Normalizing The IBOC And FM/AM-Analog Audio Signal Paths

Frank Foti, Omnia Audio
Glynn Walden, iBiquity Corp.

October, 2002

A critical component to the IBOC transmission system is the relative audio levels of the IBOC and FM/AM-Analog signals in the receiver. The key issue here is being able to create audio levels that are perceived subjectively to be relatively the same, in average volume, when the signal is blending[1] between modes. The listener experience could be adversely affected if the audio level abruptly changes, in the blending process. Thus, the question becomes: How can this be *normalized*, and what are the operating levels required to accomplish this? There may be differences between the "offset" needed for AM and FM, this report covers a testing program to develop the "offset" for the FM channel, testing to determine the AM "offset" will follow.

The analog signals are limited by channel conditions and receiver performance to less than 70 dB of dynamic range. In addition the broadcast stations use audio processing to further reduce dynamic range to overcome the effects of the analog channel. The digital signal is not subject to such limitations and may be delivered with a dynamic range of greater than 92 dB. There are four key elements that differentiate the IBOC and FM/AM-Analog signals:

1. RMS Level:
   - The function of audio processing in an analog transmission system is to reduce the dynamic range and increase the audio RMS level. In analog systems, this function essentially is used to mask the effects of a noisy channel. More moderate use of audio processing on the digital transmission is used to enhance the digital quality and differentiate digital from analog audio. Without similar dynamic range restriction on the digital channel the analog channel, will always have greater apparent loudness. Imposing analog processing criteria destroys the digital audio quality advantage.
2. High Frequency Limiting on the Inverse of the Pre-Emphasis Curve:
   - AM and FM transmissions use pre-emphasis to increase the high frequency energy in analog transmission and de-emphasis in the receiver to restore flat frequency response and mask noise in the channel. Pre-emphasis compensation reduces the overall average audio level by7-8 dB for AM and 15 dB for FM. Current analog audio processing uses

[1] The IBOC system the analog and digital paths carry the same audio. Upon initial tuning to an IBOC station the receiver produces audio output from tha analog stream and blends to the digital stream when the signal is acquired. Furthermore, the analog signal is used as a back-up to the digital stream. In the event of the loss of the digital signal the receiver smoothly blends back to the analog audio.

limiting, following the pre-emphasis compensation to preserve overall audio level and increase the density of the high frequencies at the expense of clarity. No such processing is done in the digital channel, therefore the high frequencies in the digital transmission are more open and less distorted, a primary advantage of IBOC.

3. Frequency Response:
    . Analog FM is limited at both the high and low extremes of the frequency range. The lower frequencies are limited to prevent problems with the phase locked loops of the analog exciter and the high frequencies are limited to 15 kHz to provide protection to the stereo pilot at 19 kHz. Analog AM is primarily a 3 – 5 kHz medium, due primarily to receiver limitations, however, IBOC imposes a 5 kHz limitation on the analog transmission. The digital frequency response of the IBOC FM channel is approximately 18 kHz and 10 – 15 kHz in the AM digital channel.
4. Dynamic Range:
    . The dynamic range of an analog transmission, under ideal circumstances, is 70 dB for FM and 50 dB for AM. The dynamic range of an IBOC digital channel is perceptually 96 dB. Analog audio processing dynamically restricts dynamic ranges to increase RMS audio levels masking channel impairments at the expense of quality. There are no such benefits to dynamic range restriction on the digital channel. Minimal use of digital audio processing preserves the dynamics and qualities of the IBOC audio.

Transmission Path Reference Levels…IBOC and FM/AM-Analog

The FM/AM-Analog path transmits, over the air, using a maximum peak deviation of +/-75kHz for FM, and double the RF carrier level for AM. These levels correlate to 100% modulation. Assuming that 100% modulation will create a peak level of 0dB in a receiver, an average level will be derived based upon the amount of processing employed, which produce a larger RMS level value when more processing is used.

Most FM and AM Stations employ sufficient processing, that the RMS level is usually within a few dB, whether or not the processing is set for light or aggressive operation. Present generations of audio processors do an extremely good job of maintaining a normalized RMS level. Basically the sonic difference to light and aggressive processing is the perceived *density*. It sounds anywhere from *packed up and thick*, to *open and airy*. The concern for this discussion is not the aural *texture* but the perceived average level of the analog path.

As stated earlier in this discussion, one of the advantages to the IBOC path is the ability to offer wider dynamic range, which allows less processing to be employed. This would reduce the RMS average level, and sound perceptibly softer or quieter to the FM/AM-Analog path. The question, to be determined herein is what “offset” to set in either the IBOC signal or analog path so that perceived audio levels are equal.

While the IBOC path offers a wider dynamic range, one that approaches the CD, it makes sense to employ some level of dynamic control so that a consistent and pleasing audio level is presented to the listener. A perfect example of this is automobile listening, where it is desirable to provide a consistent level so that road noise does not drown out what is being heard. Moderate audio processing will provide this, while maintaining extremely high audio quality. This is due to the fact that processing for IBOC *is not* penalized by high frequency limiting the inverse of the preemphasis curve, which drives the presence and treble frequencies into heavy processing. This will cause a difference in the *texture* of this frequency range. The IBOC processor operates on a *flat* signal, and thus the presence and treble range appear perceptibly more *open* and less dynamically distorted.

The IBOC processor will create an aural texture that will be different than it's FM/AM-Analog counterpart. The already mentioned preemphasis issue is one reason. Additionally, the IBOC system will operate on a wider frequency response, and the level of processing will generally be reduced to allow the benefits of wider dynamic range. Make no mistake, aggressive processing can be employed in the IBOC system, but it will not generate the same *effective* sound as it's counterpart due to the differences in the transmission channel.

Determining the FM "Offset"

As a means towards finding what would be the optimum operating level for the IBOC processing system, the following subjective test was derived. Two dedicated processors, one for FM/AM-Analog and one for IBOC, were set side by side and aurally compared. The FM/AM-Analog processor was set for a relative *reference* level of 0dBu. Think of this as the given 100% modulation level that would feed a transmitter. Since all preemphasis/deemphasis and peak control are handled in the processor, the output level can be set to a known reference. Likewise the IBOC processor can be setup in the same fashion. Since both units will provide absolute, precise peak control, the output levels can be set to maximize the dynamic range of their respective transmission channels.

The FM/AM-Analog processor was set for heavy, aggressive processing, whereas the IBOC system was set for light processing. Once setup, the processing parameters were not further adjusted during the testing. Fourteen audio clips including voice, voice-over and music were recorded with the digital processor, serving as the reference, held at 0 dB and the output of the analog processor recorded in 1 dB steps from 0 to – 9 dB. The cuts were then assembled into a matrix on a computer screen where, through a mouse, instantaneous comparisons between the digital reference and the 9 levels of the analog processed audio could be performed. Figures 1 and 2 depict the interface used in the evaluation program. The information on the test setup of the processors is contained in Appendix A.

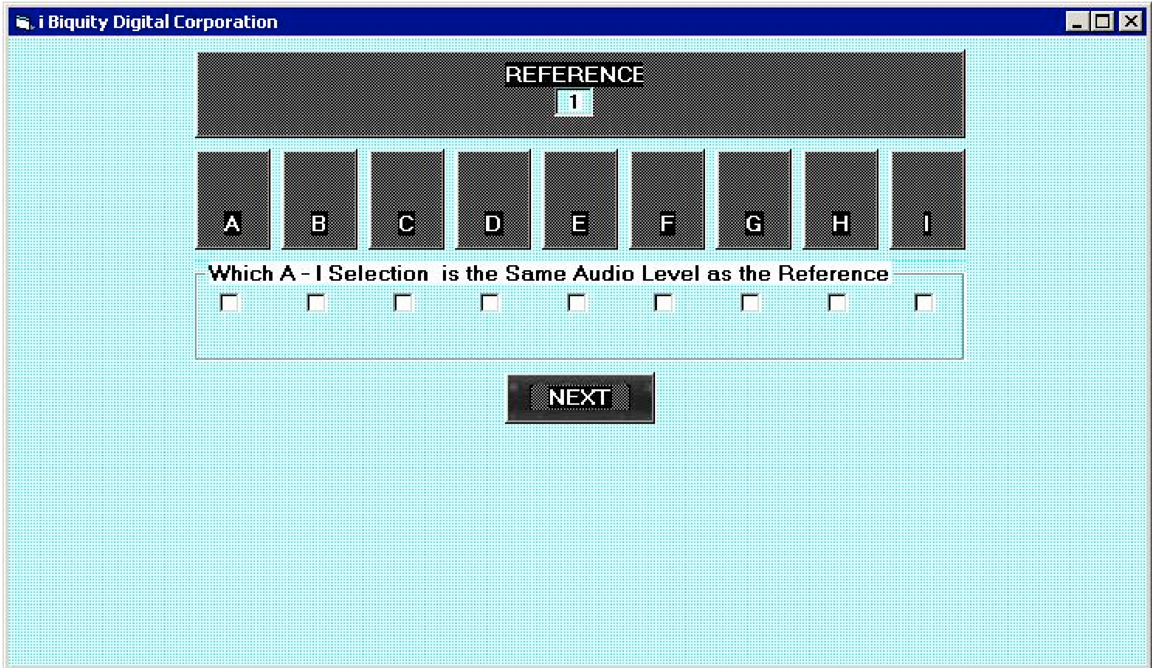


Figure 1

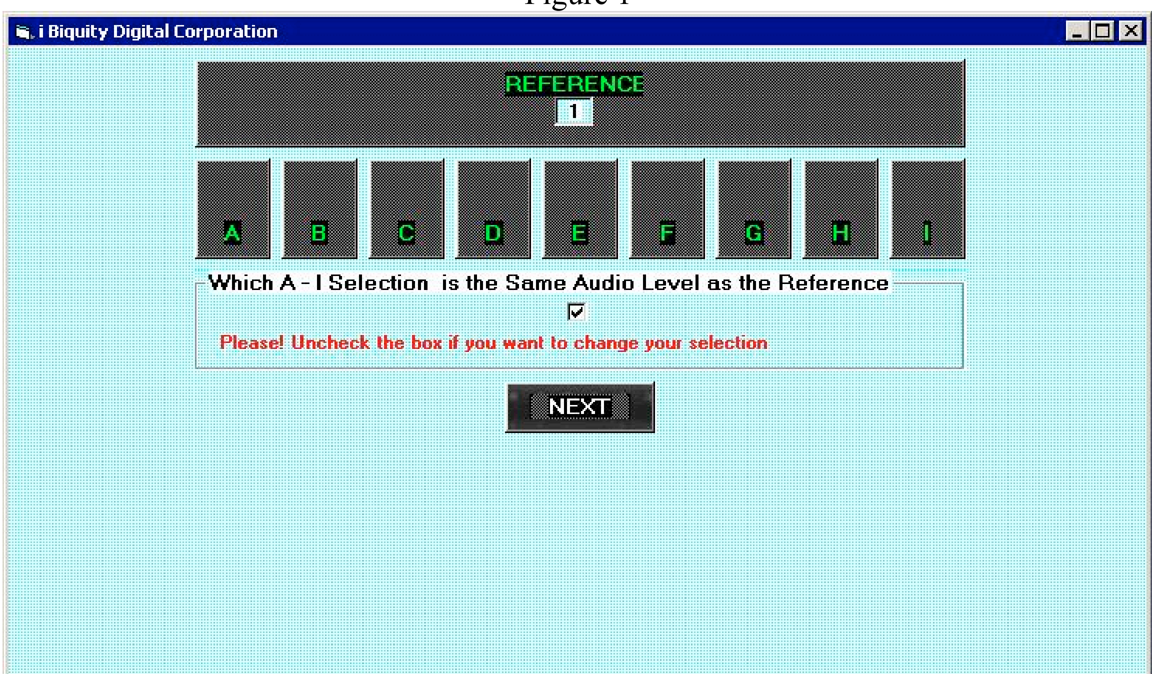


Figure 2

Thirty one subjects from iBiquity's offices in Maryland, New Jersey, and Omnia's Office in Ohio participated in the test. The subjects were asked to match the audio level[2] of the reference to the samples A through I and mark their choice with a checkmark. Figure 3 depicts the results with the 14 sample cuts represented along the X axis and the level deemed to match is shown on the Y axis. The red line is the average for the point and the orange line shows the running average. The result of this evaluation shows that the perceptual difference between a heavily processed analog and lightly processed digital transmission is 3.57 dB.

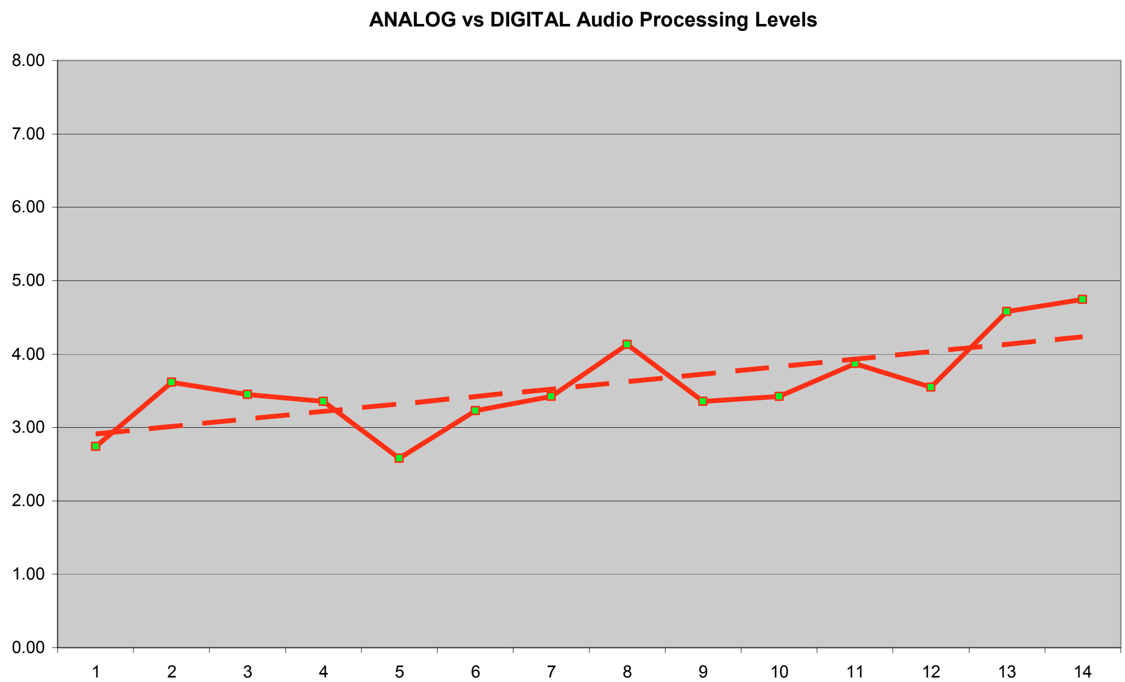


Figure 3
Red (Solid Line)= Average Score
Orange (Dashed Line) = Running Average

Normalized IBOC FM Levels:

In the transmission system there are two parameters that can't be changed; first the FM/AM-Analog is set to 100% peak modulation, and second the IBOC channel is limited to 0dBfs peak operation. Therefore to insure smooth blending between the analog and

---

2 It is of interest to note that with some cuts the sonic differences were clearly evident between the digital and analog paths. Actually, due to the broader dynamic range, and lack of emphasis processing in the IBOC unit, the analog signal sounded noticeably dull and lacking clarity, when compared to the IBOC path. When quickly switching between the two signals, the IBOC signal appeared to have more excitement to the aural presentation.

digital sources, the “offset” to equalize these levels will have to be incorporated in the receiver

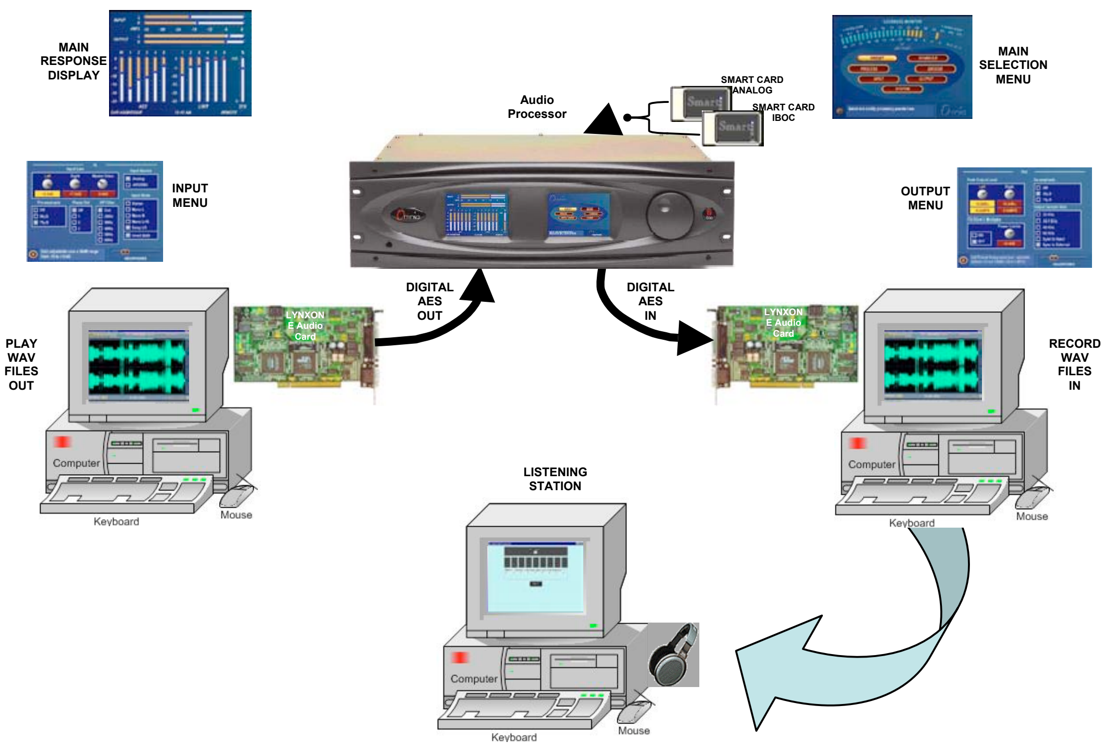
Based upon the results of the subjective test, it is recommended that to normalize the audio levels between the IBOC and FM/AM-Analog signal paths, a 5.0 dB relational difference in level needs to be implemented. This number, for FM operation, is derived from the 3.57 dB determined through subjective evaluation and approximate 1.5 dB of pad to allow broadcaster flexibility. To insure proper blending, every IBOC radio, independent of manufacture, will be required to have the same relative offset.

Automotive receiver manufacturers currently match the levels of various sources including CD players, AM & FM radio, DVD’s such there is minimal level disparities between the devices. For IBOC the offset can be done in one of two ways either the receiver manufacturer can choose to increase the level of the digital by 4.5 dB or decrease the level of the analog by 4.5 dB.

At the broadcast transmission facility, the station will use a calibrated reference receiver to match the apparent loudness between the analog and digital signals.

Appendix A

Omnia Processor Setup



Omnia Setup

FM Analog Audio Recordings Used Parameters As Defined By Omnia As "Heavy Aggressive" See Table 1 Below

FM Digital Recordings Used Parameters As Defined By Omnia As "Light Processing" See Table 2 Below

Omnia-6 Parameter Worksheet

Preset Name: FM Analog

By: ______________________________

Date: ____________________

Input Submenu

Parameter	Value
Input Source	AES
Input Gain Left	0.00
Input Gain Right	0.00
Master Gain	0.00
Input Mode	Stereo
High Pass Filter	OFF
Phase Rotator	3.00
Pre-emphasis	ON
Invert Both?	NO

WB-AGC

Parameter	Value
AGC Drive	0.00
Attack	4.00
Release	3.50
Make-Up Gain	4.00
Gate Thresh	2.00
RTP Speed	Slow
RTP Level	-10.00
AGC In/Out	IN

AGC X-Over

Parameter	Value
Low Gain	0.00
Mid-Low Gain	0.00
Mid-High Gain	0.00
High Gain	0.00
Super-High Gain	0.00
LF->ML X-over Freq	150.00
ML->MH X-over Freq	700.00
MH->HF X-over Freq	3.2kHz
HF->SHF X-over Freq	7.0kHz

LF-AGC

Parameter	Value
Attack	1.50
Release	1.50
Make-Up Gain	2.00
Gate Thresh	5.00
RTP Speed	SLOW
RTP Level	-10.00

ML-AGC

Parameter	Value
Attack	1.50
Release	2.00
Make-Up Gain	2.00
Gate Thresh	5.00
RTP Speed	SLOW
RTP Level	-10.00

MH-AGC

Parameter	Value
Attack	2.00
Release	2.00
Make-Up Gain	3.00
Gate Thresh	3.00
RTP Speed	SLOW
RTP Level	-10.00

HF-AGC

Parameter	Value
Attack	2.50
Release	1.50
Make-Up Gain	4.00
Gate Thresh	2.00
RTP Speed	SLOW
RTP Level	-10.00

SH-AGC

Parameter	Value
Attack	2.50
Release	1.50
Make-Up Gain	4.00
Gate Thresh	2.00
RTP Speed	SLOW
RTP Level	-10.00

AGC Mixer

Parameter	Value
Low Band	1.50
Mid-Low Band	1.50
Mid-High Band	1.50
High Band	2.00
Super High Band	2.50

Enhancers

Parameter	Value
Deep Bass	6.00
Phat Bass	3.00
Warmth	2.00
Stereo-EXP	0.00

Limiter X-Over

Parameter	Value
Super Low Gain	1.00
Low Gain	1.00
Mid-Low Gain	0.00
Mid-High Gain	0.00
High Gain	0.00
Super-High Gain	0.00

SL-Limiter

Parameter	Value
Attack	2.50
Release	4.50
Hold Thresh	2.00
Limit Thresh	0.50

LO-Limiter

Parameter	Value
Attack	4.50
Release	3.00
Hold Thresh	2.00
Limit Thresh	0.00

ML-Limiter

Parameter	Value
Attack	4.50
Release	3.50
Hold Thresh	2.00
Limit Thresh	1.50

MH-Limiter

Parameter	Value
Attack	3.00
Release	3.50
Hold Thresh	1.00
Limit Thresh	1.50

HI-Limiter

Parameter	Value
Attack	3.50
Release	3.00
Hold Thresh	1.00
Limit Thresh	1.00

SH-Limiter

Parameter	Value
Attack	4.00
Release	3.50
Hold Thresh	1.00
Limit Thresh	-2.00

Limiters Mixer

Parameter	Value
Super-Low Band	0.00
Low Band	0.00
Mid-Low Band	0.00
Mid-High Band	0.00
High Band	0.00
Super-High Band	0.00

Clipper

Parameter	Value
Bass Clip Thresh	-6.00
Drive	1.00
Clipper Silk	6.00
Comp Clip Drive	N/A

Output Submenu

Parameter	Value
Peak Level Left	
Peak Level Right	
Bypass?	N/A
BS-412 Limiter In?	N/A
Multiplex Pwr Level	N/A
De-emphasis	ON
Output Sample Rate	44.10

Table 1 Omnia 6 FM Analog Parameters Defining "Heavy Aggressive"

Omnia-6 Parameter Worksheet

Preset Name: IBOC Processing

By: ______________________________

Date: ____________________

Parameter	Value
Input Submenu	
Input Source	AES
Input Gain Left	0.00
Input Gain Right	0.00
Master Gain	0.00
Input Mode	Stereo
High Pass Filter	OFF
Phase Rotator	OFF
Pre-emphasis	OFF
Invert Both?	NO

Parameter	Value
WB-AGC	
AGC Drive	0.00
Attack	4.00
Release	1.00
Make-Up Gain	4.00
Gate Thresh	3.00
RTP Speed	Slow
RTP Level	-5.00
AGC In/Out	IN
AGC X-Over	
Low Gain	-2.00
Mid-Low Gain	-2.00
Mid-High Gain	-2.00
High Gain	-2.00
Super-High Gain	-2.00
LF->ML X-over Freq	150.00
ML->MH X-over Freq	700.00
MH->HF X-over Freq	3.2kHz
HF->SHF X-over Freq	7.0kHz

Parameter	Value
LF-AGC	
Attack	0.00
Release	1.50
Make-Up Gain	2.00
Gate Thresh	6.00
RTP Speed	SLOW
RTP Level	-5.00
ML-AGC	
Attack	0.00
Release	2.00
Make-Up Gain	2.00
Gate Thresh	6.00
RTP Speed	SLOW
RTP Level	-5.00
MH-AGC	
Attack	2.00
Release	2.00
Make-Up Gain	3.00
Gate Thresh	5.00
RTP Speed	SLOW
RTP Level	-5.00
HF-AGC	
Attack	1.00
Release	1.50
Make-Up Gain	4.00
Gate Thresh	1.00
RTP Speed	SLOW
RTP Level	-5.00
SH-AGC	
Attack	1.50
Release	1.50
Make-Up Gain	4.00
Gate Thresh	1.00
RTP Speed	SLOW
RTP Level	-5.00
AGC Mixer	
Low Band	0.00
Mid-Low Band	0.00
Mid-High Band	0.00
High Band	0.50
Super High Band	1.50

Parameter	Value
Enhancers	
Deep Bass	4.00
Phat Bass	2.00
Warmth	2.00
Stereo-EXP	0.00
Limiter X-Over	
Super Low Gain	0.00
Low Gain	0.00
Mid-Low Gain	0.00
Mid-High Gain	0.00
High Gain	0.00
Super-High Gain	0.00
SL-Limiter	
Attack	2.50
Release	4.50
Hold Thresh	2.00
Limit Thresh	0.50
LO-Limiter	
Attack	5.50
Release	3.00
Hold Thresh	2.00
Limit Thresh	0.00
ML-Limiter	
Attack	5.50
Release	3.50
Hold Thresh	1.00
Limit Thresh	0.00
MH-Limiter	
Attack	3.00
Release	3.50
Hold Thresh	1.00
Limit Thresh	0.00
HI-Limiter	
Attack	3.50
Release	3.00
Hold Thresh	1.00
Limit Thresh	0.00
SH-Limiter	
Attack	4.00
Release	3.50
Hold Thresh	1.00
Limit Thresh	0.00

Parameter	Value
Limiters Mixer	
Super-Low Band	0.00
Low Band	0.00
Mid-Low Band	0.00
Mid-High Band	0.00
High Band	0.00
Super-High Band	0.00
Clipper	
Bass Clip Thresh	-3.50
Drive	0.00
Clipper Silk	7.00
Comp Clip Drive	N/A

Parameter	Value
Output Submenu	
Peak Level Left	
Peak Level Right	
Bypass?	N/A
BS-412 Limiter In?	N/A
Multiplex Pwr Level	N/A
De-emphasis	OFF
Output Sample Rate	44.10

Table 2 Omnia 6 FM Digital Parameters Defining "Light Processing"