



# **LineMonitor**

**Sergey Klimenko**  
**University of Florida**

Other contributors: E.Daw (LSU), A.Sazonov(UF), J.Zweizig (Caltech)

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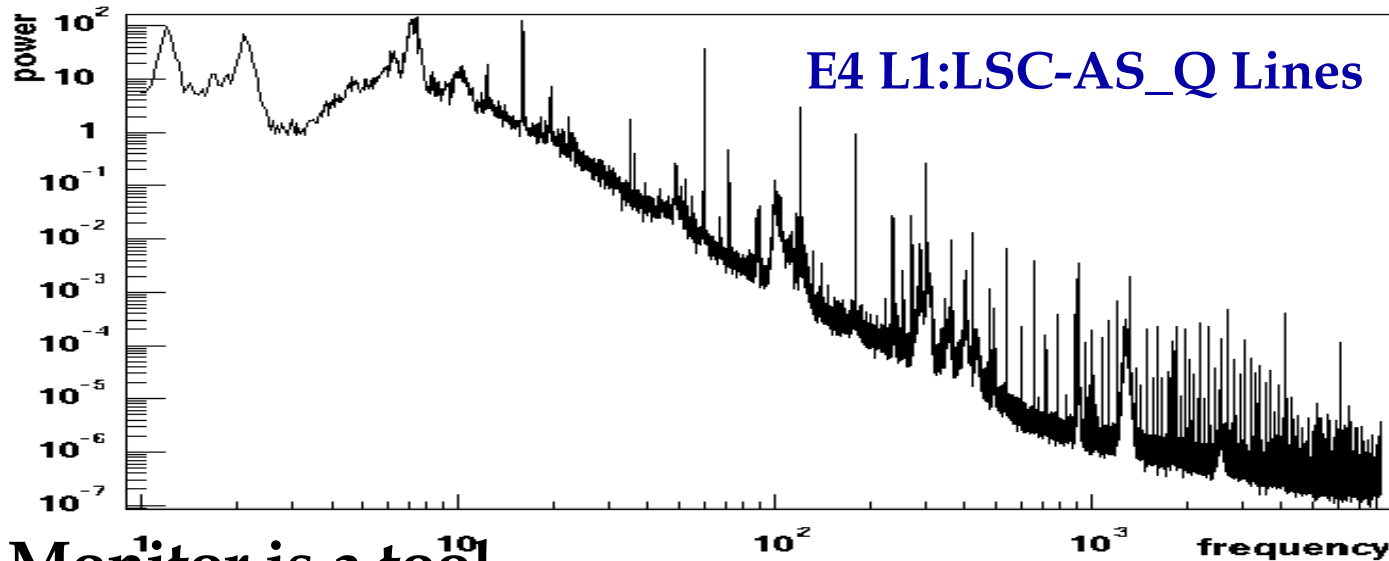
### ➤ **Conclusion**

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# Introduction

- **Narrow lines in the LIGO detector output:**
  - **mechanical (violin modes, mirror modes, stacks&suspensions)**
  - **environmental (power (60Hz and harmonics), generators&equipment)**



- **Line Monitor is a tool**
  - to monitor parameters of selected line
    - frequency
    - amplitude
    - phase
  - to study narrow lines (LM is a main tool for LNI group)



# Line Monitoring

- **line interference signal  $I(t)$**  – sum of line harmonics
- given a data set with time stride  $T$  and sampling rate  $f_0$ , use approximation of line interference signal  $I(t)$  in the form

$$I(t) = \sum_n a_n \cdot \cos(\Psi_n(t)) = \sum_n a_n \cdot \cos(2\pi nft + \phi_n)$$

- we assume that the harmonic's amplitudes  $a_n$  and linear functions  $\Psi_n(t)$  do not change much during time  $T$  (line width  $\ll 1/T$ )
- to monitor lines we estimate the  $I(t)$  signal (or  $a_n, f$  and  $\phi_n$ ) for sequence of data strides
- The  $I(t)$  signal is estimated using the QMLR algorithm



# The QMLR Algorithm

- basis of orthogonal Fourier functions:

$$F_k(n) = e^{-2\pi i n k/N}, \quad k, n = 0, \dots, N-1; \quad \delta_{ij} = \sum_n F_i(n) F_j(n)$$

- for sampled harmonic signal  $L(n) = a e^{-i2\pi n f/f_0}$ ,

- $f$  - harmonic signal frequency

- $f_0$  - sampling rate

- $L(n) \sim F_k(n)$  - one of the basis Fourier functions, if  $f/f_0 = k/N$

- estimating of  $I(t) \{L_k(n)\}$ .

- resample data with new sampling rate  $f_s$ :  $f_s/f = \text{int}(f_0/f) + 1$

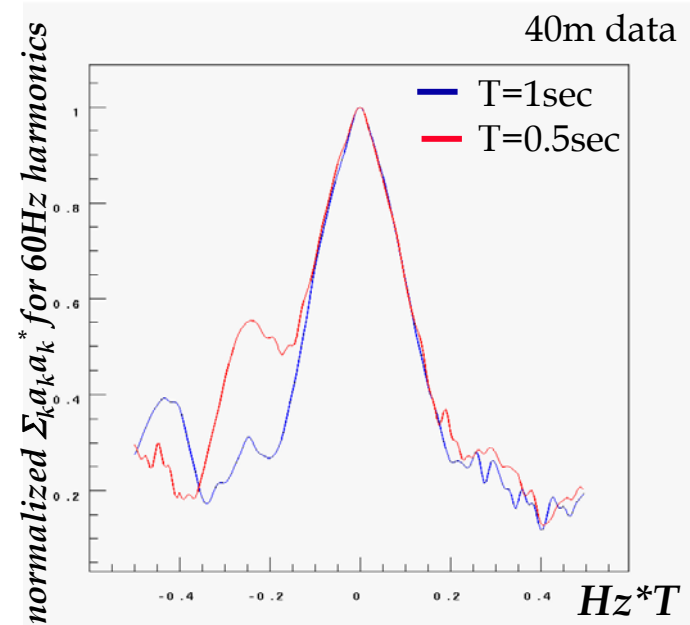
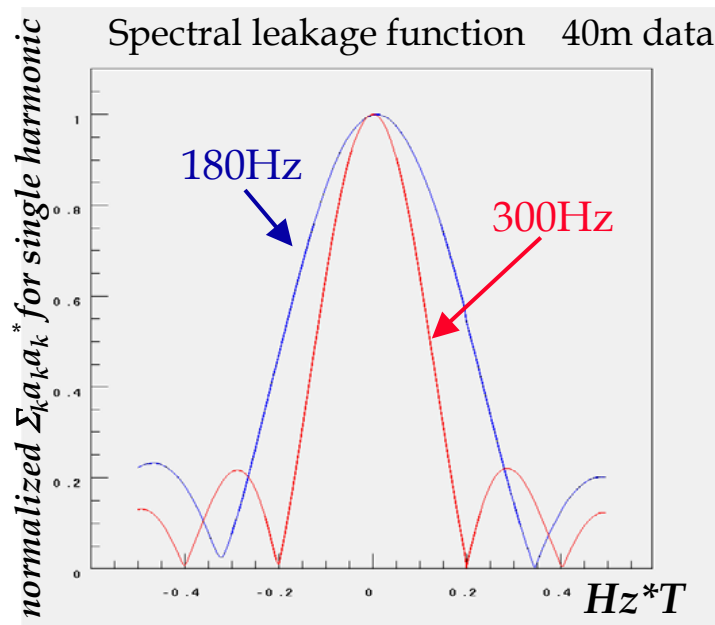
- select data sample length:  $N = k f_s/f$ ,  $k$ -integer

- estimated interference signal in F domain:  $I_F = \sum_k L_k = \sum_k a_k F_k$



# Fundamental Line Frequency

- To monitor lines an accurate measurement of line fundamental frequency  $f$  is required.
- DFT gives rough estimate of  $f$ :  $\delta f \sim f_0 / N = 1/T$ ,  $T$  - time stride
- $f$  estimation:
  - re-sample data for given  $f$  and find harmonic amplitudes  $a_k$
  - tune  $f$  to maximize  $\sum_k a_k a_k^*$  for all (or group of) harmonics





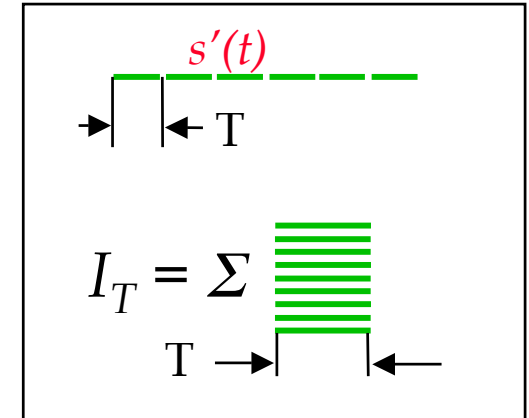
# Line Interference Signal

- Estimate the  $I(t)$  from re-sampled signal  $s'(t)$ 
  - in Fourier domain (comb filter)

$$I_F = \sum_k a_k F_k^* \phi_k$$

- $a_k$  - Fourier coefficient for  $k^{\text{th}}$  harmonic
- $\phi_k$  - optimal filter;  $\phi_k = 1$ , if neglect noise for  $k^{\text{th}}$  harmonic

- in Time domain ( $\phi_k = 1$ ) :
  - $I(t)$  is a periodic function (period  $T$ )
  - $T$  - period of fundamental harmonic
  - $I_T$  - one period of the line Interference signal
  - allows avoid FFT of long data sets

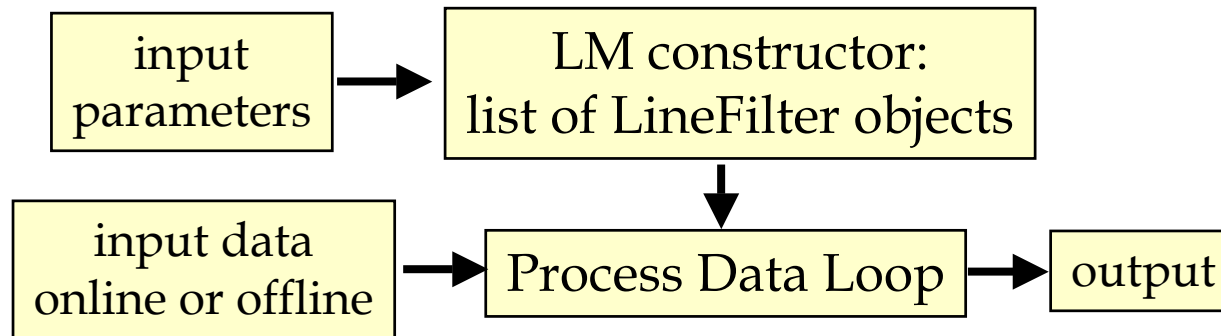


- signals  $s'(t) - I(t)$  and  $I(t)$  are orthogonal by definition



# Design & Implementation

- **LineFilter** - distributed with DMT shared library (ROOT)
  - **apply(s)** - process time series s and store trend data
    - **fScan(s)** - estimate fundamental frequency
    - **Interference(s)** - estimate the Line Interference Signal
  - **data access functions**
    - **DumpTrend(file)** - dump trend data into file
    - **LoadTrend(file)** - load data from trend file to LineFilter object
    - **getTrend(data)** - access specified data in the LineFilter database
- **LineMonitor** - a DMT monitor





# Input & Output

## ● LineMonitor Input

- configuration parameters
  - command line (for single line)
  - configuration file (for many lines or if run by DMT process manager)
- data for ONE selected channel from online buffer OR frame files
- to monitor several channels, several monitors should be launched

## ● LineMonitor Output

- trend data (one file/line):  $a(t)$ ,  $\phi(t)$ ,  $f(t)$ ,  $SNR(t)$ , ....
  - can be read and processed in ROOT using LineFilter access functions
- data to the DMT viewer
- html summary





# html summary

LineMonitor statistics at: February 11, 2002 13:59

channel: H2:LSC-AS\_Q

start GPS time: 693847776

current GPS time: 693851296

live time, sec: 3520

### Monitored Lines

frequency seed, Hz	frequency current, Hz	frequency average, Hz	amplitude average	entries
12.0001	12.0033	11.9848	1.86e+01	27
16.2999	16.2592	16.2584	1.20e+01	36
17.6001	17.6525	17.6566	2.14e+01	47
60.0001	59.9951	60.0009	5.96e+00	52
234.4	234.373	234.475	8.33e-01	41
236.1	236.088	236.09	4.37e-01	37
293.1	293.1	293.038	5.08e-01	2
344	344.421	344.164	2.24e-01	14
349.3	349.199	349.228	2.99e-01	47

**monitored by LM**  
 -specified in conf. file  
 -trend data produced  
 -serve to DMT viewer

### Detected Lines

frequency Hz	amplitude 1/sqrt(Hz)	width Hz	SNR	entries	duty cycle %
1.22	2.88e+01	< 0.22	1.20e+01	47	85.44
2.18	6.03e+01	< 0.39	1.63e+01	49	89.08
6.21	1.84e+02	< 0.25	8.43e+00	6	10.9
9.87	7.27e+01	< 0.41	1.56e+01	53	96.35
11.92	3.36e+01	< 0.29	9.37e+00	38	69.08
16.25	3.24e+01	< 0.24	1.05e+01	28	50.9
17.46	2.94e+01	< 0.55	5.07e+01	52	94.53
60.01	5.41e+00	< 0.53	2.07e+01	50	90.9
120.01	5.86e+00	< 0.59	3.43e+01	52	94.53

**detected by LM**  
 - no monitoring  
 - no trend data  
 - no DMT viewer

Legend in the end of  
 the page is available



# LineMonitor Parameters

- **usage: LineMonitor** [list of parameters]
  - **-c <channel name> [required]**
  - **-H <output html file name> [synthesized]**
  - **-l <lock condition> (\*:Both\_arms\_locked for IFO chan.)**
  - **-f <seed frequency (Hz)> [60.]**
  - **-t <time stride (s)> [1.]**
  - **-I <filter ID (-1/0/1)> [1]**
  - **-n <number of stride subdivisions> [1]**
  - **-s <no frequency scan>**
  - **-F <first harmonic> [1]**
  - **-L <last harmonic> [1]**
  - **-S <skip harmonics> [0]**
  - **-R <limit on signal to noise ratio> [2.]**
  - **-d <dump trend data every n strides> n=[1]**
  - **-b <length of the DMTVIEWER buffer> length=[1024]**
  - **-W <select number of decimation by 2 steps>**
  - **-i <input config file> [optional] (required to monitor many lines)**



# Configuration File (ASCII)

```
-c H1:LSC-AS_Q // channel name
-l H1:Both_arms_locked // lock condition
-H h1_darm.html // html output file
-t 64. // stride
-d 5 // dump every 5 strides
-W 3 // dicimate down to 2kHz
-----
-f 12.0 -n 16 -W 4 // list of lines
-f 17.6 -n 16 -W 4
-f 34.93 -n 16 -W 3
-f 53.58 -n 16 -W 3 -N 9
-f 60. -n 8 -L 10
-f 98.37 -n 16
-f 343.50 -n 8 -L 2 -t 32
-f 346.95 -n 8 -L 2 -t 32
```



# Usage & Performance

- **LineMonitors run by process manager**
  - predefined list of channels, lines & parameters
    - max 3 LM/interferometer, total 9 monitors
    - channels: X:LSC-AS\_Q, X:LSC-CARM\_CTRL, X:IOO-MC\_F
  - still working to define the “standard” configuration
- **LineMonitors for expert use**
  - executable is distributed with the DMT
  - customized set of lines & parameters
  - user defined input&output
- **Help**
  - If to call **LineMonitor** without parameters, **help** is printed out.
- **Performance:**
  - one monitor consumes **2%+0.5%/line** of one CPU on sand or delaronde.



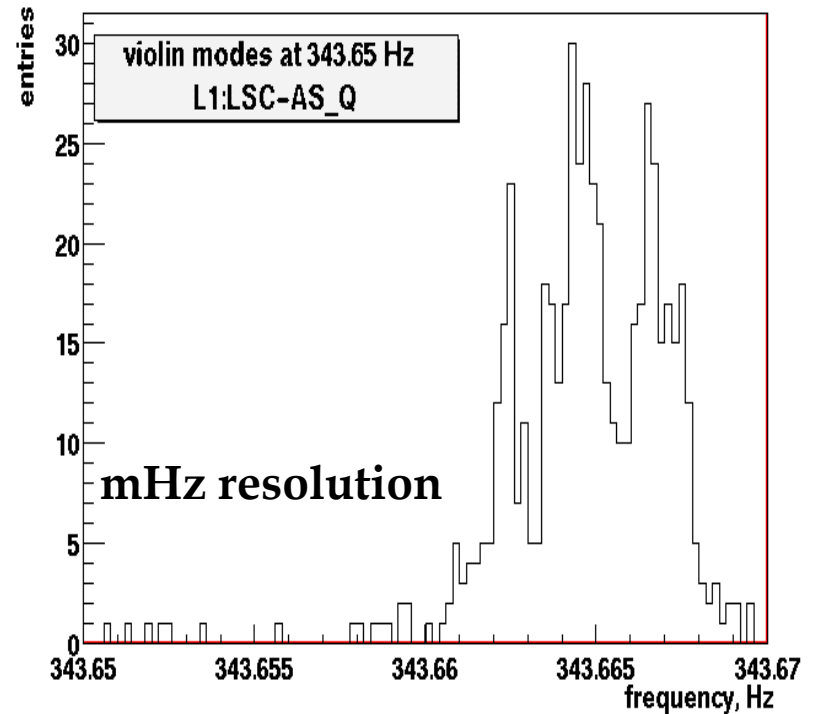
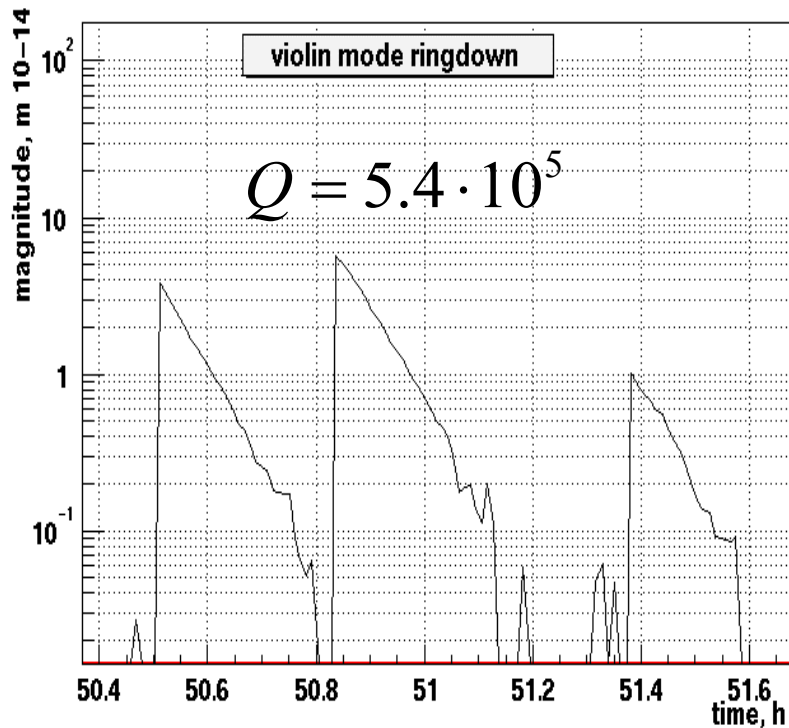
# Conclusion

- **monitoring tool**
  - stationarity of line noise
  - monitoring of violin modes & power lines
  - run standard configurations for E & S runs
- **investigation tool**
  - characterization of line noise (including classification of lines)
  - accurate measurement of line frequencies ( $\sim$ mHz)
  - measurement of Q of violin modes
- **development**
  - in first approximation completed
  - add option to write some trend data to database
  - no plans for GUI development
- **documentation**
  - publish LIGO note



# Violin Lines

excitation in the beginning of lock section

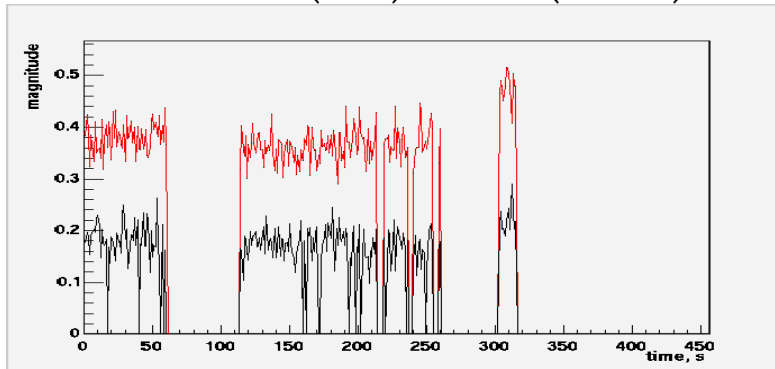




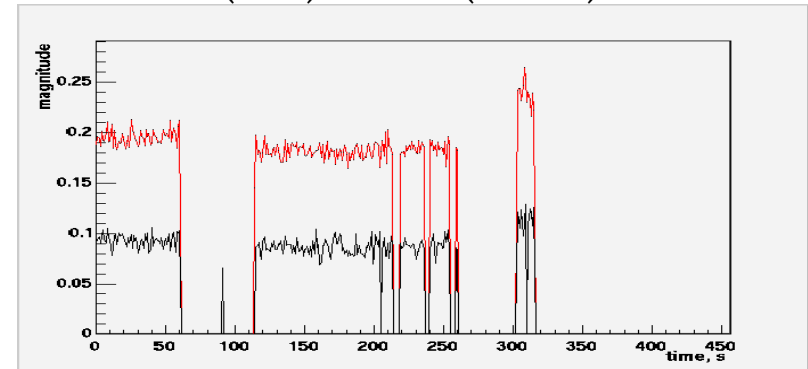
# calibration lines (amplitude)

- E4 run
- 8 calibration lines for X arm
  - ITMX(35, 71, 271, 1001) (red curves)
  - ETMX(36, 72, 272, 1002) (black curves)

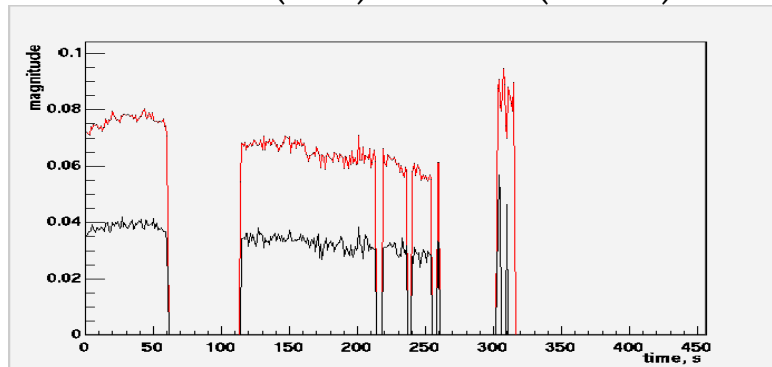
35Hz (red), 36Hz(black)



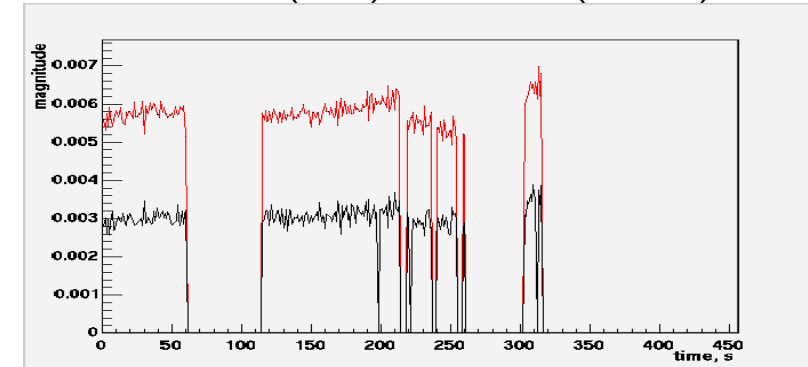
71Hz (red), 72Hz(black)



271Hz (red), 272Hz(black)



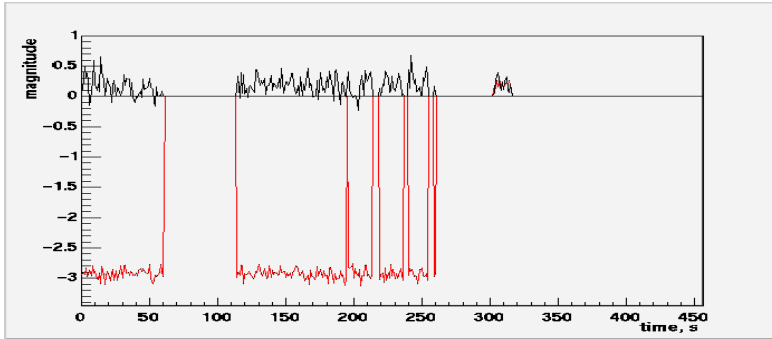
1001Hz (red), 1002Hz(black)



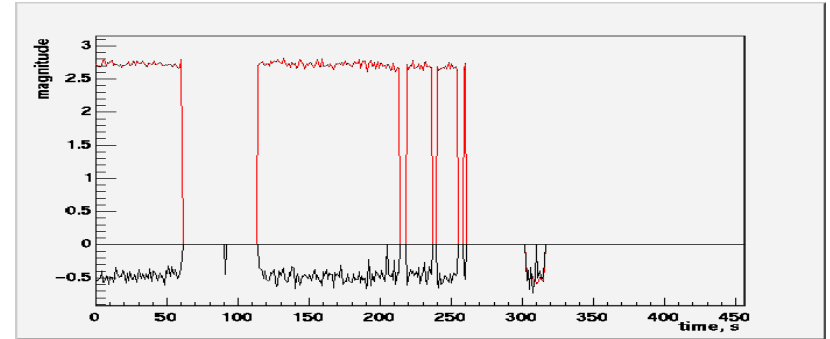


# calibration lines (phase)

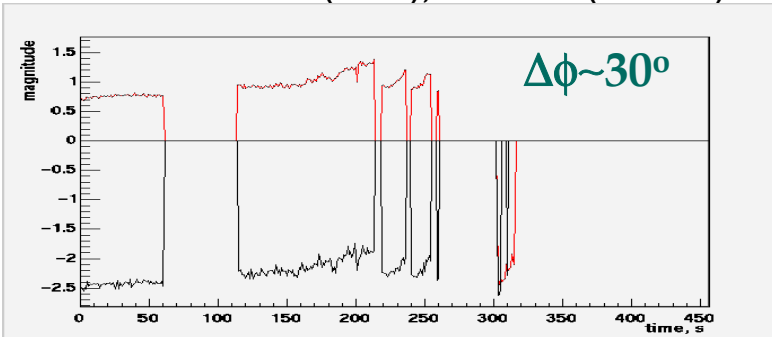
35Hz (red), 36Hz(black)



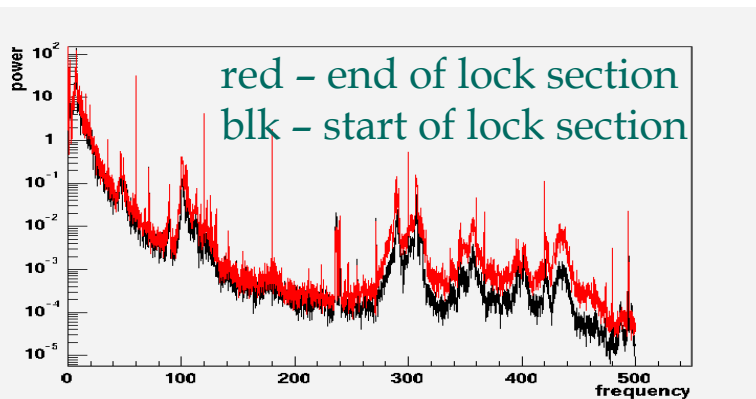
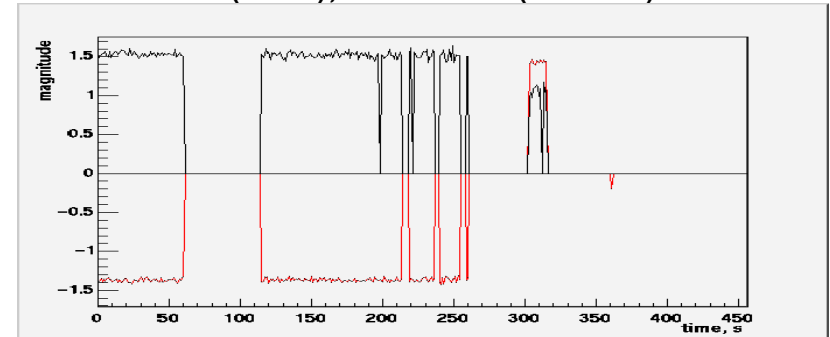
71Hz (red), 72Hz(black)



271Hz (red), 272Hz(black)



1001Hz (red), 1002Hz(black)



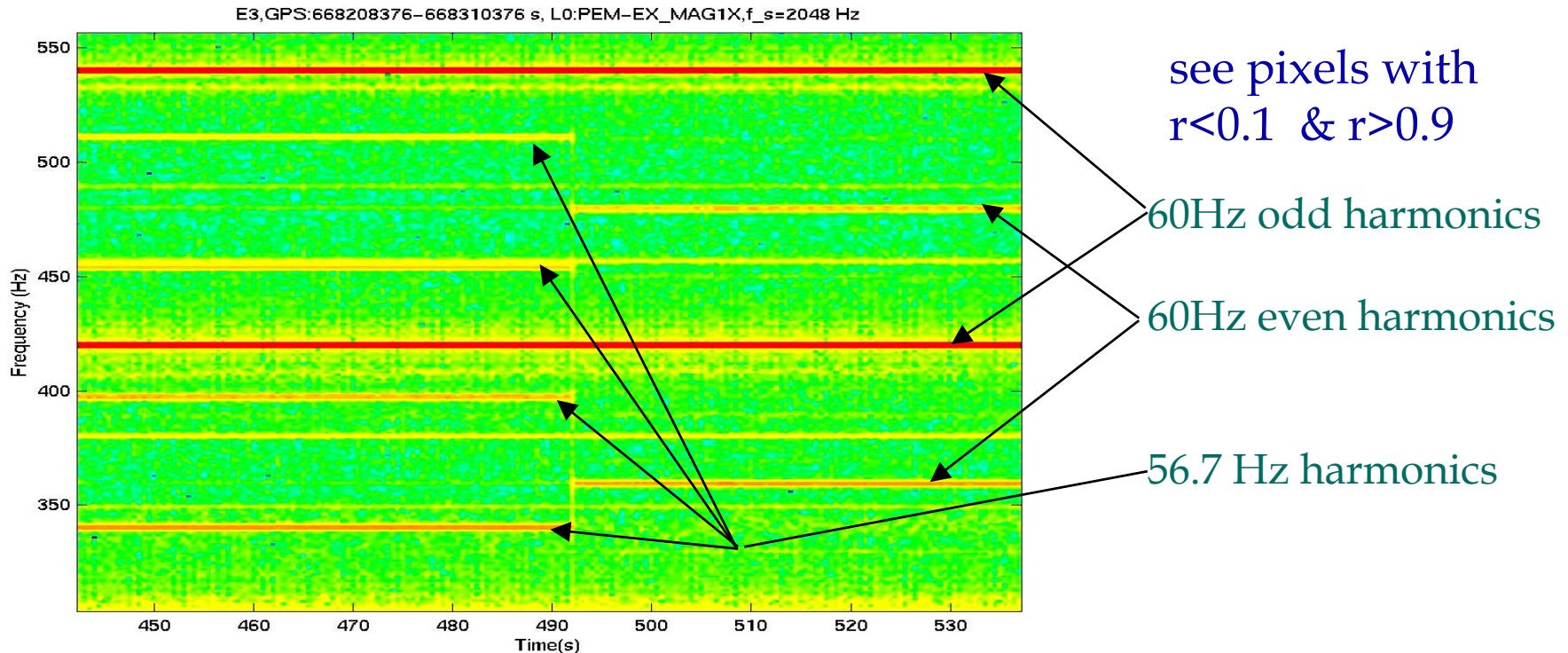
Non-stationary TF  
around 270Hz





# Magnetometers study

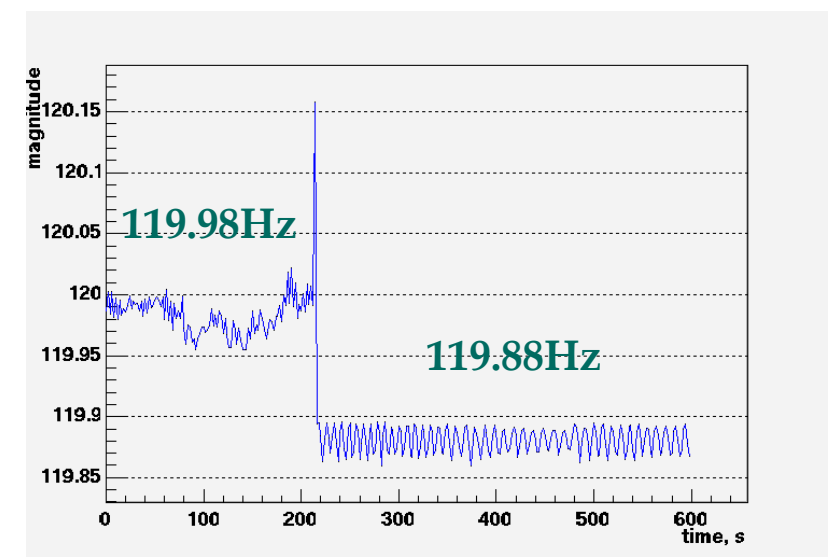
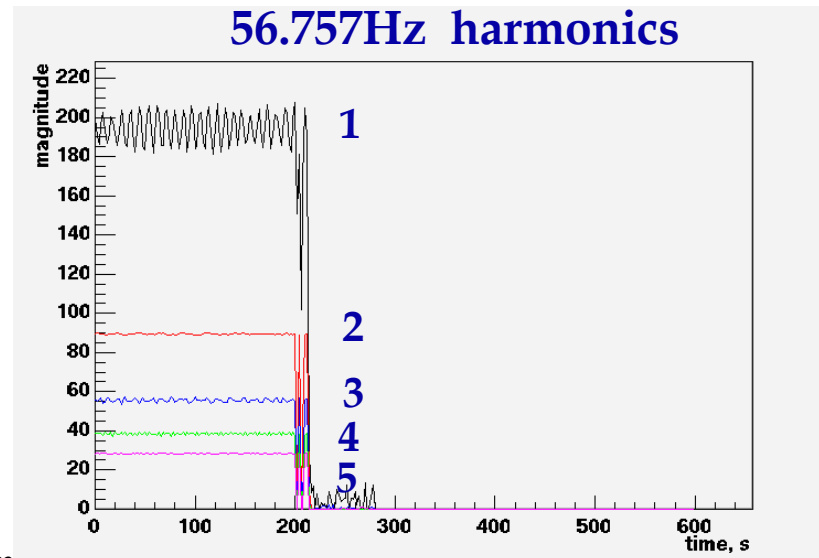
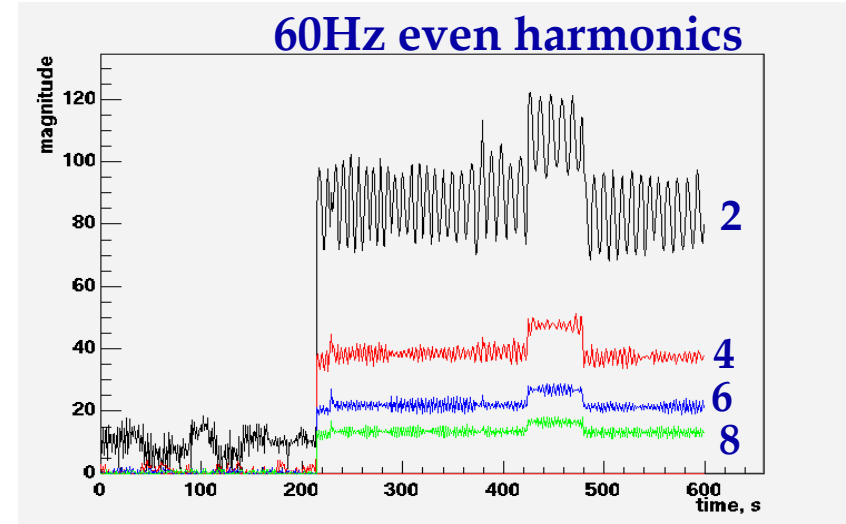
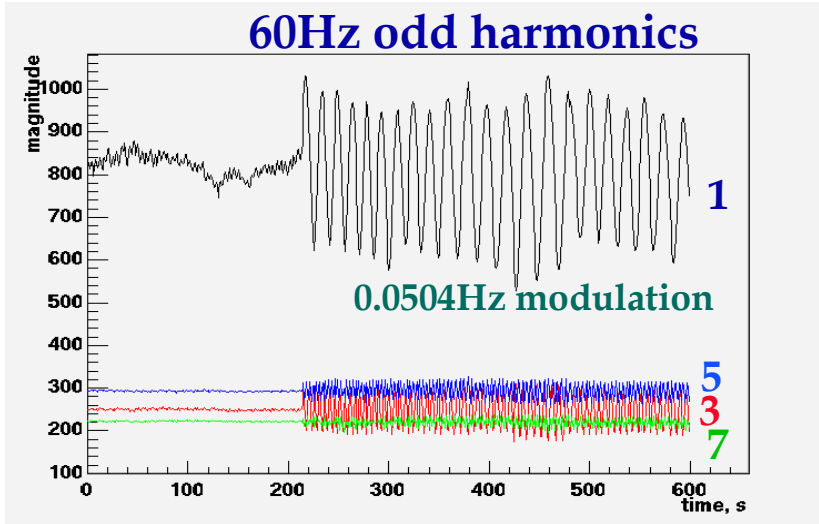
- time-frequency analysis of L0:PEM-EX\_MAG1X & H0:PEM-EX\_MAG1X
  - correlation of Im and Re parts of data in Fourier domain
  - for details see S.Mukherjee report at <http://blue.ligo-wa.caltech.edu/engrun/E3/Results/LineMonitor/index.html>
- data section (E3) 1800s long: GPS time 668208654-668210176





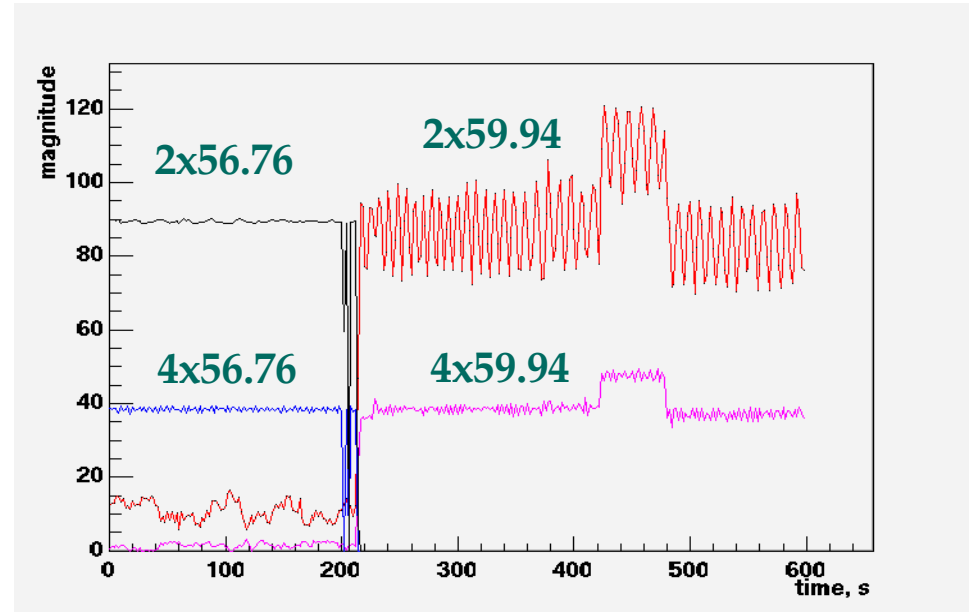
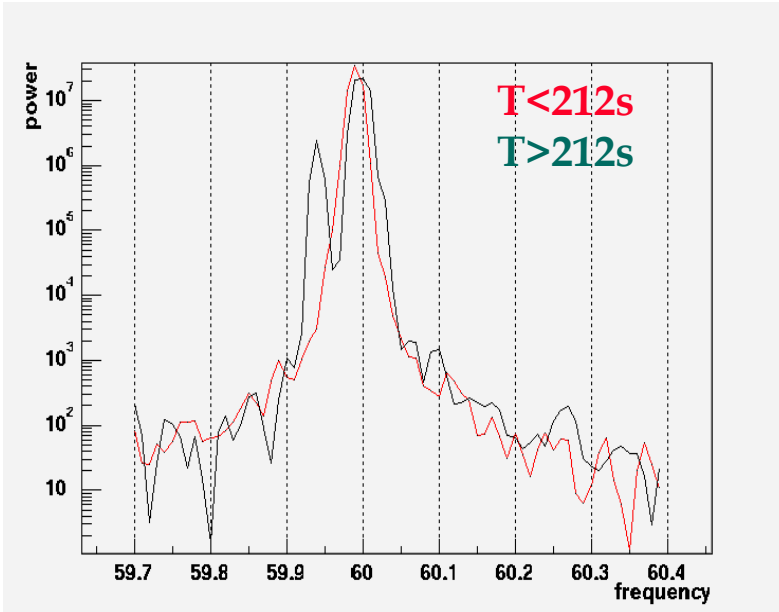
# LineMonitor results

- close look at L0:PEM-EX\_MAG1X with the Line Monitor





# LineMonitor results (continue)



- What happened?
  - 2 sets of power lines – power mains & compressor
  - at 212sec motor was switched off -> 56.76Hz lines shifted to 59.94Hz  
amplitudes of 56.76Hz & 59.94Hz harmonics are exactly the same
  - does it affect the interferometer channel?