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# **Chapter 5**

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## **Relative Spectral Analysis-RASTA**

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The need for noise reduction and suppression technology is more important than ever. Mobile phones, portable communication devices and other phones are widely used in noisy environments. As a result, phone calls contain, in addition to the speaker's voice, unwanted signals like other people talking around, vehicle engine noise and horns, wind noise, keyboard-strokes etc. A background noise suppression system developed by Motorola is included as a feature in IS-127, the TIA/EIA standard for the Enhanced Variable Rate Codec (EVRC) to be used in CDMA based telephone systems [1]. EVRC was modified to EVRC-B and later on replaced by Selectable Mode Vocoder (SMV) which retained the speech quality at the same time improved network capacity. Recently, however, SMV itself has been replaced by the new CDMA2000 4GV codecs. 4GV is the next generation 3GPP2 standards-based EVRC-B codec [2]. The EVRC based codec uses combination of STSA based approaches: multiband spectral subtraction (MBSS) and minimum mean square error (MMSE) gain function estimator for background noise suppression as a preprocessor. The **voice activity detector** (VAD) used to decide speech/silence frame is embedded within the algorithm. Its quality has been proven good through commercial products. Nevertheless, the quality may not be sufficiently good for a wide range of SNRs, which were not given much attention when it was standardized. Another algorithm suggested by A.Sugiyama, M.Kato and M. Serizawa [3] uses modified MMSE-STSA approach based on weighted noise estimation. The subjective tests on this algorithm claim to give maximum difference in mean opinion score (MOS) of 0.35 to 0.40 compared to EVRC and hence its later version is equipped within 3G handsets [3].

The STSA based algorithms are able to suppress the noise effectively subject to accurate estimation of noise during silence interval detected by VAD. Its performance depends on VAD. Also, the STSA based approaches have their common problems of musical noise and speech distortion. Hence it is needed to shift the enhancement domain itself. This leads to investigate the use of RelAtive SpecTral Amplitude (RASTA) processing of speech originally proposed by Hermansky and Morgan [4] and designed to alleviate effects of convolutional and additive noise in automatic speech recognition (ASR). Recently, RASTA was also applied to direct enhancement of noisy speech in communication systems [4, 6]. A noise suppression system for cellular communications based on RASTA has been proposed in [5].

This chapter describes the RASTA (Relative Spectral Analysis) processing of speech. It involves temporal processing and motivated by some auditory masking features. This algorithm for speech enhancement is simulated in MATLAB and evaluated under different noise conditions using NOIZEUS database. The results are compared with STSA based algorithms. The original filter is redesigned to have better performance. The algorithm throws the challenge for real time implementation as it is non linear and non causal. However, it does not require the use of VAD and can be used to combat with additive and convolutive distortions.

## 5.1 Auditory Masking Features

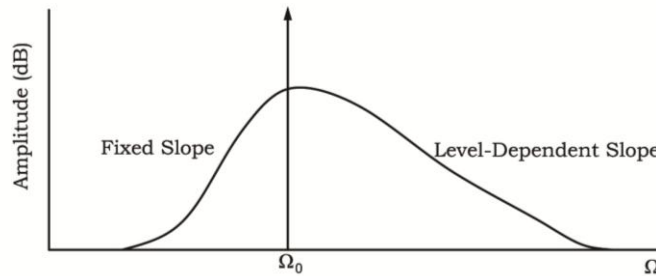
In the phenomenon of auditory masking, one sound component is concealed by the presence of another sound component. The RASTA algorithm use auditory masking principle in reducing the perception of noise. There are two different psychoacoustic phenomena referred to as frequency and temporal masking. Research in psychoacoustic has also shown that human ear can have difficulty in hearing weak signals that fall in frequency or time vicinity of stronger signals (as well as those superimposed in time or frequency on the masking signal, as in the above two cases). A small spectral component may be masked by a stronger nearby spectral component. A similar masking can occur in time for two closely-spaced sounds. In speech enhancement, this principle of masking is exploited for noise-reduction in frequency domain. While temporal masking by adjacent sounds has proven useful, particularly in wideband audio coding [12], it has been less widely used in speech processing because it is more difficult to quantify. The frequency domain masking is based on the concept of a critical band. Using this paradigm, it is possible to determine the masking threshold for complex signals such as speech. The speech masking threshold is the spectral level (determined from the speech spectrum) below which non-speech components are masked by speech components in frequency.

### 5.1.1 Frequency-Domain Masking Principles

As explained in [13] the basilar membrane, located at the front-end of the human auditory system, can be modeled as a bank of about 10,000 overlapping band-pass filters, each turned to a specific frequency (the characteristic frequency) and with bandwidths that increase roughly logarithmically with increasing characteristic frequency. These psychologically based filters thus perform a spectral analysis of sound pressure level appearing at the ear-drum. In contrast, there also exist psycho-acoustically based filters that relate to human's ability to

perceptually resolve sound with respect to frequency. The bandwidths of these filters are known as the critical bands of hearing and are similar in nature to the physiologically based filters.

Frequency analysis by a human has been studied by using perceptual masking. A tone at some intensity that human ear trying to perceive is called the maskee. A second tone, adjacent in frequency, attempts to drown out the presence of the maskee called the masker. If one can determine the intensity level of the maskee (relative to the absolute level of hearing) at which it is not audible in the presence of the masker. This intensity level is called the masking threshold of the maskee. The general shape [12] of the masking curve for a masking tone at frequency  $\Omega_0$  with a particular sound-pressure level (SPL) in decibels is shown in figure 5.1. Adjacent tones that have an SPL below the solid lines are not audible in the presence of the tone at  $\Omega_0$ . As it is shown that there is a range of frequencies about the masker whose audibility is affected. Tones with intensity below the masking threshold curve are masked by the masking tone. The curve has asymmetric nature around  $\Omega_0$ .



**Fig. 5.1 General shape of the masking threshold curve for a masking tone at frequency  $\Omega_0$**

Another important property of masking curves is that the bandwidth of these curves increases roughly logarithmically as the frequency of the masker increases. Experiments conducted have given the roughly logarithmically increasing width of the critical band filters and suggested about 24 critical band filters cover our maximum frequency range of 15000Hz for human perception. A means of mapping linear frequency to this perceptual representation is through the bark scale. In this mapping, one bark covers one critical band with the functional relation of frequency  $f$  to bark  $z$  given by [15].

$$z = 13 \tan^{-1}(0.76f) + 3.5 \tan^{-1}\left(\frac{f}{7500}\right) \quad (5.1)$$

In the low end of the bark scale ( $<1000$  Hz), the bandwidths of the critical band filters are found

to be about 100Hz and in higher frequencies the bandwidths reach up to about 3000Hz [15]. A similar mapping uses the mel scale. The mel scale is approximately linear up to 1000Hz and logarithmic thereafter [15].

$$m = 2595 \log_{10} \left( 1 + \frac{f}{700} \right) \quad (5.2)$$

Although equation 5.2 provides a continuous mapping from linear to bark scale, most perceptually motivated speech processing algorithms use quantized bark numbers of 1,2,3...24 that correspond approximately to the upper band edges of the 24 critical bands that cover range of hearing of human ear. This allows exploiting the perceptual masking properties with feasible computation in speech signal processing.

### 5.1.2 Masking Threshold Computation

For speech signal, the effects of individual masking components are additive; the overall masking at a frequency component due to all the other frequency components is given by the sum of the masking due to the individual frequency components, giving a single masking threshold [16]. For a background noise disturbance (the maskee) in the presence of speech (the masker) it is required to determine the masking threshold curve, as determined from the speech spectrum, below which background noise would be inaudible. For the speech threshold calculation, the masking ability of tonal and noise components of speech (in masking background noise) is different.

### 5.1.3 Exploiting Frequency Masking in Noise Reduction

In exploiting frequency masking, the basic approach is to attempt to make inaudible spectral components of annoying background residual (from an enhancement process) by forcing them to fall below a masking threshold curve as derived from a measured speech spectrum. The interest is in masking this annoying (often musical) residual while maximizing noise reduction and minimizing speech distortion. There are a variety of psycho-acoustically motivated speech enhancement algorithms that seek to achieve this goal by using suppression filters similar to those from spectral subtraction and Wiener filtering [16-18]. Each algorithm establishes a different optimal perceptual tradeoff between the noise reduction, background residual (musical) artifacts, and speech distortion.

There are two particular suppression algorithms that exploit masking in different ways. The first approach by Virag [19] applies less attenuation when noise is heavily masked so as to

limit speech distortion. In this approach a masking threshold curve is used to modify parameters of a Berouti spectral subtraction scheme. The parameters  $\alpha$  and  $\beta$  are adapted to the masking threshold curve on each frame. Virag found that the proposed spectral subtraction scheme that adapts to auditory masking outperformed the more classical spectral subtraction approaches, according to the objective measures. Finally Virag used the subjective Mean Opinion Score (MOS) test to show that the auditory based algorithm also outperforms other subtractive type noise suppression algorithms with respect to human perception; the algorithm was judged to reduce musical artifacts and give acceptable speech distortion. These results motivate the research work to include perceptual features in speech enhancement algorithms.

The second approach by Gustafsson, Jax, and Vary [20] seeks residual noise that is perceptually equivalent to an attenuated version of the input noise without explicit consideration of speech distortion. In this approach, rather than using the masking threshold curve to modify a standard suppression filter, the masking threshold is used to derive a new suppression filter that results in perceived noise which is an attenuated version of the original background noise.

An extension of the suppression algorithm by Gustafsson, Jax, and Vary that reduces speech distortion has been introduced by Govindasamy [18]. This method uses frequency-domain masking to explicitly seek to hide speech distortion simultaneously with the noise distortion.

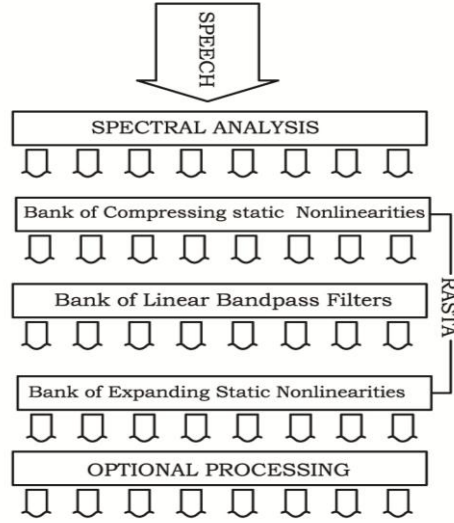
However, all these approaches which exploit the auditory masking features; but perform speech enhancement by applying various forms of spectral subtraction and Wiener filtering on short time speech segments, holding the time variable fixed in the STFT. Throughout the review process it has been observed that if the same direction of thinking continues; the inherent problems of musical noise and speech distortion will not be solved together. So if a different approach is taken in which the frequency variable is kept fixed and the filtering is applied along time trajectories of STFT (temporal domain filtering) the problems may get resolved. It is also required to embed the perceptual features described here in the temporal domain filter. This leads to the development of RASTA processing of speech. Frame-by-frame analysis of speech dates from early days of speech analysis-synthesis. RASTA processing represents a departure from this paradigm. It is a step in the direction of modeling some temporal properties of human auditory processing. It has a potential for further improvements as more knowledge about the

modeling of human auditory perception will be available.

## 5.2 RASTA Processing System

In ASR the task is to decode the linguistic message in speech. This linguistic message is coded into the movements of the vocal tract. The speech signal reflects these movements. The rate of change of non linguistic components in speech often lies outside the typical rate of change of vocal tract shape. The relative spectral processing (RASTA) uses this fact. It is motivated by some auditory features which are, in part, similar to that for adaptivity in the Wiener filter of Section 5.2.3. It suppresses the spectral components that changes more slowly or quickly than the typical range of change of speech. This rate of change of the short-time spectral envelope can be described by the modulation spectrum (temporal feature), i.e. the spectrum of the time trajectories described by the short-time spectral envelope [7]. For a wide range of frequency bands, the modulation spectrum of speech exhibits a maximum at about 4Hz, the average syllabic rate. RASTA exploits this modulation frequency preference. With slowly varying (rather than fixed) channel degradation, and given human ear insensitivity to low modulation frequencies, in RASTA a filter that notches out frequency components at and near DC is applied to each channel. In addition, the RASTA filter suppresses high modulation frequencies to account for the human's preference for signal change at a 4Hz rate. Disturbances such as additive noise may have different modulation spectrum properties than speech and often have modulation frequency components outside the speech range, and could in principle be attenuated without significantly affecting the range with relevant linguistic information. The RASTA processing suppresses the spectral components outside the typical modulation spectrum of speech. The maximum modulation frequency of the modulation spectrum is half of the sampling frequency of RASTA filter. The sampling frequency of RASTA filter is decided by frame rate. The frame rate is obtained by taking ratio of sampling frequency of speech signal to the number of shift points in a frame.

RASTA based speech enhancement suggested in [6] involves linear filtering of the trajectory of the short-term power spectrum of noisy speech signal as shown in figure 5.2.



**Fig. 5.2 Block diagram: RASTA processing system**

**RASTA algorithm processing steps for each analysis frame are...**

- Compute the short time power spectrum of windowed signal.
- Transform spectral amplitude through a compressing static nonlinear transformation.
- Filter the time trajectory of each transformed spectral component.
- Transform the filtered speech representation through expanding static nonlinear transformation.
- Perform the overlap add synthesis and reconstruct the signal.

### 5.3 RASTA Method

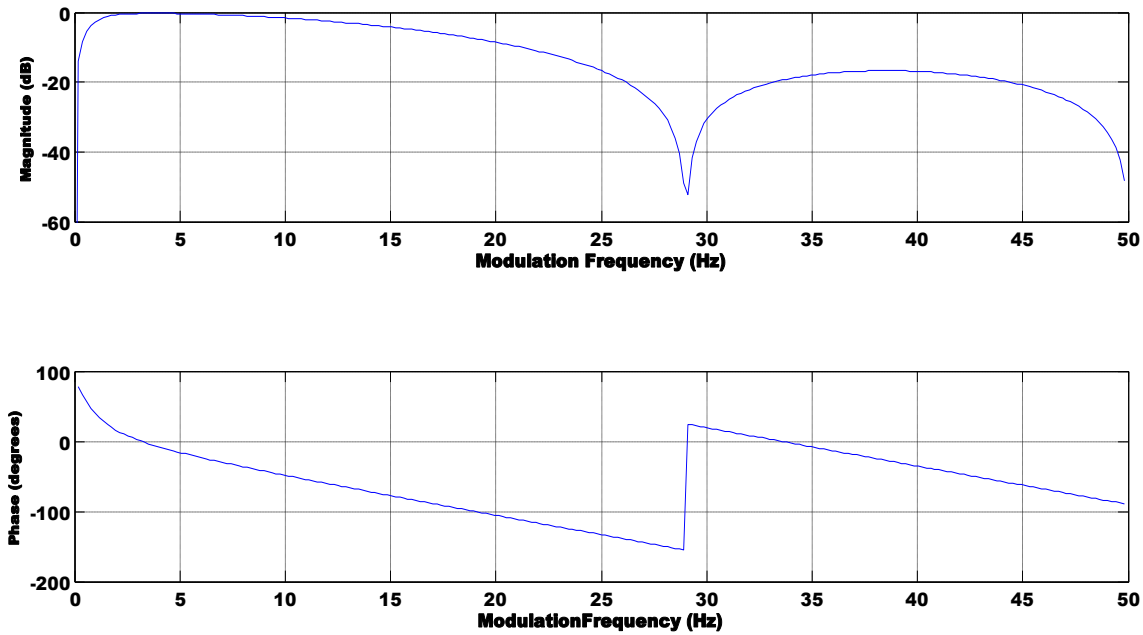
It is a generalization of cepstral mean subtraction (CMS) that was introduced in section 2.2.2.2. The original algorithm addresses the problem of a slowly time-varying linear channel (i.e., convolutional distortion) in contrast to the time invariant channel removed by CMS. The essence of RASTA is a cepstral lifter that removes low and high modulation frequencies and not simply the DC component, as does CMS. The filter suggested in [4] is the fixed IIR band pass filter for all time trajectories given by transfer function

$$P(z) = 0.1z^4 * \frac{2 + z^{-1} - z^{-3} - 2z^{-4}}{1 - 0.94z^{-1}} \quad (5.2)$$

For the sampling frequency of 100Hz i.e., the frame interval corresponds to 10ms, the filter is designed with lower cut-off frequency of 0.26Hz. The filter slope decline 6dB/octave from 12.8Hz with sharp zeros at 28.9Hz and at 50Hz. The frequency response of the filter is shown in figure 5.3.



The low cut-off frequency of the filter determines the fastest spectral change of the non-linearly transformed spectrum, which is ignored in the output, whereas the high cut-off frequency determines the fastest spectral change that is preserved in the output parameters. The high-pass portion of the equivalent band pass filter is expected to alleviate the effect of convolutional noise introduced in the channel. The low-pass filtering helps to smooth some of the fast frame-to-frame spectral changes present in the short-term spectral estimate due to analysis artifacts.



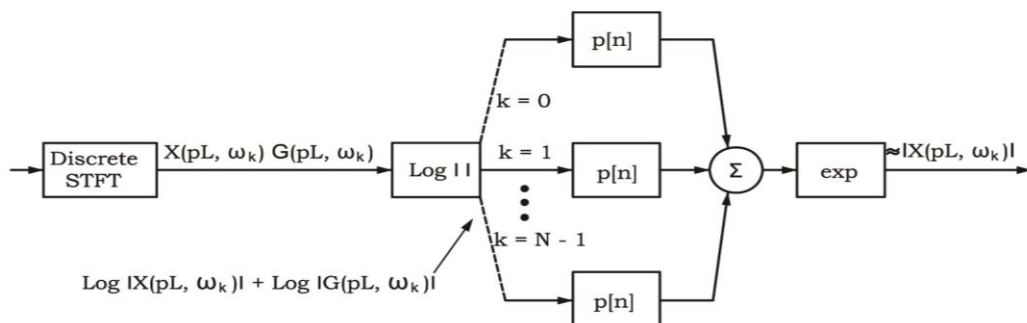
**Fig. 5.3 Frequency response of fixed IIR RASTA filter**

In RASTA for convolutive distortion reduction, the compressing static nonlinear operator becomes the magnitude followed by the logarithm operator. The expanding static nonlinear operator is inverse logarithm (exponential). The RASTA enhancement for convolutive distortion reduction is given by

$$|\hat{X}(n, \omega)| = \exp \left\{ \sum_{m=-\infty}^{\infty} p(n-m) \log |Y(m, \omega)| \right\} \quad (5.3)$$

The RASTA filter is seen to peak at about 4Hz. As does CMS, RASTA reduces slowly varying signal components, but in addition, suppresses variations above about 16Hz. The complete RASTA temporal processing for blind de-convolution is illustrated in figure 5.4. In this figure, a

slowly varying distortion  $\log|G(n, \omega)|$ , due to a convolutional distortion  $g(n)$  to be removed by the RASTA filter  $p(n)$ , is added to the rapidly varying speech contribution  $\log|X(n, \omega)|$ .

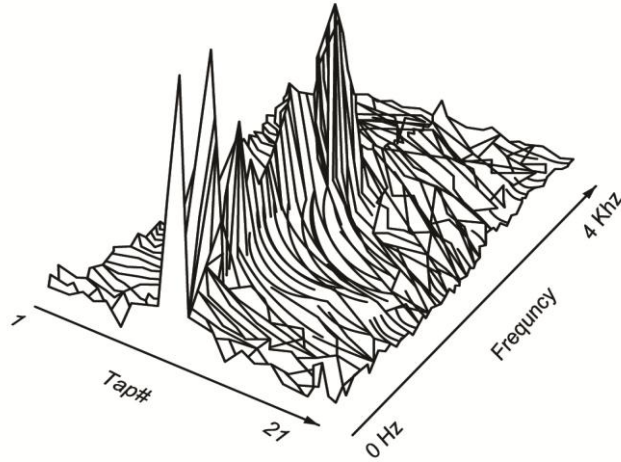


**Fig. 5.4 Flow diagram of RASTA processing for de-convolution**

In addition to reducing convolutional distortion, RASTA can also be used to reduce additive noise. The temporal processing is applied to the STFT magnitude and the original (noisy) phase along each temporal trajectory is kept intact. In performing noise reduction along STFT temporal trajectories, **it is assumed that the noise background changes slowly relative to the rate of change of speech, which is concentrated in the 1-16Hz range.** A nonlinear operator used in equation 5.3 such as the logarithm, however does not preserve the additive noise property and thus linear trajectory filtering is not strictly appropriate. Nevertheless, a cubic-root for compression and cubic power for expansion of the power spectrum ( $2/3^{\text{rd}}$  power for compression and  $3/2^{\text{th}}$  power for expansion of magnitude spectrum) results in a noise reduction [6-8]. However, applying rather aggressive fixed ARMA RASTA filters (designed for suppression of convolutional distortions in ASR) yields results similar to spectral subtraction, i.e., enhanced speech often contains musical noise and the technique typically degrades clean speech. Also, in [4] it is stated that for the RASTA enhancement processing described above, neither formal perceptual experiments were run nor any significance objective evaluation using corpus of noisy data was performed. The parameters and filter described are influenced by audible results only.

A noise suppression system for cellular communication based on RASTA processing [5] has been proposed. In this method the fixed IIR band pass filter is replaced by multiband non-causal FIR Wiener like filters with 21 tapes to achieve more reliable noise reduction. The impulse response of the filter bank is shown in figure 5.5. Here the 256 point window with 192

points of overlap for 8 KHz signal sampling frequency is used. This gives sampling frequency of RASTA filter as 125Hz. The filter in the band 0-100Hz is having almost flat frequency response and has all pass characteristics. In the bands 150-250Hz and 2700-4000Hz the filters low gain low pass filters with at least 10dB attenuation for modulation frequencies above 5Hz. For region 300-2300Hz the filter have a band pass characteristics, emphasizing modulation frequencies around 6-8Hz. Compared to original fixed IIR filter, the low frequency band stop is much milder, being only at most 10dB down from the maximum. Here each filter is designed optimally to map a time window of noisy speech spectrum of specific frequency to a single estimate of short time magnitude spectrum of clean speech as determined from a training speech database.

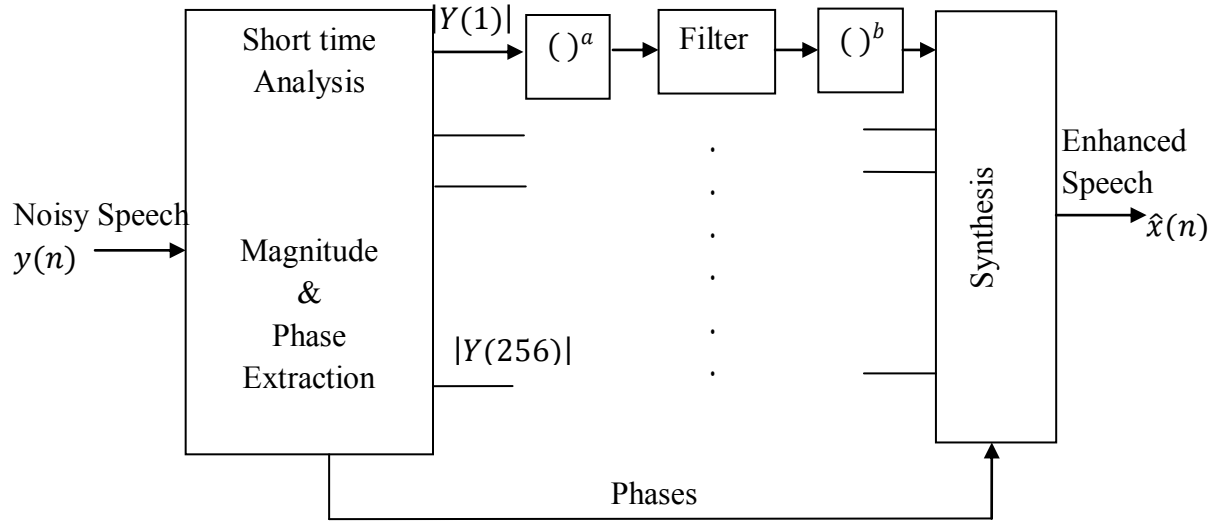


**Fig. 5.5 Impulse response of multiband 21 taps FIR filters for additive noise removal in RASTA processing**

In general the power law modification of the magnitude trajectories for additive noise removal is given by following equation.

$$|\hat{X}(n, \omega)| = \left\{ \sum_{m=-\infty}^{\infty} P(n-m, \omega) |Y(m, \omega)|^{1/\gamma} \right\}^{\gamma} \quad (5.4)$$

With the filter design technique described above, the value of  $\gamma=3/2$  for the power-law nonlinearity was found in informal listening to give preferred perceptual quality. The general block diagram of RASTA processing for additive noise removal is shown in figure 5.6.



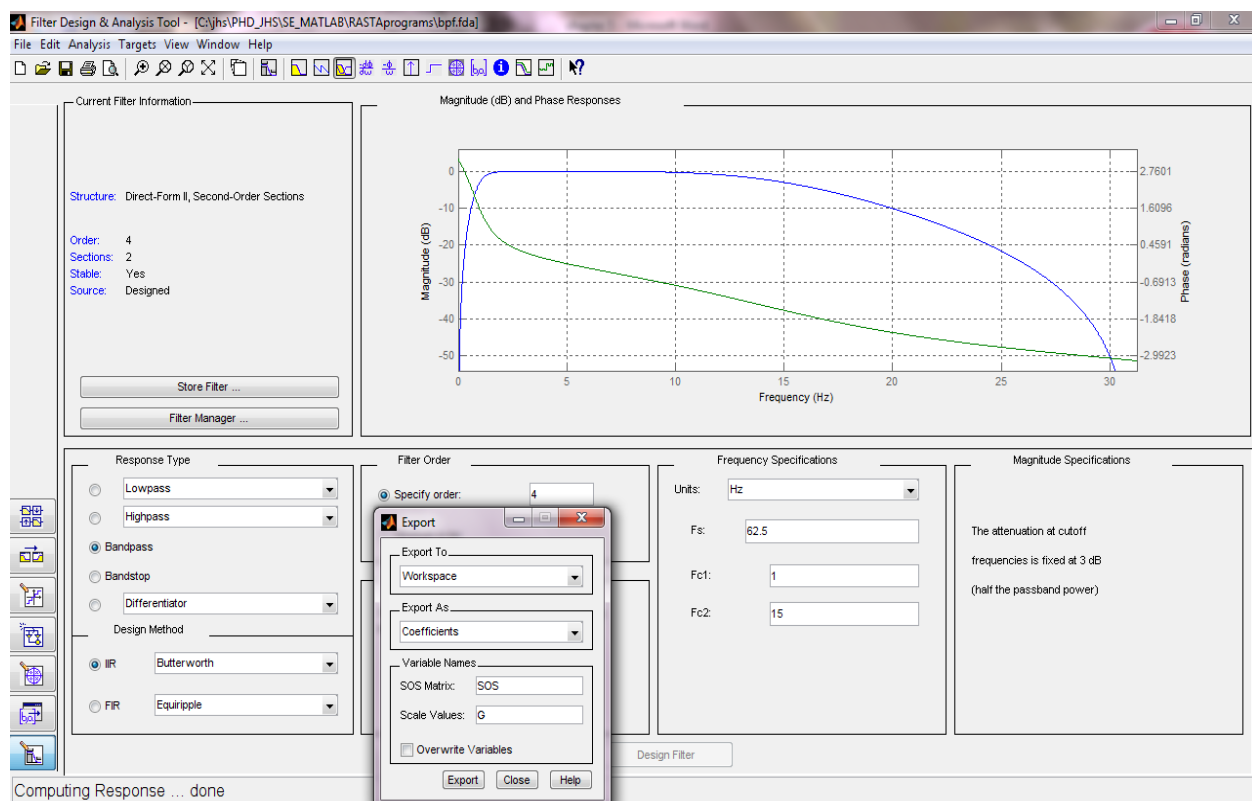
**Fig. 5.6 Flow diagram of RASTA processing for additive noise removal ( $b=1/a=\gamma$ )**

#### 5.4 RASTA Algorithm Implementation and Modifications

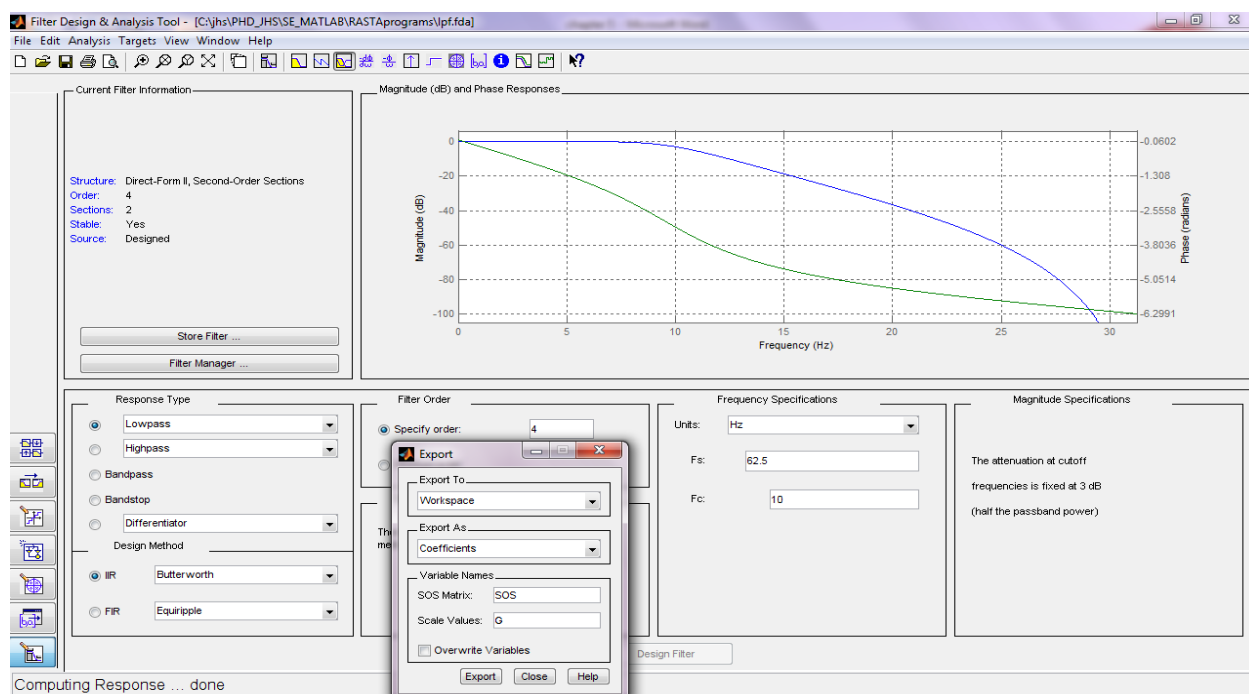
In simulation of original RASTA filter; the filter for each time trajectory is implemented by fixed IIR band pass filter with transfer function given by equation 5.2. To perform the RASTA filtering a Hamming window of 200 samples length with an overlap of 120 samples is used. With 8 KHz signal sampling frequency this gives 25ms window duration and 15ms overlap. The frame rate and hence the sampling frequency of RASTA filter is 100Hz. The maximum modulation frequency is 50Hz. The filter is designed with lower cut-off frequency of 0.26Hz. The filter slope decline 6dB/octave from 12.8Hz with sharp zeros at 28.9Hz and at 50 Hz. The frequency response of the filter is shown in figure 5.3. The algorithm used for obtaining FFT generates 256 points complex FFT, which gives magnitude and phase for first 129 points. Each spectral value is filtered using the filter described in equation 5.2. These filtered spectral values are combined with the phase of noisy spectrum, 256 point IFFT is applied and overlap-add operation is performed to reconstruct the enhanced speech. The value of parameter  $a$  is set to  $2/3$  and hence  $b$  is set to  $3/2$  which are proposed in [4-6].

As per auditory principles; the nonlinear compression and expansion is critical in RASTA approach. In simulation experiment the parameters  $a$  and  $b$  are tested for different values. The parameters suggested in [4] are based on audible experience only. Hence the simulation is carried out with originally fixed values of parameters  $a$  and  $b$  as well as with the

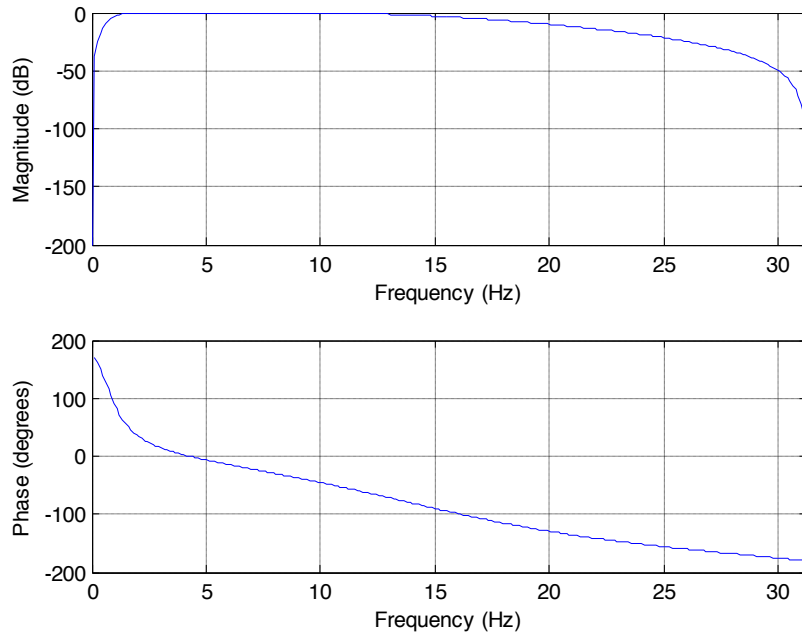
modified values. From the listening experience the parameter values  $a=3/4$  and  $b=4/3$  are found more satisfactory. To confirm it the evaluation is carried out here. The objective evaluation explained in next section as well as subjective listening test explained in chapter 6 also backs the results. Also the original fixed RASTA filter is modified and it is replaced by multiband filters as suggested in [5]. However, from better implementation point of view the non-causal FIR Wiener like filters are approximated by fourth order Butterworth filters. For implementation 256 point Hamming window with 50% overlap is used which gives the sampling frequency of RASTA filter as 62.5Hz. For very low frequency band 0-100Hz no filtering is performed. The filters for the band 300-2300Hz are approximated by band-pass filter with lower cut-off frequency of 1Hz and higher cutoff frequency of 15Hz. The filters for the bands 100-300 Hz and 2300-4000Hz are approximated by low pass filters with cut-off frequency of 10Hz. The design of the filters using FDATOOL in MATLAB [9, 10] is illustrated in figure 5.7 and 5.8. The frequency responses of these filters are shown in figures 5.9 and 5.10.



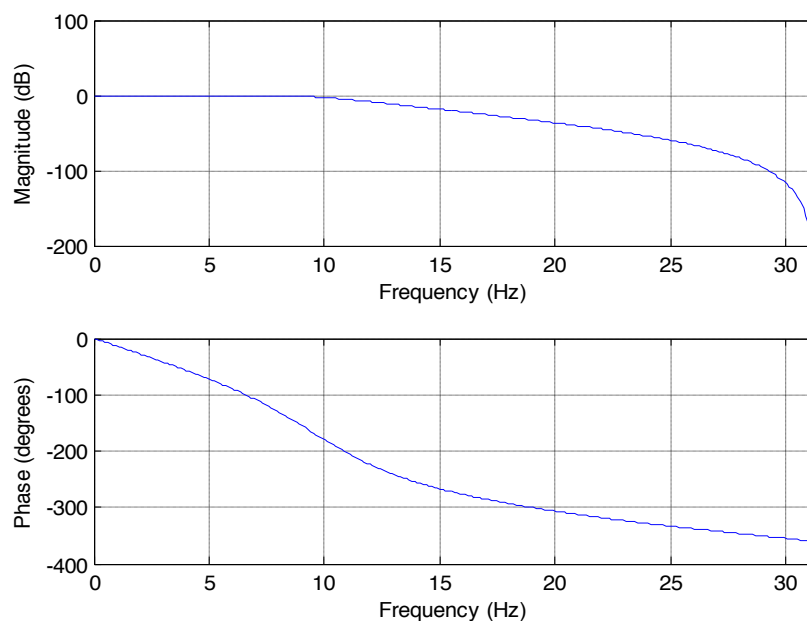
**Fig. 5.7 Design of multiband RASTA filter in 300-2300Hz band**



**Fig. 5.8 Design of multiband RASTA filter in 100-300Hz and 2300-4000Hz band**



**Fig. 5.9 Frequency response of multiband RASTA filter in 300-2300Hz band**



**Fig. 5.10 Frequency response of multiband RASTA filter in 100-300Hz and 2300-4000Hz band**

The band pass filter is designed using FDATOOL in MATLAB [9, 10]. The implementation details are given below.

```
%
% Generated by MATLAB(R) 7.8 and the Signal Processing Toolbox 6.11.
%
% Generated on: 12-May-2011 18:20:50
%
```

```
% Coefficient Format: Decimal
```

```
% Discrete-Time IIR Filter (real)
```

```
% -----
```

```
% Filter Structure      : Direct-Form II, Second-Order Sections
```

```
% Number of Sections   : 2
```

```
% Stable                : Yes
```

```
% Linear Phase          : No
```

```
SOS matrix:
```

```
1  2  1  1  -0.80995029893913273  0.51158976469417017
1  2  1  1  -0.60203320225744494  0.12355934398734861
```

```
Scale Values:
```

```
0.17540986643875933
0.13038153543247591
```

Following are the implementation details of the low pass filter designed using FDATOOL in MATLAB [9, 10].

```
%
% Generated by MATLAB(R) 7.8 and the Signal Processing Toolbox 6.11.
%
% Generated on: 12-May-2011 18:25:12
%

% Coefficient Format: Decimal

% Discrete-Time IIR Filter (real)
% -----
% Filter Structure      : Direct-Form II, Second-Order Sections
% Number of Sections   : 2
% Stable               : Yes
% Linear Phase         : No

SOS matrix:
1  0  -1  1  -1.8586755234480816   0.8690982221474296
1  0  -1  1  -0.13519171958723636   0.20489026841573793

Scale Values:
0.49660644391298536
0.49660644391298536
```

## 5.5 Objective Evaluation and Results

To test and evaluate performance of RASTA algorithms; the objective measures are obtained by using test files from NOIZEUS database [11]. Speech enhancement for white noise, and eight different colored noises at 0dB, 5dB and 10dB SNR level is carried out using two STSA algorithms: MBSS and MMSE-LSA and using the RASTA filtering algorithm with two different cases of parameters  $a$  and  $b$ .

Figures 5.11 to 5.15 illustrate SSNR, WSS, LLR and PESQ score bar chart comparison of five algorithms (two good performing STSA algorithms and three versions of RASTA algorithms explained in previous section) with eight different colored noises at 0, 5 and 10dB SNRs. Also the same comparison is given under white noise. It can be observed that at relatively high SNR two STSA algorithms are performing well compared to RASTA algorithms. But at the lower SNRs the RASTA algorithms have performance comparable to STSA algorithms. Also the performance of RASTA algorithms is consistent in white and colored noise environments. The modified RASTA algorithm performs well in most noise conditions compared to its original



version. Also the RASTA algorithm has unique advantage that it does not require voice activity detector (VAD). So it can be concluded that neither STSA nor RASTA method alone is not self sufficient for noise reduction. Though RASTA method alone is not able to perform satisfactorily, its capability of suppressing the slowly varying spectral components from the noisy speech can be used for achieving better speech enhancement along with STSA based method. So it is required to combine the RASTA approach in some way with the STSA approaches to have better results. This is explained in next chapter.<sup>1</sup>

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<sup>1</sup> A paper entitled “Evaluation of RASTA Approach with Modified Parameters for Speech Enhancement in Communication Systems” is presented in IEEE symposium on Computers and Informatics (ISCI 2011) Organized by IEEE Malaysia section at Kuala Lumpur, Malaysia in March 2011. ISBN: 978-1-61284-690-3. Listed and Indexed in IEEE Xplore, DOI:10.1109/ISCI.2011.5958902, pp.159-162, INSPEC 12123318.

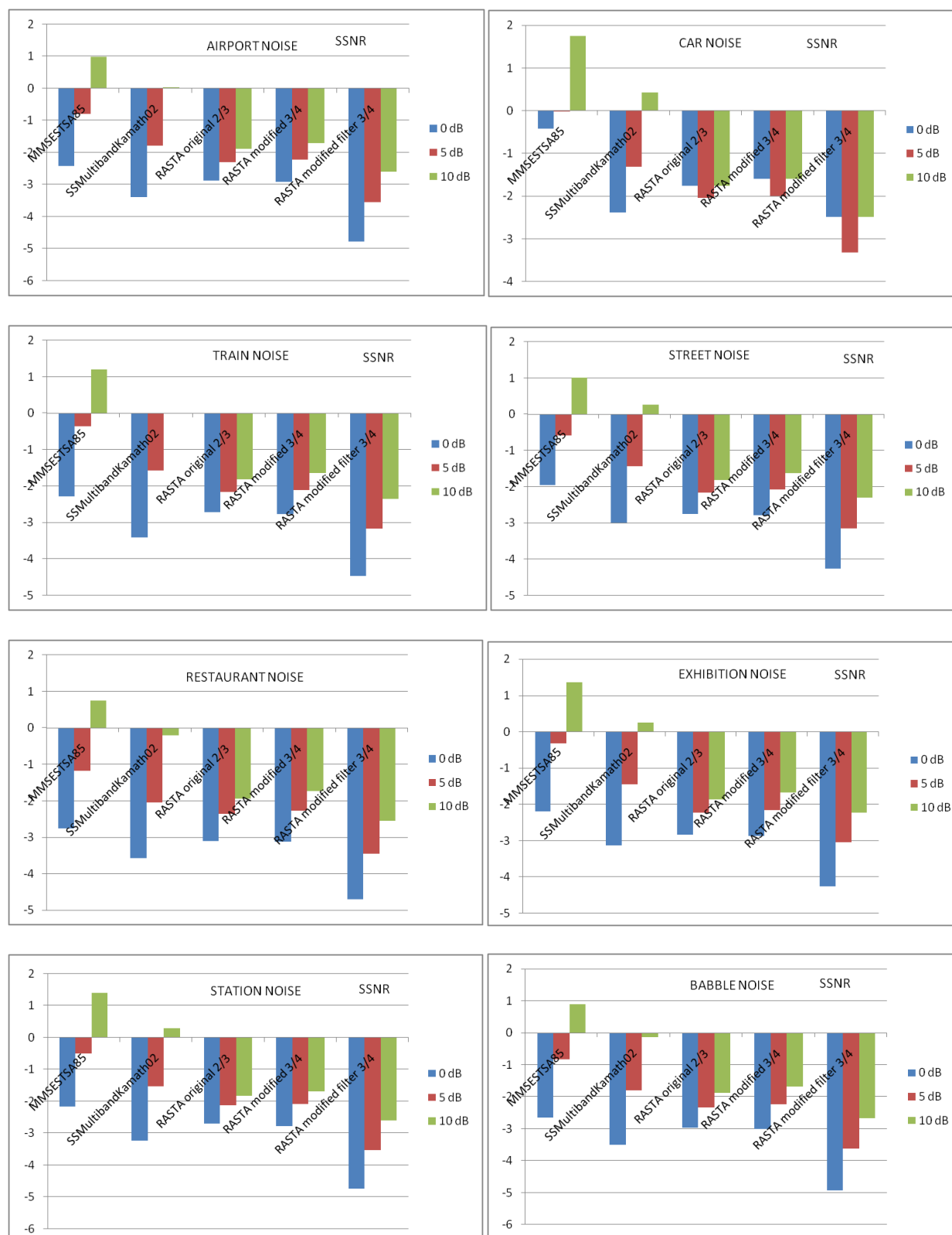


Fig. 5.11 SSNR comparison of RASTA algorithms over NOIZEUS database

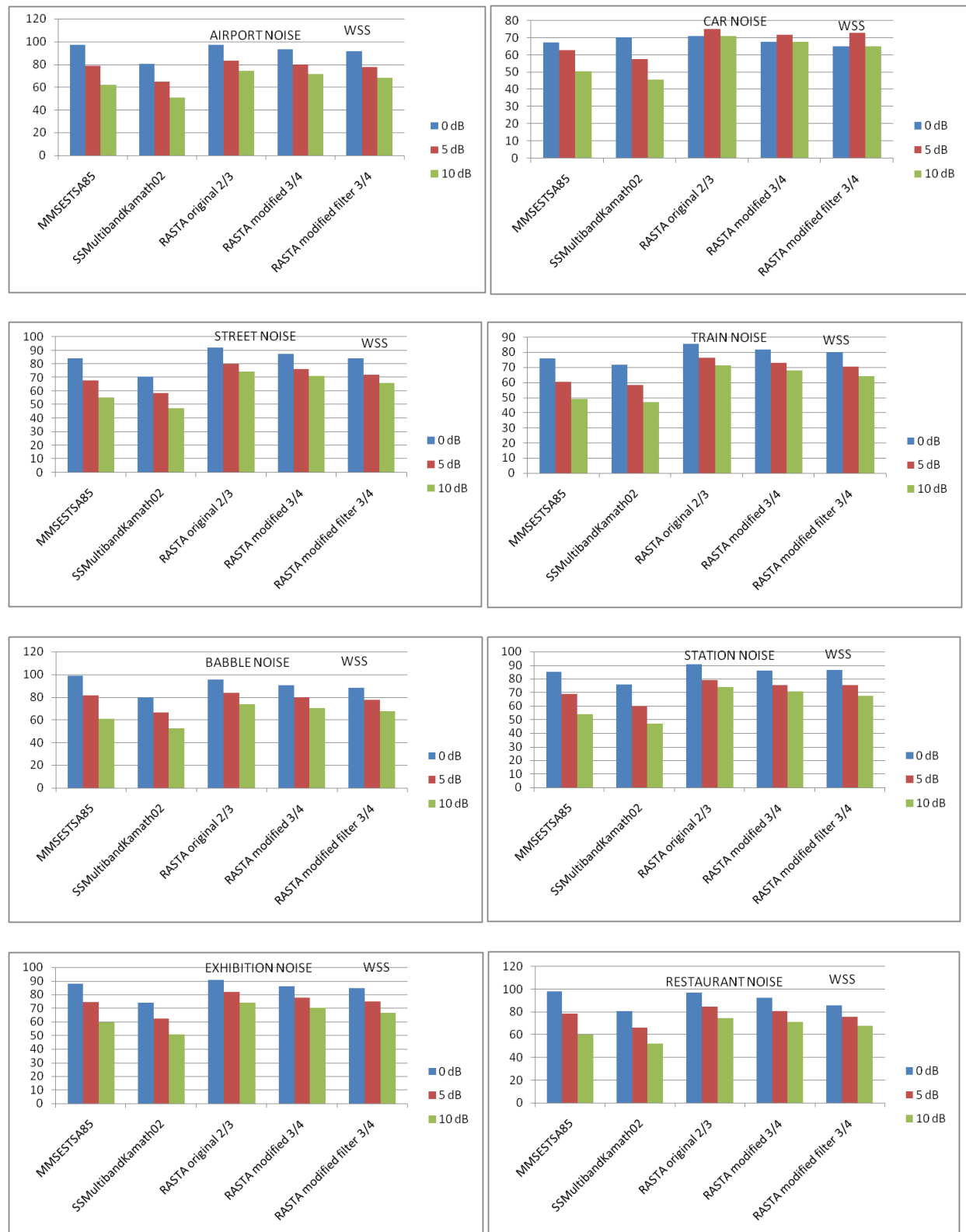


Fig. 5.12 WSS comparison of RASTA algorithms over NOIZEUS database

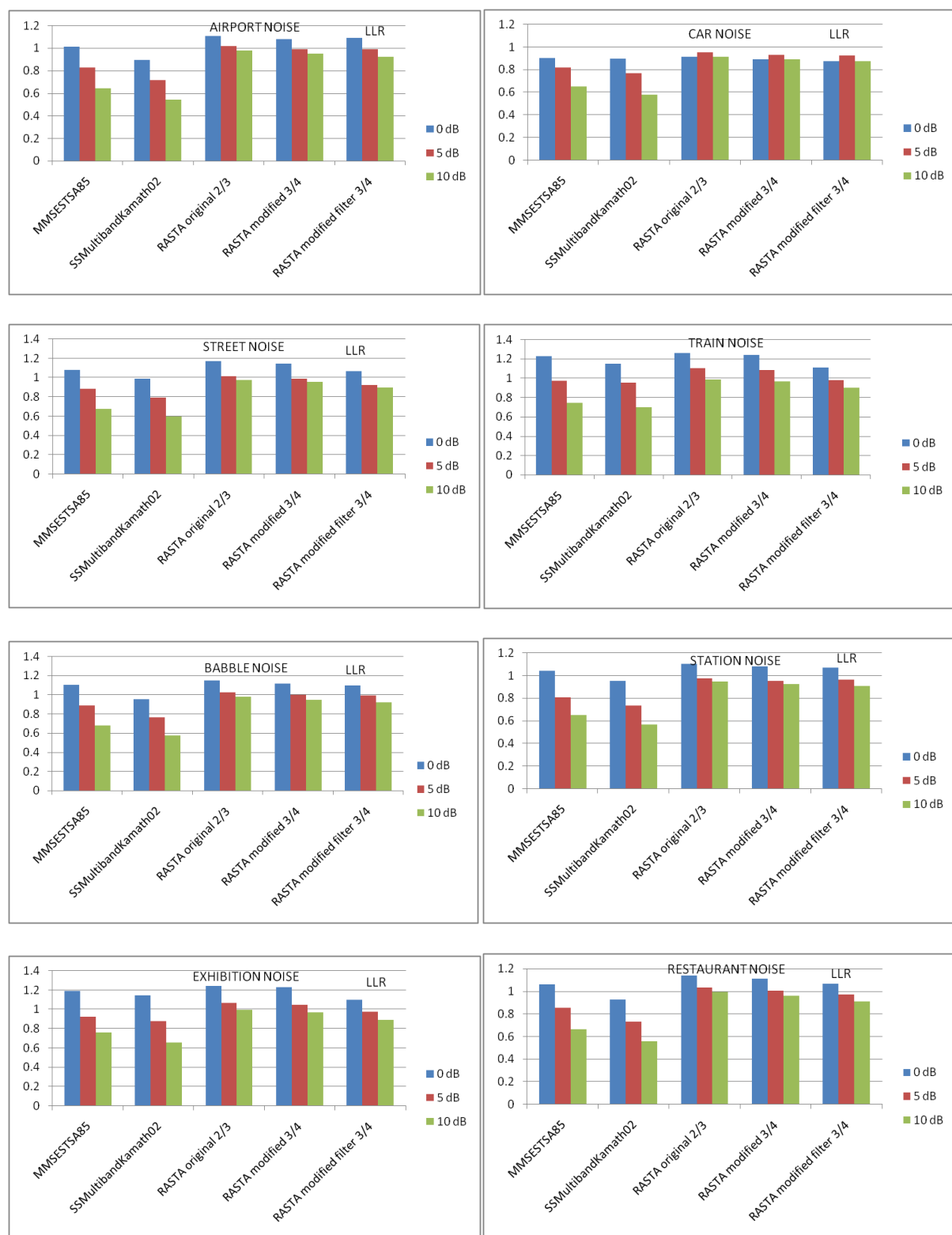


Fig. 5.13 LLR comparison of RASTA algorithms over NOIZEUS database

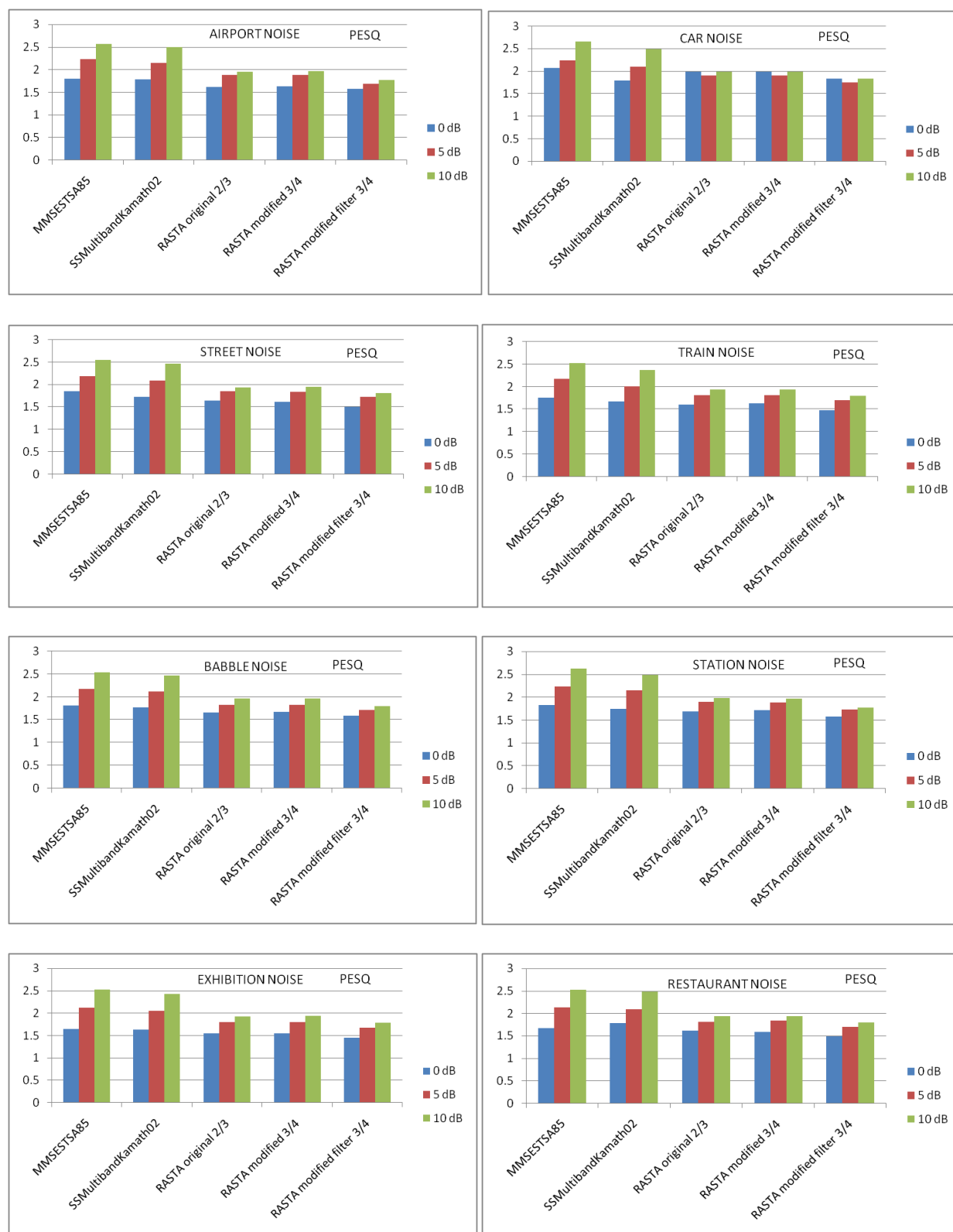
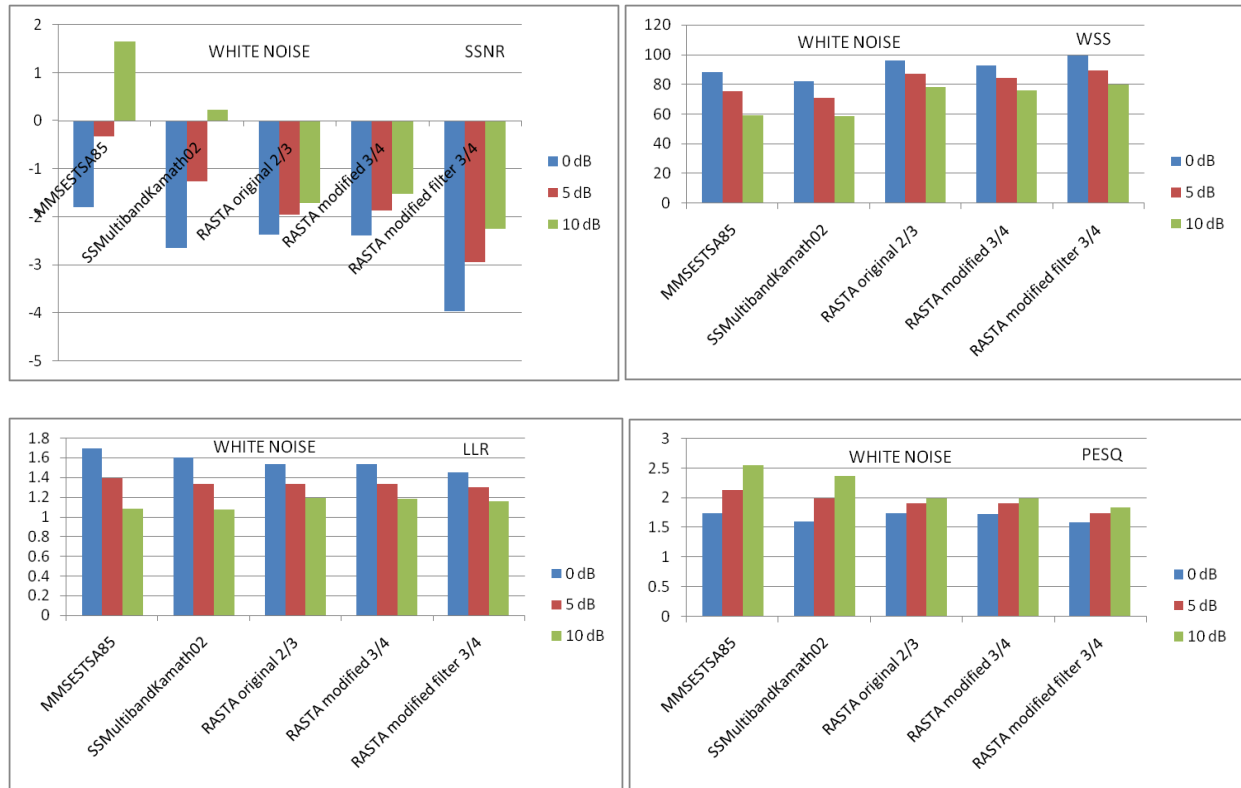
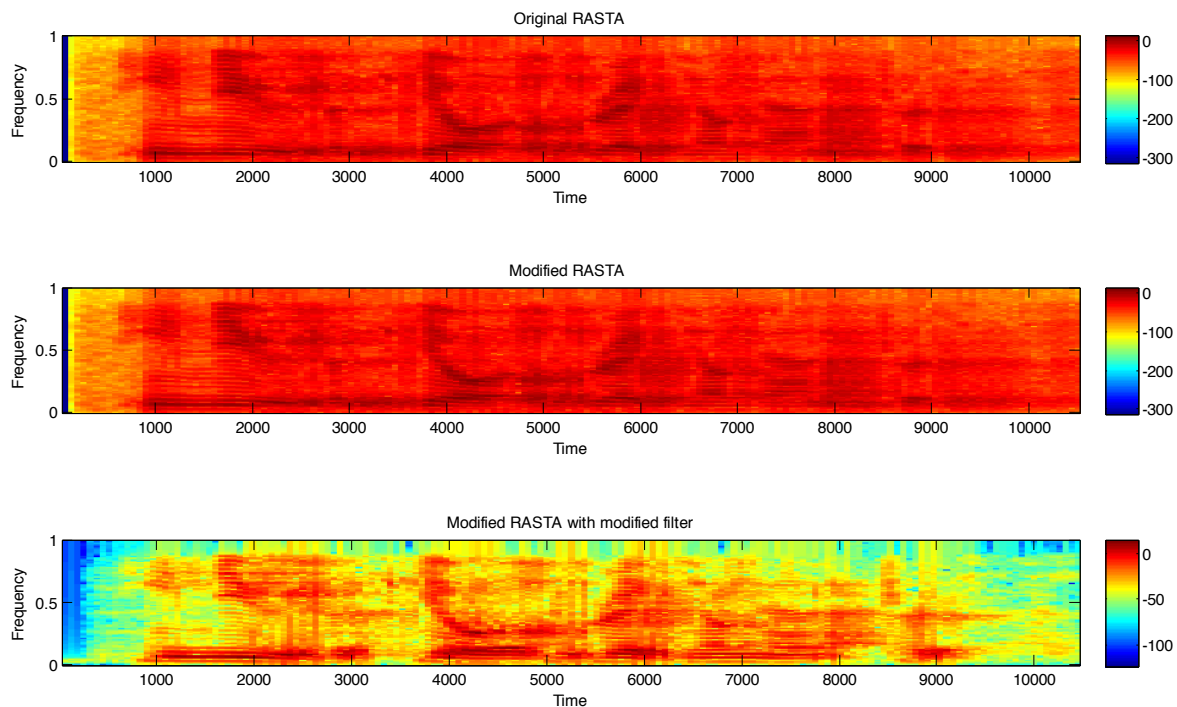


Fig. 5.14 PESQ comparison of RASTA algorithms over NOIZEUS database



**Fig. 5.15 Objective evaluation of RASTA algorithms under white noise conditions**

Figure 5.16 also shows the spectrogram of the enhanced speech form 0dB white noise using various RASTA algorithms. The clean speech signal spectrogram and noisy signal spectrogram are shown in figure 4.5. The comparison is self explanatory that modified RASTA with modified filter algorithm is better speech enhancer of the three. Also it can be compared with spectrogram of enhanced speech by various STSA algorithms as shown in figure 4.6. The performance of modified RASTA with modified filter algorithm is comparable with the MMSE LSA (STSA85) and MBSS – the two outstanding STSA algorithms. Also it can be seen that the speech enhanced by RASTA methods have very high residual noise during the initial portion of the enhanced speech (Initial 4 to 10 frames). Generally this initial period is assumed to be silence period and not much more to bother about it. After this period the filters get initialized and residual noise starts reducing. Like STSA methods RASTA processed speech also generates musical noise and speech distortion as seen from the spectrograms. So a better performance can be expected by combining these two different approaches.



**Fig. 5.16 Spectrogram of enhanced speech signal using various RASTA algorithms containing sentence ‘He knew the skill of the great young actress’**

## 5.6 Summary

The RASTA algorithm which utilizes temporal processing and auditory features is discussed and simulated here for performance evaluation. The original RASTA algorithm is used for de-convolution and later on it is modified for additive noise removal. However, the objective measures indicate the poor performance of RASTA algorithm compared to MMSE STSA85 algorithm. The original fixed RASTA filter is modified to multiband filter. The static nonlinear compression and expansion factor is also moderately changed to alleviate the additive noise. Even with the modification the RASTA algorithm gives distortion in output speech compared to STSA counterpart. But the positive outcome is the improvement at lower SNRs. So it is suggested here to use the hybrid algorithm which combines STSA and RASTA approach by some means. This hybrid approach is discussed in next chapter.