Unsolved problems in instrumentation for noise measurements

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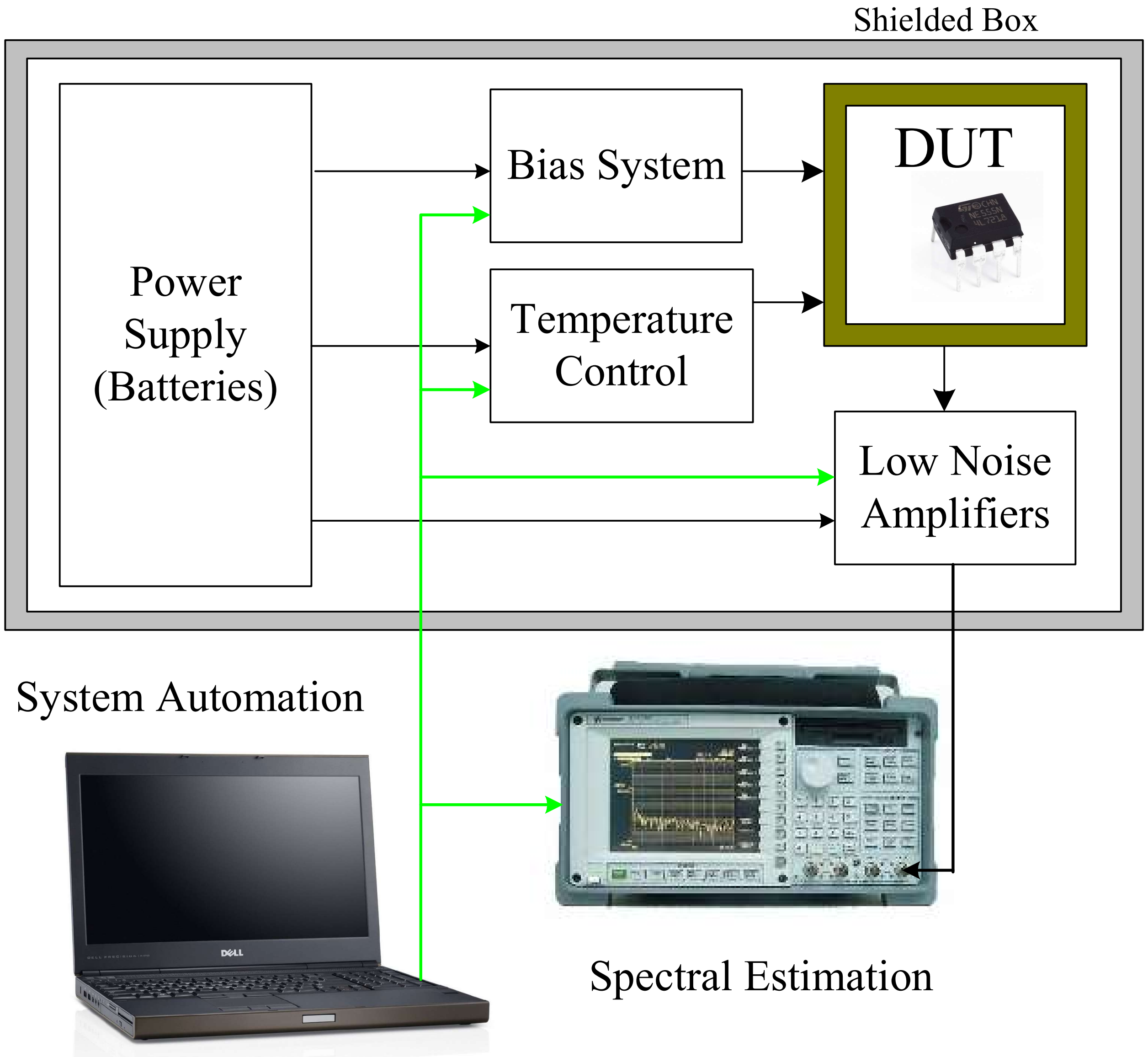
Components of a noise measurement system



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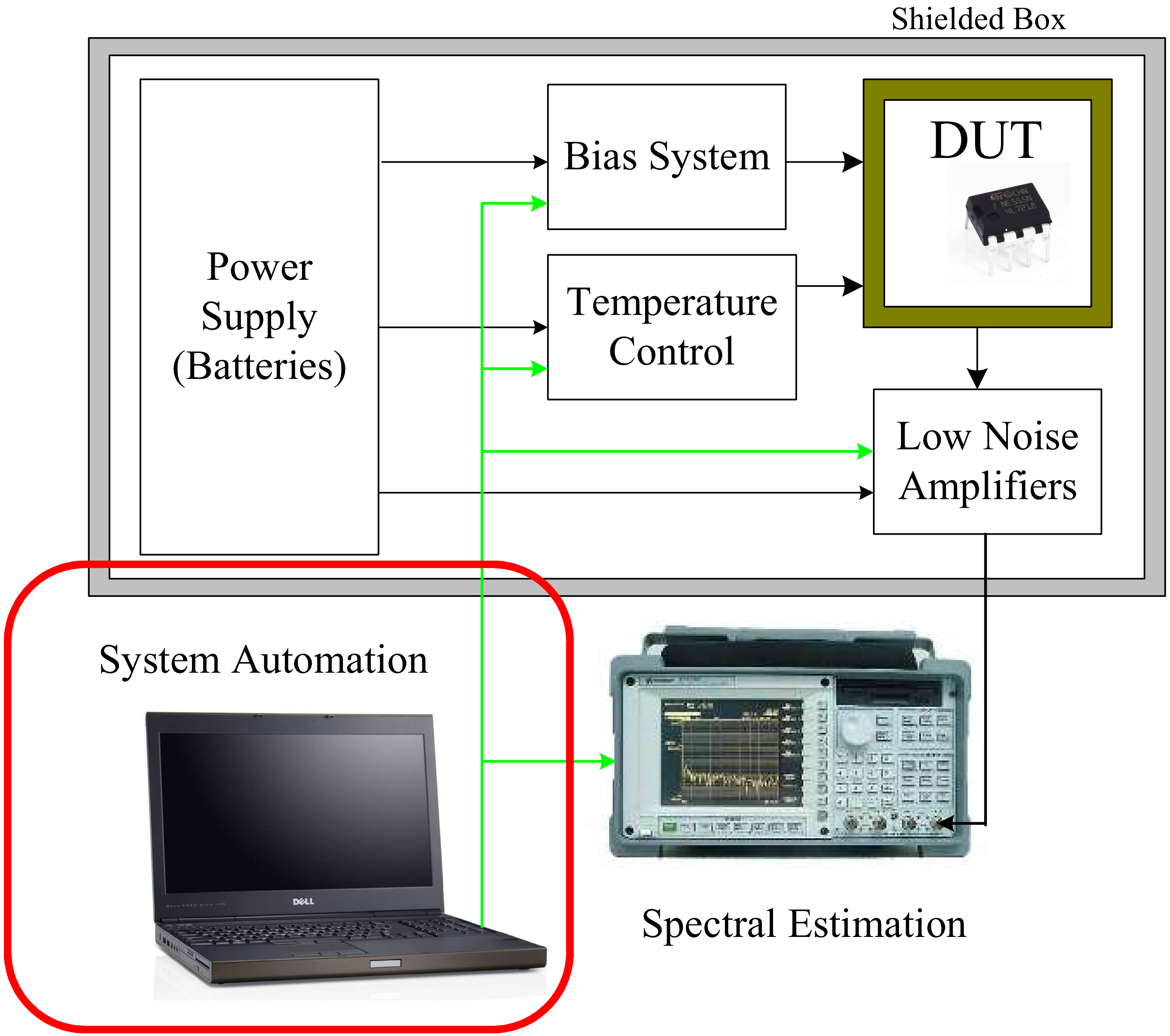
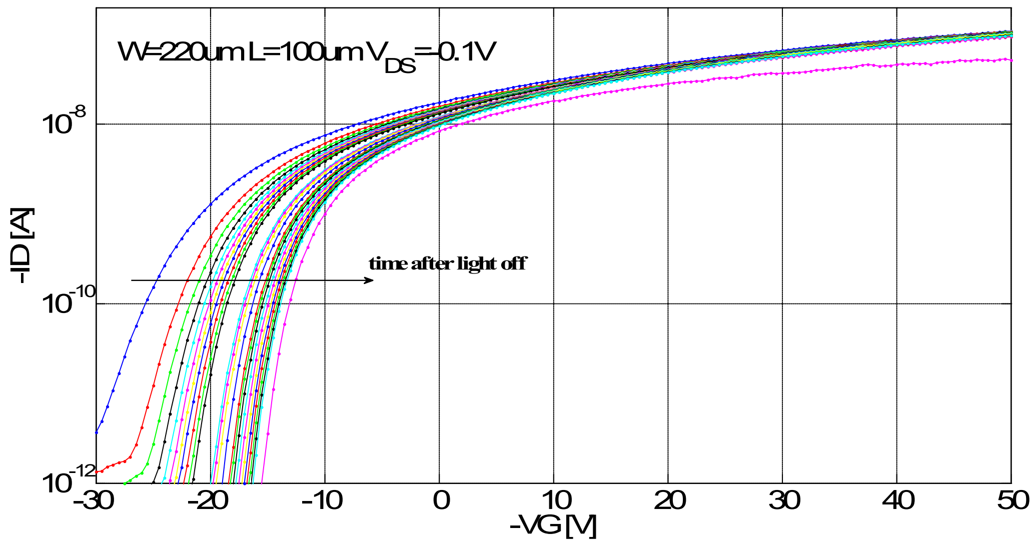
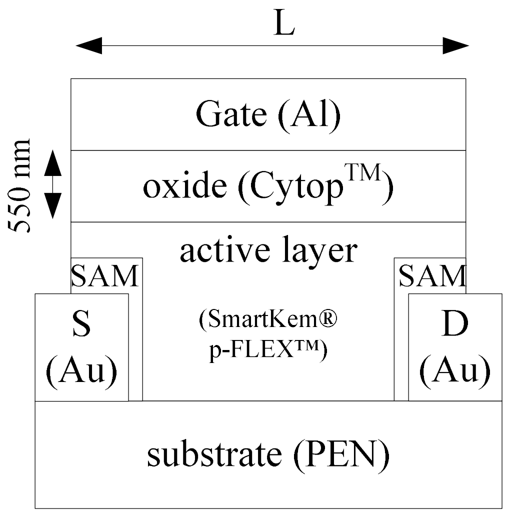


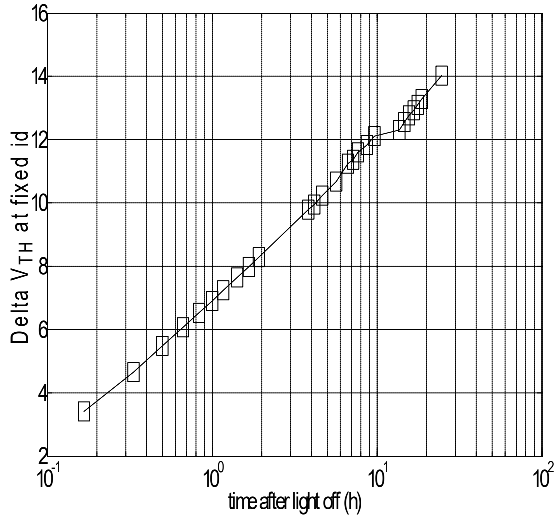
Example of system automation

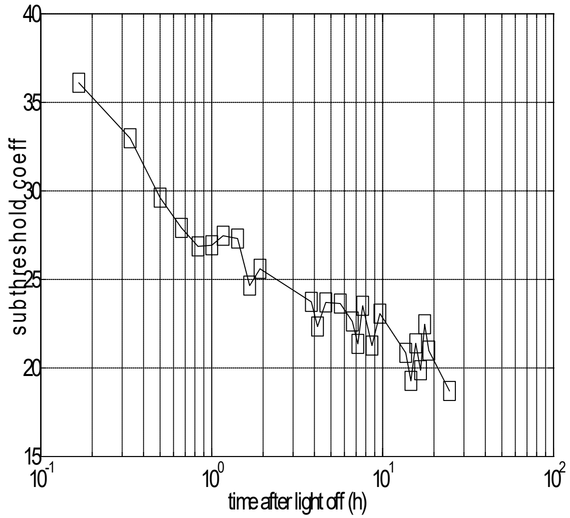
Problem: devices exhibit large threshold voltage and subthreshold slope change after light off

We need an automated system for collecting enough noise data while monitoring the DC behaviour

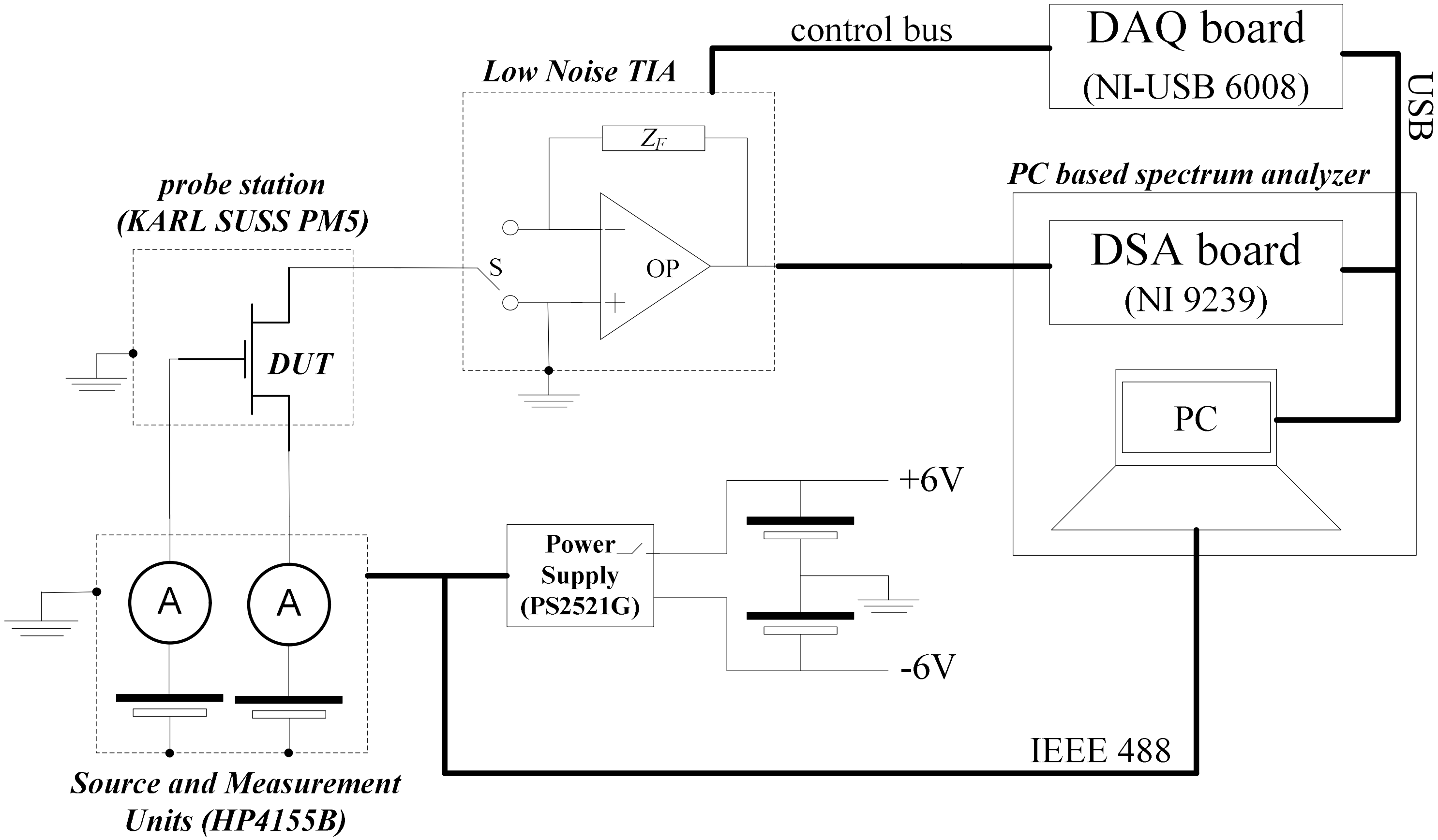








Ezample of system automation

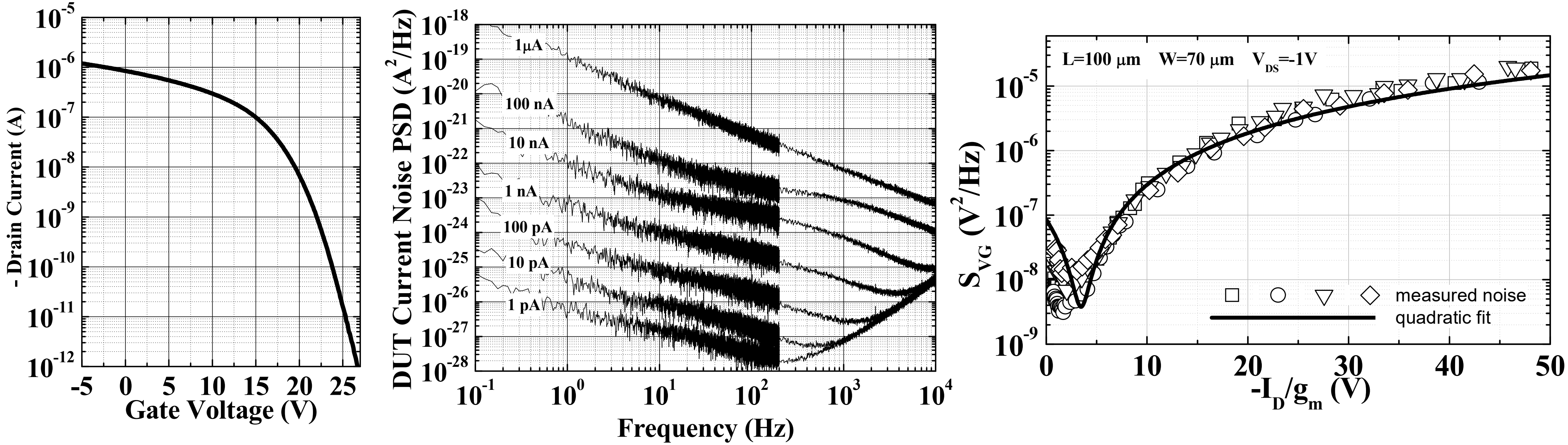


We have succeeded in integrating noise measurement into a standard DC characterization system.

Example of system automation

Drain current vs. Gate voltage, current noise PSD and gate referred noise at f=1Hz.

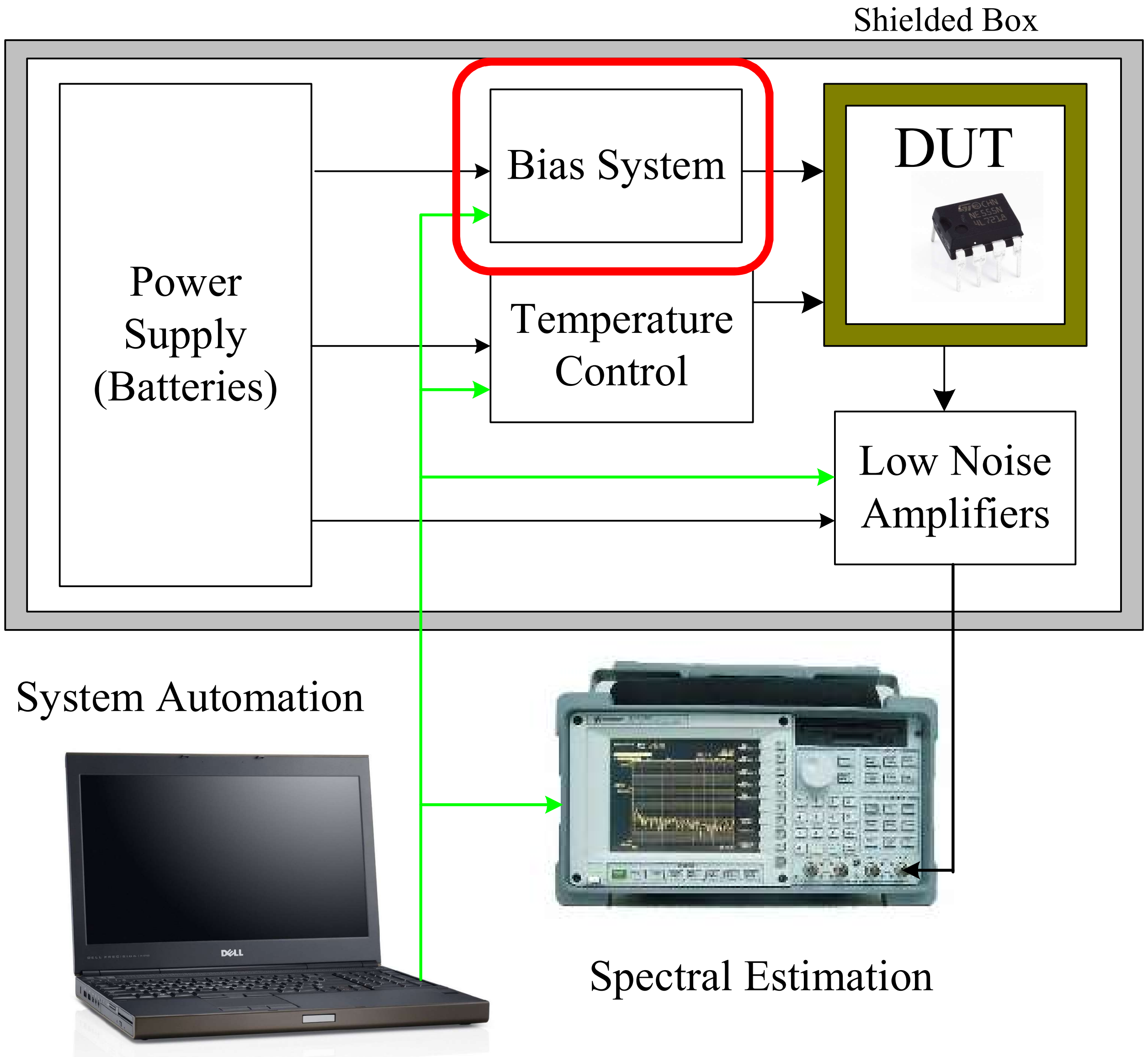
(devices with L=100 μm, W=70 μm; V_{DS}=-1V)



➢1/f noise measured down to 1pA; the sample size (number of measurement in different bias point and devices) is unprecedented for this type of investigation.

➢The gate referred flicker noise evidences a strong effect of correlated mobility fluctuations in OTFTs (G. Giusi et Al, EDL 2015 vol.36, no.5).

Components of a noise measurement system



Our first programmable voltage source

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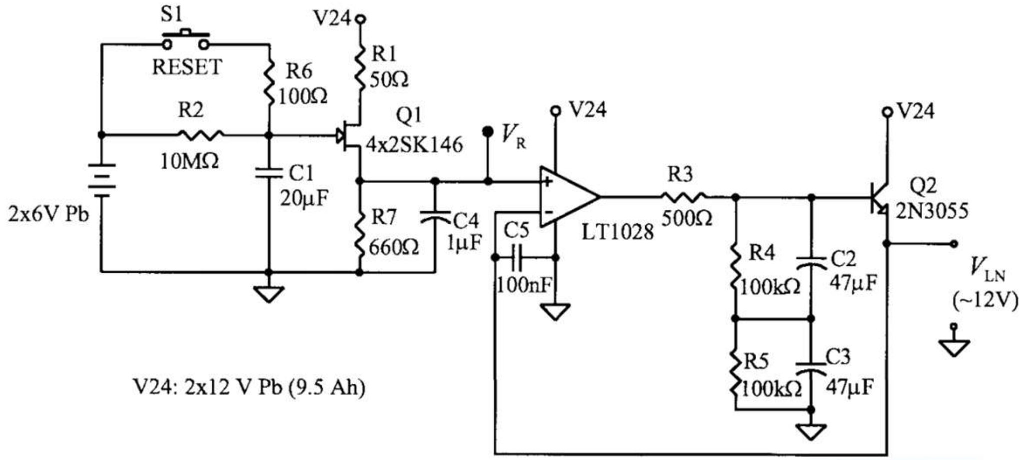
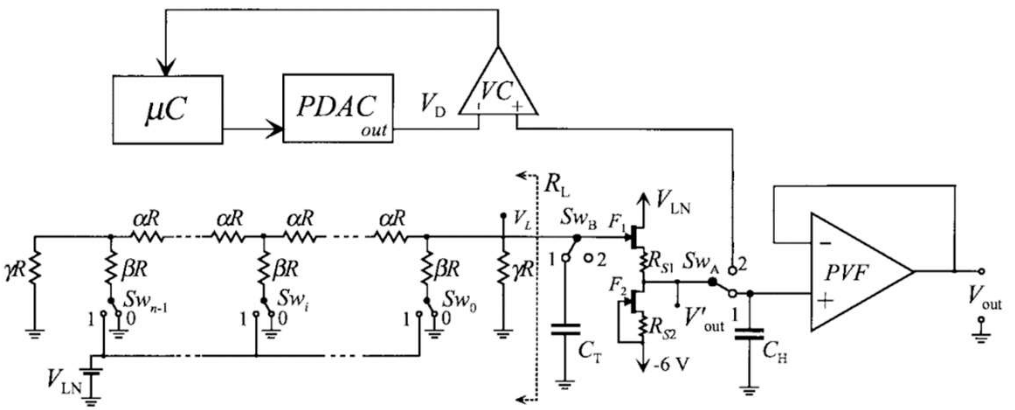
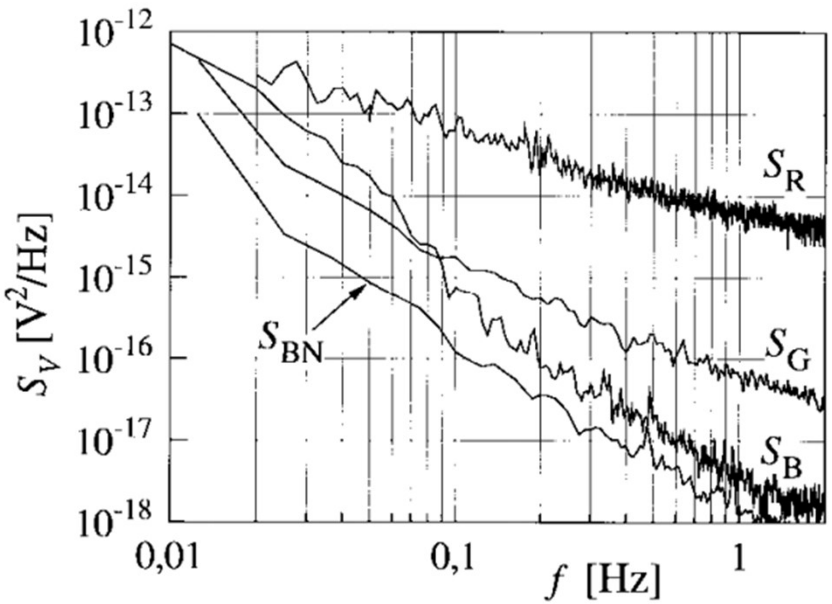
Baracchino, L., Basso, G., Ciofi, C., Neri, B., "Ultralow-noise programmable voltage source", IEEE Trans. Instr. Meas. **46** (6), pp. 1256-1261 (1997).





0-8 V, accuracy better than 1.5 mV, current up to 500 mA.



S_R: output of LTZ1000 (0A)

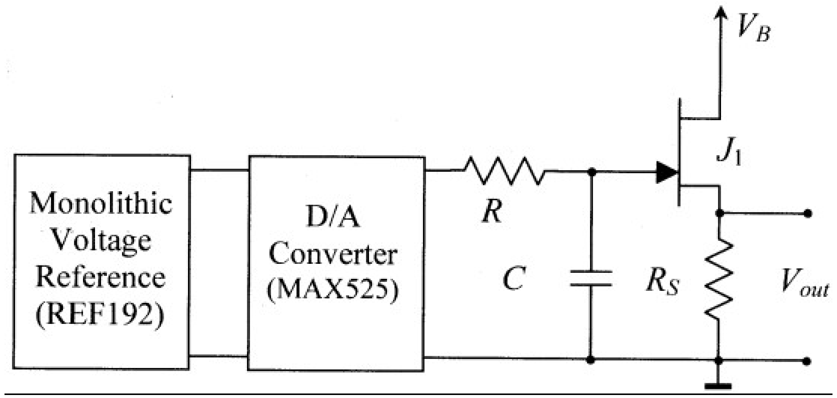
S_G: our system (100 mA)

S_B: battery (100mA)

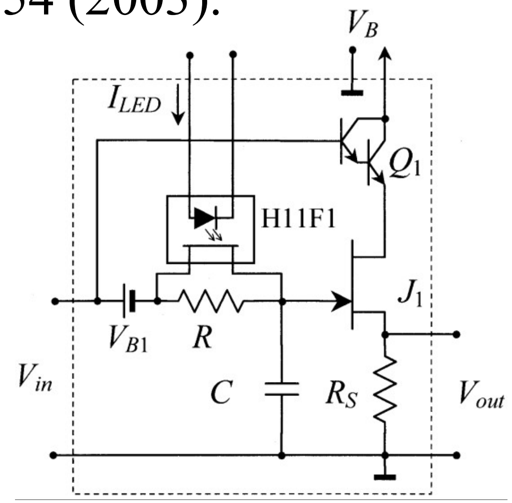
Problems: complexity, cost, size.

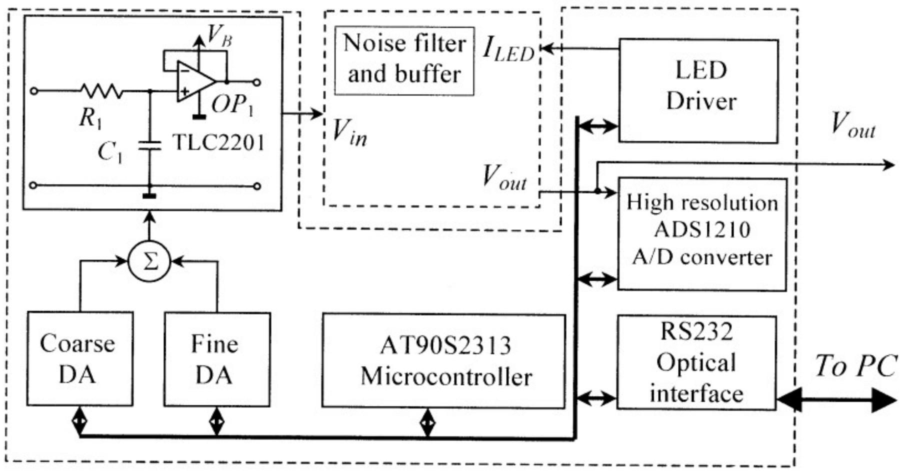
A low noise programmable voltage reference

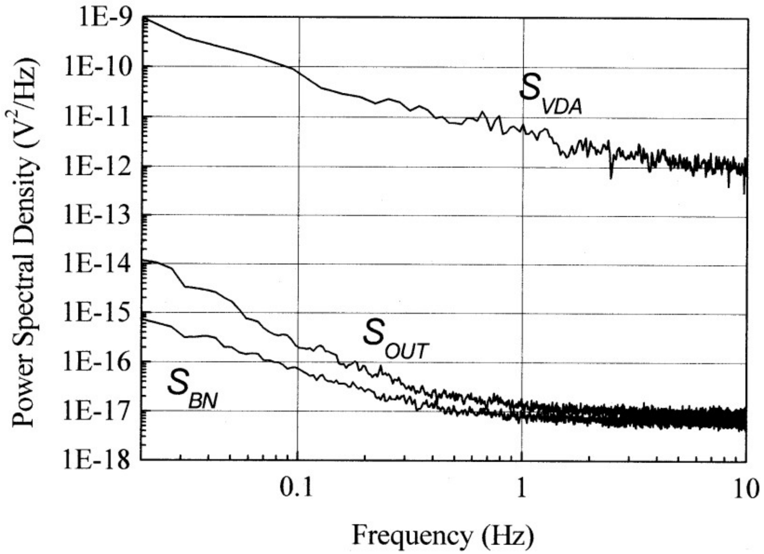
Pace, C., Ciofi, C., Crupi, F., "Very low-noise, high-accuracy programmable voltage reference" IEEE Trans. Instr. Meas., **52** (4), pp. 1251-1254 (2003).



R=100 MΩ
C=20 μF

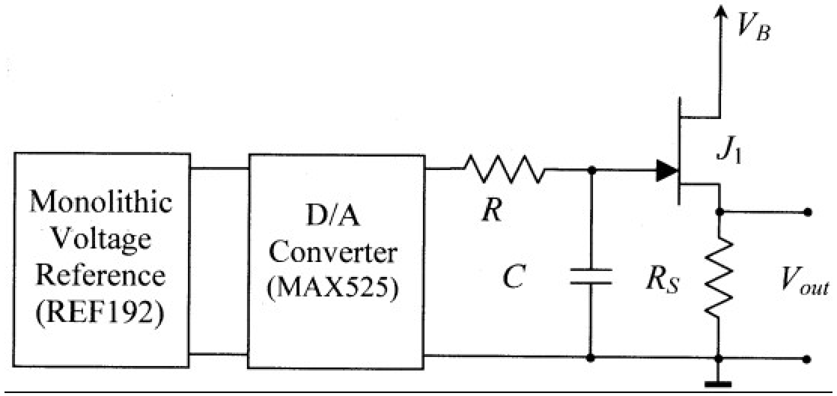






Problems: complexity, cost

Capacitors and ultracapacitors



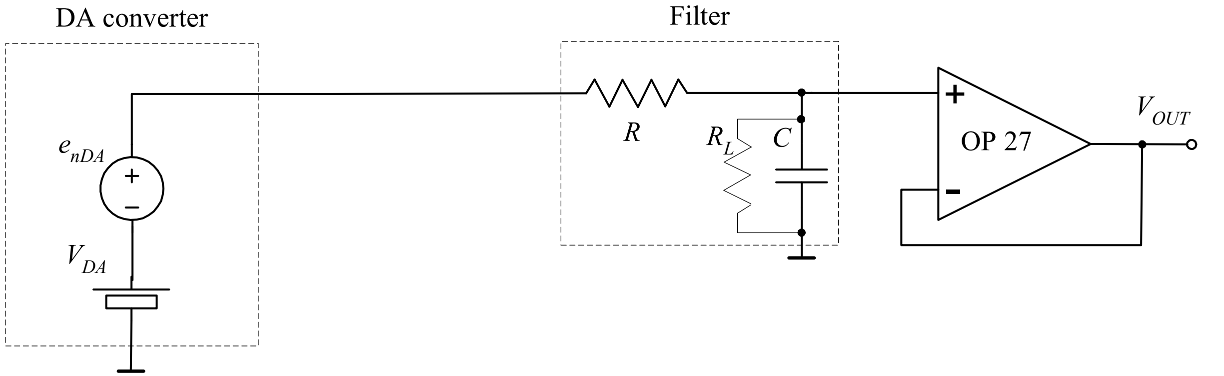
- In low frequency noise applications electrolitic capacitors cannot be used due to micro discharge effects that translate into high low frequency noise contributions.

- Polyester and polipropylene capacitors have to be used, and this limits the maximum capacitance, if we want to maintain reasonable size, to a few tens of micro Farads.

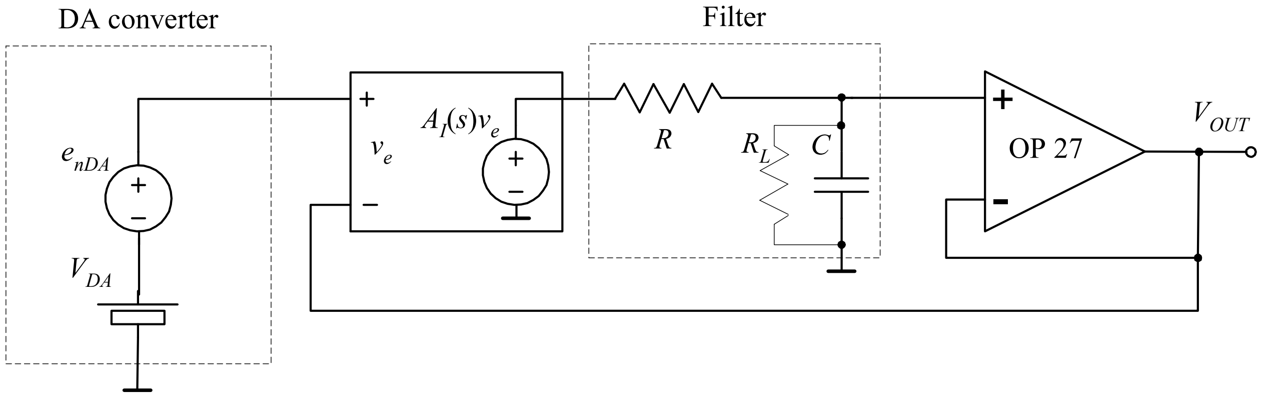
- With such relatively low capacitance, high accuracy, low offset, bipolar input low voltage noise buffers cannot be used due to the large value of current noise. Dicrete JFET buffer stage introduce significant offset that makes it difficult to obtain high accuracy.

Capacitors and ultracapacitors

- Supercapacitors are not affected by discharge effects so that simpler configurations can be used. Accuracy is in this case limited by the leakage resistance (OP offset is negligible)

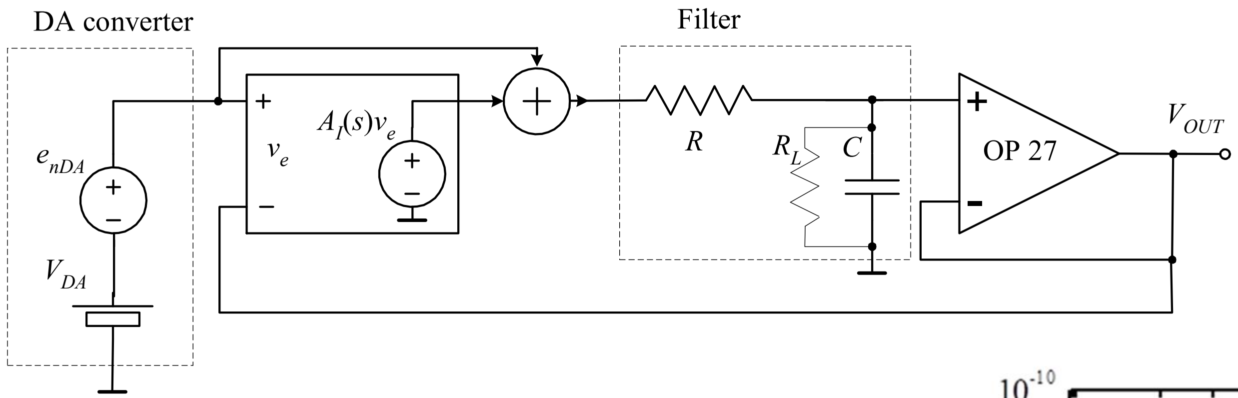


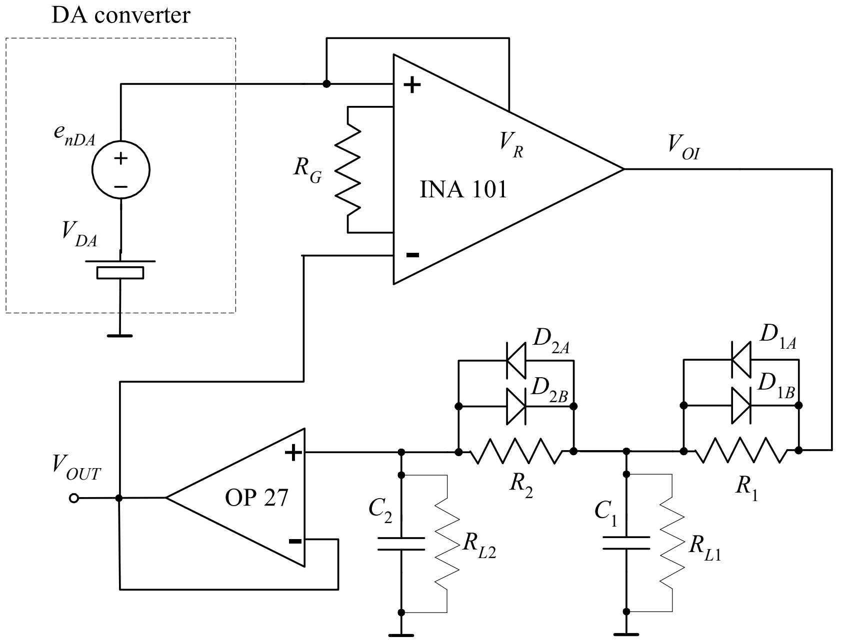
- Reducing the offset by means of feeback may be difficul: noise is set by error amplifier.

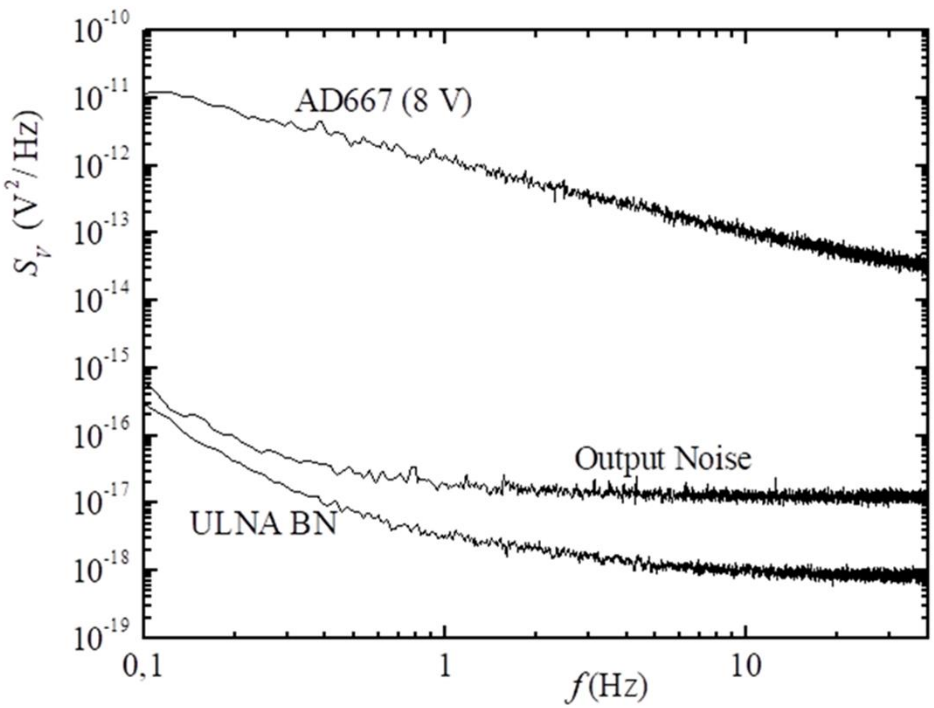


Capacitors and ultracapacitors

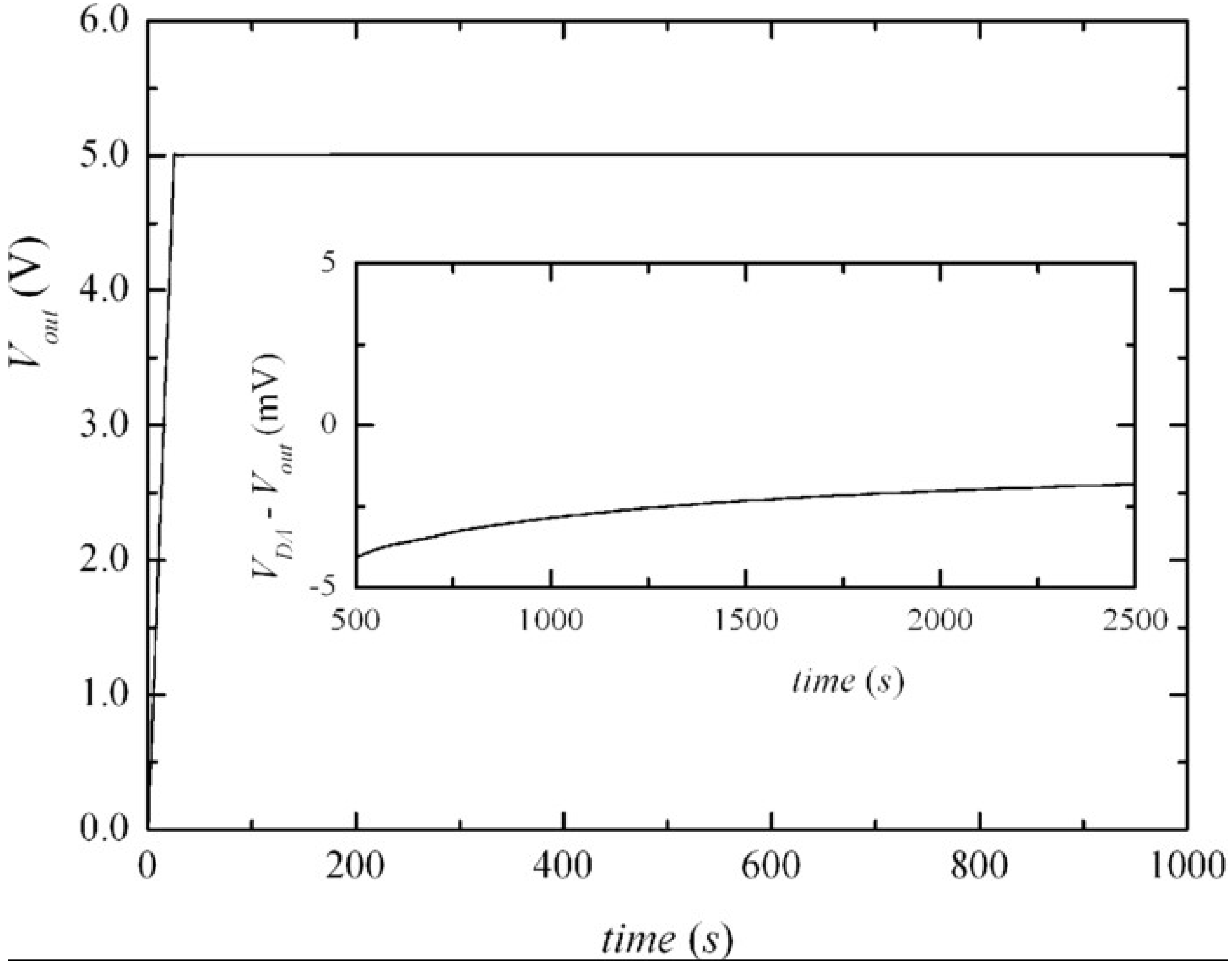
- Effective approach (G. Scandurra, G. Giusi, C. Ciofi, *Rev Ssci. Instr.,* **85**, 044702, 2014)





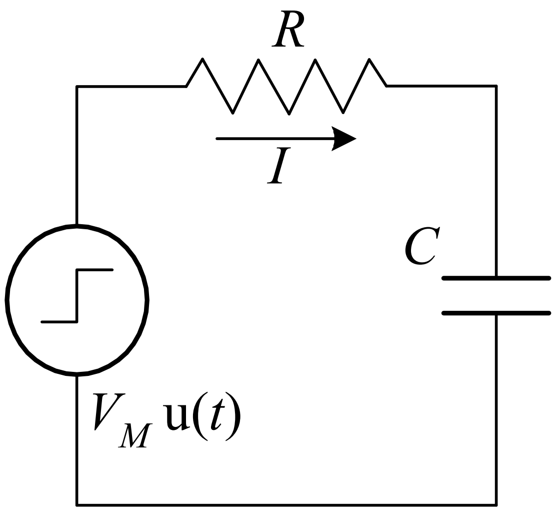


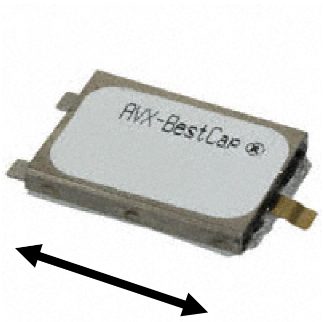
Supercapacitor issue



Very long transients!

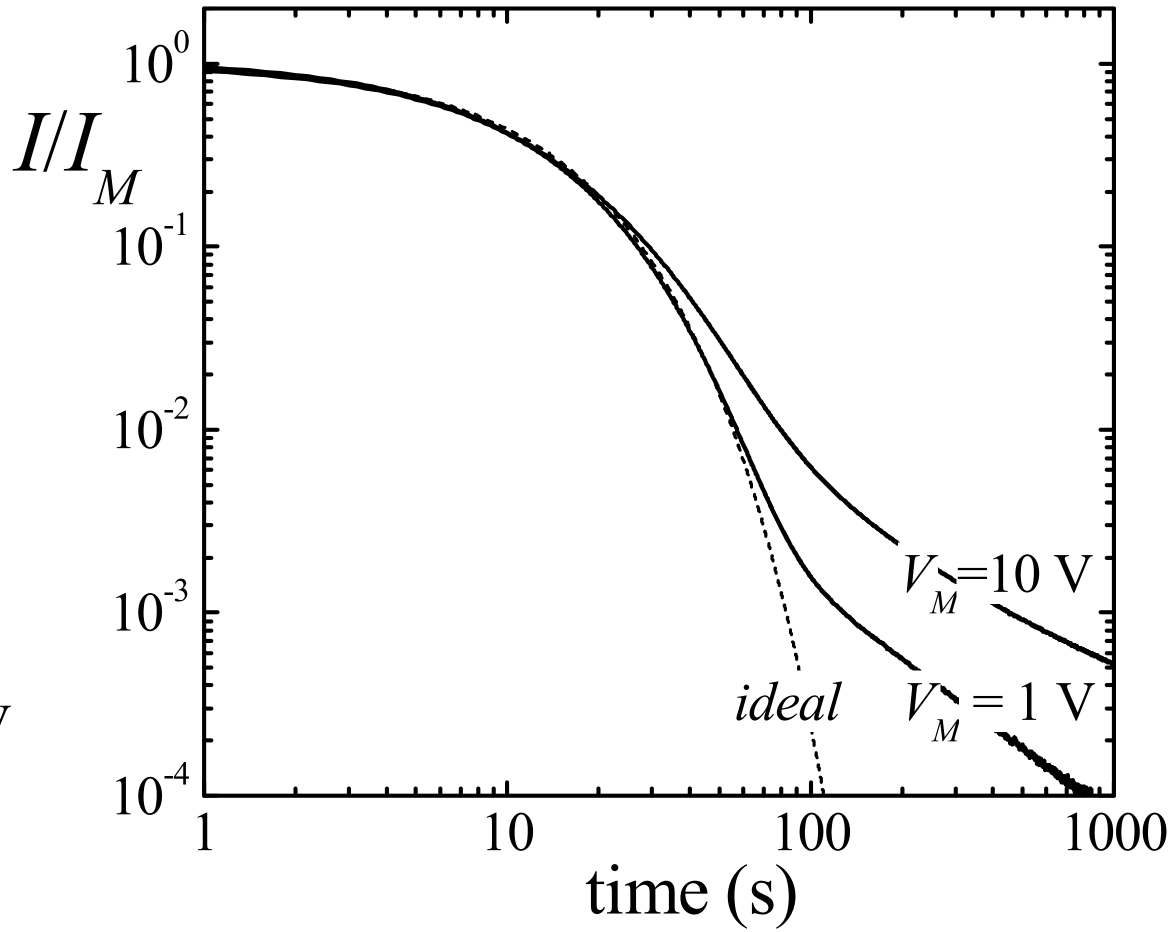
Supercapacitor transient



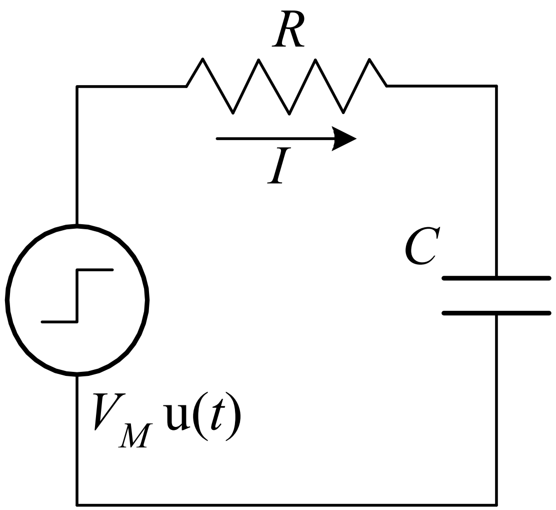


20 mm

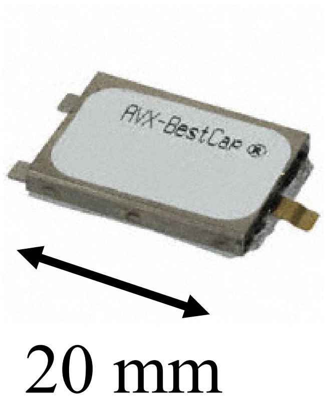
R=1 kΩ
C=10 mF/12 V

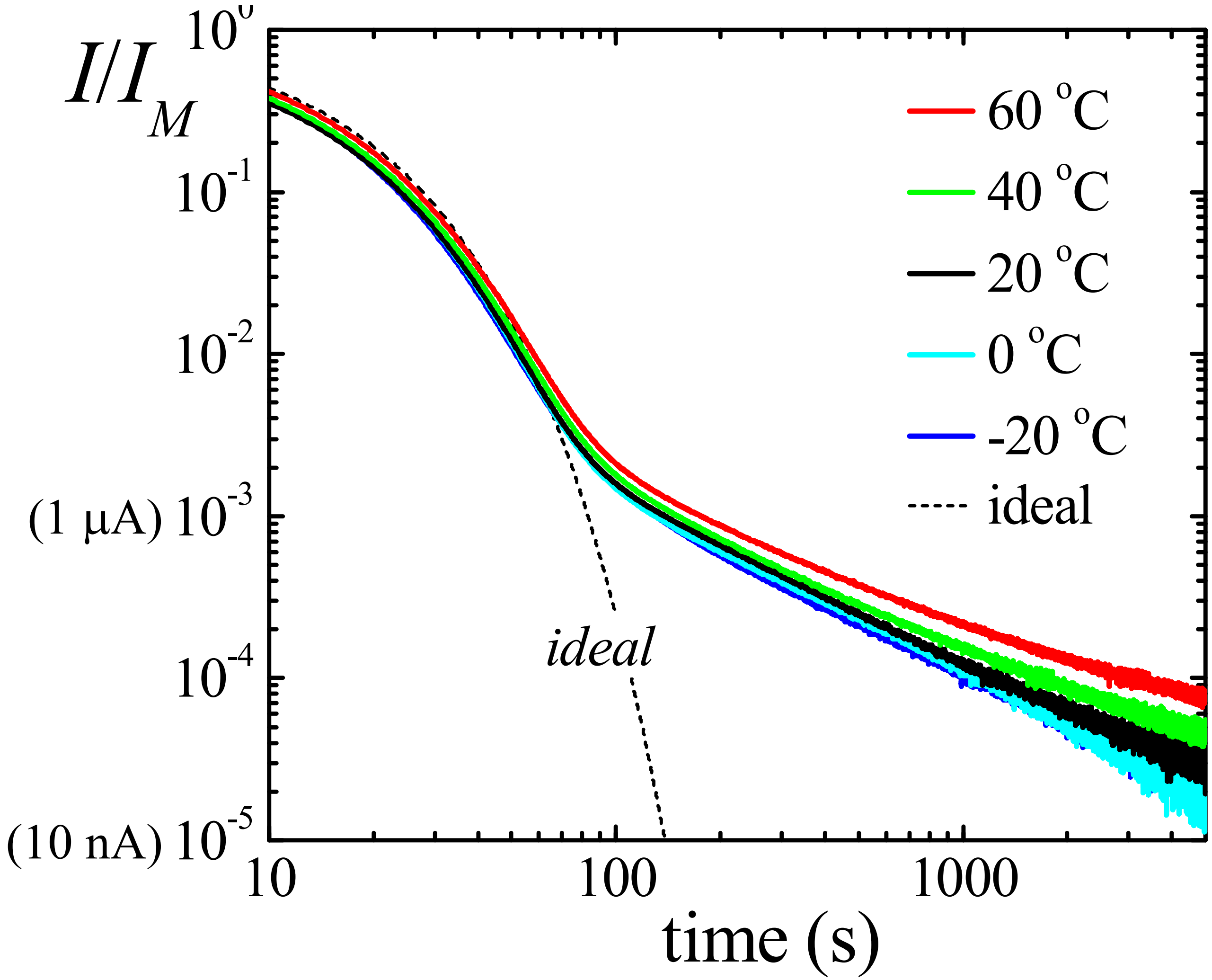


Supercapacitor transient



R=1 kΩ
C=10 mF/12 V

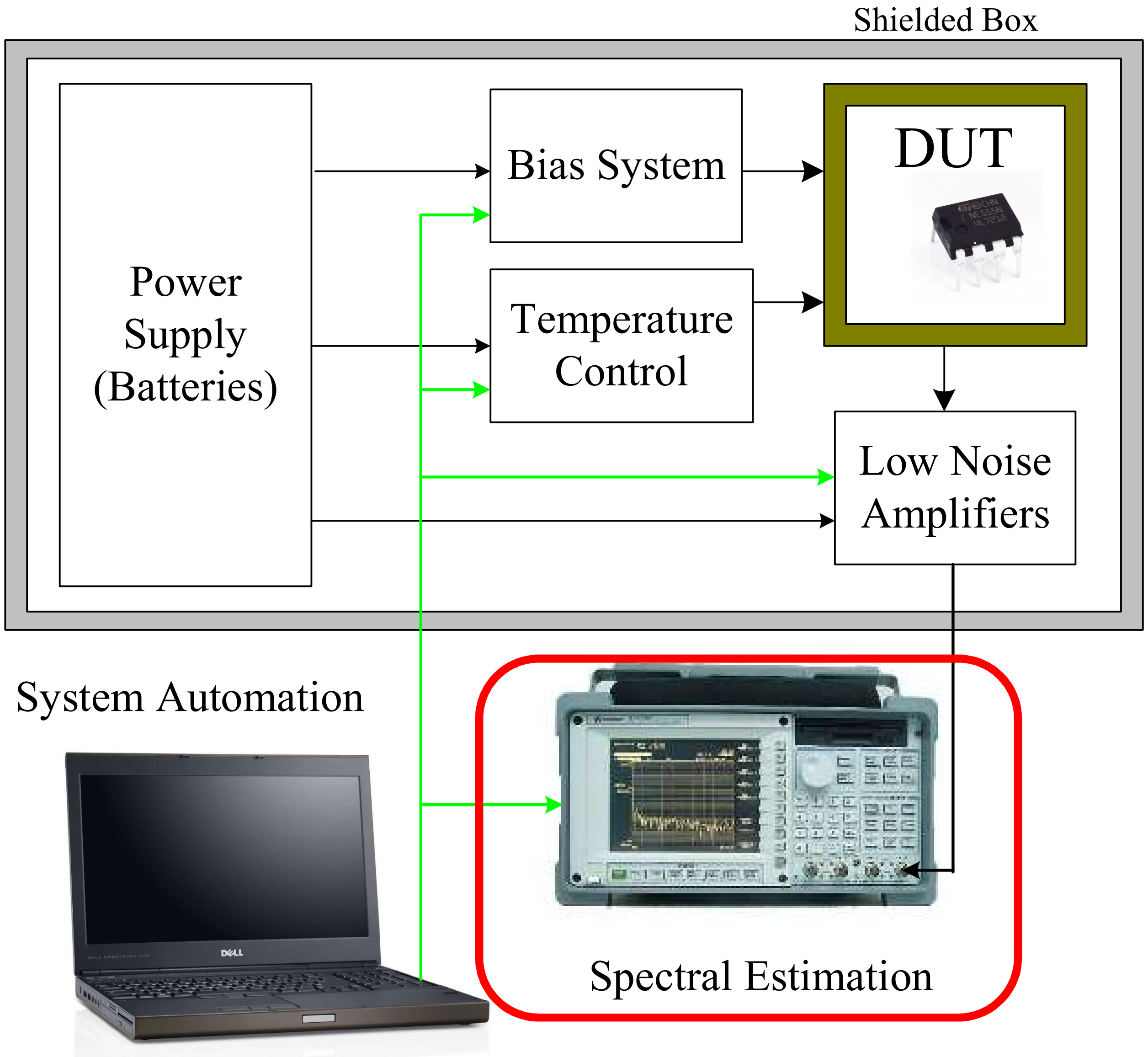




Open questions

- Supercapacitor may represent a key component toward the realization of fully programmable, high accuracy, very low noise voltage and current sources;
- The peculiar behaviour during charging and discharging leads to very long transients that may not be tolerated in many applications;
- Understanding an mitigating the observed "virtual leakage effects" might considerably simplify the design of fully automated noise measurement systems.

Components of a noise measurement system



Spectral estimation parameters setting

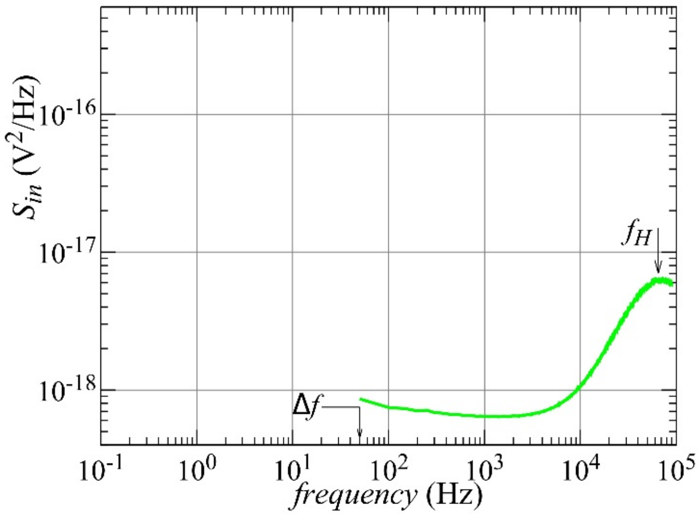
f_S: sampling frequency;

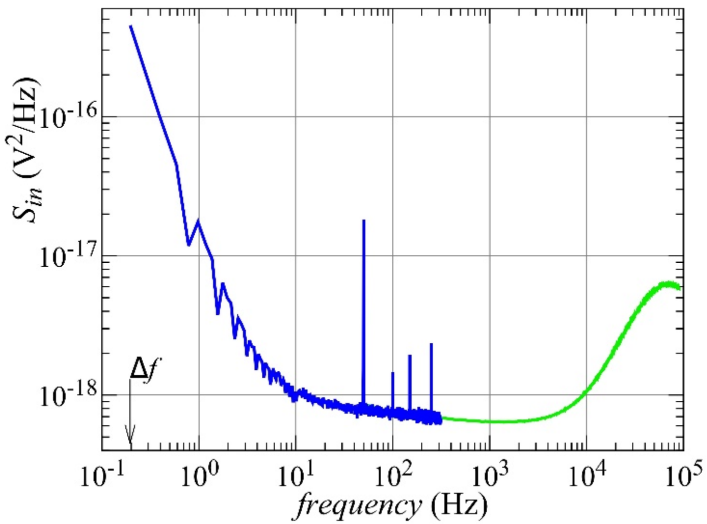
N: record length;

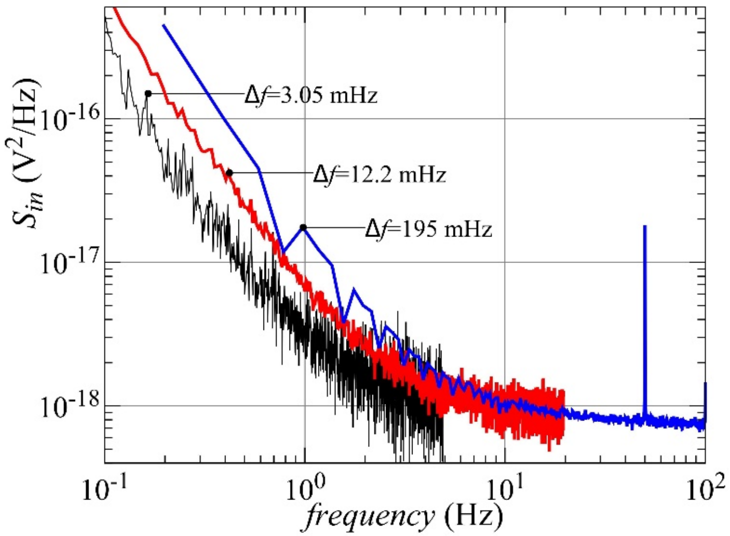
Δf: resolution

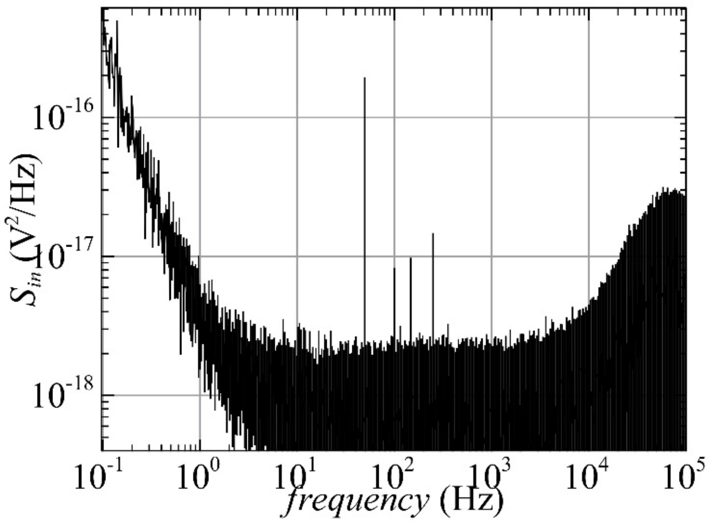
$$\Delta f = \frac{f_S}{N}$$

Measurement time: 30 minutes in all cases

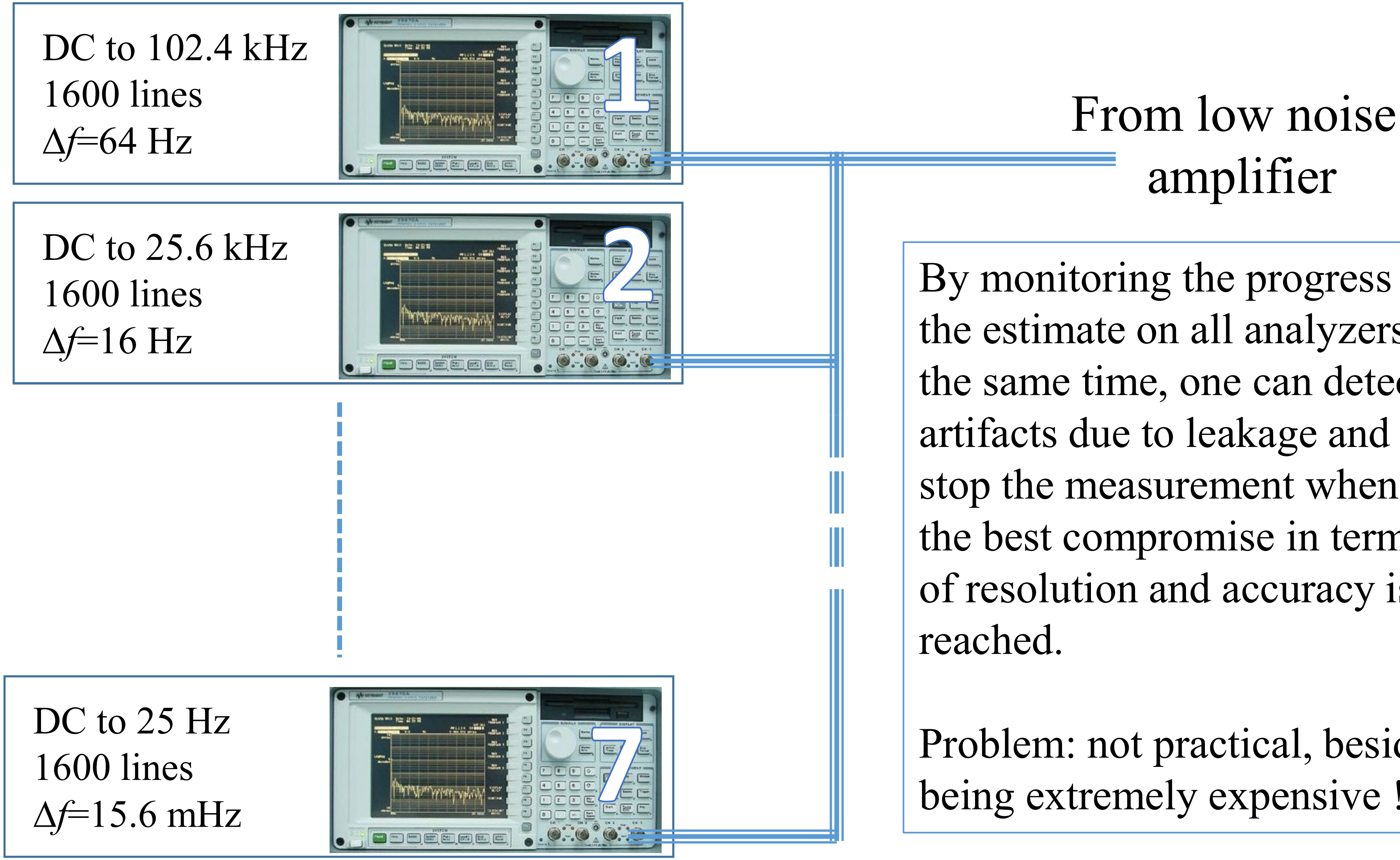








A possible solution........?

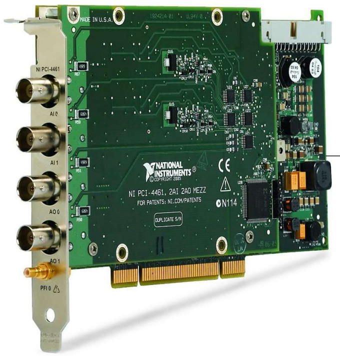


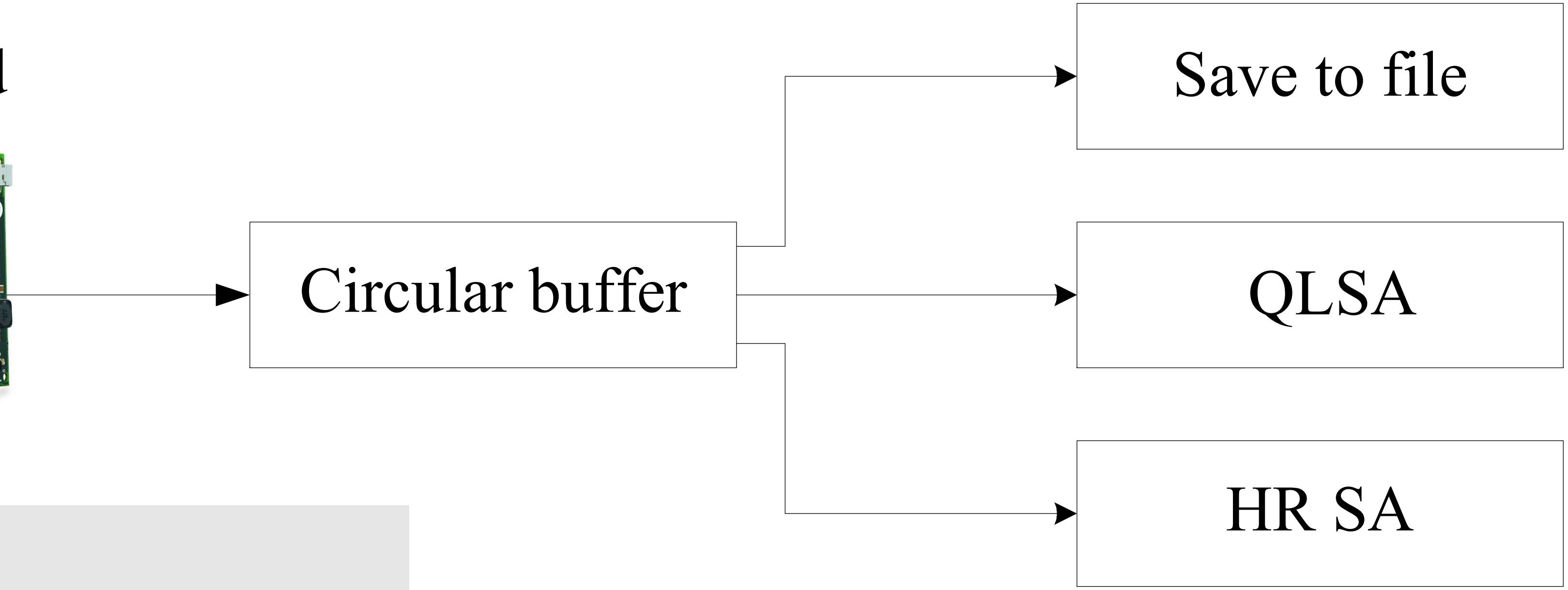
By monitoring the progress of the estimate on all analyzers at the same time, one can detect artifacts due to leakage and stop the measurement when the best compromise in terms of resolution and accuracy is reached.

Problem: not practical, besides being extremely expensive !

QLSA operation

DSA Board

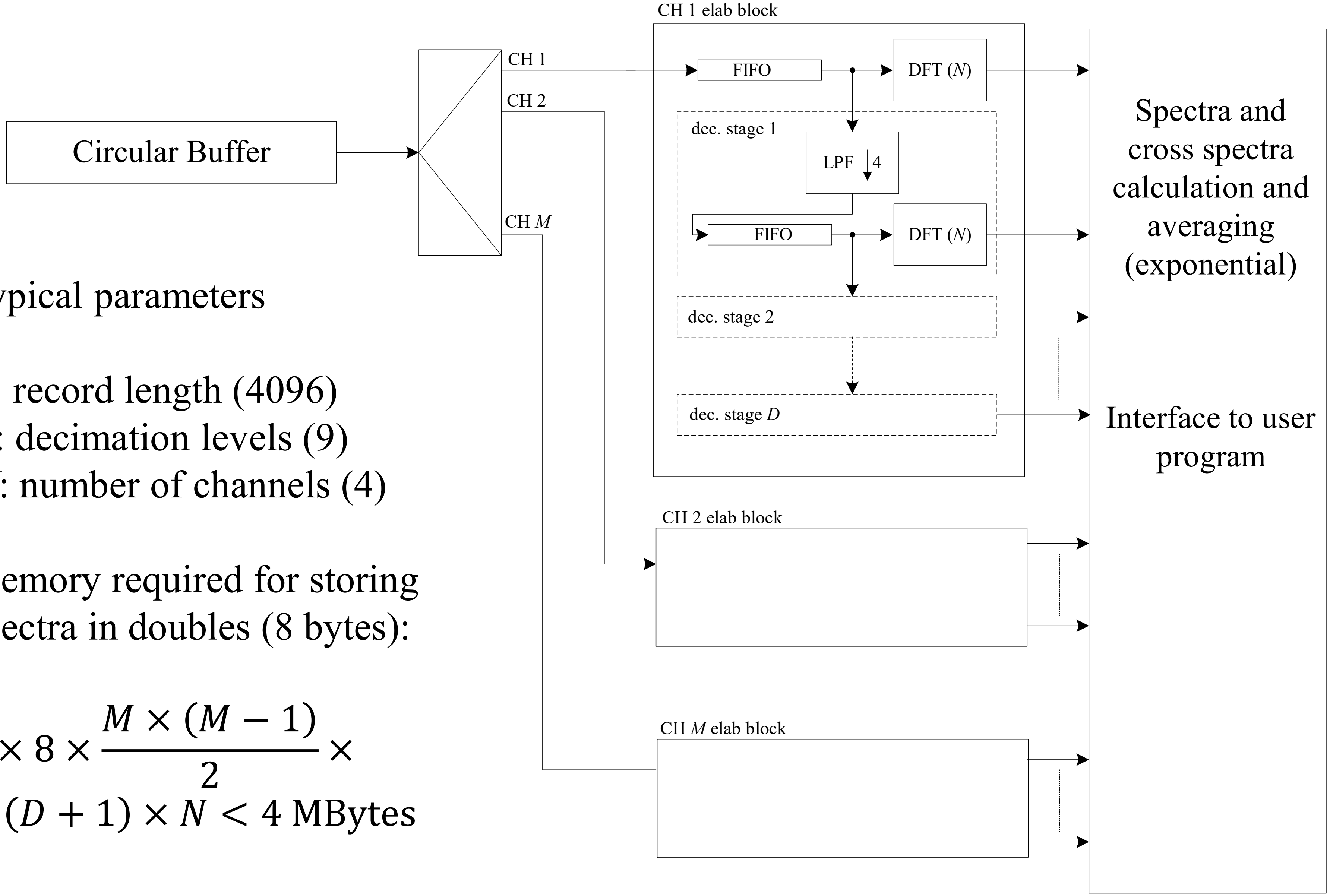





```
main()
{
  .....
  QLSA_Init(4,12,8,8);
  // 4 channles,
  // 2^12 (4096) rec len
  // 8 is the buffer size
  // 8 dec stages
  ........
  QLSA_Close();
}
```

```
int DSA_callback (void)
{
        double * intl_data_ptr;
        ...
        ...
        QLSA_New_Data(intl_data_ptr);
        ...
        return 0;
}
```

QLSA function



Typical parameters

N: record length (4096)
D: decimation levels (9)
M: number of channels (4)

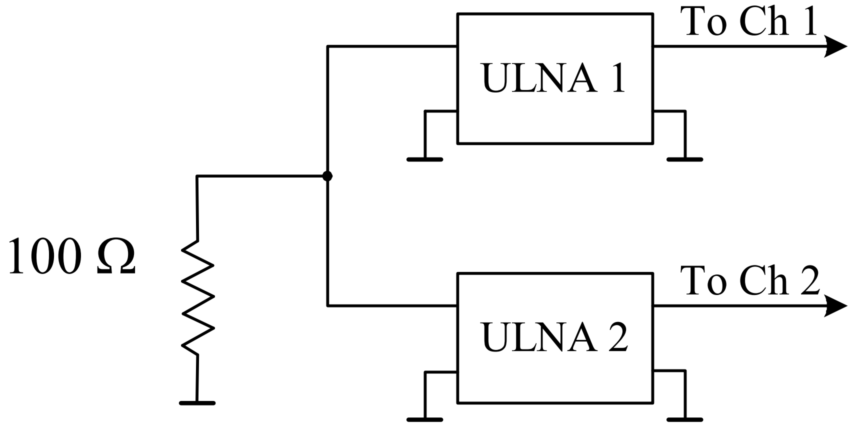
Memory required for storing spectra in doubles (8 bytes):

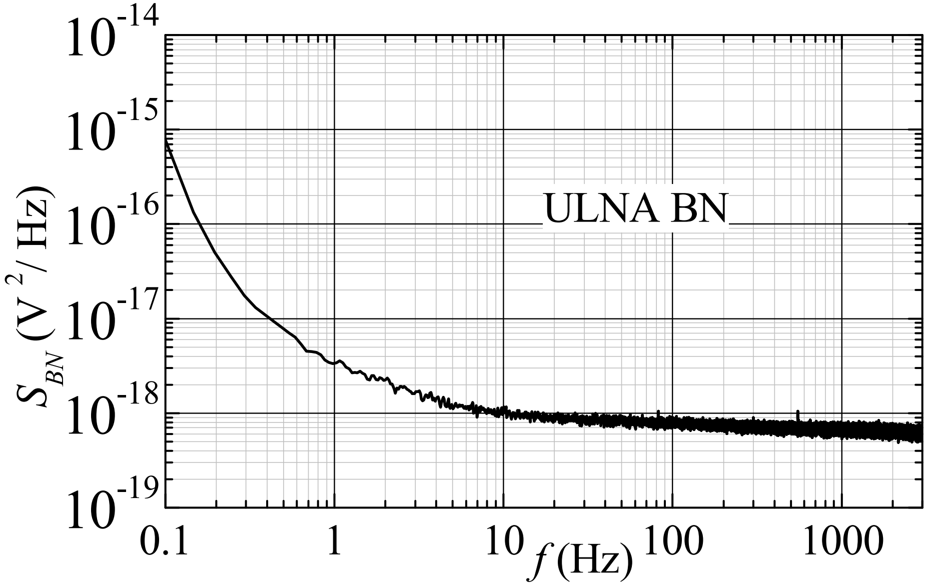
$$2 \times 8 \times \frac{M \times (M-1)}{2} \times (D+1) \times N < 4 \text{ MBytes}$$

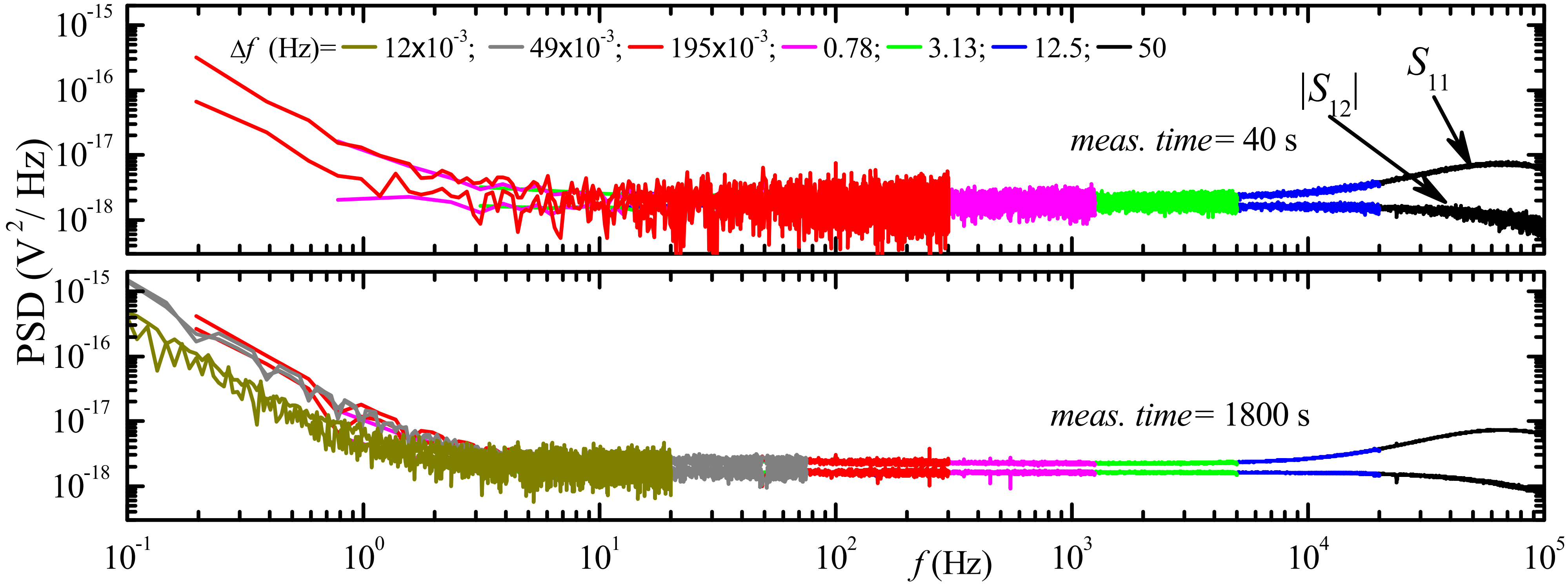
QLSA API


```
int QLSA_Init(int ch_num, int rec_len_log2, int buf_rec_num, int dec_stages_num );
int QLSA_Close(void);

int QLSA_New_Data(double * pdata);

int QLSA_Start_Save(char * filename);
int QLSA_Stop_Save(void);

int QLSA_Set_Spec_Par(int wt, int equiv_N, int adv_by0, int adv_by1, double fs);
int QLSA_Set_User_Window (double *uwp);

int QLSA_Start_Elab(void);
int QLSA_Stop_Elab(void);

int QLSA_Req_Power(void);
int QLSA_Get_Spec(int ch1, int ch2, int dec_lvl, double **re, double **im,
                                                              int * num_ave);
int QLSA_Req_Time(void);
int QLSA_Get_Time(int ch1, int dec_lvl, double **re);

// functions for high resolution (HR) functioality are not shown
```

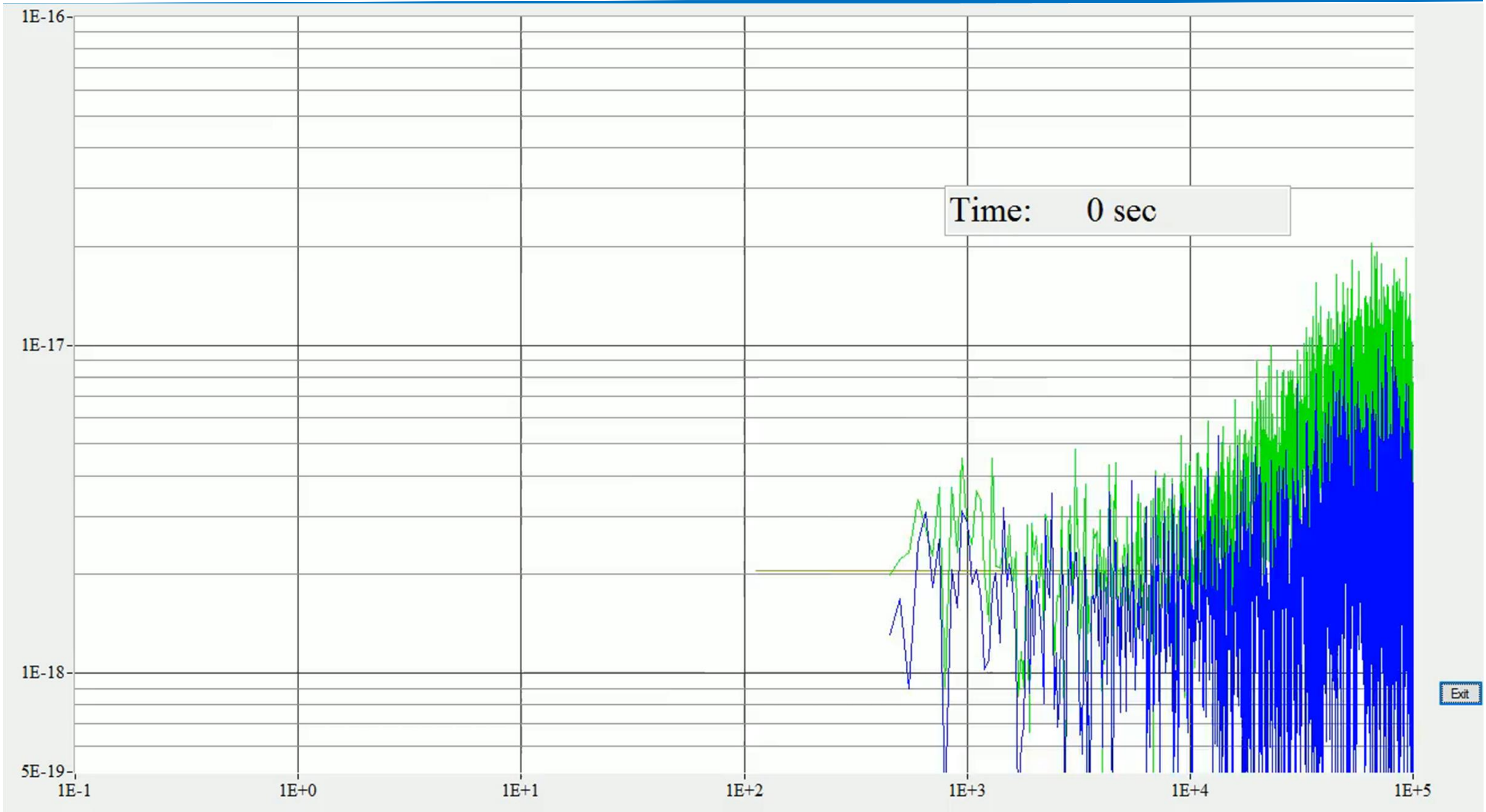
QLSA operation



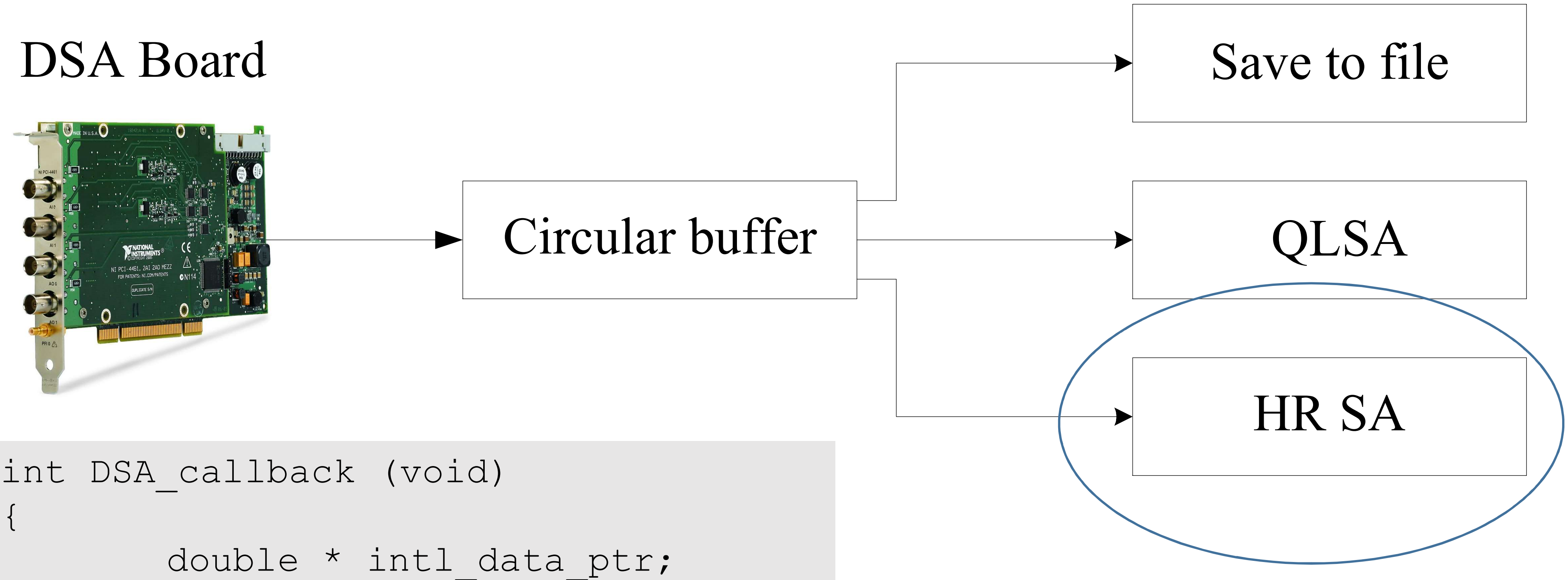




QLSA operation



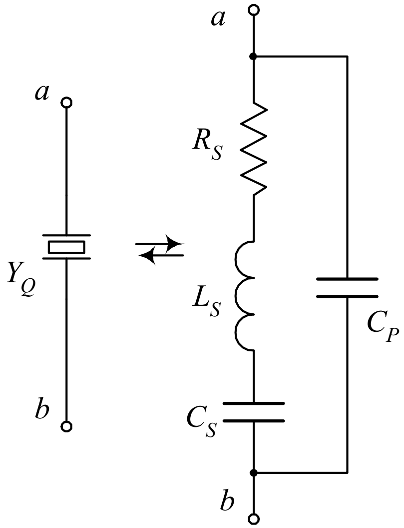
QLSA operation




```
int DSA_callback (void)
{
        double * intl_data_ptr;
        ...
        ...
        QLSA_New_Data(intl_data_ptr);
        ...
        return 0;
}
```

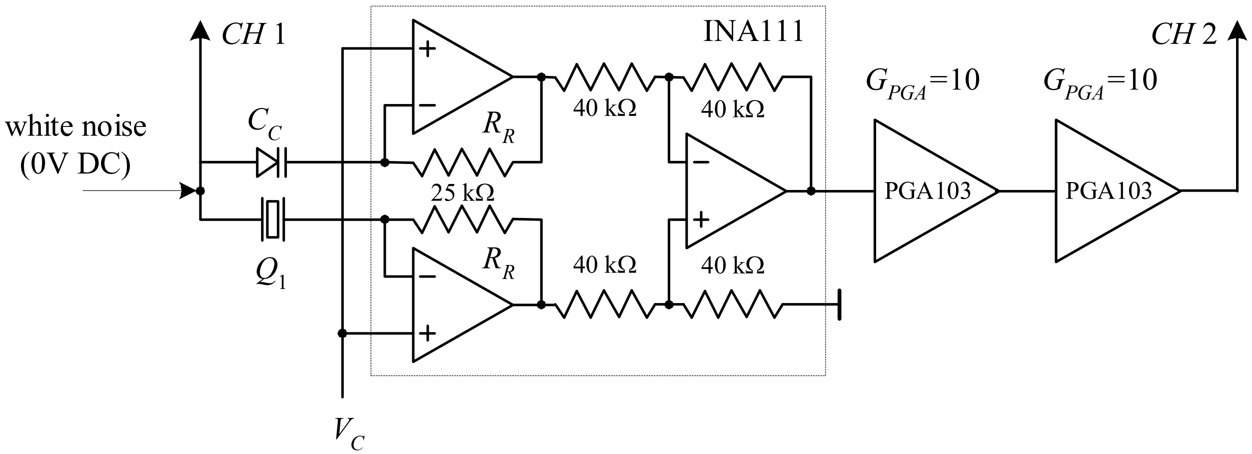
The three main functions (save to file, QLSA and HRSA) can be activated independently on the same data stream

Why HR SA: Noise and QCM (QTF)

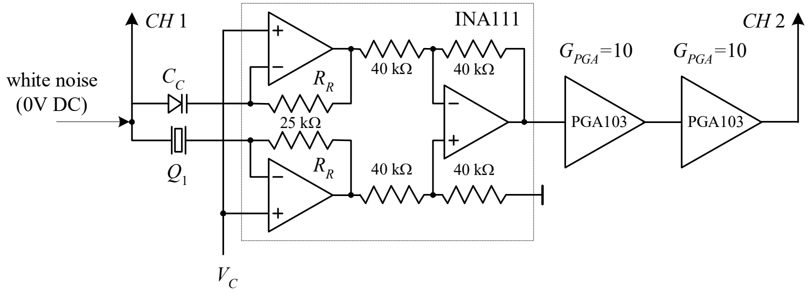


$$Y_Q(j\omega) = j\frac{1}{R_S}\frac{f}{Qf_S}\left(b + \frac{1}{\left(1 - \frac{f^2}{f_S^2}\right) + j\frac{f}{Qf_S}}\right)$$

$$f_S = \frac{1}{2\pi\sqrt{L_S C_S}}; \quad Q = \frac{f_S L_S}{2\pi R_S}; \quad b = \frac{C_P}{C_S}$$

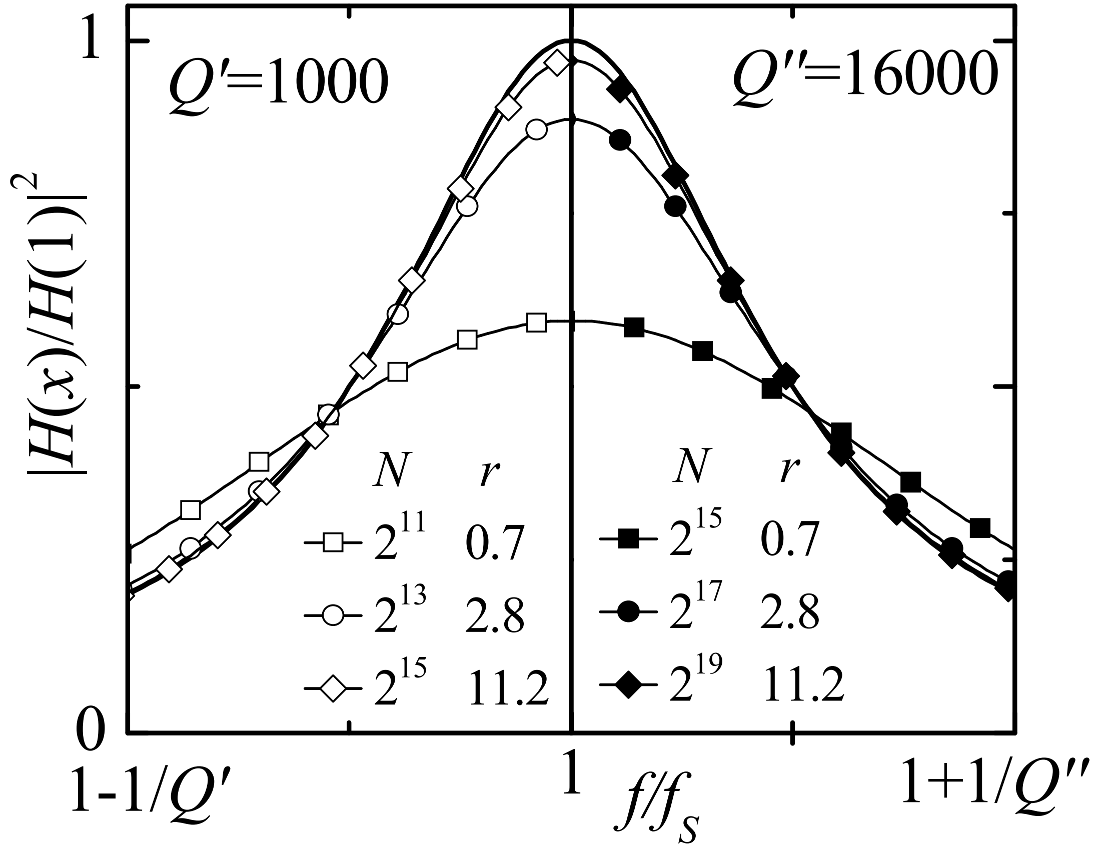


Noise and QCM (QTF)



Resonance frequency (f_S): 32 kHz
Sampling frequency (f_{samp}): 96 kHz

$$r = \frac{f_S/Q}{f_{samp}/N}$$

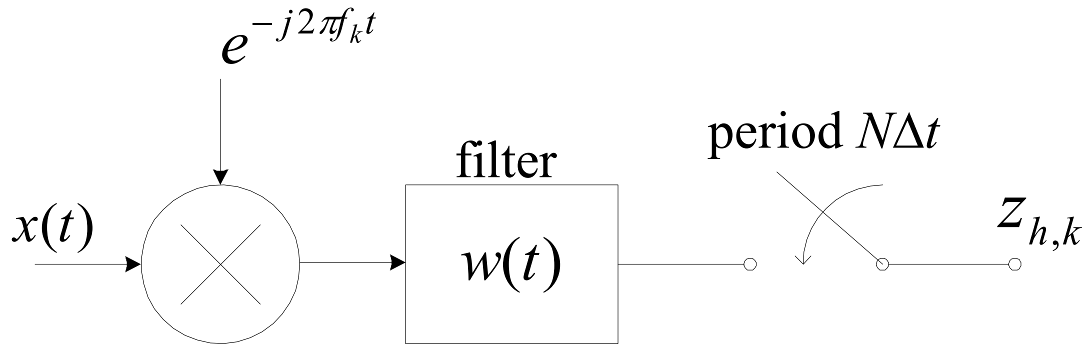


HR SA

Conventional spectral estimation relies on FFT.
When a record of *N* samples is elaborated, one obtains, with high computational efficency, an estimate of the spectrum at frequencies:

$$f_k = k\Delta f;\ 0 \le k < \frac{N}{2}\ ;\ \Delta f = \frac{f_S}{N}\quad ;\ f_S \text{ is the sampling frequency}$$

In principle one can obtain finer resolution for the same time record, but is not very useful since the Equivalent Noise Bandwidth (*ENB*) of the filter across each frequency is set by the the duration of the time record (duration of the impulse response of the filter).



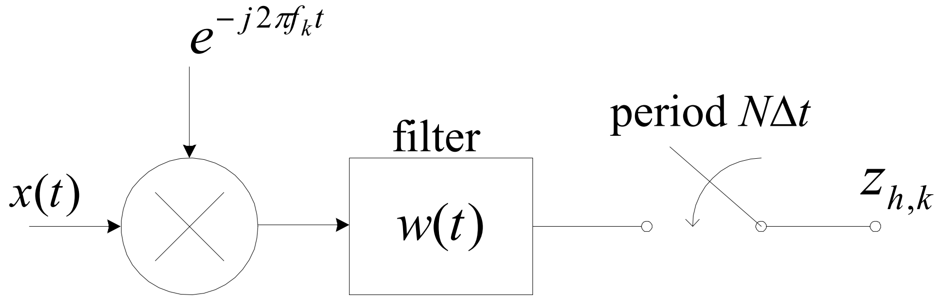
With conventional FFT approach:

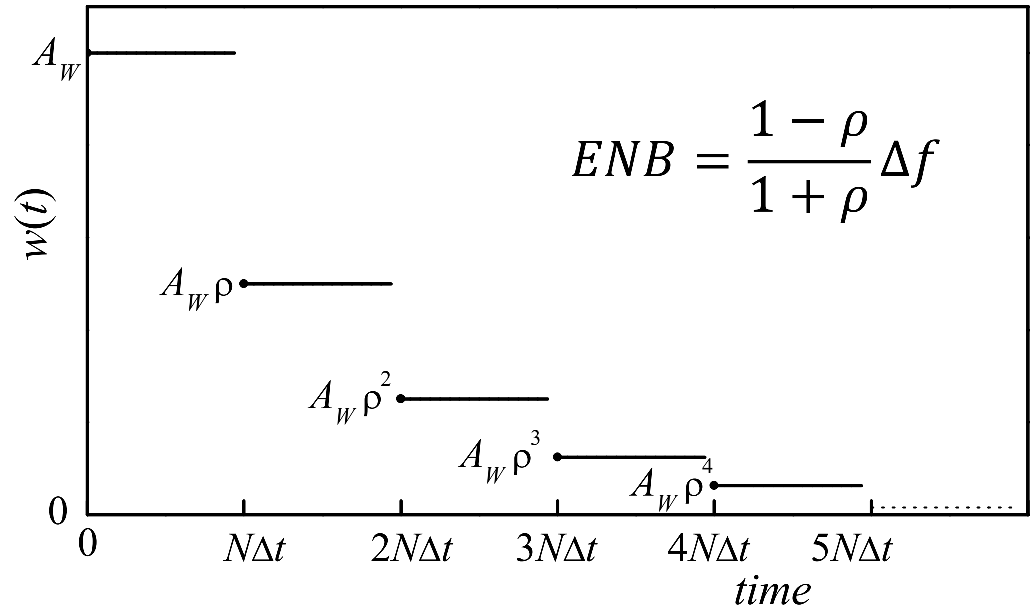
$$ENB \approx \Delta f$$

Narrow ENB can be obtained only with long time records (large *N*)

HR SA

With the approach we propose, we break the link between ENB and Δf.
We can obtain arbitrarily small ENBs by working with relatively short time records.





$$z_{h+1,k} = \rho\, z_{h+1,k} + A_W\, e^{-j2\pi k} \sum_{m=0}^{N-1} x_{hN+m}\, e^{-j2\pi \frac{k}{N} m}$$

DFT

$$k \text{ any real number } 0 \le k < \frac{N}{2}$$

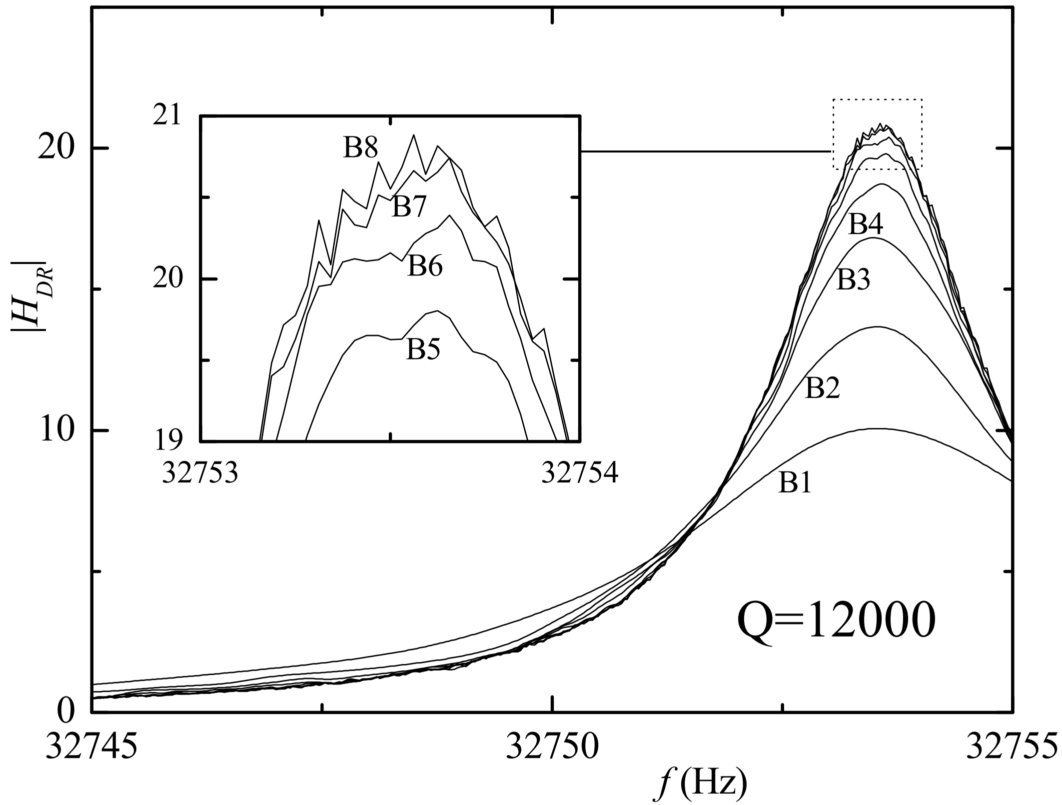
HR SA operation

$$z_{h+1,k} = \rho\, z_{h+1,k} + A_W\, e^{-j2\pi k h} \sum_{m=0}^{N-1} x_{hN+m}\, e^{-j2\pi \frac{k}{N} m}$$

DFT

- Given an input record of length N, Chirp Z-tranform is used to calculate the DFT in frequency range (f_1, f_2) with resolution $\Delta f_C = (f_2 - f_1)/N$ (at the cost of 2 FFT of length $2N$);
- z is calculated for several values of ρ in parallel, with different compromises in terms of ENB and spectral residual statistical error.

f_S=96 kHz, N=8192, f_2-f_1=256 Hz, Δf_C=31 mHz



QLSA API (HR SA)

```
int QLSA_HR_Init(int max_rbw_number);

int QLSA_HR_Close(void);

int QLSA_HR_Set_Par(double f_start, double f_stop, double f_sample,
                    double equiv_N, int rbw_num, double * rbw_values);

int QLSA_HR_Set_Autorbw(double f_start, double f_stop,
                        double f_sample, double equiv_N);

int QLSA_HR_Start_Elab(void);

int QLSA_HR_Stop_Elab(void );

int QLSA_Req_HR_Power(void);

int QLSA_HR_Get_Spec(int ch1, int ch2, int rbw_index,
                     double **re, double **im, int * num_ave);
```

Getting QLSA

- Check information at page:

  http://www.celec.org/QLSA/doku.php

- Request a working copy of the QLSA library to me (cciofi@unime.it)

Open issues

- Extensive testing need to be completed;
- Efficient and user friendly representation of the spectra when more than two channels are used need to be implemented.