APPLICATION NOTE

GT-713A

Improving Signal-to-Noise by Identifying Sources of Noise in Mass Spectrometer Systems

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Introduction:

With increasing demands on the sensitivity of mass spectrometers, signal-to-noise ratios are of greater importance. Increasing signal strength may not help if noise levels also increase. Therefore, it is of the utmost importance to reduce noise. To do so, one must correctly identify its source. Noise may be defined as “anything in the spectrum that is unwanted.” However, this would include everything from gaseous background peaks to an unexpected resultant spectrum to a conductor sporadically shorting to another conductor or to ground.

To locate the source of the noise, one must first characterize it. Is the noise completely random, or is there some pattern to it? What parameters affect the noise?

We have shown ways to improve signal-to-noise in previous papers. One could configure the analyzing quad and detector off-axis, as shown in figure 1, so that neutrals from the beam do not add noise to the detected signal[1] or filter out any on-axis stray electrons or photons with an axial energy filter as shown in figure 2. This on-axis design resulted in an increased partial pressure detection[2].

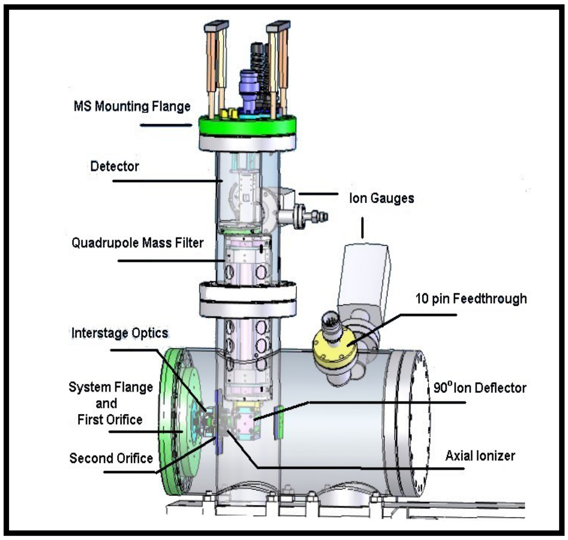


Figure 1

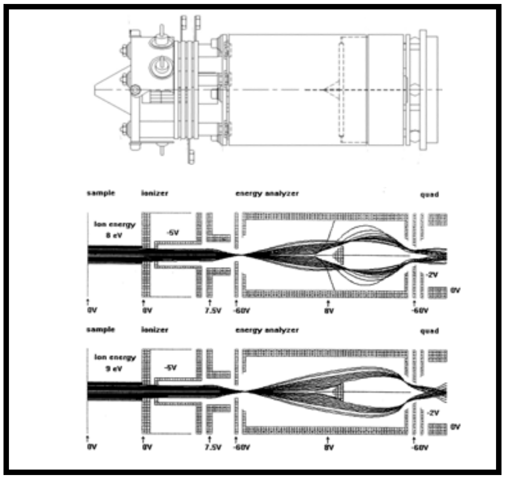
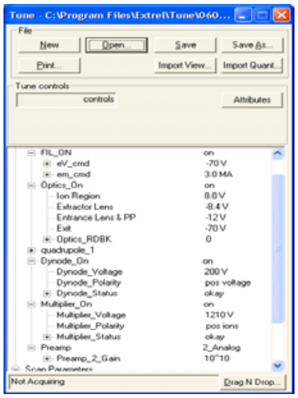


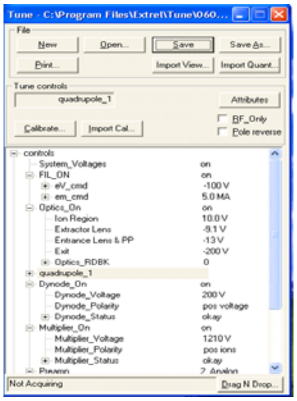
Figure 2 Axial Energy Filter

The following tuning parameters, figure 3, are an example of a way to increase signal on a Quadrupole mass spectrometer when using an EI ionizer. These tuning changes resulted in a signal increase of 5.6x. However, the increased emission also resulted in an increase in noise. Without the use of an energy filter, as shown earlier, the overall signal/noise increase did not prove beneficial.



```
FIL_ON                    on
  eV_cmd                  -70 V
  em_cmd                  3.0 MA
Optics_On                 on
  Ion Region              8.0 V
  Extractor Lens          -8.4 V
  Entrance Lens & PP      -12 V
  Exit                    -70 V
  Optics_RDBK             0
quadrupole_1
Dynode_On                 on
  Dynode_Voltage          200 V
  Dynode_Polarity         pos voltage
  Dynode_Status           okay
Multiplier_On             on
  Multiplier_Voltage      1210 V
  Multiplier_Polarity     pos ions
  Multiplier_Status       okay
Preamp                    2_Analog
  Preamp_2_Gain           10^10
Scan Parameters
Not Acquiring
```

Initial Ion
Signal: 164.2pA



```
quadrupole_1
☐ RF_Only
☐ Pole reverse
controls
  System_Voltages         on
  FIL_ON                  on
    eV_cmd                -100 V
    em_cmd                5.0 MA
  Optics_On               on
    Ion Region            10.0 V
    Extractor Lens        -9.1 V
    Entrance Lens & PP    -13 V
    Exit                  -200 V
    Optics_RDBK           0
  quadrupole_1
  Dynode_On               on
    Dynode_Voltage        200 V
    Dynode_Polarity       pos voltage
    Dynode_Status         okay
  Multiplier_On           on
    Multiplier_Voltage    1210 V
    Multiplier_Polarity   pos ions
    Multiplier_Status     okay
  Preamp                  2_Analog
Not Acquiring
```

Resultant Ion
Signal: 929.4pA

Figure 3

Extrel
Core Mass Spectrometers

Background Information:

It is apparent that, unless some sort of filter is utilized, that noise must be decreased. The origin of a noise can often times be difficult to identify. The types of noise often seen in mass spectrometer systems are electrical and/or mechanical. Sometimes, complex forms of these noise spectra can be present in a spectrum. As we all know, mass spectrometers operate in vacuum chambers that use pumps to generate said vacuum. This fact should make it easy to identify any vibrational noise frequency. However, mass spectrometers are also controlled by electronics. Electronics often use switching DC power supplies that switch at specific frequencies. Is it possible to differentiate these different sources of noise?

Before we can discuss specifics, let's look at some basic frequency characteristics[3]:

To define a wave function, we must first define our variables.

$\omega_0 := 1 \quad \omega_1 := 2 \quad \phi_0 := 1 \quad \phi_1 := 0.5$

Now we can define the function.

$f(t) := \sin(\omega_0 \cdot t + \phi_0)$

$f_1(t) := \sin(\omega_1 \cdot t + \phi_1)$

$z(t) := f(t) + f_1(t)$

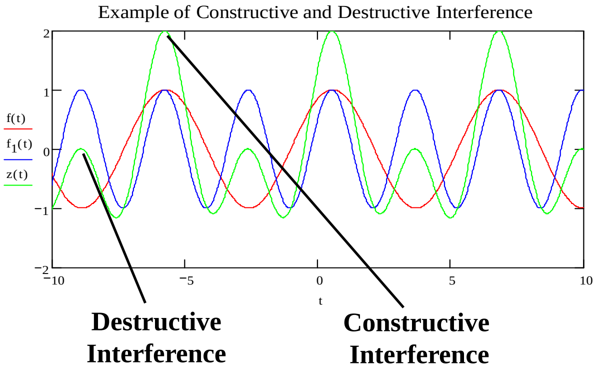


Figure 4

Constructive interference occurs when the crests of two waves line up. This gives an additive result with the resultant peak having a higher amplitude.

Destructive interference occurs when the crest of one wave lines up with the trough of another wave. This reduces the amplitude of the resultant wave.

Another phenomenon that can make noise and frequency analysis complicated is harmonic representation. As shown below, the fundamental frequency can be seen at 1, 2, 3,....x . Although the amplitude can vary for harmonics, the following example is shown with the first and second harmonic multiplied by 2 and 3, respectively.

Harmonics Example:

To define a wave function, we must first define our variables

$\omega_0 := 1 \quad \omega_1 := 2 \quad \omega_2 := 3 \quad \phi := 1$

Now we can define the function.

$f(t) := \sin(\omega_0 \cdot t + \phi)$

$f_1(t) := 2\sin(\omega_1 \cdot t + \phi)$

$f_2(t) := 3\sin(\omega_2 t + \phi)$

The second and third harmonic functions have been multiplied to make them stand out

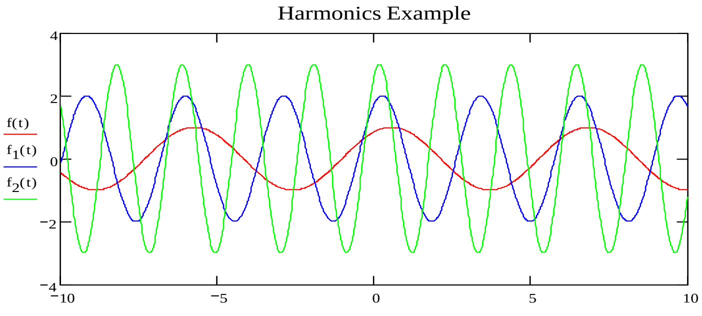


Figure 5

Experimental Data:

The following data are shown as extreme cases to exemplify the types of noise seen in typical mass spectrometer systems. The noise spectra were recorded on a digital oscilloscope and deconvoluted by the scopemeter's own software using a Fast Fourier Transform (FFT) algorithm.

Several common situations were modeled. Roughing pumps can "walk" on the laboratory floor while operating. Often, the pump can walk right into the mass spectrometer's chamber rack, thus slightly vibrating the rack at the frequency at which the pump operates. This causes the in-vacuum, unshielded leads to vibrate. When unshielded leads vibrate, they can induce small voltages into themselves or neighboring conductors. The amplitude of the induced voltage can vary due to the strength of the vibration, the rigidity of the conductor and the environment in which it operates or its proximity to other electric fields, including ground.

Figures 6 and 7 on the next page show the result of a diaphragm roughing pump vibrating against the chamber rack. The pump rotates at 1200 rpm, or 20 Hz. This frequency can be seen in the FFT spectrum. However, it also created a beat pattern of a much higher amplitude seen at a higher frequency than the fundamental frequency.

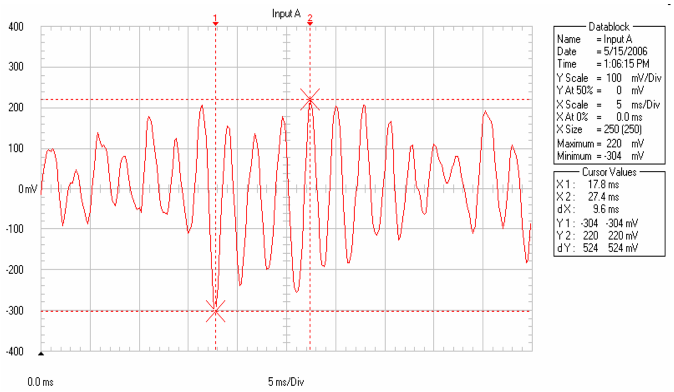
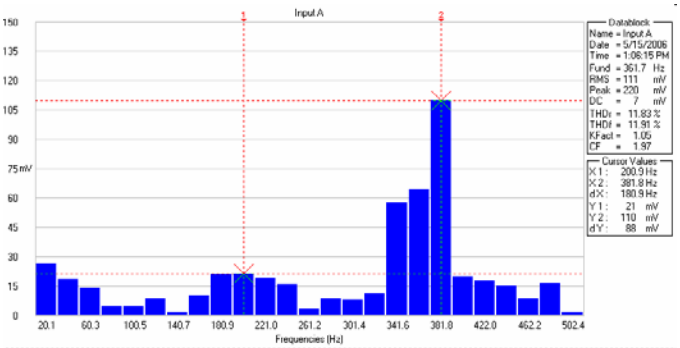


Figure 6



Vibrational spectrum with diaphragm roughing pump.

Figure 7

Figures 8 and 9 show the result of a rotary vane roughing pump vibrating against the chamber rack. The pump rotates at very close to the same speed. However, its amplitude is much lower due to the lower intensity of the vibration.

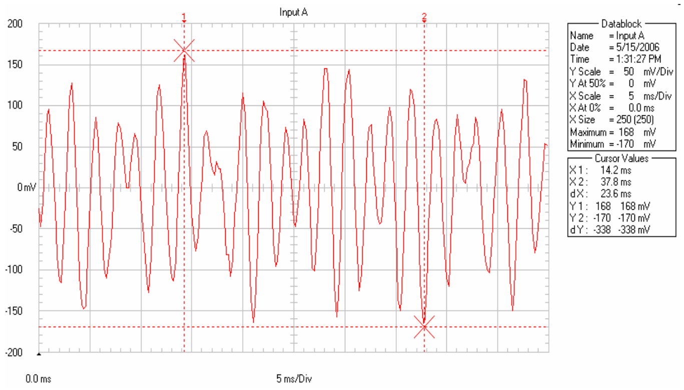
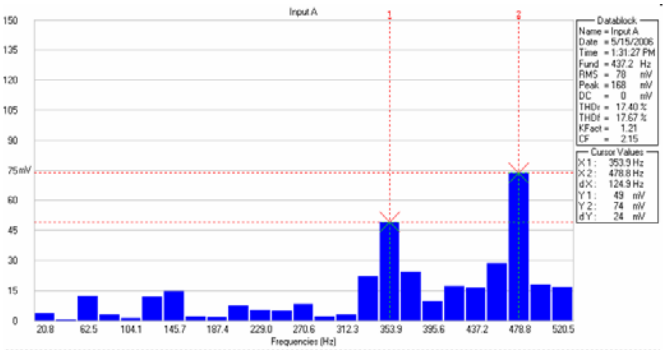


Figure 8



Vibrational spectrum with rotary vane roughing pump.

Figure 9

Figures 10 and 11 show an example of both a rotary vane pump and a turbo molecular pump. Notice in the wave form that both frequencies can be seen.

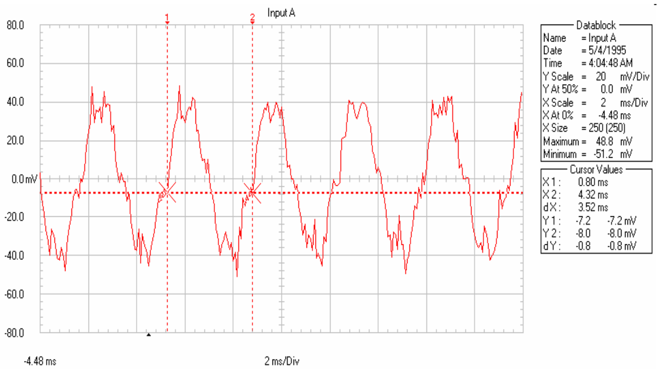
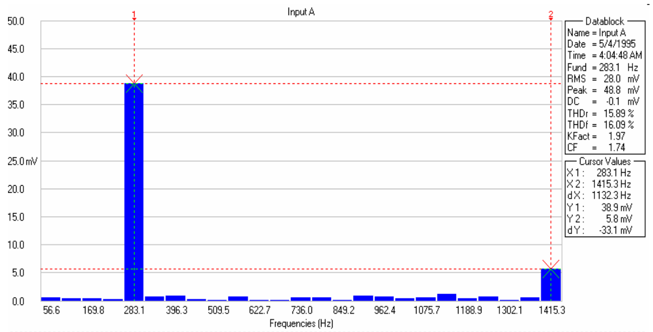


Figure 10

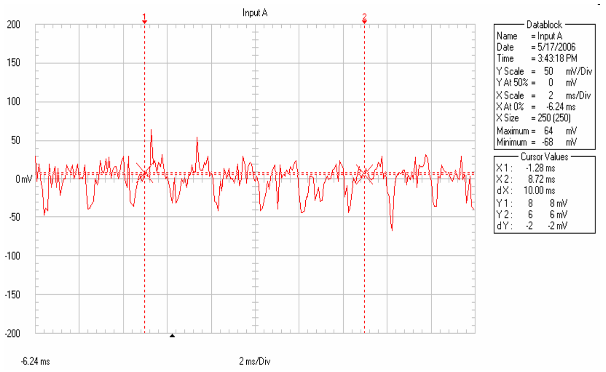


Deconvoluted spectrum showing two prominent frequencies, roughing pump and an harmonic of the turbo-molecular pump

Figure 11

It is important to note that in the previous examples, the more intense amplitudes are seen at a much higher frequencies than the pumps' operating rotational frequencies. This is most often the case. The constructive interference of frequencies from roughing pump and turbo-molecular pumps produces a frequency higher than the fundamental frequency of the roughing pump and lower than the rotational frequency of the TMP. This beat pattern can be deceiving and make it difficult to identify the source of the noise.

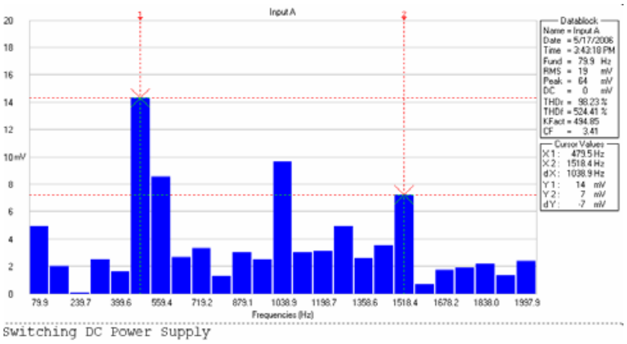
Electronic frequencies, such as those seen from switching DC power supplies, present themselves less sinusoidal than vibrational noises. The noise spectrum shown in figures 12 and 13 is that of a switching DC supply. Notice that its amplitude is much lower than that of vibrational noise sources. Also, notice the harmonics seen in the FFT spectrum.



Datablock
Name = Input A
Date = 5/17/2006
Time = 3:43:18 PM
Y Scale = 50 mV/Div
Y At 50% = 0 mV
X Scale = 2 ms/Div
X At 0% = -6.24 ms
X Size = 250 (250)
Maximum = 64 mV
Minimum = -68 mV

Cursor Values
X 1 : -1.28 ms
X 2 : 8.72 ms
d X : 10.00 ms
Y 1 : 8 8 mV
Y 2 : 6 6 mV
d Y : -2 -2 mV

Figure 12



Datablock
Name = Input A
Date = 5/17/2006
Time = 3:42:10 PM
Fund = 79.9 Hz
RMS = 19 mV
Peak = 64 mV
DC = 0 mV
THDr = 98.23 %
THDf = 524.41 %
KFact = 494.85
CF = 3.41

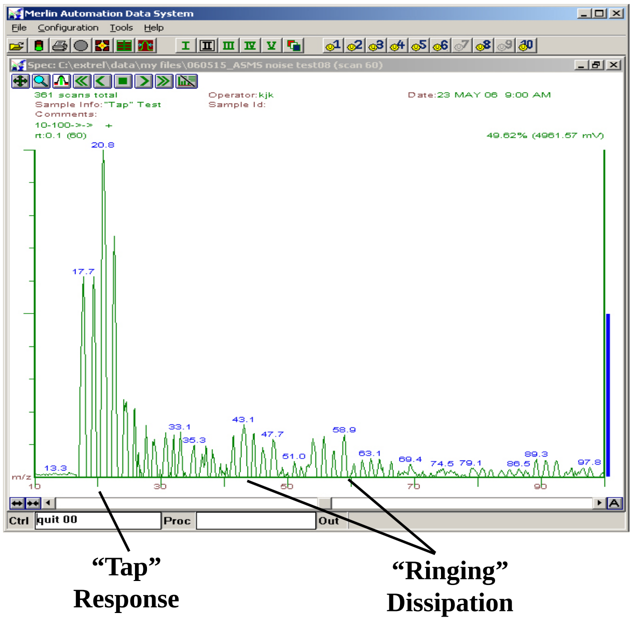
Cursor Values
X 1 : 479.5 Hz
X 2 : 1518.4 Hz
d X : 1038.9 Hz
Y 1 : 14 mV
Y 2 : 7 mV
d Y : -7 mV

Switching DC Power Supply

Figure 13

The easiest way to tell if the source of a noise is mechanical or electrical is the "tap test." Tapping on the chamber with a small mallet or the handle of a screwdriver while observing can show, sometimes very obviously, if the noise source is mechanical.

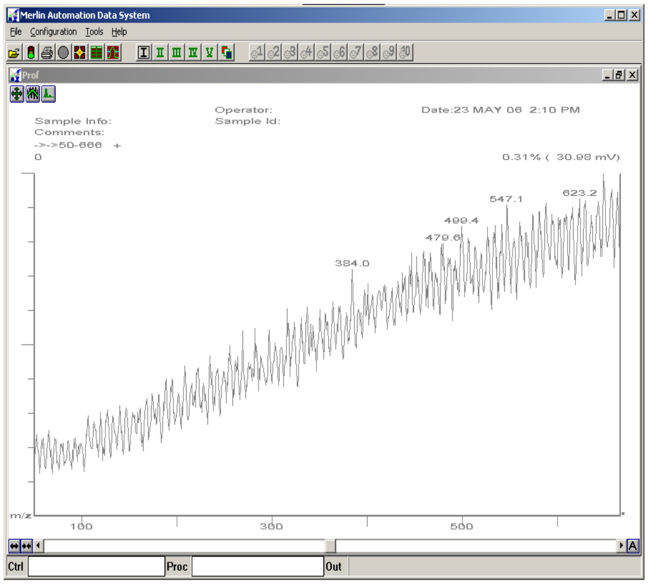
Figure 14 shows a noise spectrum taken during a tap test. Notice the "ringing" of the noise. Ringing is a term used to describe the prolonged decay time of a frequency as it dissipates.



361 scans total
Sample Info:"Tap" Test
Comments:
10-100->-> +
rt:0.1 (60)
Operator:kjk
Sample Id:
Date:23 MAY 06 9:00 AM
49.62% (4961.57 mV)
Ctrl quit 00

Figure 14

Quadrupole mass spectrometers use RF voltage to filter ions. If in-vacuum conductors are too close to the RF leads, it can be seen in the spectrum. In the example is shown in figure 15. Notice how the noise increases as the RF voltage increases, that is with higher mass. Again, this is an extreme case, but exemplifies the condition.



Operator:
Date:23 MAY 06 2:10 PM
Sample Info:
Sample Id:
Comments:
->->50-666 +
0
0.31% (30.98 mV)

Figure 15

Various lengths of in-vacuum leads were tested. The previous spectra were taken with "standard" or "off the shelf" continuous dynode electron multipliers in analog mode. In figures 16 and 17 the spectrum was obtained with an electron multiplier mounted directly to a flange and used very rigid, glass-coated in-vacuum leads.

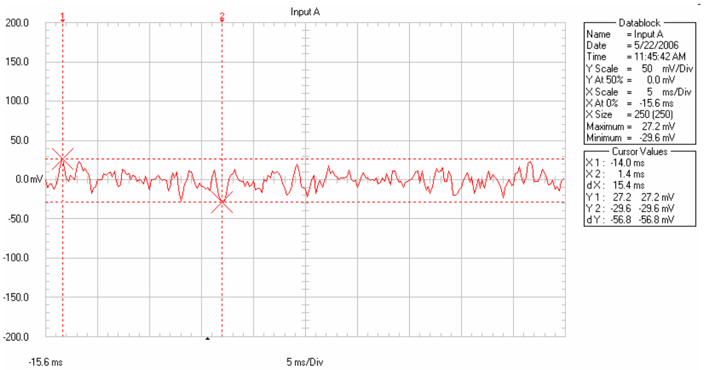


Figure 16

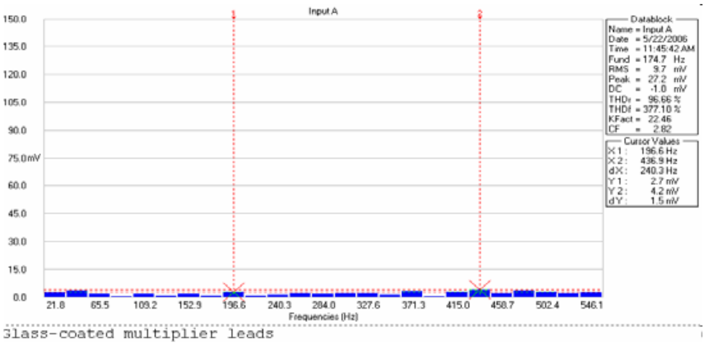


Figure 17

Conclusion:

Increasing signal does not necessarily increase signal to noise. It is more important to identify the source of the noise. Sources of noise in mass spectrometers can be varied and very difficult to identify. One must take an holistic approach to analyzing the amplitude, frequency and even shape of the noise spectrum. Mechanical noise frequencies produce more sinusoidal patterns. Multiple mechanical sources often produce beat patterns with each other resulting in a frequency faster than one and slower than the other parent frequency. Conversely, electronic noise frequencies tend to take on a more digital or square wave pattern. Electronic noise sources also often produce harmonics that can be seen at multiples of the fundamental frequency.

Since pumps and other sources of vibration may not be able to be eliminated, the affect they have on spectra may be minimized. Shortening in-vacuum leads and supporting them rigidly greatly reduced the affects of mechanical vibrations.

References:

1. Randall E. Pedder, "New Cross Beam Ionizer Design for Plasma Monitoring," *Presented at the1996 AVS Conference in Philadelphia, PA, October 16, 1996*
2. Jian Wei and Randall E. Pedder, "Improvement in Signal-to-Noise and Minimization of analyzer related background contributions in ultra high vacuum residual gas analysis," *Presented at the 43rd National Symposium of AVS, October 14-18, 1996*
3. Douglas A. Skoog and James J. Leary, "Principles of Instrumental Analysis, Fourth Edition," Saunders College Publishing, 1992

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