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## Experimental Investigation of Sound Pressure Levels Variation during Modulation of a Compressor in a Unit - Case Study

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### ABSTRACT

Energy saving has governed digital compressors in existence. Digital Scroll™ compressors require a special modulation control for the loading and unloading of the compression mechanism. During the transition of the mode of operation, loaded or unloaded, a clicking sound is produced as well as variation in sound pressure levels. Original Equipment Manufacturers (OEMs) have attempted with no success to resolve this issue by the use of a partial sound barrier around the compressor. The objective of the paper is to improve the sound performance during the modulation event.

### 1. INTRODUCTION

The compressor alternates between 2 states, the loaded state and the unloaded state. During the loaded state, the compressor delivers full capacity (1) and during the unloaded state it delivers no capacity (0). Since it alternates between 1 and 0, it is called Digital Scroll™. Because of the modulated feature in the compressor, there is a need of an extra component, an external solenoid valve. The solenoid valve is in a normally closed condition. Power is supplied to the solenoid valve, which causes pressure equalization in the compressor, resulting in the unloaded state. During this part of the cycle the motor is in an idle mode and there is no compression of the refrigerant. The load demand is met by the average capacity over a given duty cycle; for example, with 50% duty cycle, the compressor will compress during one half of cycle and idle during the remaining half on the cycle. Digital Scroll™ compressors are increasingly being used in refrigeration applications with R404A and air condition application with R22, R407C and R410A refrigerant.

It is possible to start the Digital Scroll™ into an unloaded state, first, with the solenoid and make sure that the current consumption is lower. The unloaded power consumption is only a fraction of full load power, which is a parasitic loss as no flow is produced during that half of the cycle. The high Energy Efficiency Ratio (EER) comes from the reduced integrated capacity effect on the system. The external solenoid in the Digital Scroll™ is a specially designed long life valve. It should never be replaced by a standard solenoid valve. This valve has a life of

more than 15 years of continuous operation. All the components in the Digital Scroll™ have been qualified to handle the continuous loading and unloading. The energy savings of the system is normally measured through seasonal energy efficiency ratio (SEER). Compared to SEER of a standard scroll system, a Digital Scroll™ system is an improvement. This number depends on the system design, but it can be said conservatively that the energy savings will be higher in the Digital Scroll™ compressor as compared to a fixed speed system.

The maximum duty cycle time can be established by the manufacturer or determined experimentally. The Digital Scroll compressor always rotates at the same speed during both the loaded and unloaded state. Since the motor is always running, a change from unloaded to loaded state does not require additional starting current. The fluctuations in the current during the loaded and unloaded state being low, and other electrical appliances are not affected.

The present work was performed to resolve a customer complain, in which the problem was ill-defined. There is a sound level difference between the loaded and unloaded state, that of the loaded state being higher. The quality of the sound produced under the two states is also different. In general, when sound level is an issue, a sound barrier on the compressor is provides an effective solution. Both steady state and transient sounds presented an issue in the outdoor unit in both operating modes. A sound enclosure was used to resolve the steady state sound issue, and the transient part by the solenoid valve configuration.

## 2. MEASUREMENT SET UP

Outdoor unit was mounted in hemi-echoic room with temperature control. A three-ton evaporator unit was installed for air handling. There were two sets of measurements (95°F and 70°F outdoor temperature). The operating pressure variation of the digital compressor is shown in Figure 1 during these outdoor temperatures. Each operating outdoor temperature was maintained in the hemi-anechoic room during the measurements. Cooling Fans and solenoid were supplied electric power directly. The fans were operated at 986 RPM and 971 RPM. Pressure Gauges were installed at suction and discharge of the compressor for monitoring the pressure during modulation.

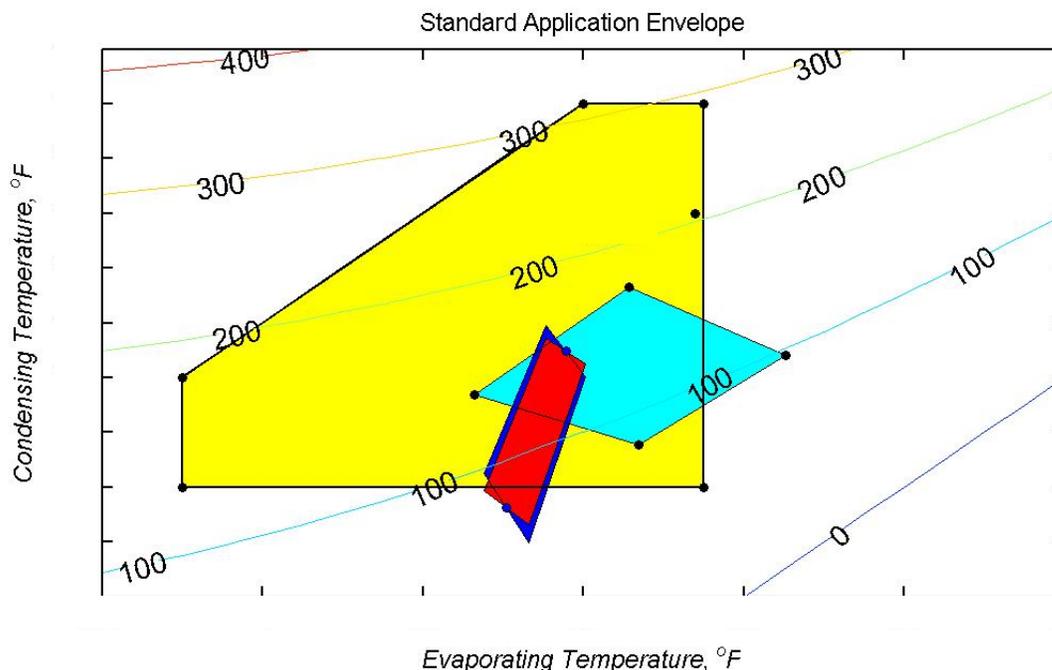


Figure 1: Application envelop of the digital compressor during modulation

Measurements were taken at five different positions, which are shown in Figure 2. Microphone locations were 1m away from unit surface and 1 meter above ground. The unit had only a partial enclosure because of the openings for cables, installation and mounting of the compressor.

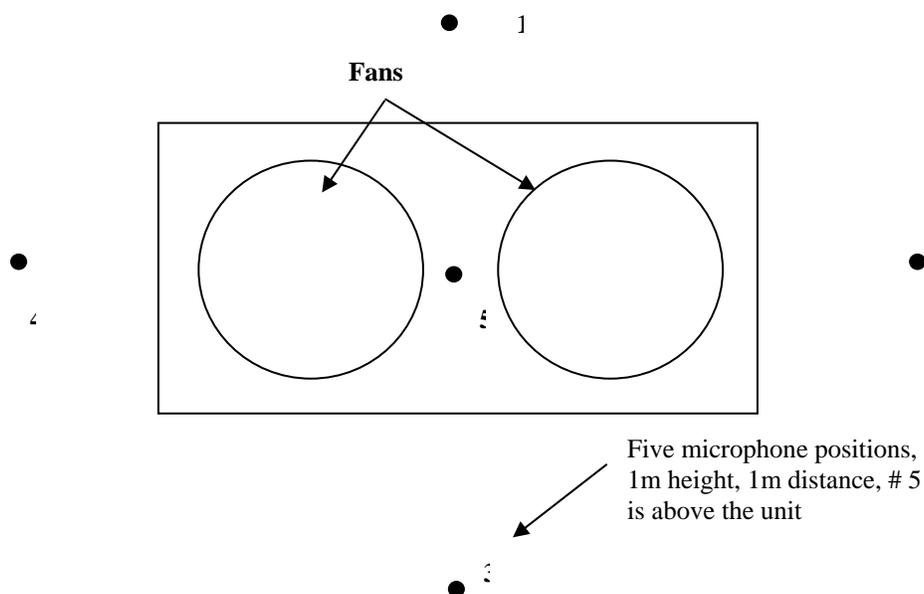


Figure 2: Mapping of Outdoor unit and Microphone Position.

Leo (1988) suggested that unsealed enclosure insertion loss can be predicted and has limitation on higher cut off frequency and causes also sound magnification, which will degrade its performance in the current situation. Mezache *et al.* (2003) have designed an enclosure for refrigerant compressor which produced 15 dB overall insertion loss. Tweed (1978) has derived an analytical expression for closed-fit enclosure. Harris (1998) has given the information on transmission loss for different leakage analysis in the enclosure design. Based on this literature two options were tried: sealing the holes and constructing a total enclosure.

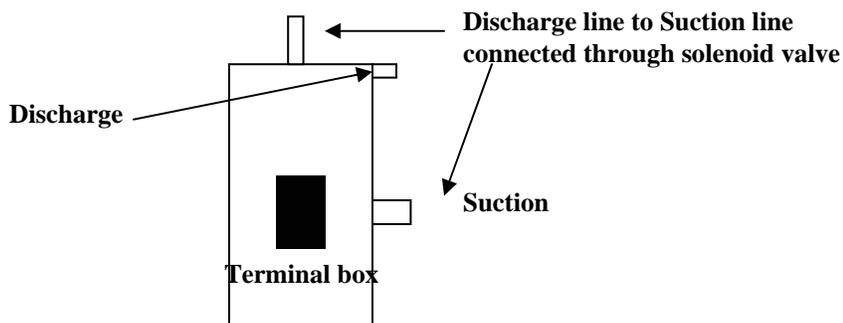
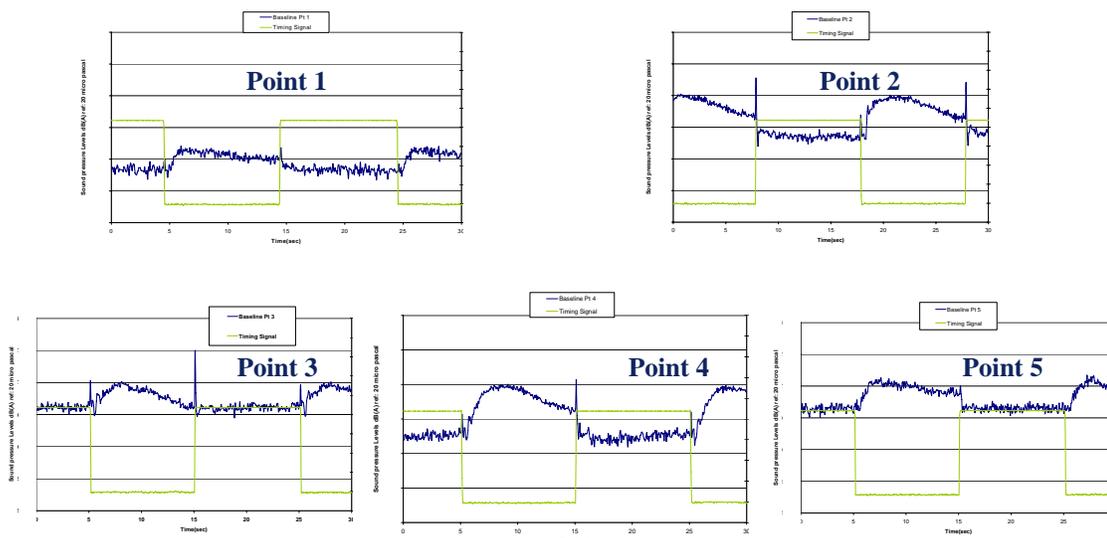


Figure 3: Digital Compressor showing suction and discharge tube for modulation

Transient sound is governed by two factors: the solenoid valve click and modulation tubing design. The coil type tubing supplied by the OEM produced delay in the pressure equalization, resulting in higher fluctuation in sound pressure levels. The use of a straight tube helped to reduce these fluctuations. The quieter solenoid valve, in turn, reduced the click sound. All the three modifications results are given in the next section.

### 3. RESULTS AND DISCUSSION



**Note:** Point# 2 and #3 are near compressor. Point # 5 is middle of two fans in the top.  
 Figure 4: Sound Pressure levels at five different positions shown in figure 2 at 95° C out door .

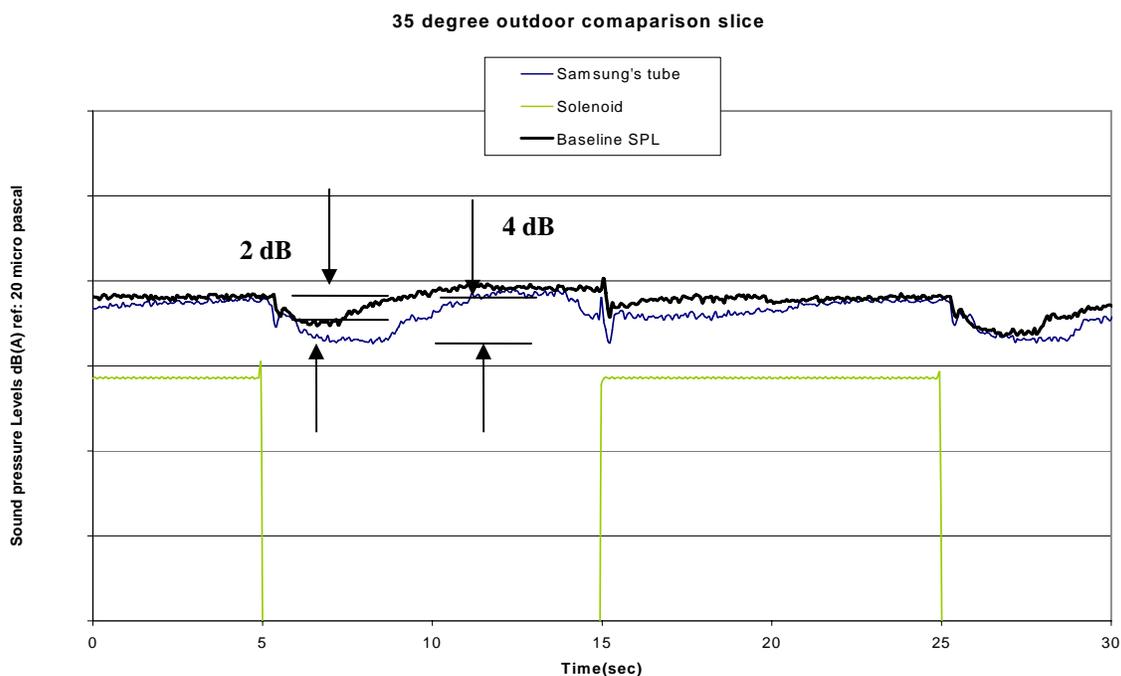


Figure 5: Sound Pressure levels at # 3 with OEM’s design tube vs. Straight tube at 95° C out door.

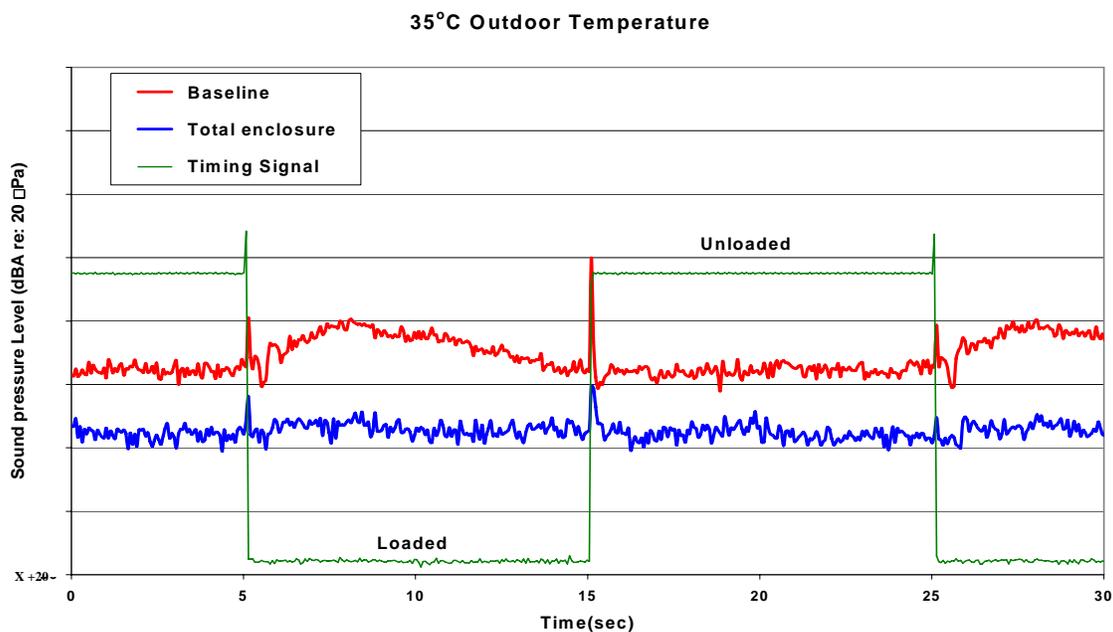


Figure 6: Sound Pressure levels at # 3 with OEM's design partial enclosure vs. complete enclosure at 95° F out door.

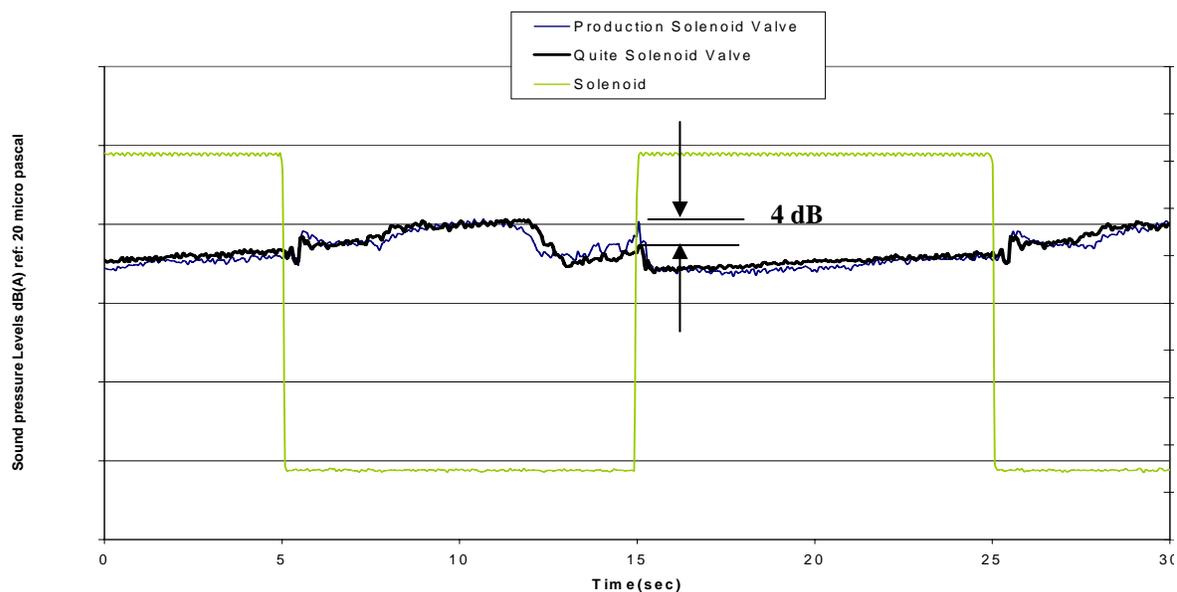


Figure 7: Sound Pressure levels at # 3 with current solenoid valve vs. quite solenoid valve at 95° F out door.

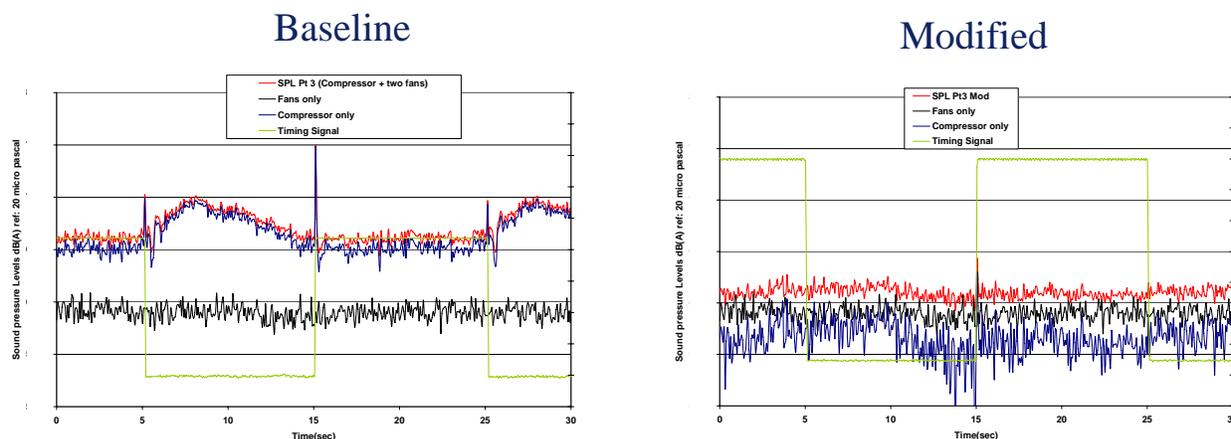


Figure 8: Sound Pressure levels at # 3 with OEM unit as it is vs. all three modifications at 95° F out door.

Figure 4 shows the sound pressure levels at five different points which is baseline measurement. Since most of modification was on compressor point # 3 was chosen as reference point for all the measurement. Figure 5 shows effect straight tube from coil tube it increases the sound by 2 dB however fluctuation of sound reduced from 4 dB to 2 dB. Hence quality of sound is increased. Figure 6 shows the effect of completed enclosure, clicking sound of solenoid can be visible as well as heard hence quieter solenoid is needed. Effect of the solenoid is shown in Figure 7, which is reduced the click sound by 4 dB. The combined effect of all three modification are given Figure 8, Sound pressure levels are as good as fan noise. All the plots have same Y axis except figure 6. Figure 6 has 20 dB shift on the lower side. Based on the discussion, conclusion is given in the next section.

#### 4. CONCLUSIONS AND FUTURE WORK

The following conclusion can be made:

- Plugging holes helps in overall sound reduction 5 to 9 dB during modulation.
- Quite solenoid valve reduces 4 dB clicking sound pressure levels.
- Constant diameter tube helps in smoothening during transition. But the sound pressure levels are increased up to 2 dB.

Future work on this paper will be as follows:

- Stress analysis need to be investigated for straight tube
- Accessibility study can be performed for partial enclosure to become full enclosure

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