone state an upper limit of 174dB for the model. A series of tests were also carried out to measure the microphones response to tonal excitation. Non-linear behaviour for this test-set up manifests as harmonics of the fundamental tone. Although not shown here, results for measured THD (Total Harmonics Distortion) are consistent with the broadband excitation limits. The upper limit is controlled, in part, by the sensitivity of the electret capsule and by the driving voltage: the objective is to allow the output voltage to increase with acoustic pressure without the output signal clipping. For this reason, the two different E1 and E2 assemblies were tested. The dynamic range for E1 was measured to be -10dB/106dB whereas E2 had a range of 0dB/118dB.

## 5. CONCLUSIONS

Low cost, off the shelf electret capsules allow affordable, accurate microphone assemblies to be designed and manufactured by end users. This paper presents a solution which includes amplifier, power supply and packaging design. Two assemblies are tested, one for low level measurements and a second with a high upper dynamic range. The amplifiers use a high specification surface mount microphone amplifier which due to its small size allows the PCB to be located inside the microphone housing, improving signal to noise ratio by its proximity to the electret and also simplifying cabling. Comparative tests with a high specification production microphone show that the magnitude and phase response of the assemblies are frequency dependent, and that this variation changes from one assembly to another. These variations can be measured and thus accommodated for however by pre-calibration with a high quality reference microphone.

## ACKNOWLEDGEMENTS

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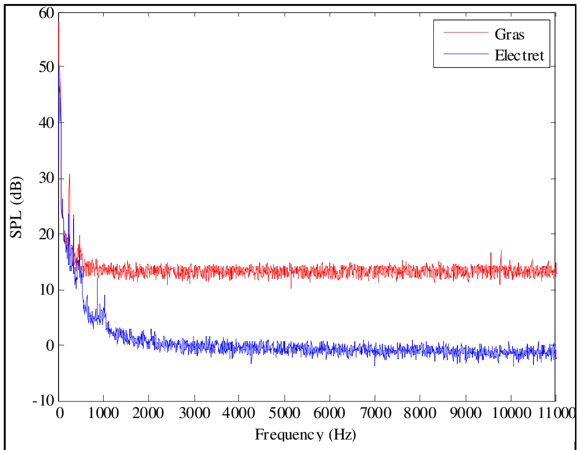

**Figure 7.** Noise floor for the E2 and G.R.A.S. assemblies

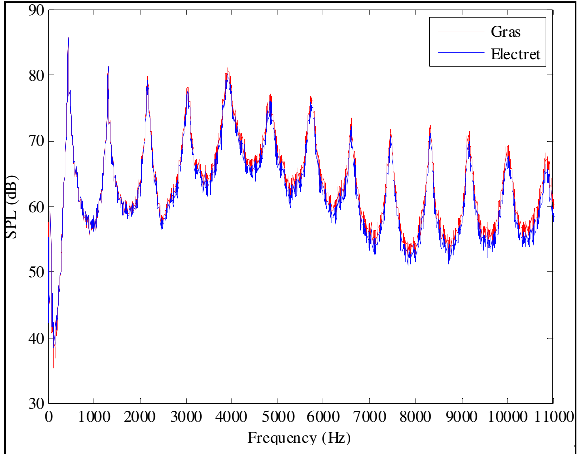

**Figure 8.** Auto-spectra for E2 and G.R.A.S.-white noise in impedance tube

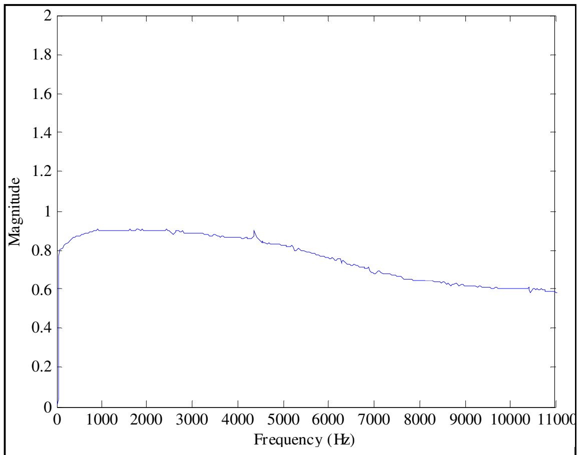

**Figure 9.** FRF E2/reference assembly - Magnitude

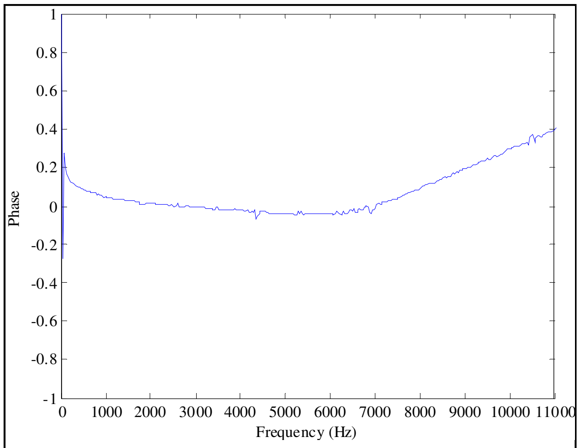

**Figure 10.** FRF E2/reference assembly - Phase

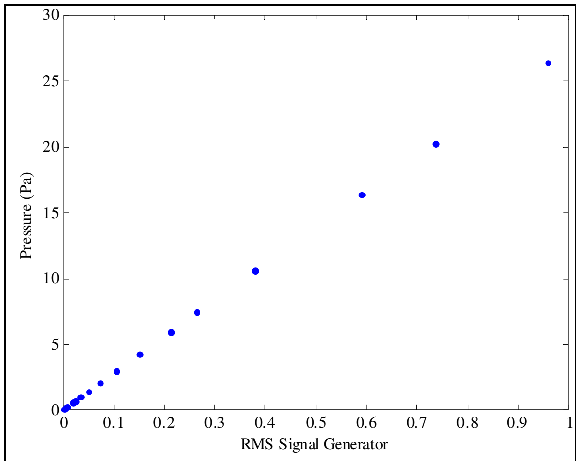

**Figure 11.** Input/output relationship - Reference assembly

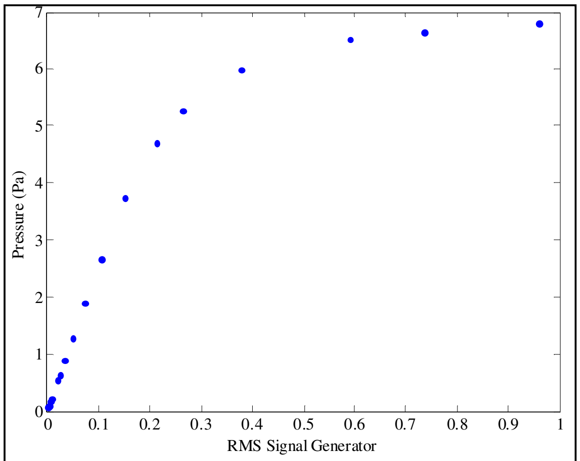

**Figure 12.** Input/output relationship – E2 assembly