Rohde & Schwarz

Optimization of Squelch Parameters for Efficient Ressource Allocation in Software-Defined Radios

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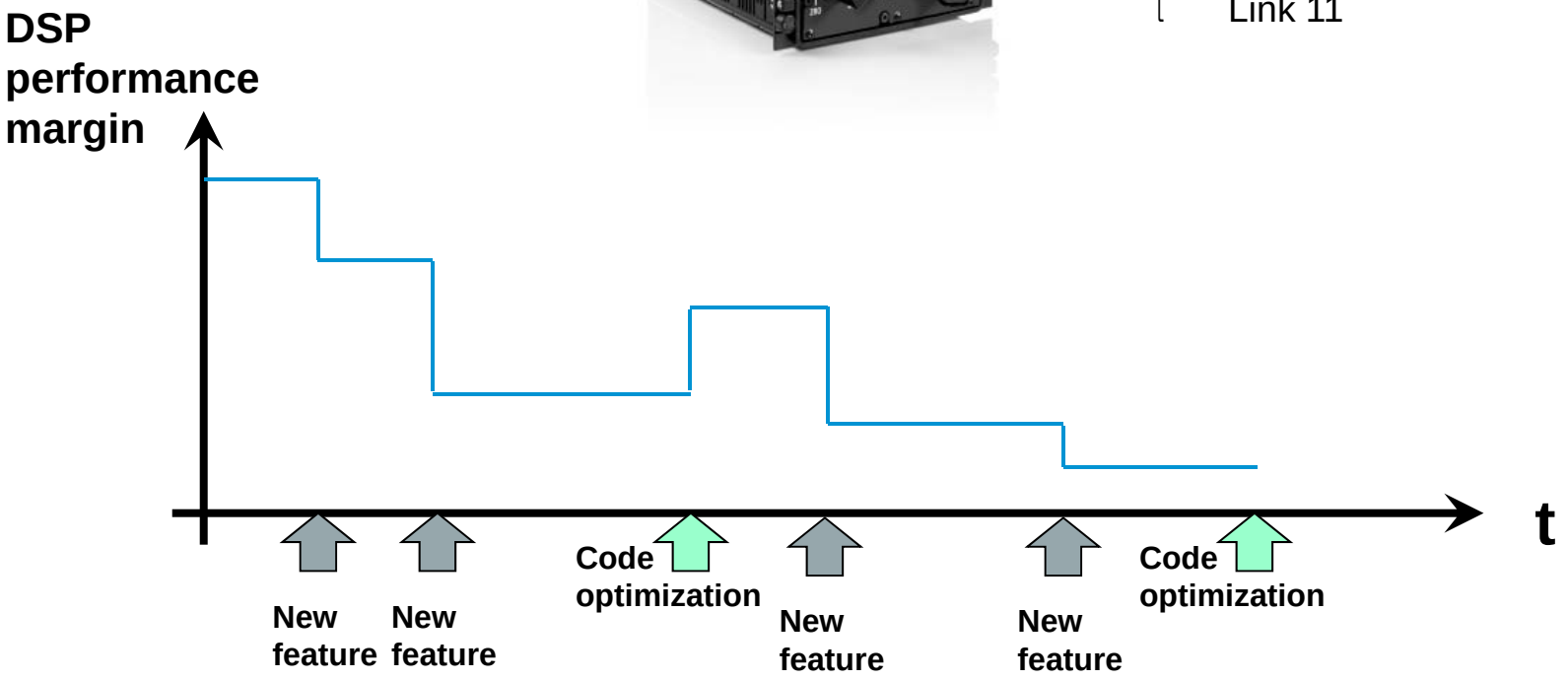
75 Years of Driving Innovation

ROHDE&SCHWARZ

Motivation

Legacy SDR

- **Multitude of waveforms:**
  - STANAG 4204, 4205
  - HQ / SATURN
  - R&S®SECOS
  - Link 11



Content

- **Squelch Modes**
- **Squelch Behaviour**
- **The Necessity for Change**
- **Optimization Approach**
- **Results**
- **Summary**

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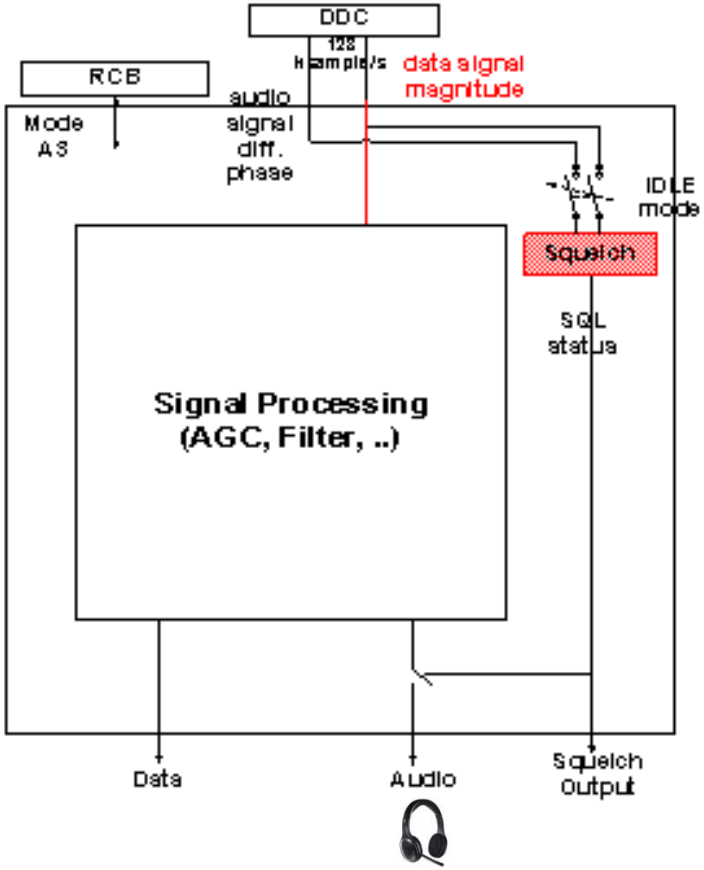
Squelch in the Receiver

A3E Mode

AM Telephony

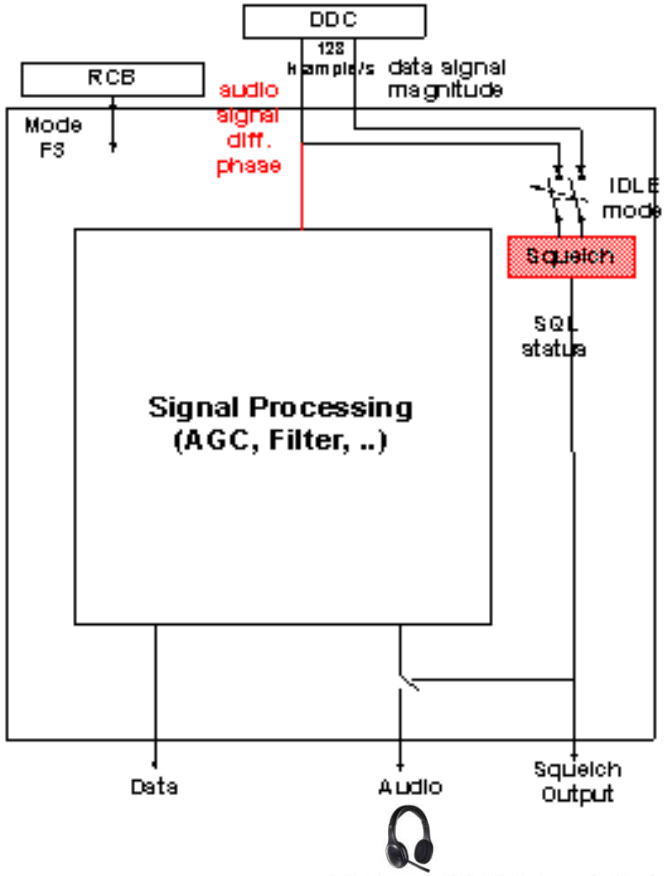
Single analog channel



F3E Mode

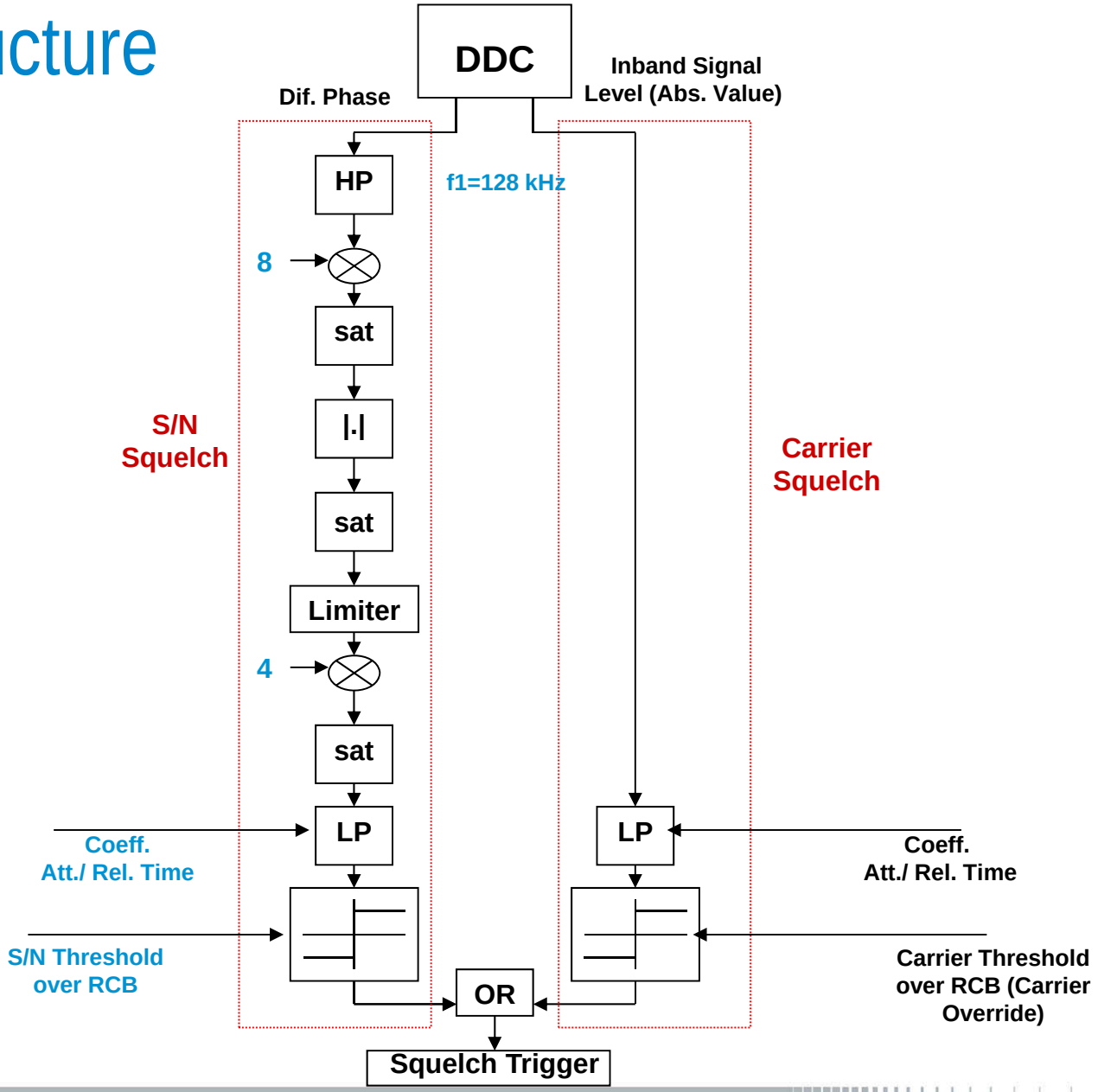
FM Telephony

Single analog channel



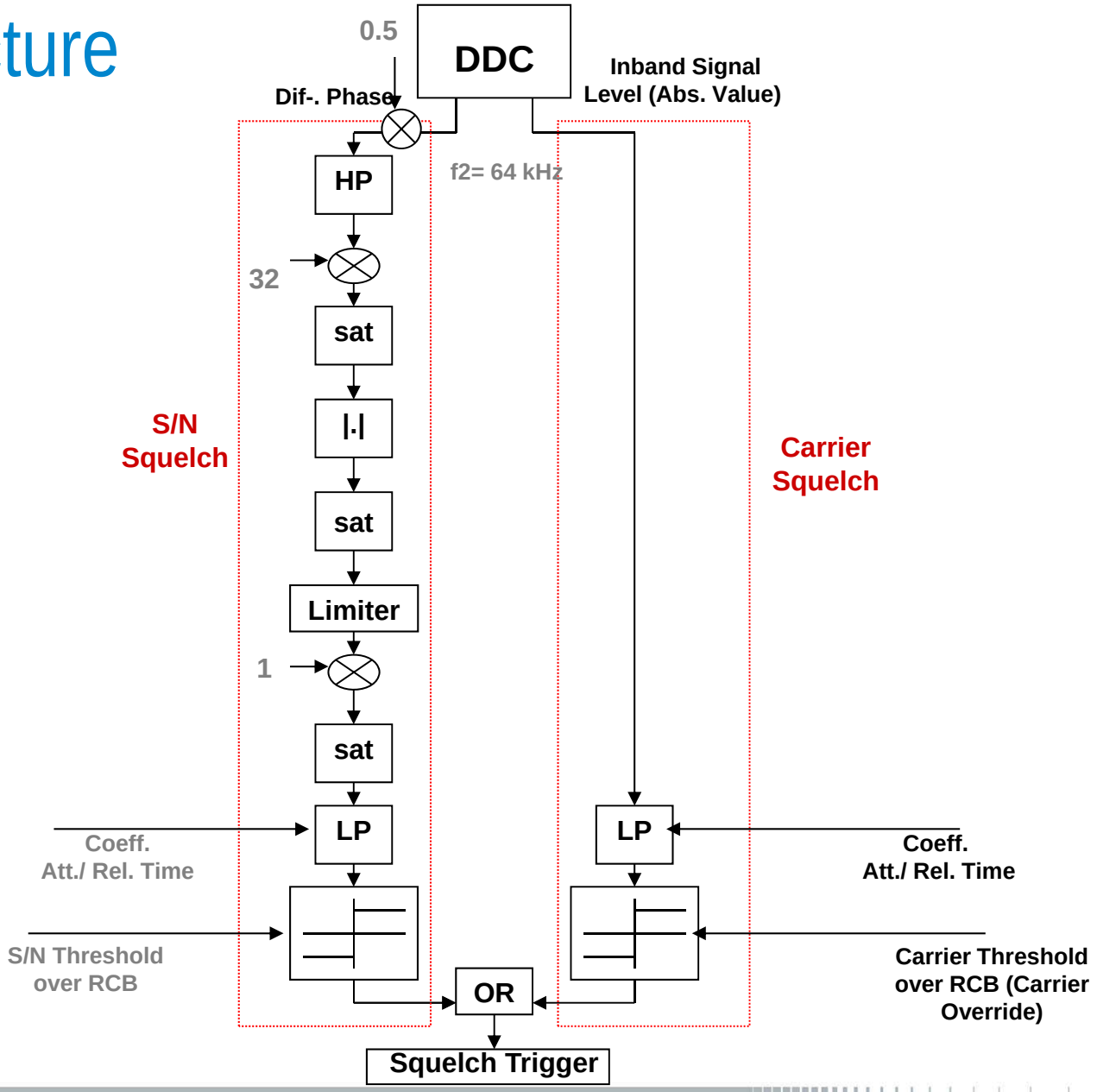
Squelch Structure

A3E Mode



Squelch Structure

F3E Mode



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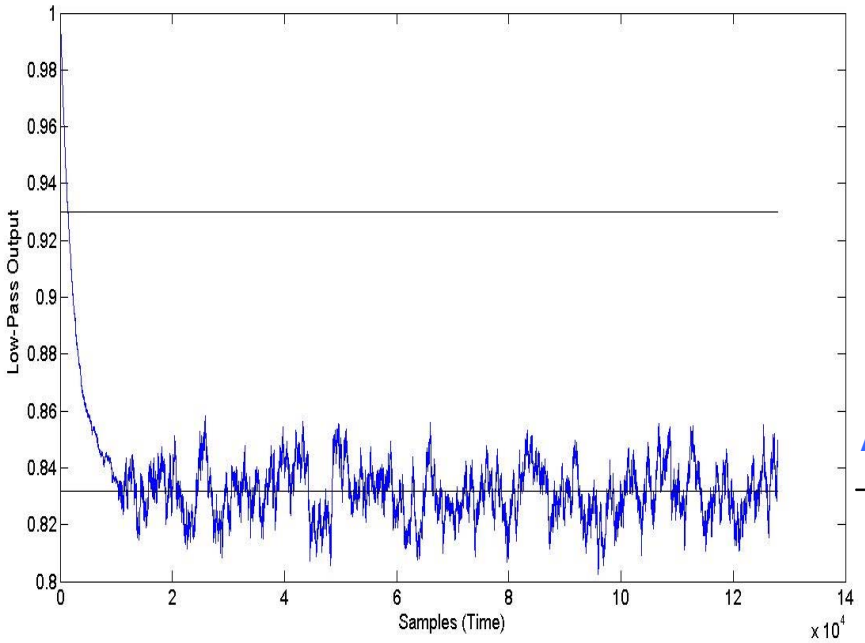
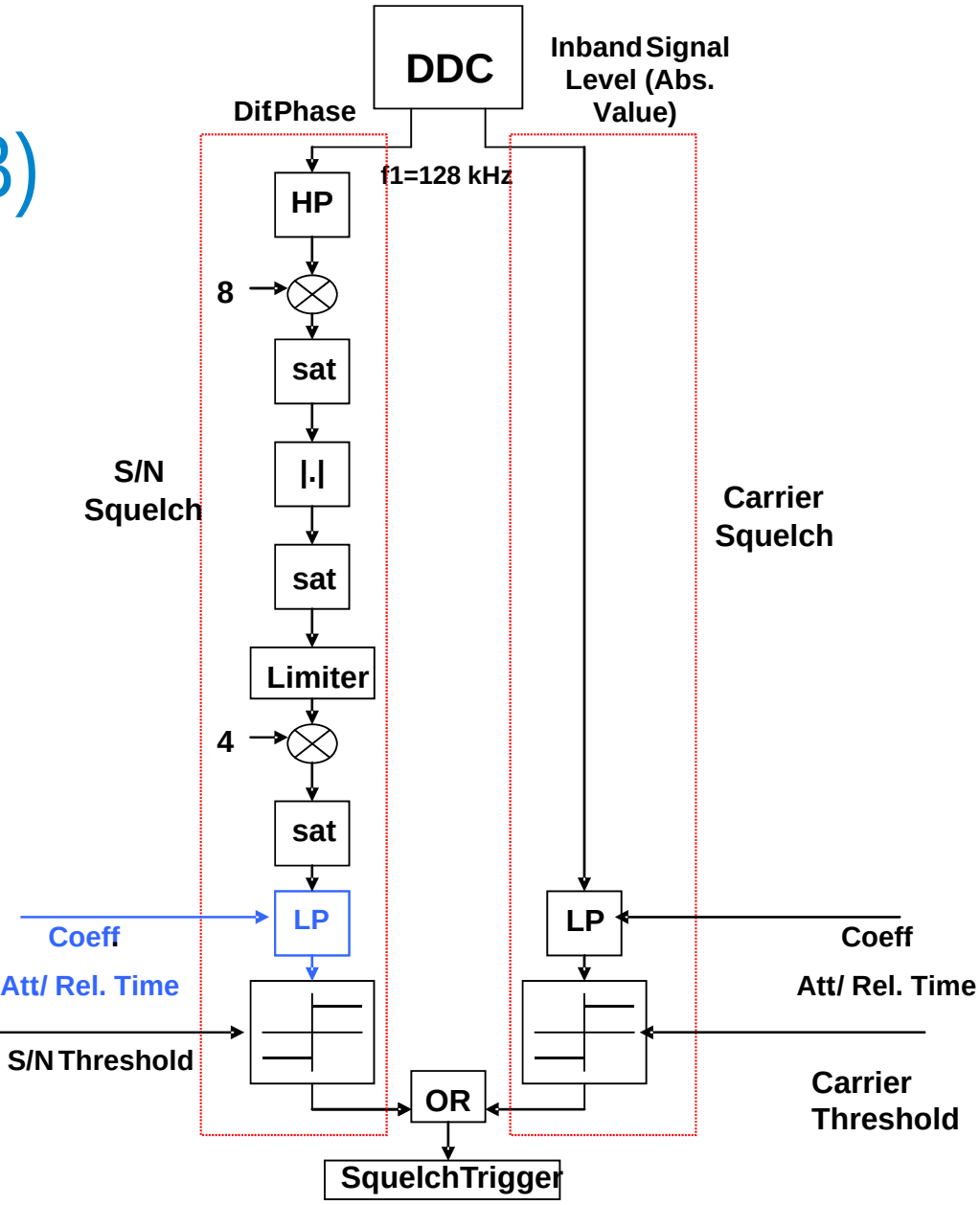
Squelch Structure (A3E Mode, SNR=6 dB)

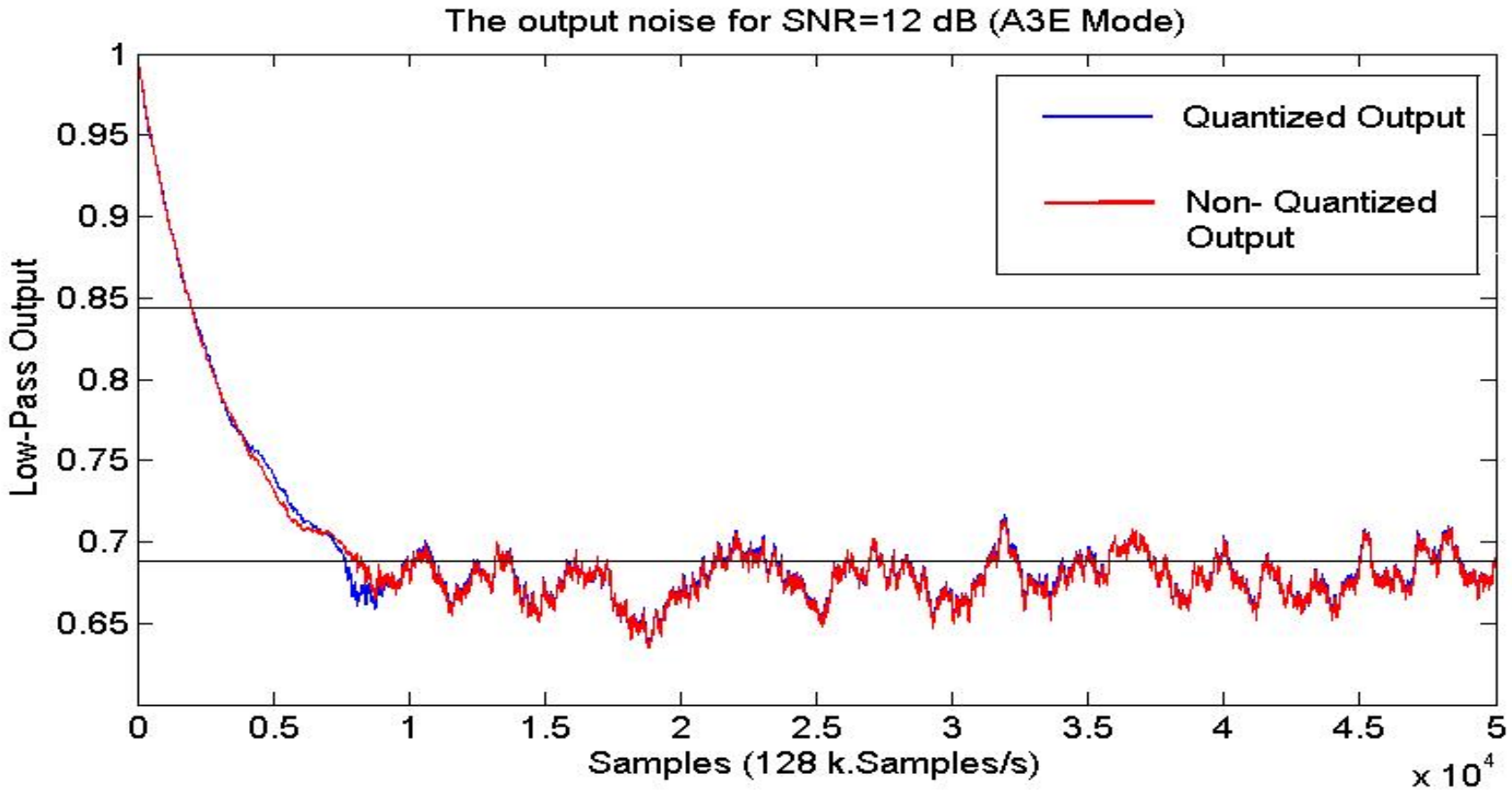




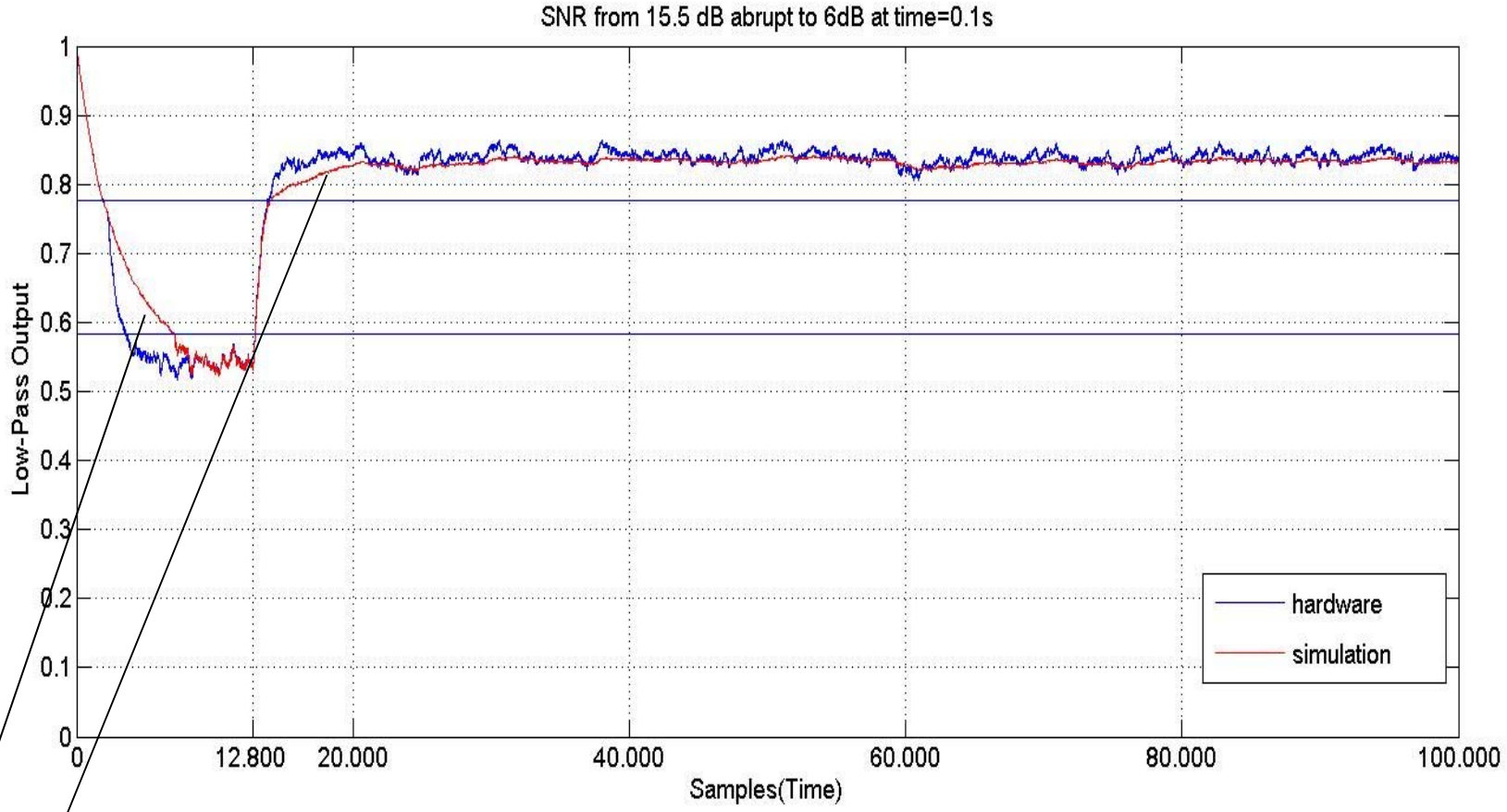
Quantization (example: A3E Mode)

Matlab Quantized: **16 bit fixed-point representation**

Matlab Non-Quantized : **32 bit floating point numbers**



Attack and Release Time (A3E Mode)



Deviation due to slow interface HW for data acquisition (JTAG)

Time for squelch to open in Simulation: 0.055s
Time for squelch to open in Hardware: 0.027s

Attack time

Time for squelch to close in Simulation: 0.109s
Time for squelch to close in Hardware: 0.107s

Release Time

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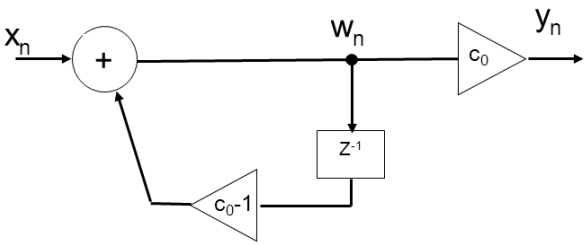
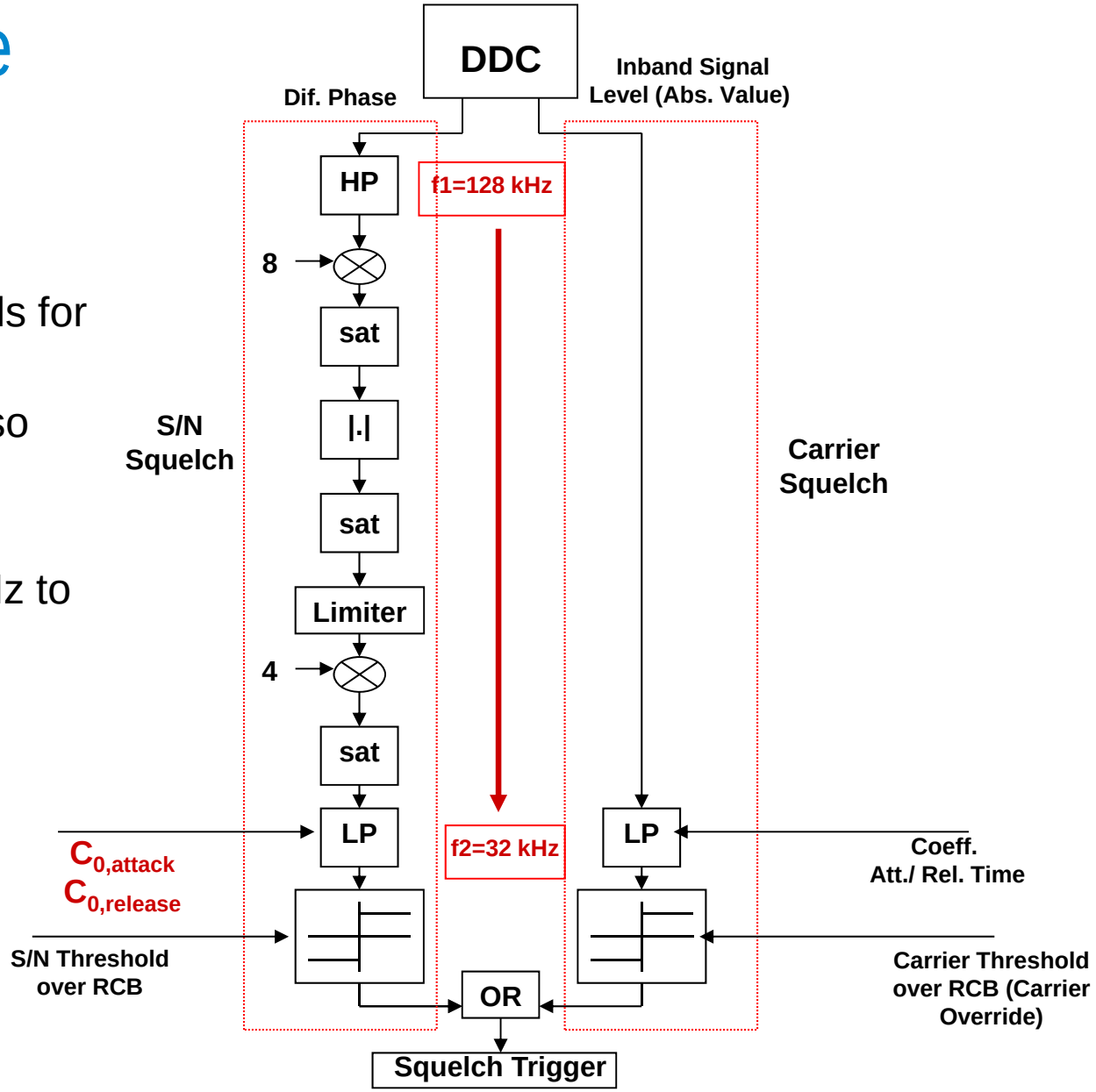
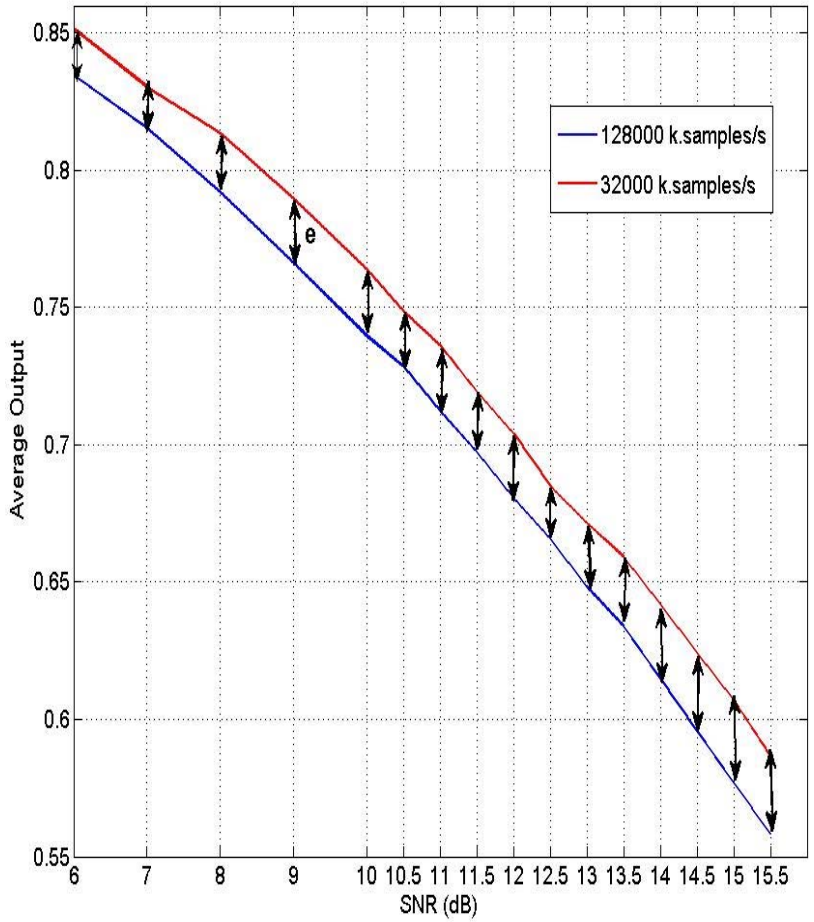
Intended Change (A3E Mode)

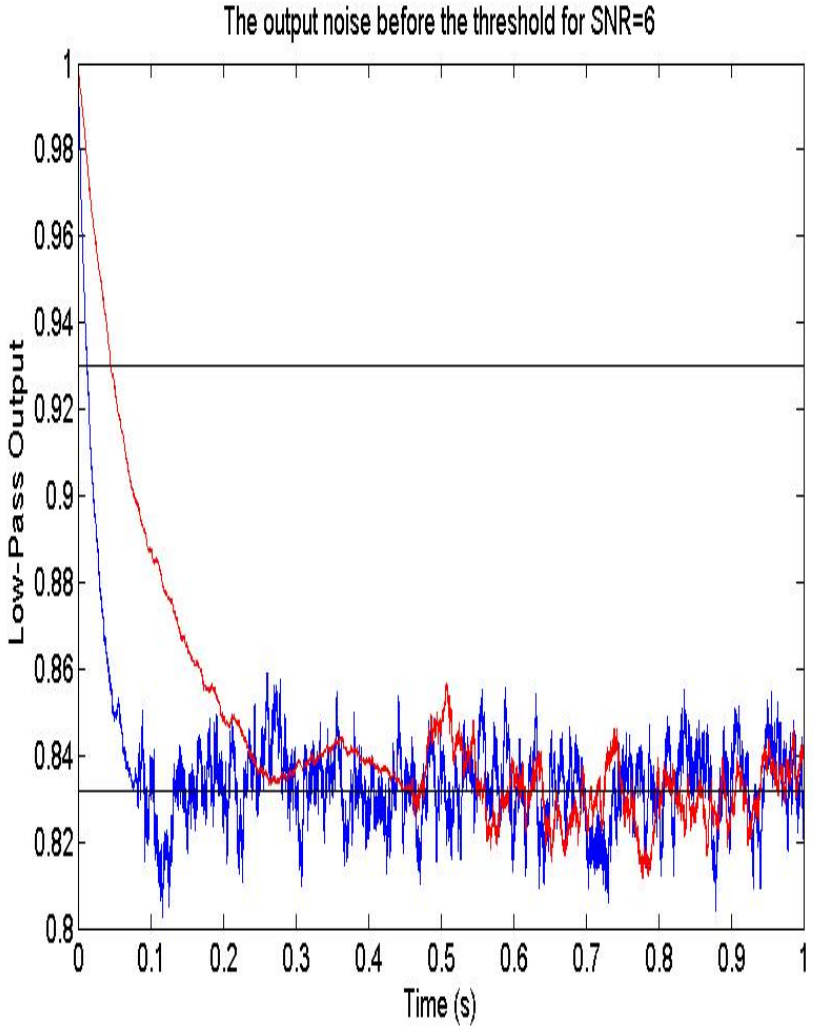
- New DSP functionality calls for saving of cycles
- Squelch is oversampled, so cycles can be saved there
- Decision: LP shall be downsampled from 128kHz to 32kHz





Results After Downsampling (A3E Mode)





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Optimization Problem (A3E Mode)

$$\min_{LP\,coeff.,attack\_time\ \&\ \text{release\_time}} f = \sum_{SNR=6}^{15.5dB} (e_{SNR})^2$$

Two separate optimizations (for attack and release)

$$\min_{LP\,coeff.,attack\_time} f_1 = \sum_{SNR=6}^{15.5dB} (e_{SNR})^2$$

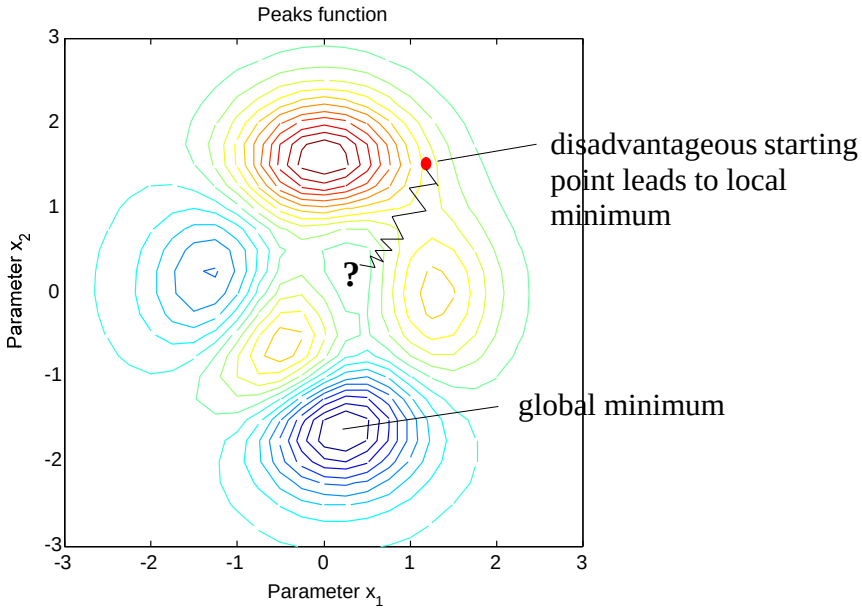
$$\min_{LP\,coeff.,release\_time} f_2 = \sum_{SNR=6}^{15.5dB} (e_{SNR})^2$$

- **What if the error function is multimodal (has several minima) ?**
- **What if the error surface is (partly) non-differentiable ?**
- **How can constraints be incorporated ?**
- **What if the parameters need to be quantized ?**

Classical gradient-based methods ineffective

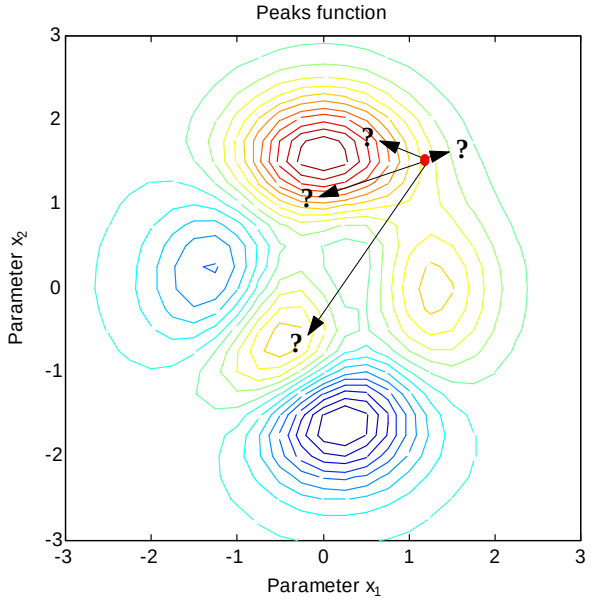
Example: Problems with Multimodality

Starting point problem



Local optimization methods find the minimum close to the starting point → need to use several starting points

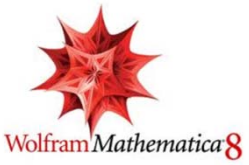
Step size problem



How large must the stepsize be if the topology of the error surface is unknown ?

Differential Evolution (DE) – „The FFT of Global Optimization“

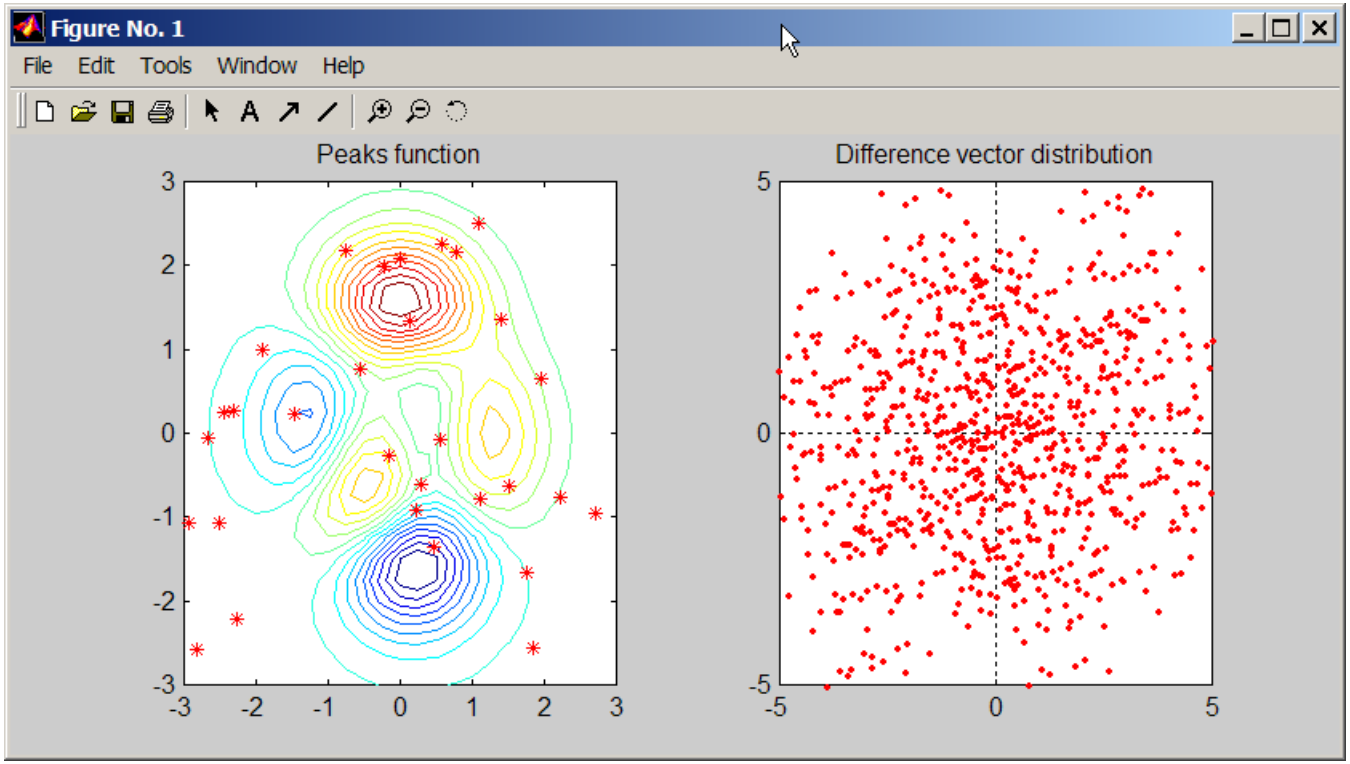
- **Gradient-free evolution optimizer**
- **Simple to use, good convergence**
- **Global optimization capability**
- **Can handle**
  - **Constraints**
  - **Multimodality**
  - **Mixed-integer**



Storn, R., “Optimization of Wireless Communication Applications using Differential Evolution”, *SDR Technical Conference SDR’07*, Denver, Colorado, Nov. 5-9, 2007.

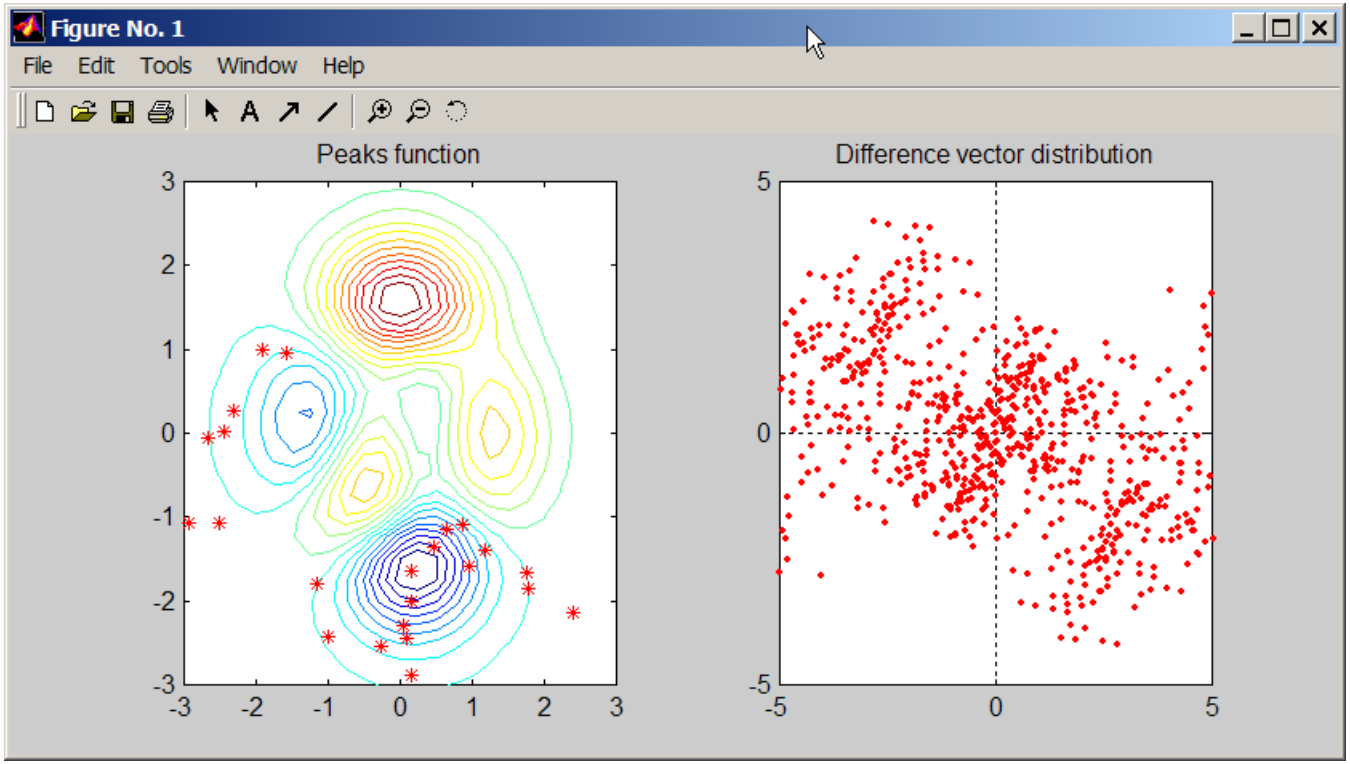
Commercial or Educational SW-packages with DE built-in

DE – Iteration Count 0



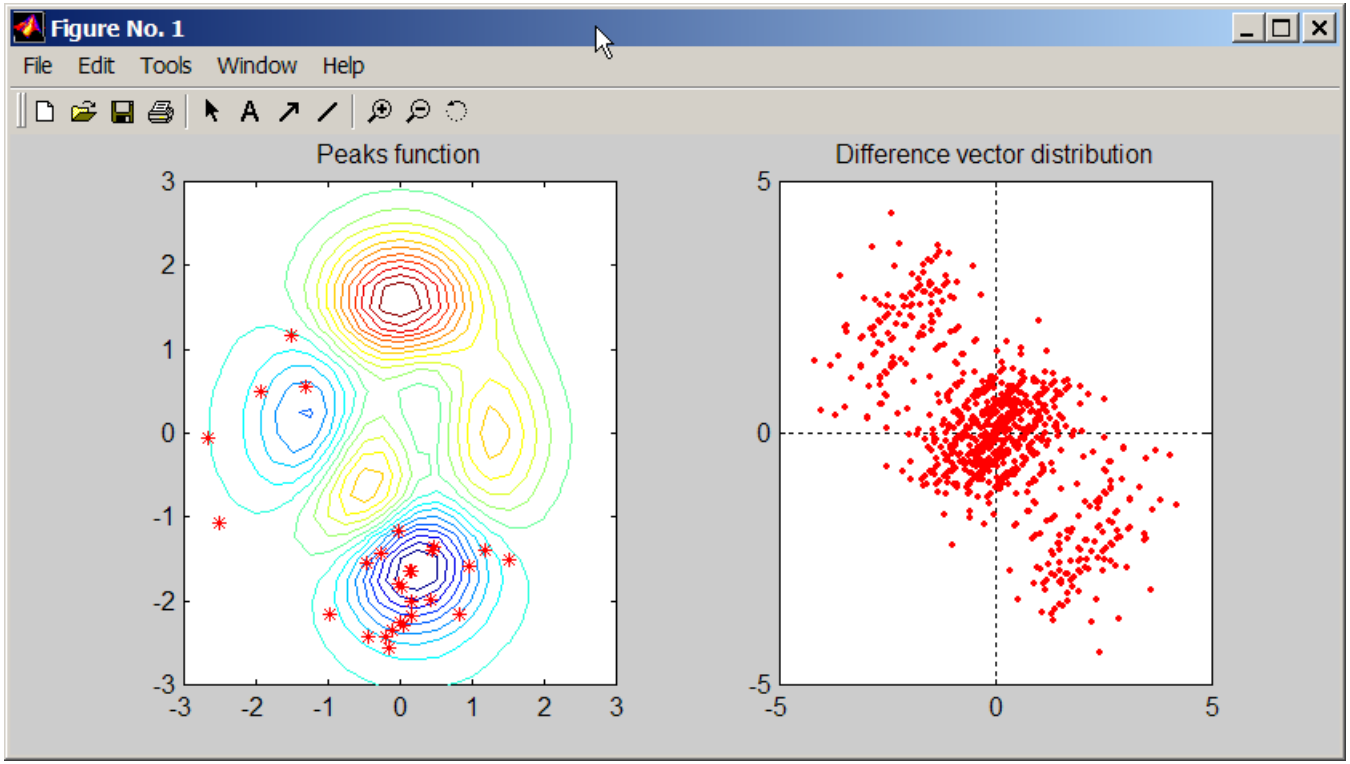
DE/best/1 + jitter, Np = 30, F = 0.85

DE – Iteration Count 3



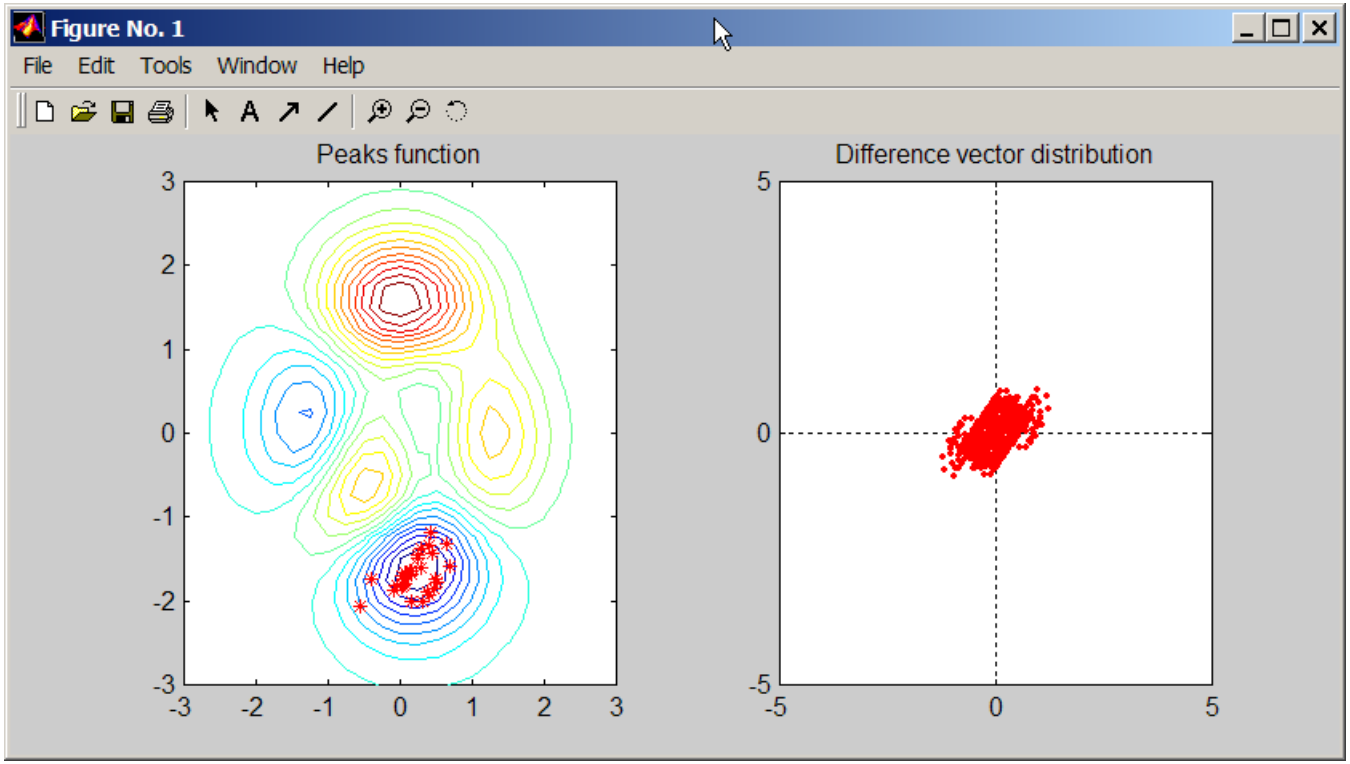
DE/best/1 + jitter, Np = 30, F = 0.85

DE – Iteration Count 6



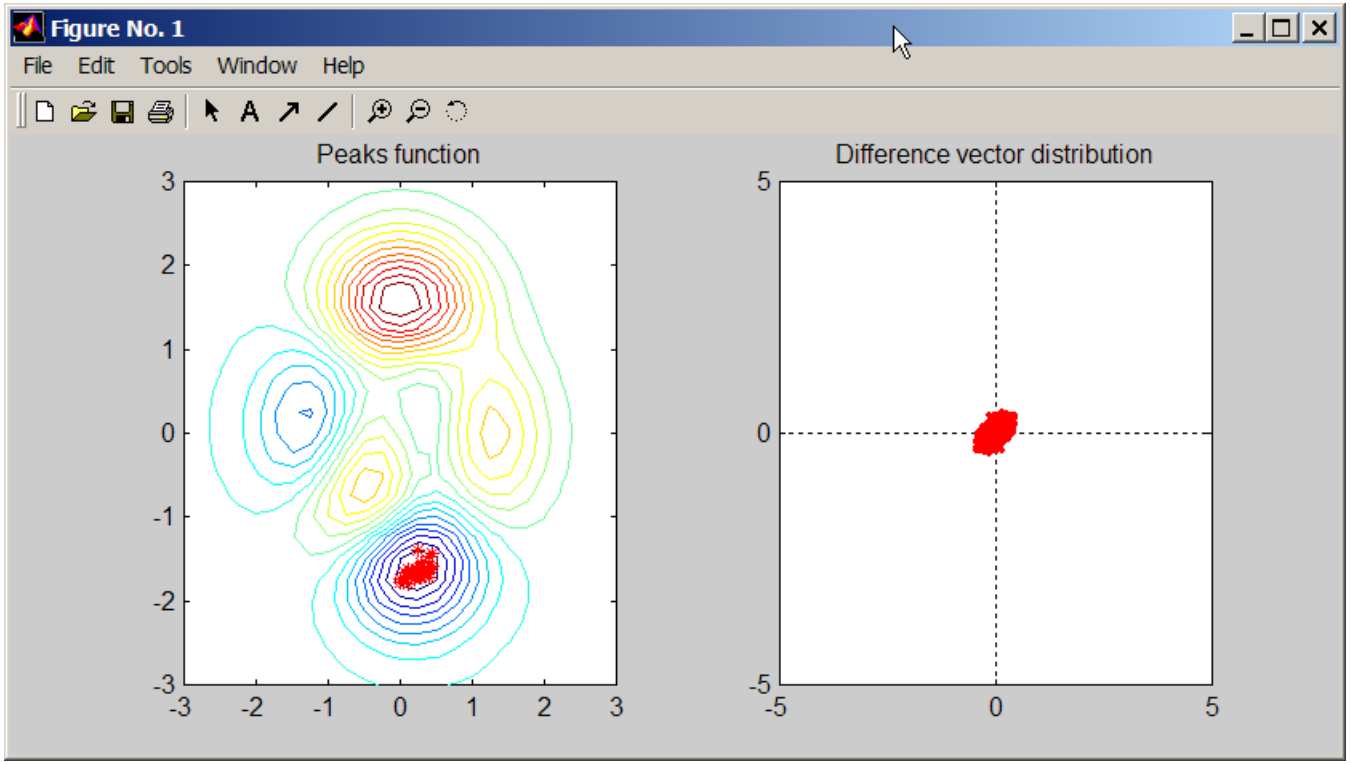
DE/best/1 + jitter, Np = 30, F = 0.85

DE – Iteration Count 9



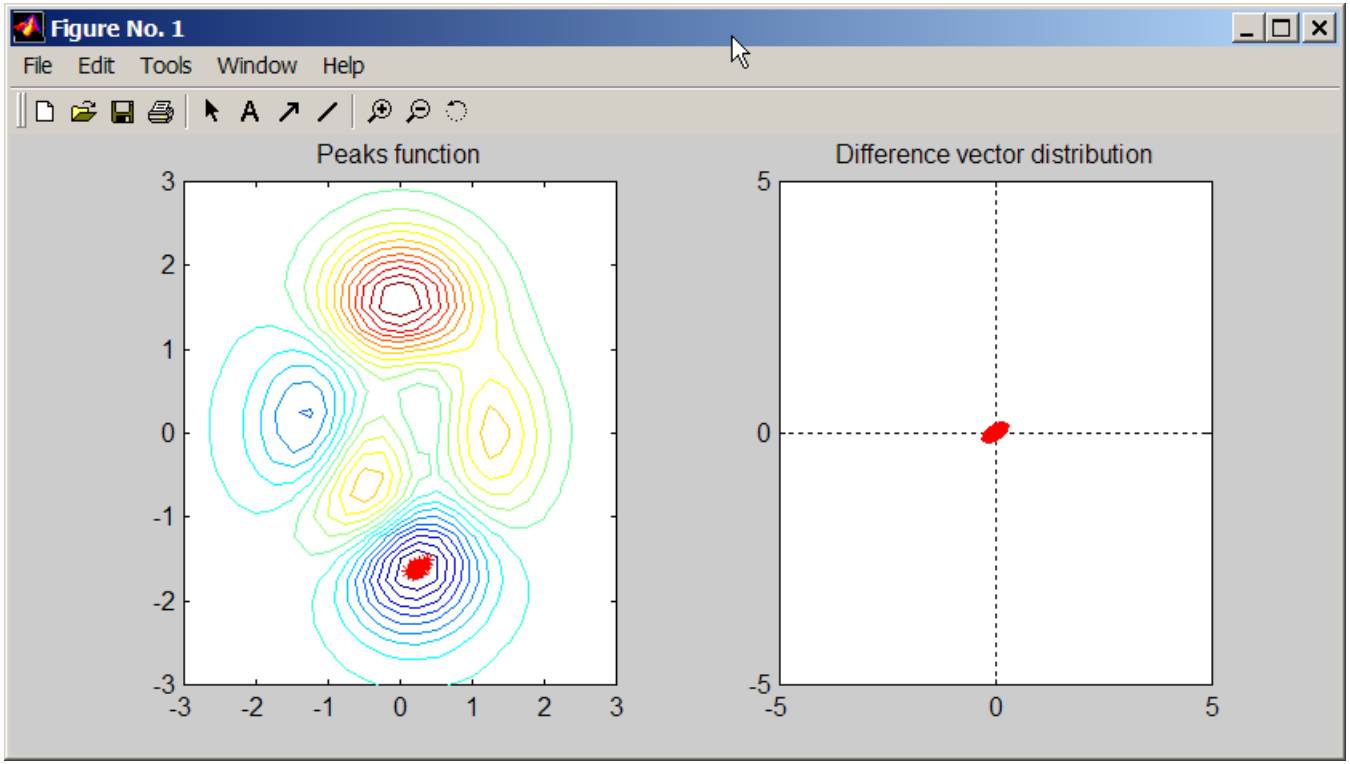
DE/best/1 + jitter, Np = 30, F = 0.85

DE – Iteration Count 12



DE/best/1 + jitter, Np = 30, F = 0.85

DE – Iteration Count 15



DE/best/1 + jitter, Np = 30, F = 0.85

DE –Pseudocode (Basic Algorithm)

```
while (convergence criterion not yet met)
{
    //---x_i defines a vector of the current vector population-------
    //---y_i defines a vector of the new vector population-----------
    for (i=0; i<N_P; i++)
    {
       r1 = rand(N_P); //select a random index from 1, 2, ..., N_p
       r2 = rand(N_P); //select a random index from 1, 2, ..., N_p
       r3 = rand(N_P); //select a random index from 1, 2, ..., N_p
       u_i = x_r3 + F*(x_r1 - x_r2);
       if (f(u_i) <= f(x_i))
       {
         y_i = u_i;
       }
       else
       {
         y_i = x_i;
       }
    }
    swap(Y,X); //new population Y becomes current one
    ...
}//end while
...
```

DE Psuedo Code with Parameter Constraints

- **Parameters can be forced to stay within bounds**

```
while (convergence criterion not yet met)
{
    //---x_i defines a vector of the current vector population-------
    //---y_i defines a vector of the new vector population-----------
    for (i=0; i<N_P; i++)
    {
       r1 = rand(N_P); //select a random index from 1, 2, ..., N_p
       r2 = rand(N_P); //select a random index from 1, 2, ..., N_p
       r3 = rand(N_P); //select a random index from 1, 2, ..., N_p
       u_i = x_r3 + F*(x_r1 - x_r2);
       for (j=0; j<D; j++) //----BOUNCE BACK-----
       {
          if (u_j,i<x_j,L) //if child parameter exceeds lower bound
          {
             u_j,i = x_j,r0 + rand(0,1)*(x_j,L-x_j,r0);
          }
          if (u_j,i>x_j,U) //if child parameter exceeds upper bound
          {
             u_j,i = x_j,r0 + rand(0,1)*(x_j,U-x_j,r0);
          }
       }
       if (f(u_i) <= f(x_i)) y_i = u_i;
       else y_i = x_i;
    }
    swap(Y,X); //new population Y becomes current one
    ...
}//end while
...
```

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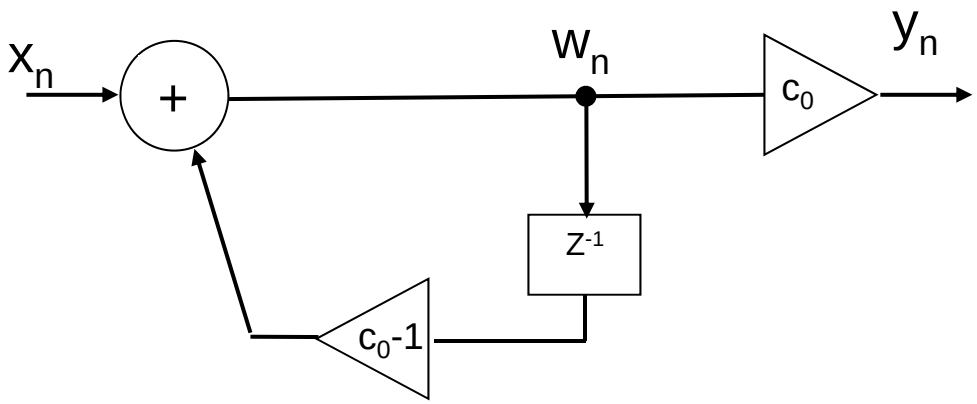
Optimization of Squelch (A3E-Mode)



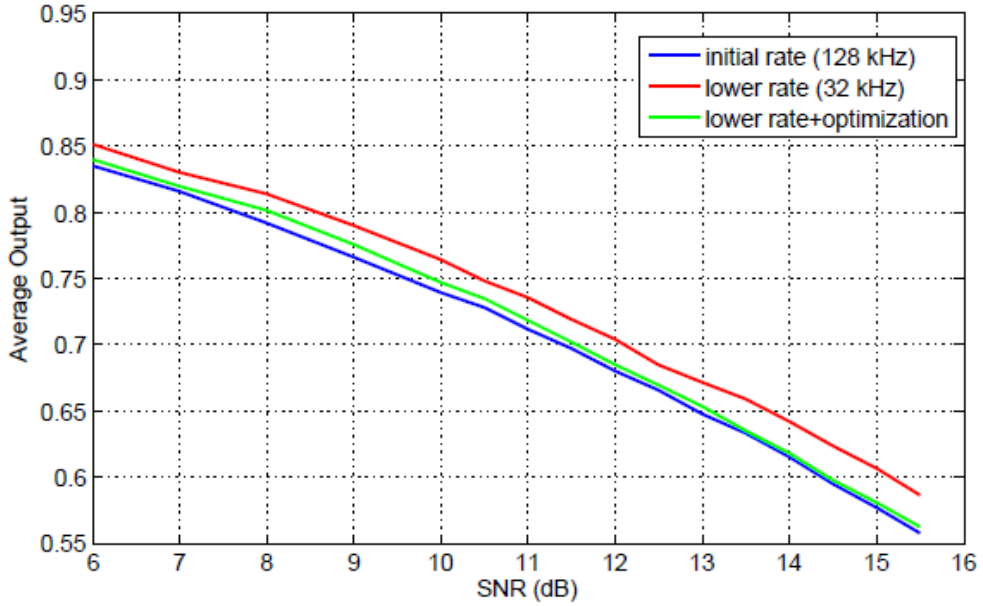
Parameters

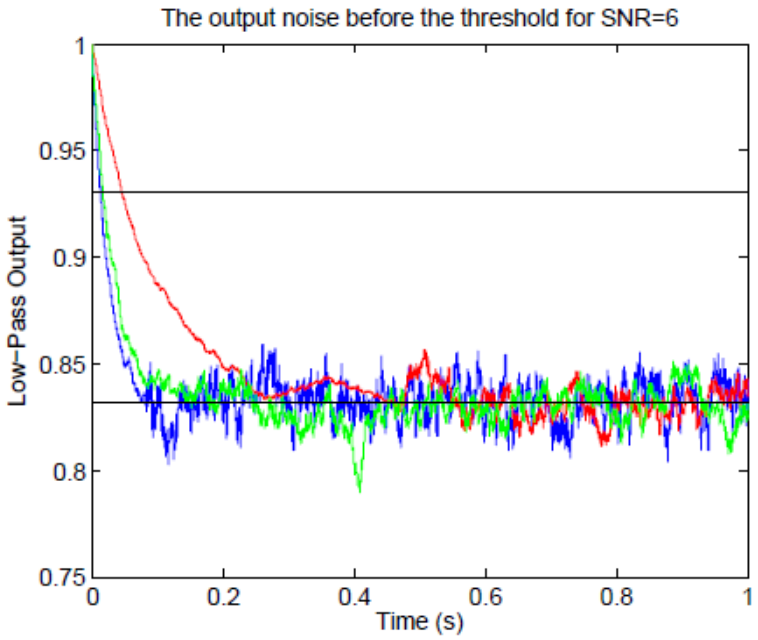
- c_0

Constraints

- **Filter must be stable (Pole 1-c_0 inside unit circle)**
- **c_0 must be ex [0, 1]**

Results for A3E

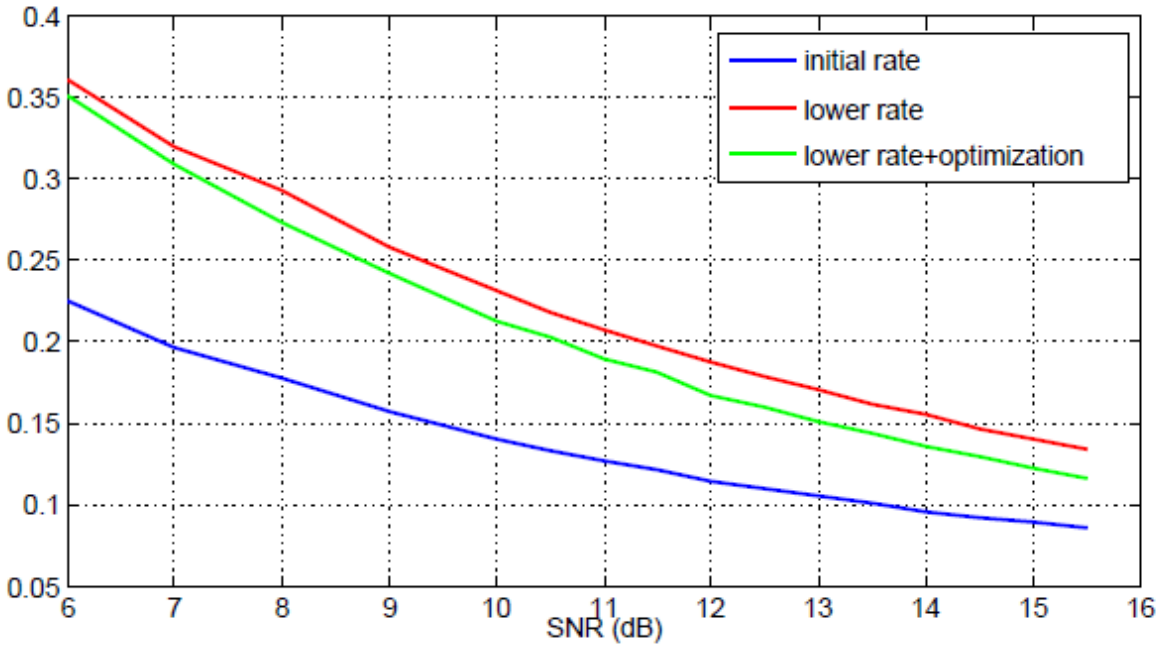




- **Population Size $N_P = 5$**
- **Dimension D = 1 (c_0)**
- **Iteration count = 5**

Co coefficient with 128 kHz sample rate		Co coefficient with 32 kHz sample rate	
attack	release	attack	release
0 0 0 B	0 0 3 3	0 0 2 0	0 0 3 6

Results for F3E using the same approach



- **Population Size $N_P = 5$**
- **Iteration count = 50**
- ***Optimization of c_0 only obviously not sufficient***

Optimization of Squelch (F3E Mode)

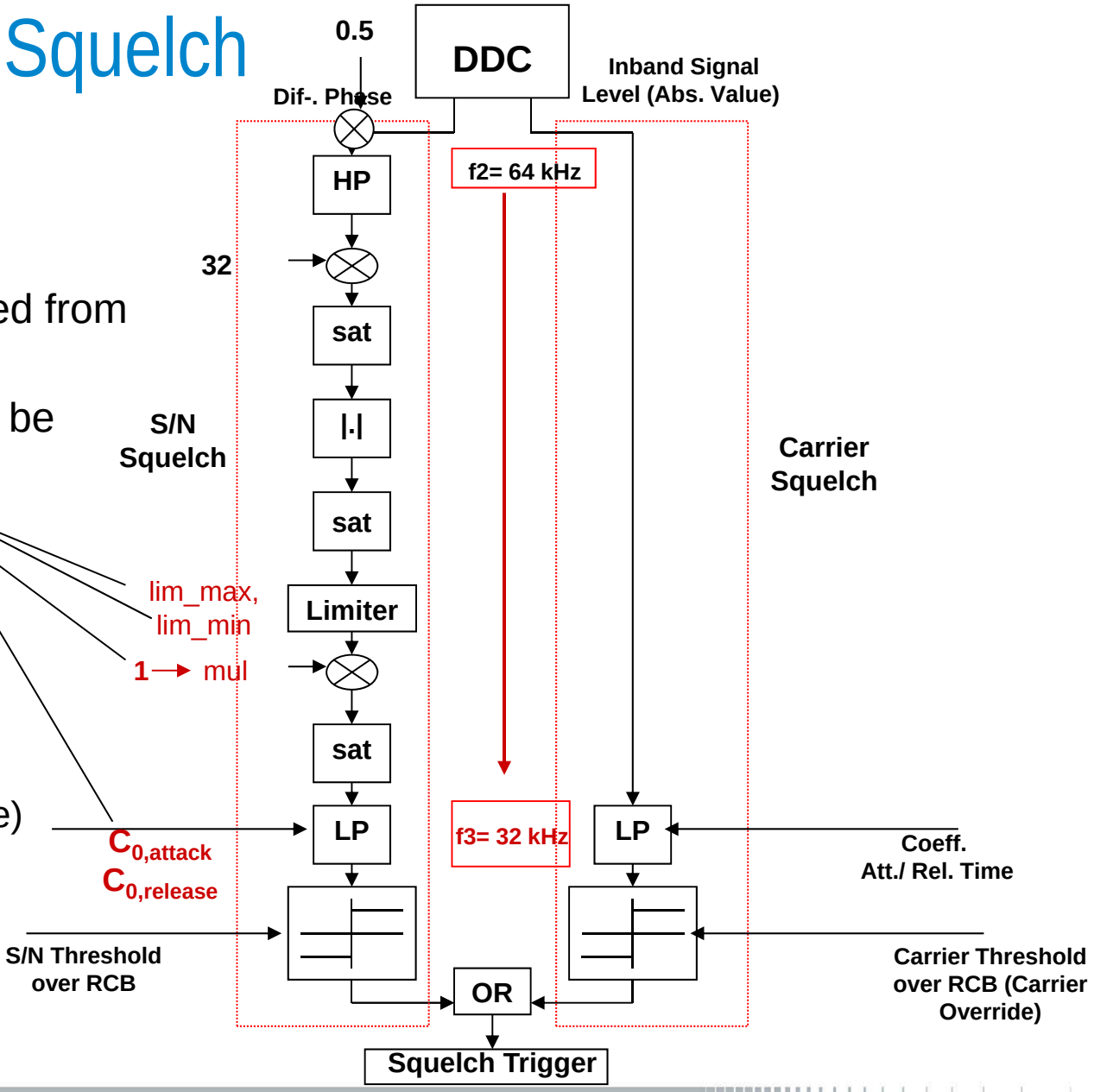
- LP shall be downsampled from 64kHz to 32kHz
- Total of 4 parameters to be tuned simultaneously

Parameters

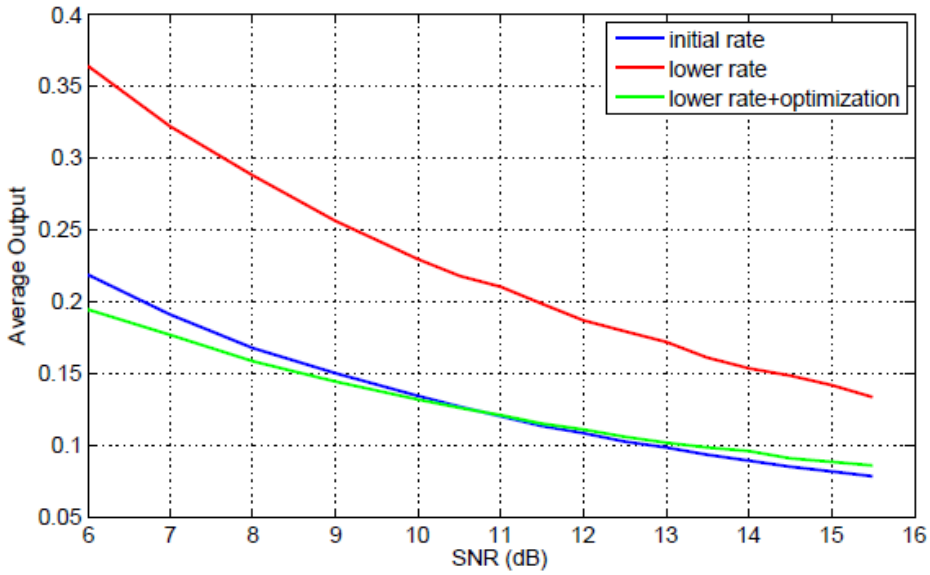
- c_0, lim_{min}, lim_{max}, mul

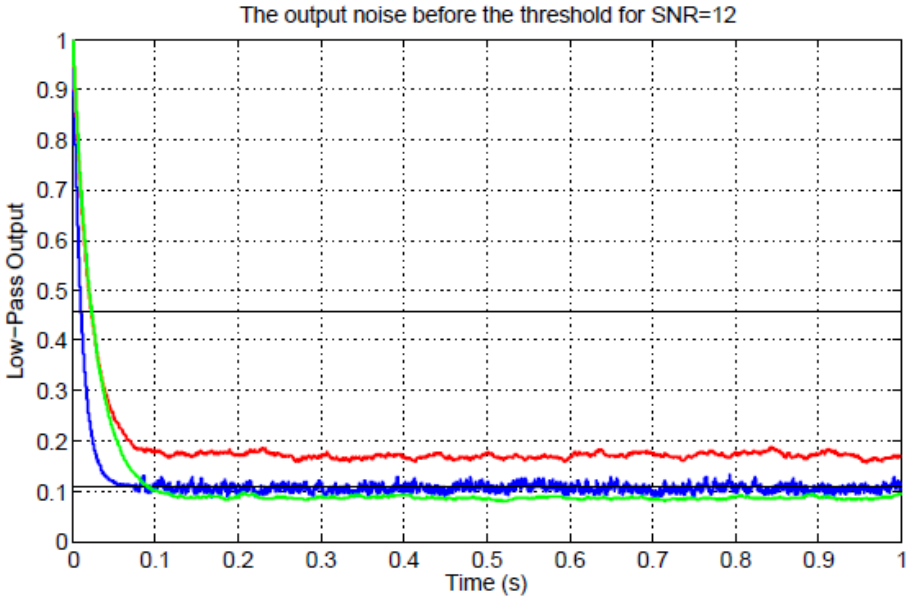
Constraints

- Filter must be stable (Pole 1-c_0 inside unit circle)
- c_0 must be ex [0, 1]
- mul = 2^i, i integer



Optimization of the F3E Mode





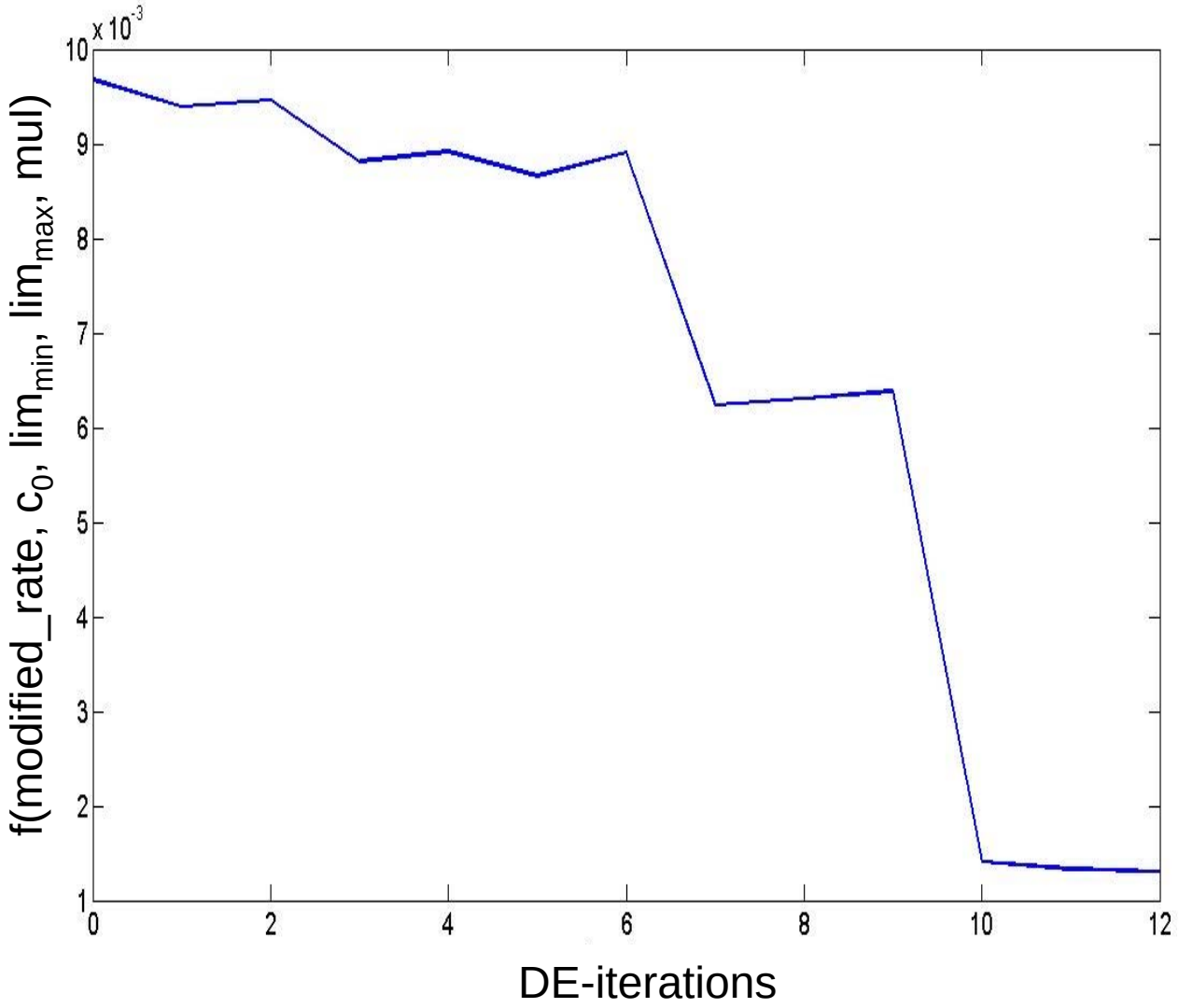
- **Population Size N_P = 20**
- **Dimension D = 4**
  (c_0, lim_{min}, lim_{max}, mul)
- **Iteration count = 12**

Opening of the squelch with 64 kHz: 0.074 s

Opening of the squelch with 32 Khz: 0.092 s

	64 kHz sample rate	32 kHz sample rate
$C_{0,attack}$	0030	0028
$C_{0,release}$	0033	0034
lim_{max}	6500	6B02
lim_{min}	0600	0890
mul	2^0	2^1

Optimization of the F3E Mode – Convergence Graph



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Summary

- **Task**:
  Freeing up cycles in an SDR-DSP
- **Target**:
  IIR-Filter in Squelch-Circuit to be downsampled
- **Requirement**:
  Keep the squelch behaviour so that the change goes unnoticed by the user, keep the squelch algorithm
- **Approach**:
  Minimize nonlinear cost-function in a simulation model by Differential Evolution
- **Result**:
  Satisfactory performance for both A3E and F3E

Questions ?

Thank you