University of Tabriz, Faculty of Electrical and Computer Engineering
Department of Biomedical Engineering

Title

Digital Feedforward Compressor Design and Implementation

(by connecting different parts of compressor (based on *Giannoulis* [3]))

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1. Theory

Dynamic Range Compression (DRC) is the process of mapping the dynamic range of an audio signal to a smaller range [1-2], i.e., reducing the signal level of the higher peaks while leaving the quieter parts untreated [3].

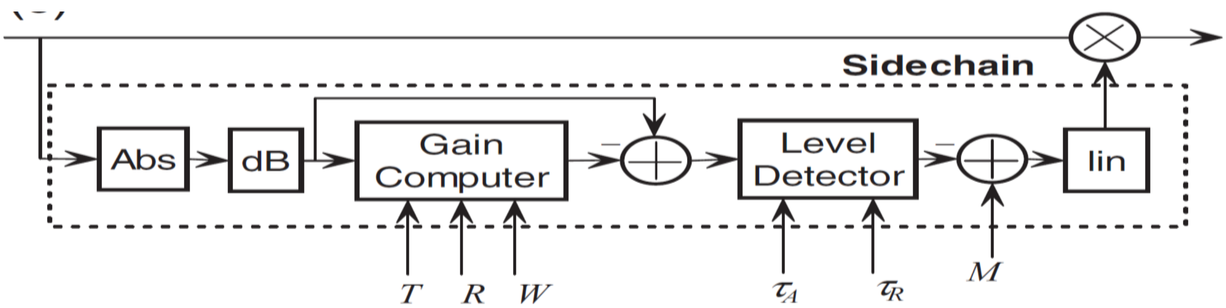


Figure 1: Schematic diagram of the system. The system finds the absolute value of input signal and converts it to dB, then peak detection method and gain computation will be applied, at last signal domain will be linearized. [3]

Stage 1: ABS (Absolute value), dB (Decibel converter), Level detection (Peak detection)

In the first stage, the absolute value of the input signal is calculated in dB, then the Peak detection method is selected and applied to the signal.

Five kinds of peak detectors were simulated in this project:

- Analog Peak Detector

  This Peak detector was simulated according to Eq. (1): [3]

  $$yL\,[n] = \alpha R\, yL\,[n-1] + (1-\alpha A)\max\,(xL\,[n] - yL\,[n-1],\, 0) \tag{1}$$

- Branching Peak Detector

  This Peak detector was simulated according to Eq. (2): [3]

  $$yL[n] = \begin{cases} \alpha A\, yL\,[n-1] + (1-\alpha A) xL\,[n] & xL\,[n] > yL\,[n-1] \\ \alpha R\, yL\,[n-1] & xL\,[n] \le yL\,[n-1] \end{cases} \tag{2}$$

- Branching Smooth Peak Detector

  This Peak detector was simulated according to Eq. (3): [3]

$$yL[n] = \begin{cases} \alpha A\ yL\ [n - 1] + (1 - \alpha A)xL\ [n] & xL\ [n] > yL\ [n - 1] \\ \alpha R\ yL\ [n - 1] + (1 - \alpha R)xL\ [n] & xL\ [n] \leq yL\ [n - 1] \end{cases} \qquad (3)$$

- Decoupled Peak Detector

  This Peak detector was simulated according to Eq. (4): [3]

$$y1[n] = max\ (xL\ [n],\ \alpha R\ y1[n - 1]) \qquad (4)$$

$$yL\ [n] = \alpha A\ yL\ [n - 1] + (1 - \alpha A)\ y1[n]$$

- Decoupled Smooth Peak Detector

  This Peak detector was simulated according to Eq. (5): [3]

$$y1[n] = max\ (xL\ [n],\ \alpha R\ y1[n - 1] + (1 - \alpha R)\ xL\ [n]) \qquad (5)$$

$$yL\ [n] = \alpha A\ yL\ [n - 1] + (1 - \alpha A)\ y1[n]$$

Stage 2: Gain Computer

The second stage is the gain computer that generates the control voltage. The control voltage determines the gain reduction to be applied to the signal. This stage involves the Threshold T, Ratio R, and Knee Width W parameters. These define the static input-to-output characteristic of compression. Once the signal level exceeds the threshold value, it is attenuated according to the ratio.

The compression ratio is defined as the reciprocal of the slope of the line segment above the threshold, that is: [3]

$$R=\frac{xG-T}{yG-T} \quad \text{for } xG > T, \tag{6}$$

the static compression characteristic is described by the following relationship: [3]

$$yG = \begin{cases} xG & xG \le T \\ T + \frac{xG-T}{R} & xG > T \end{cases} \tag{7}$$

In order to smooth the transition between compression and no compression at the threshold point, we can soften the compressor's knee. The width W of the knee (in decibels) is equally distributed on both sides of the threshold.

To implement this, we replace the hard knee characteristic used in Eq. (7) with a soft knee characteristic, giving the following piecewise, continuous function,

$$yG = \begin{cases} xG & 2(xG - T) < -W \\ xG + (1/R - 1)(xG - T + W/2)2/(2W) & 2|(xG - T)| \le W \\ T + \frac{xG-T}{R} & 2(xG - T) > W \end{cases}$$

(8)

When the knee width is set to zero, the smooth knee is identical to the hard knee.[3]

Stage 3: Lin

In this stage the logarithmic domain of the signal will be linearized.

Stage 4: Plotting the Outputs

In the plotting stage, input, output signals, selected peak detector output and gain will be shown in plot.

Stage 5: Creating the Compressed Signal File

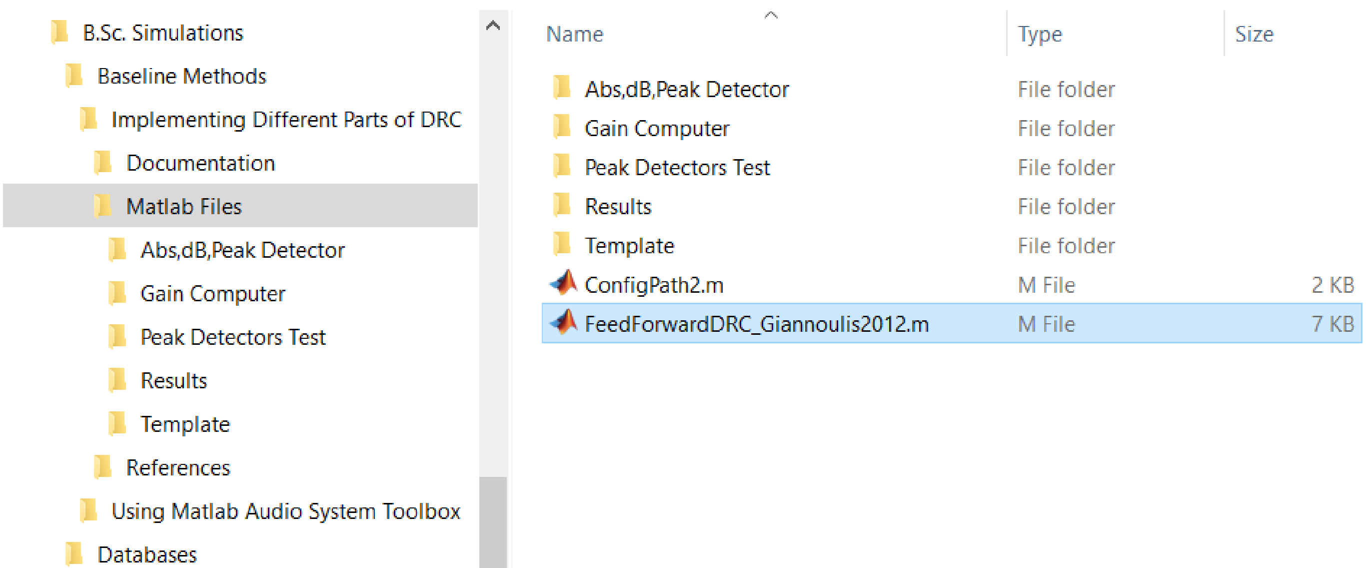
In the last stage the compressed signal will be saved as 'CompressedSignal.wav' in current path.

2. The Structure of Programs

In this project different parts of compressor were defined as functions and in the main compressor code different parts were called.

In this project we have a main function and several sub-functions, as follows:

- ## Main Function:



- **FeedForwardDRC_Giannoulis2012.m**

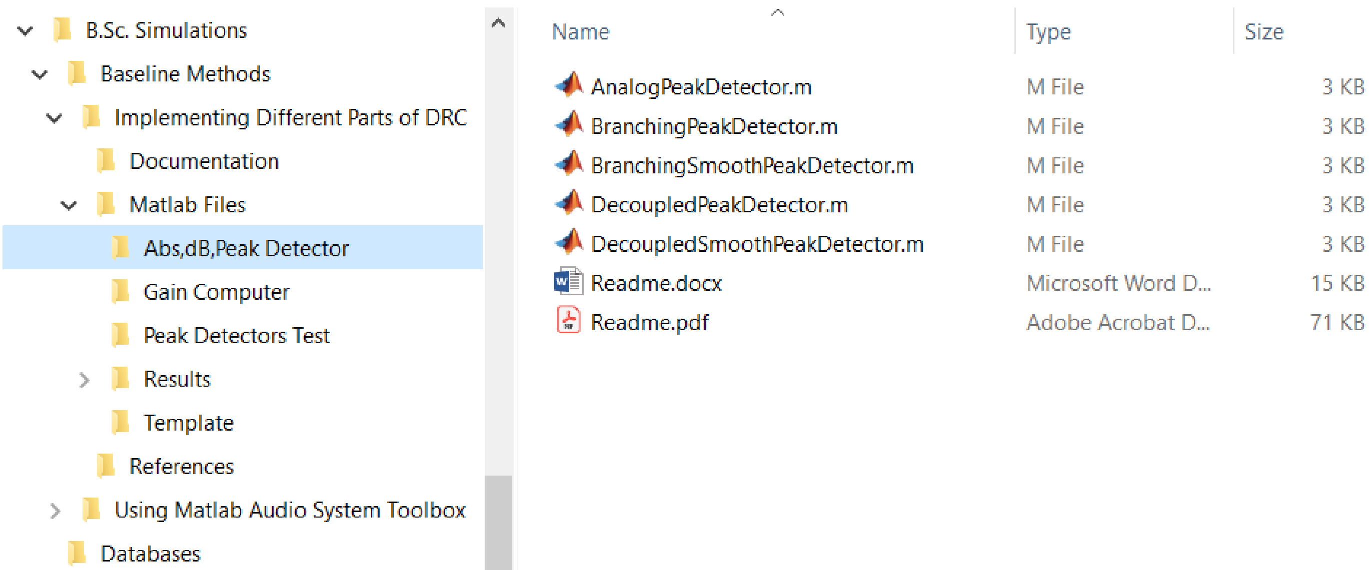
Description:

This program is the main compressor program which contains one main stage of compression and it is divided into the following steps:

Compression Procedure:

Stage 1: ABS (Absolute value), dB (Decibel converter), Peak detection
Stage 2: Gain Computer
Stage 3: Lin (Linear Domain)
Stage 4: Plotting the outputs
Stage 5: Creating the compressed signal File

2.1 Stage 1: ABS (Absolute value), dB (Decibel converter), Peak detection

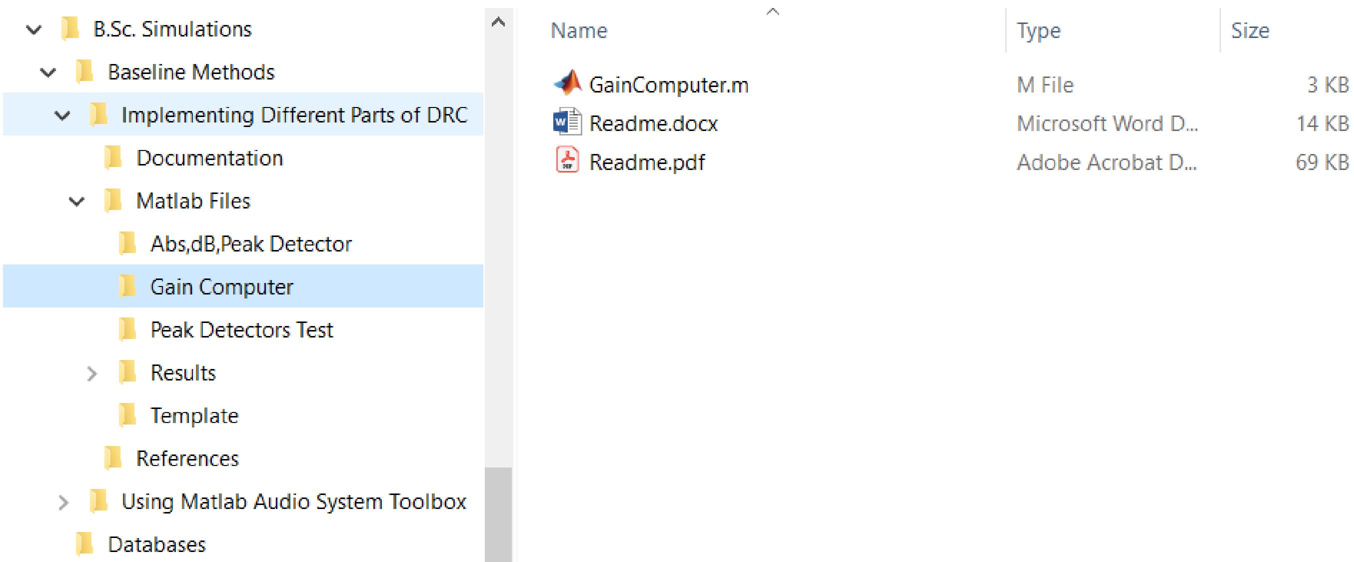


Description:

In this stage signal absolute value is found then the signal domain is converted to dB. At last, Peak Detection method is applied. Matlab Files of Five different peak detectors (which they have Abs and dB stages too) are defined as:

- AnalogPeakDetector.m
- BranchingPeakDetector.m
- BranchingSmoothPeakDetector.m
- DecoupledPeakDetector.m
- DecoupledSmoothPeakDetector.m

2.2 Stage 2: Gain Computer



- **GainComputer.m**

Description:

In this function the gain value which is going to be applied to the input signal is calculated.

2.3 Stage 3: Lin (Linear Domain)

Description:

In this stage the logarithmic domain of the signal will be linearized. This stage is defined in the main compressor Matlab file (FeedForwardCompressor.m).

2.4 Stage 4: Plotting the outputs

Description:

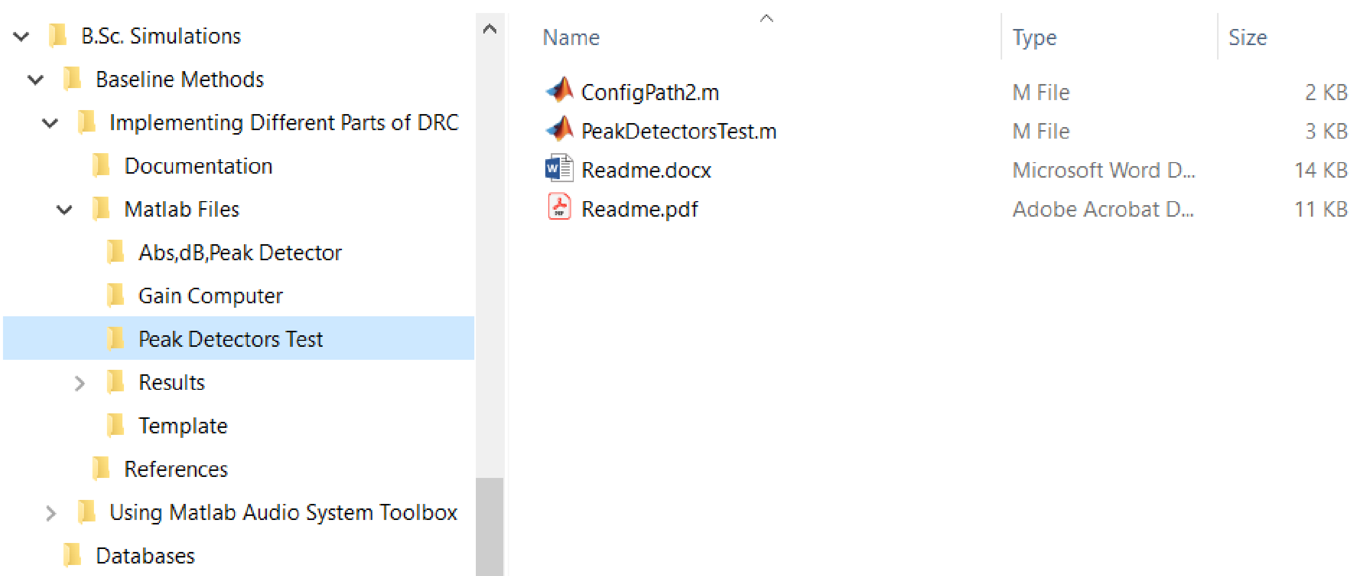
In the plotting stage, input, output signals, selected peak detector output and gain will be shown in plot. This stage is defined in the main compressor Matlab file (FeedForwardCompressor.m).

2.5 Stage 5: Creating the compressed signal File

Description:

In the last stage the compressed signal will be saved as 'CompressedSignal.wav' in current path. This stage is defined in the main compressor Matlab file (FeedForwardCompressor.m).

3. Peak detectors test



- **PeakDetectorsTest.m**

Description:

Comparing the outputs of different peak detectors in order to find the best peak detector to apply in our main compressor.

4. Simulations Results

4.1. Running the Programs

In order to run this program, write a command such as shown below, in the Command Window of MATLAB:

```
Command Window
fx >> FeedForwardDRC_Giannoulis2012('DS', 'noisy.wav', 16000, -15, 50, 0.02, 0.02, 0)
```

Note:

The input signal , ‘**noisy.wav**’ file , is located in ‘**B.Sc. Simulations\Method1_Connecting Different parts of DRC \Matlab Files\Databases**’ File.

The output signal , ‘**CompressedSignal1.wav**’ file , will be saved in ‘**B.Sc. Simulations\Method1_Connecting Different parts of DRC\Matlab Files\Results\Compressed Signal**’ File.

4.2. Experimental Results

The Peak Detectors test results are shown in Fig1 and Fig2. The compressor simulation results are shown in Fig3.

Compressed signal is saved as “CompressedSignal.wav”.

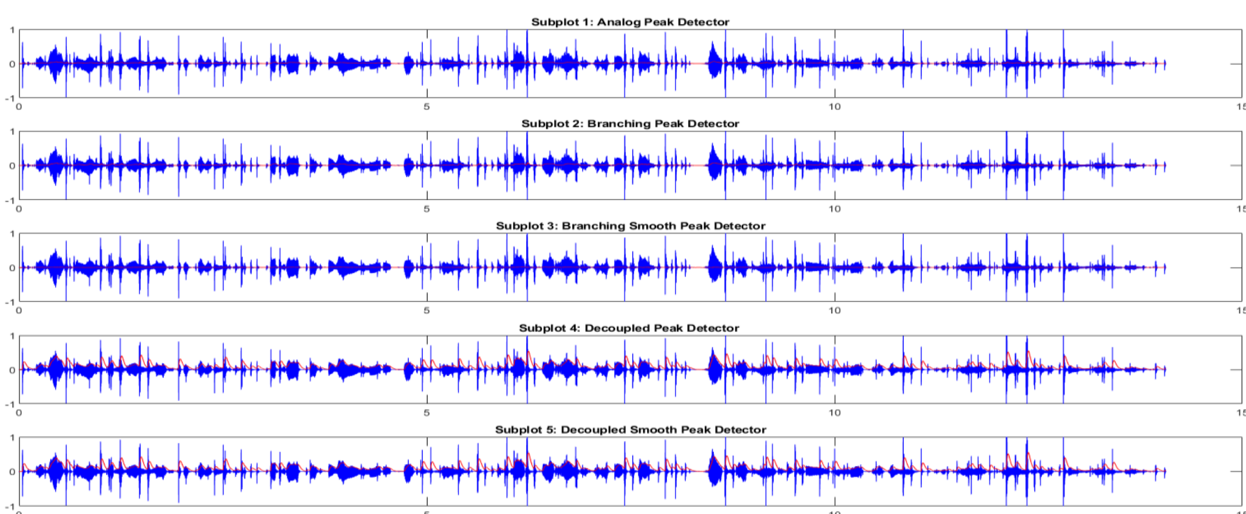


Figure 1: (1) Analog peak detector output (2) Branching peak detector output (3) Branching smooth peak detector (4) Decoupled peak detector output (5) Decoupled smooth peak detector output.

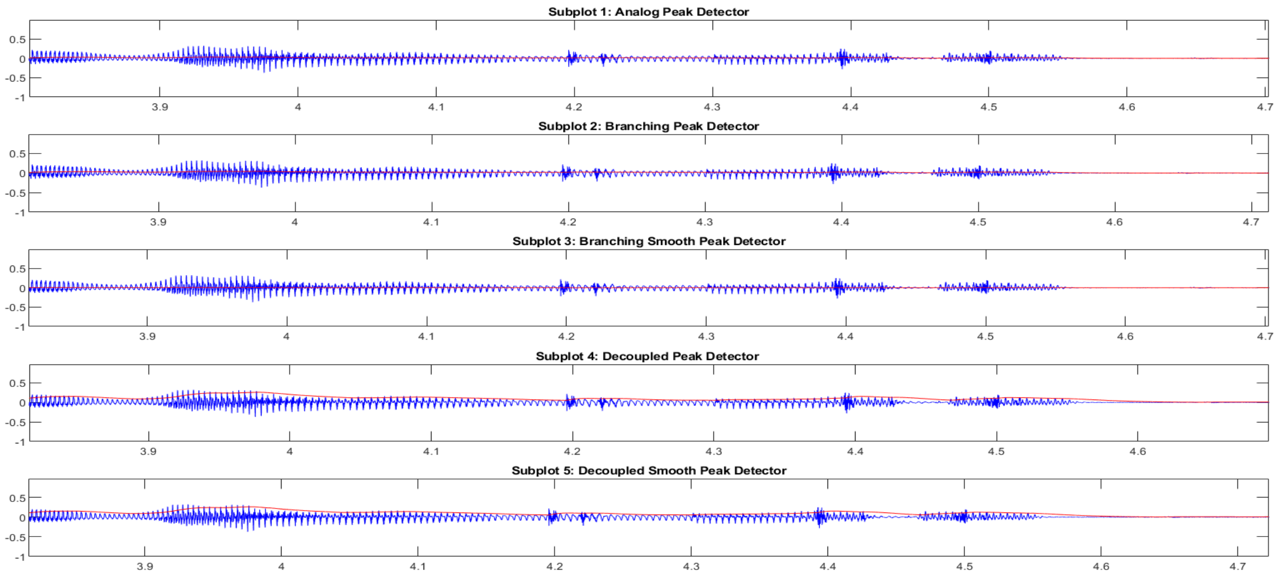


Figure 2: (1) Analog peak detector output (2) Branching peak detector output (3) Branching smooth peak detector (4) Decoupled peak detector output (5) Decoupled smooth peak detector output (zoomed).

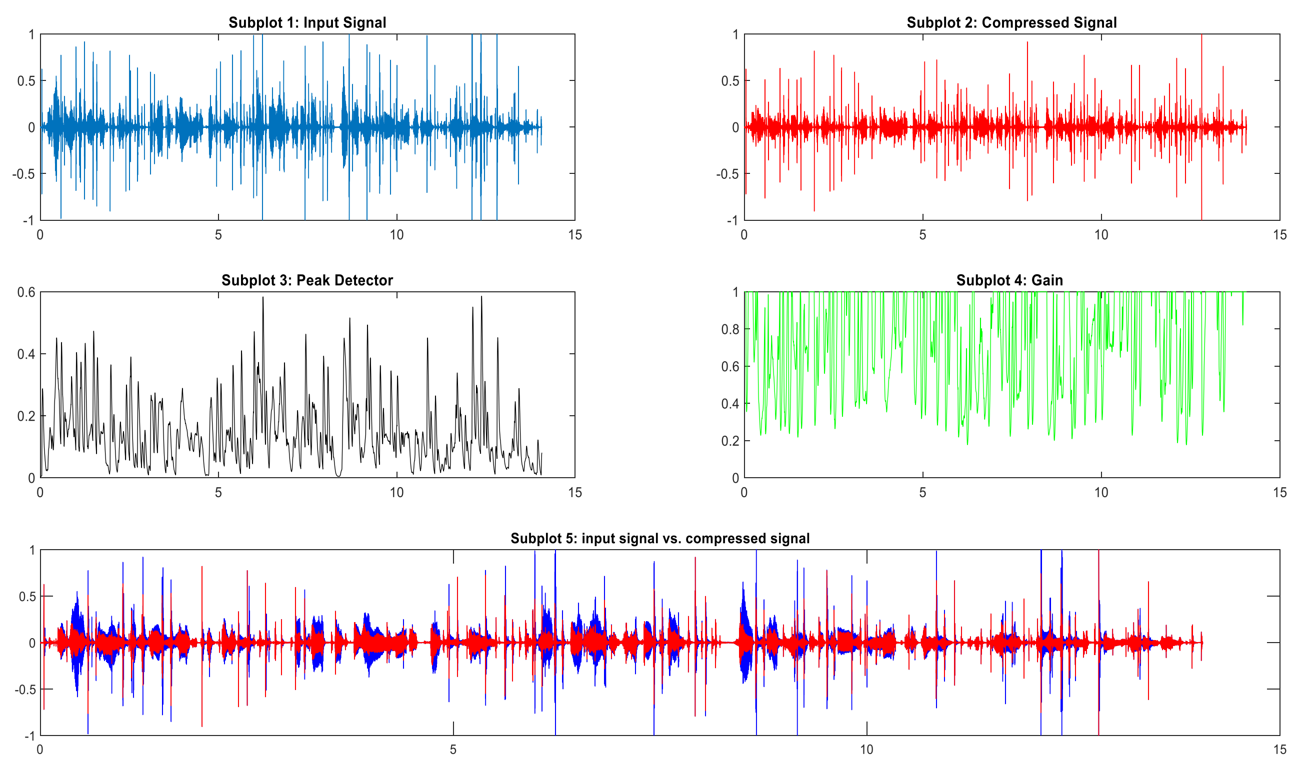


Figure 3: First method outputs

References:

[1] P. Dutilleux, et al., "Nonlinear Processing, Chap. 4," in Dafx:Digital Audio Effects, U. Zoelzer, Ed. (2nd ed: Wiley, John & Sons, 2011), p. 554.

[2] J. O. Smith, Introduction to Digital Filters with Audio Applications (Booksurge Llc, 2007).…

[3] Giannoulis, Dimitrios & Massberg, Michael & Reiss, Joshua. (2012). Digital Dynamic Range Compressor Design—A Tutorial and Analysis. AES: Journal of the Audio Engineering Society. 60.

[4] Queen Mary University of London, Center of Digital Music http://c4dm.eecs.qmul.ac.uk/audioengineering/compressors/index.html