

METHOD TO IMPROVE CONVENTIONAL FM-STEREO TRANSMISSION PERFORMANCE, REDUCE MULTIPATH, AND PROVIDE INCREASED PROTECTION TO THE BASEBAND SPECTRUM

*Frank Foti, Omnia Audio
Cleveland, Ohio
June, 2010*

ABSTRACT

The FM-Stereo transmission system employed in worldwide broadcasting has been in place since 1961. The rules governing stereophonic performance have not been altered since the mid 1980's (in the USA) when they were modified to allow an additional 0.5% total modulation (maximum of 110% total), for every 1% of SCA modulation, if an SCA was being utilized. The rules governing the requirements of the FM-Stereo baseband signal are quite explicit, and leave little - if any - room for improvement of the stereo transmission system.

This paper will express, in detail, a method utilizing single sideband suppressed carrier (SSBSC) modulation of the stereophonic subcarrier in the FM multiplex baseband that is compatible with existing radio receivers. Additionally, there are multiple overall benefits to the broadcast signal, which are perceivable to the listener. They reduce multipath induced distortion, and offer additional protection to the spectrum used for RDS, SCA signals, and HD-Radio content - thereby improving data robustness in the receiver.

Competing For Every Possible Listener

Radio broadcasting has a good fight on its hands. As a media transom to the public, it battles a multitude of additional delivery methods and systems like never before. Until recently, the choices were from television, phonograph records, compact discs, or tape, for the listener's ear. Now, with the advent of good quality portable audio playback devices, and wireless streaming, there are many more franchises available to steal the listener away from radio. What can radio do, technically, to improve its performance so a listener has less reason to abandon it as a media outlet?

HD-Radio was introduced to the marketplace within the last ten years, but has yet to make enough of an impact to keep the casual listener. What's needed is an improvement to the existing infrastructure, which does not require any change, or added expense to the listener. Within present day radio listening, the FM band is the preferred choice. Recent research and development unveiled a unique means to improve the performance of FM-Stereo. What follows is the result of that research, along with a recommendation for FM broadcasting.

Silver Anniversary Of FM-Stereo

April, 2011 marks 50 years since the Federal Communications Commission (FCC) approved stereophonic transmission for the United States. The Commission, after evaluating fourteen proponents, decided upon a method that was of similar design from both Zenith and General Electric.

A quick refresher course how the Zenith/GE system works, courtesy of subpart 73 from the FCC Rules and Regulations:

§ 73.322 *FM stereophonic sound transmission standards.*

- (a) An FM broadcast station shall not use 19 kHz +/-20 Hz, except as the stereophonic pilot frequency in a transmission system meeting the following parameters:
 - (1) The modulating signal for the main channel consists of the sum of the right and left signals.
 - (2) The pilot subcarrier at 19 kHz +/-2 Hz, must frequency modulate the main carrier between the limits of 8 and 10 percent.
 - (3) One stereophonic subcarrier must be the second harmonic of the pilot subcarrier (*i.e.*, 38 kHz) and must cross the time axis with a positive slope simultaneously with each crossing of the time axis by the pilot subcarrier. Additional stereophonic subcarriers are not precluded.
 - (4) Double sideband, suppressed-carrier, amplitude modulation of the stereophonic subcarrier at 38 kHz must be used.
 - (5) The stereophonic subcarrier at 38 kHz must be suppressed to a level less than 1% modulation of the main carrier.
 - (6) The modulating signal for the required stereophonic subcarrier must be equal to the difference of the left and right signals.
 - (7) The following modulation levels apply:
 - (i) When a signal exists in only one channel of a two channel (biphonic) sound transmission, modulation of the carrier by audio components within the baseband range of 50 Hz to 15 kHz shall not exceed 45% and modulation of the carrier by the sum of the amplitude modulated subcarrier in the baseband range of 23 kHz to 53 kHz shall not exceed 45%.
 - (ii) When a signal exists in only one channel of a stereophonic sound transmission having more than one stereophonic subcarrier in the baseband, the modulation of the carrier by audio components within the audio baseband range of 23 kHz to 99 kHz shall not exceed 53% with total modulation not to exceed 90%.

The FM-Stereo system, as described above, has worked quite well for 50 years, but not without challenges. Most notable is multipath distortion, especially in areas of hills or mountainous terrain. Also, radio broadcasters have added incremental signals within the multiplexed spectra. Radio Data Services (RDS), as well as a 92 kHz based SCA can additionally occupy the signal, if desired by the broadcaster. Modulation index of the FM carrier is further reduced with each and every added signal, thus increasing the sensitivity of multipath distortion in the receiver.

Since the inception of stereophonic broadcasting, there has been no technical change to the infrastructure of the Zenith/GE system at all. The FCC rules are quite specific regarding the multiplex spectrum, and its interoperability as a system. After 50 years of service, the system works fairly well, but it could be better. Considering the above mentioned challenges, and the alternatives a listener now has, it makes practical, as well as good business sense to investigate improvements to the present system. It stands to reason that any means proposed, must be backward compatible with existing stereo receivers. Also, after 50 years, a nice anniversary present is in order!

Technical Challenges For FM-Stereo

Multipath is easily the largest annoyance to a radio listener. Broadcast markets located in and around mountainous terrain suffer even more on account of it. Increased multipath is a direct result of low modulation index within the FM carrier. As more spectra is utilized within the multiplex signal, the index of the carrier is reduced. The following condition generates the lowest modulation index: A single audio channel of a two channel system, either Left or Right channel only, generates the maximum amount of spectra within the FM-Stereo system. By example, a 15 kHz tone in the left channel only, will produce multiplex spectra at 15 kHz, 19 kHz (stereo pilot tone), 23 kHz, and 53 kHz. Each of these signals will reduce the modulation index to its smallest level, and this increases sensitivity to multipath in the receiver. *Figure – 1* is an illustration of this.

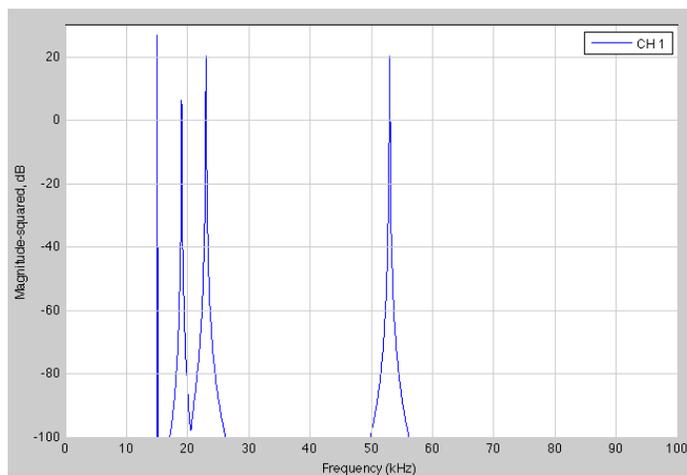


Figure-1, 15 kHz, Left channel only

Note the 30 kHz difference in the L-R subcarrier of the two sidebands located at 23 kHz and 53 kHz. These are generated by the DSBSC process of $(38 \text{ kHz} - 15 \text{ kHz})$ for the lower sideband, and $(38 \text{ kHz} + 15 \text{ kHz})$ for the upper sideband. During multipath, as the multiple reflections of the FM carrier arrive at, and then become demodulated in the receiver, the time delay difference created by the carrier reflections will offset the phase of the upper and lower sidebands. During the demux process, stereo separation, at these frequencies is reduced as the recovered L-R level is negatively altered due to phase shift brought on by multipath.

Bandwidth of the conventional analog FM channel is allocated for 99 kHz of spectrum use. The FM-Stereo system requires 53 kHz (0 Hz – 53 kHz) of this available real estate. The remaining 46 kHz (53 kHz – 99 kHz) is used for RDS and SCA services. Common practice requires the use of audio processing to insure proper peak level and bandwidth control of the various signals present in the multiplex spectrum. Current generation processors are capable of creating near-theoretical multiplex signals. In these cases, there are little, if any, transmission difficulties for the signal.

Some broadcasters choose to employ a form of processing known as composite clipping. This technique inserts a hard limiter (clipper) at the output of the stereo baseband generator, and will induce up to as much as 3dB of clipping to the multiplex signal. These devices provide no additional filtering to remove unwanted harmonic content from the clipping process. The additional harmonics will cover the entire 46 kHz, and beyond, used for RDS and SCA services. This creates interference and distortion to those signals. Also, these harmonics may interfere with the digital carriers generated for HD-Radio, as these carriers are set 120 kHz out from the main channel carrier.

Another known challenge for the system is the compromised signal-to-noise (SNR) level when broadcasting stereo. FM transmission noise will rise at 6dB per octave over the channel's passband range of 99 kHz. It has been generally accepted that FM-Stereo suffers a 23dB noise penalty compared to monophonic broadcasting. This is due to the rising noise floor over the subcarrier range of 23 kHz – 53 kHz, as compared to the SNR over the range of 0 Hz – 15 kHz which is used for mono. *Figure – 2* is an illustration of the composite baseband signal. *Figure – 3* shows the 6dB/octave noise floor slope of an FM channel, as it would appear at the output of an IF section in a receiver. *Figure – 4* represents the SNR response through the composite baseband signal. This illustration superimposes the noise response across the composite spectrum. It is easy to observe the most severe noise spectra occurs in the upper subband of the stereo subchannel.

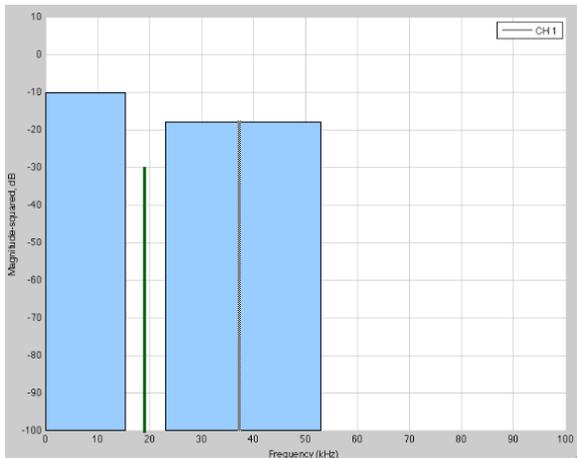


Figure – 2, Baseband Spectra

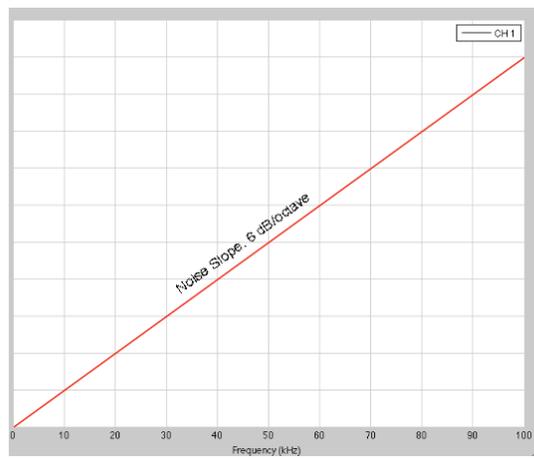


Figure – 3, FM Channel Noise Response

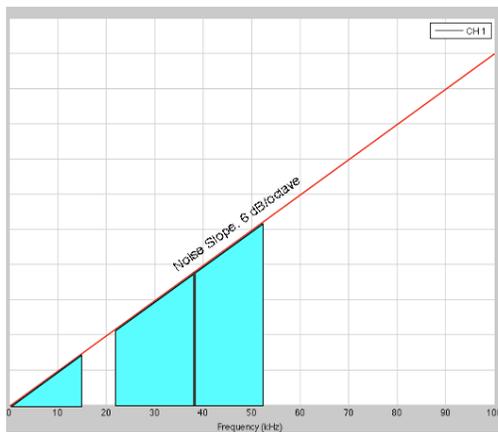


Figure – 4, Receiver IF Output SNR

Alternative Approach

Prior to 1973, when the phase locked loop (PLL) circuit was introduced into the consumer receiver market, FM detectors required the transmitted multiplex signal to employ double sideband suppressed-carrier (DSBSC) so the demodulation means could faithfully recover the stereophonic (L-R) signal. Today, there are very little, if any, pre-1973 stereo radios in use.

An alternative approach for stereo transmission would be the use of single sideband suppressed carrier (SSBSC) as the mechanism to carry to the L-R payload. The lower sideband is chosen as it reduces the occupied spectrum from 53 kHz down to 38 kHz. In order to support the correct L+R/L-R matrixing in the receiver, the amplitude of the lower sideband is increased by 6dB. This offers numerous benefits to the receiver:

1. Reduction of occupied bandwidth in the L-R subchannel range increases the FM modulation index by a factor of two. This directly reduces multipath distortion.
2. Narrows the overall FM transmission bandwidth and reduces degradation of stereo performance caused by finite bandwidth of passband filters, cavities, multiplexing systems, and antennas. If adopted internationally, this further benefits broadcasters 100 kHz channel spacing is used in some countries, as compared to the 200 kHz spacing used here in the USA.
3. Creates additional and significant protection for RDS, SCA, and HD-Radio signals. **Note:** With a HD Radio power increase looming, reduction of the composite spectrum benefits conventional receivers due to less demod overlap of the HD Radio signal.
4. Compatible with all existing modulation monitoring systems.
5. Compatible with detectors in current model (post 1973) receivers.
6. Less harmonic content generated throughout the channel spectrum when composite clipping is employed in the transmission audio processor.

The concept of utilizing SSB modulation for the L-R payload has been written about before. A white paper on this topic titled, “*A New Method of Generating FM and Television Stereo Composite Baseband Yields Improved Broadcast Performance,*” was presented by William Gillman at the 1997 NAB Engineering Conference. Reviewing Mr. Gillman’s paper, and subsequent testing by this author confirms his findings, and along with technological advances in the transmission firmware, makes this concept much more plausible.

Tech Findings

Implementing SSB modulation of the L-R signal is relatively easy to accomplish using DSP. *Figure – 5* is a spectral diagram of a 15 kHz single channel tone using DSBSC system. *Figure – 6* is the same condition, except SSBSC modulation is utilized.

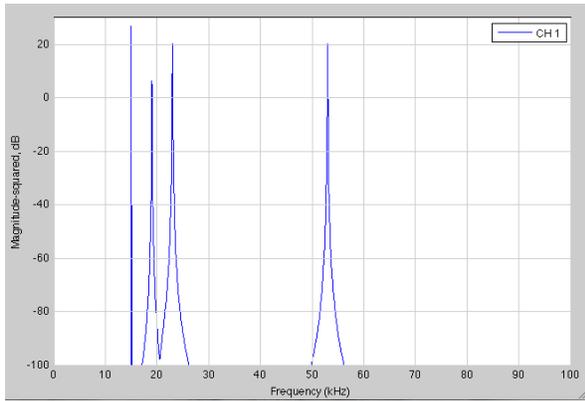


Figure – 5, 15 kHz tone, single channel, DSBSC

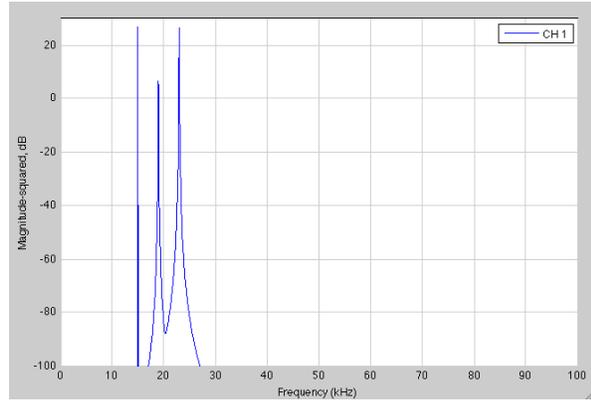


Figure – 6, 15 kHz tone, single channel, SSBSC

Note the 6dB increase in level of the SSB carrier in *Figure – 6*. This illustrates the manner in which the L+R/L-R mathematics are upheld in the receiver.

Easy to observe the significant difference in spectrum used. The DSBSC method forces the single channel condition of 15 kHz to exist across a broad range. The fundamental is at 15 kHz, and the two sidebands are at 23 kHz and 53 kHz respectively. The DSBSC example illustrates the fragility in faithful reproduction of stereophonic high frequencies during instances of multipath. The group delay at 15 kHz, 23 kHz, and 53 kHz becomes non-linear, during multipath, and this is why stereophonic high frequencies are so fragile with respect to multipath.

Compare the spectra of *Figure – 5* with that of *Figure – 6*. The close proximity of the 15 kHz fundamental, and the 23 kHz SSB carrier improves high frequency robustness during multipath. Due to the closeness of these two frequencies, there is less adverse affect when multipath non-linearities are created, and high frequency stereophonic performance is audibly improved.

Using a noise source in one channel, the same tests were performed. The results are illustrated in *Figures 7 & 8*.



Figure – 7, noise, single channel, DSBSC

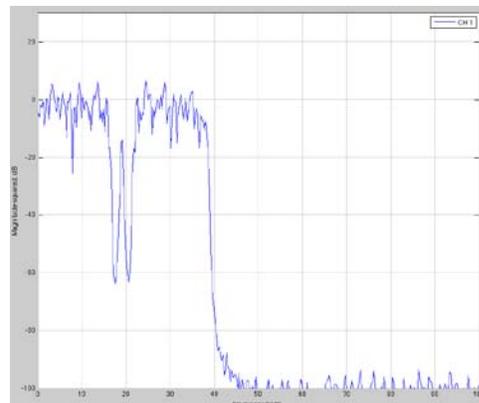


Figure – 8, noise, single channel, SSBSC

SSB subchannel modulation makes FM channel occupancy more efficient. *Figure – 9* demonstrates carrier deviation of the RF signal using DSBSC modulation of a single channel noise source. *Figure – 10* is the same test signal, except SSBSC modulation is employed. For the example shown here, the carrier frequency is 400,000 kHz, with deviation set to 4 kHz.

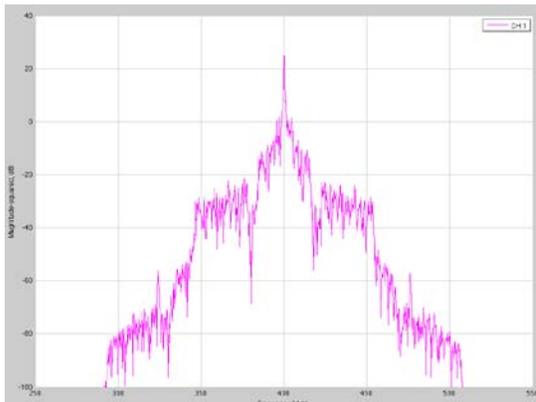


Figure – 9, FM Deviation, DSBSC, Noise, Left

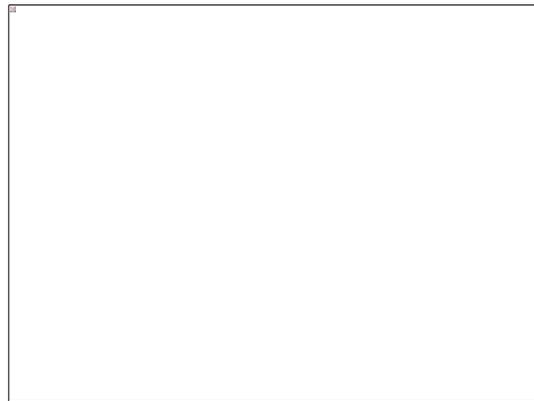


Figure – 10, FM Deviation, SSBSC, Noise, Left

Once again, it is easy to observe the reduction in utilized spectrum. The signal shown in *Figure – 10* will pass through narrow cavities, combiners, and mal-adjusted antennas with better stereo performance than the broader signal shown in *Figure – 9*.

Another mentioned benefit SSB brings to the transmission method is added spectral protection to RDS, SCA, and HD-Radio services. *Figure – 11* is an example. Single channel only pink noise is used to generate the baseband signal with SSBSC modulation. Notice the extremely wide guard band that exists between 38 kHz and where the first SCA carrier would appear at 57 kHz. The reduction in cross-talk to ancillary services is exceptional!



Figure – 11, Single Channel Only Pink Noise, SSBSC

What's Next...

Transmitting SSBSC modulation of the FM-Stereo signal can be done right now! Software exists to implement this method today. One minor item must be addressed: FCC rule 73.322, section (A), subpart (4) which states "Double sideband, suppressed-carrier, amplitude modulation of the stereophonic subcarrier at 38 kHz must be used." Seems there was a time, when rule 73.322(A)(4) was required. Times have changed. Both transmission and reception firmware have improved significantly to enable a change in the rules and regulations governing the FM-Stereo baseband signal.

The theory, testing, and findings presented here should be more than enough evidence for the FCC to consider, at the very least, a Special Temporary Authority (STA) to enable all broadcasters to implement the SSBSC transmission method. Benefit will occur immediately to those whom employ this, especially those in areas of rough terrain with significant hills, and mountains.

After 50 years of service, a modification to the rules and regulations governing FM-Stereo service would be a wonderful anniversary present indeed! Most importantly, the benefactors are the general public - radio listeners, as audible annoyances will be suppressed, and in some cases eliminated. At a time when broadcasters are looking to find every possible way to enhance their customers (the listener's) experience, this change in the rules would benefit everyone. This is total upside, with nothing downside for all.

The author would like to thank William Gillman for his exceptional paper written in 1997, which provided a point of reference in this investigation. Additionally, thanks to Steve Church for his support and enthusiasm in our joint audio processing, and transmission system efforts.