Effects of Limited Bandwidth Transmission Paths in FM on SCA/RDS Performance

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Abstract - This paper explores the effects of limited bandwidth transmission paths of FM broadcast stations on audio performance, and SCA/RDS performance.

Introduction

There has been much study and discussion regarding the effects of bandwidth limitation on FM signals in the past five years. Particular attention has focussed on the parameter of Synchronous AM. Indeed, this parameter is useful as an index of the total effective bandwidth, but experimentation and computer modeling has shown that Synchronous AM alone is not the most damaging effect of bandwidth limitation.

Types of Bandwidth Limitation

Bandwidth in an FM transmission system may be limited in many ways. The most often discussed limitations include the bandpass cavities which make up antenna combiner systems, and the output cavity design in the FM transmitter. Other areas which contribute include the antenna system, the grid matching circuit in the transmitter, a tuned intermediate power amplifier in the transmitter, and the front end / IF stages in the receiver. It is the cumulative effect of these filters which determines the overall performance of the system.

It is important to realize that there are at least two subcategories of these filters, those which precede a limiting amplifier, and those which do not. Traditionally, we have ignored those filters which precede limiting amplifiers, because it is presumed that the limiting amplifier will, by its nature, remove the amplitude effects on the signal and leave only the frequency modulation.

An example of a filter which precedes a limiting amplifier is the grid tuning / matching network, which resonates the substantial tube input capacitance and matches the 50 ohm input impedance from the IPA to the grid of the final amplifier. As the grid is normally driven into limiting, the amplitude effects of the input circuit Q masked, however the time delay induced damage that this filter may cause can be substantial.

Asymmetrical Group Delay is the problem

Group delay may be defined as the difference in time that is required for the various elements of a signal to propagate through the device. Group delay asymmetry is defined as the difference in group delay between the upper and lower sidebands. In the case of FM transmission, it is the difference in nanoseconds that it takes the upper vs lower sidebands to propagate through the transmitter. When the sidebands do not arrive at the output of the transmitter at the same time, distortion is created which manifests itself in crosstalk.

There is a group delay effect to any bandpass filter, and the effect of this group delay can be more damaging to the audio and subcarrier quality than the Synchronous AM effect. Worse, the group delay effect is NOT removed when the signal is passed through a limiting amplifier, nor can its effect be diagnosed with conventional Synchronous AM tests.

Computer Modeling

To study these effects, Broadcast Electronics co-operated with Quantics of Nevada City, CA to develop a software program which models the effects of these distortions on an FM signal. This program is available from Broadcast Electronics. The following series of graphs are generated by this program and show the differences in the generated composite baseband distortion components which are caused by the amplitude response effects (Synchronous AM) and asymmetrical group delay effects for two different cases. The first case [Figures 1 to 5] shows a second order synchronously tuned filter, each section 1 MHz wide, with the amplitude response centered on the passband, and the group delay of one section offset by 90 kHz. This is indicative of typical offset between amplitude and group delay found in many single tube transmitter designs.

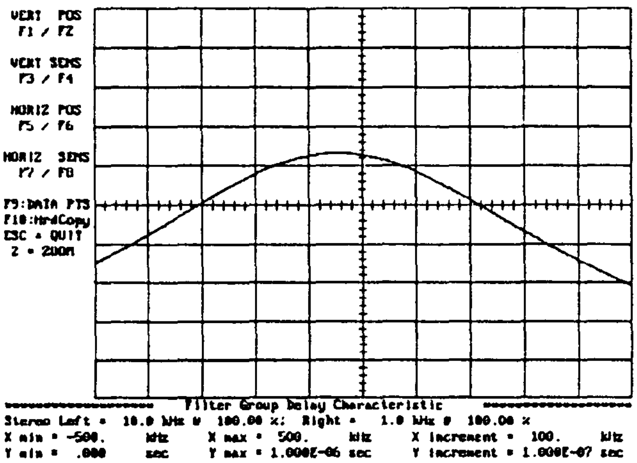

Figure 1. Group Delay Characteristic

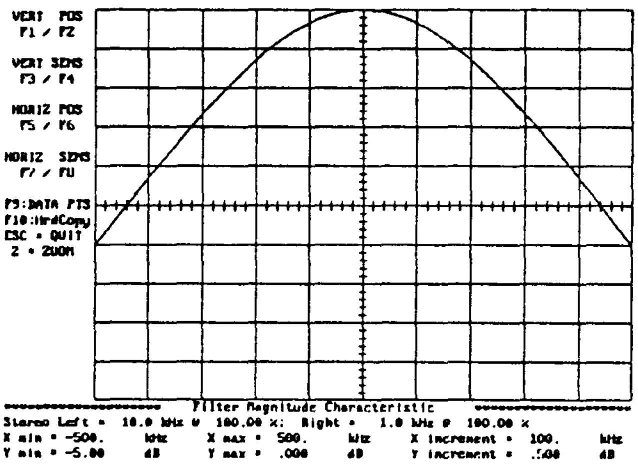

Figure 2. Magnitude Characteristic

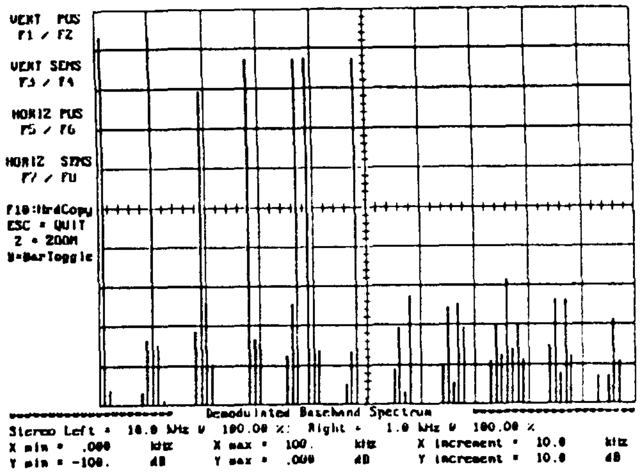

Figure 3. Total Composite Spectrum Effects

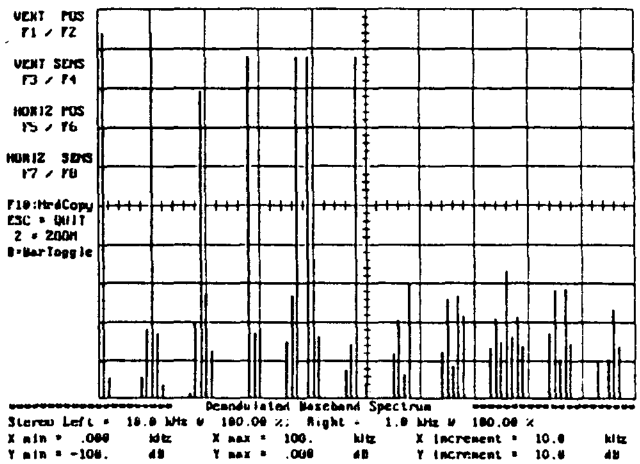

Figure 4. Group Delay Effects Only

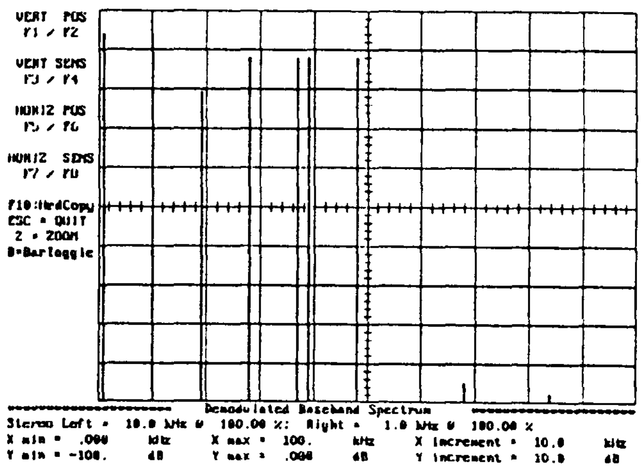

Figure 5. Magnitude Effects Only

Ignoring the six desired signals, which are at 10 and 1 kHz (L+R), 19 kHz (pilot), and 28, 37, 39 and 48 kHz (L-R), note the generation of significant distortion components, even though the Synchronous AM has been minimized by centering the amplitude response.

It is these baseband distortion products which interfere with not only the L+R and L-R signals, degrading the stereo performance of a station, but also with the SCA and RDS subcarriers which may exist above 53 kHz.

In case 2 [Figures 6 to 10], the identical modulating conditions and filter bandwidths are used. The only difference is that the group delay and amplitude response are now both centered in the passband. In both cases, the most serious effects are caused by the group delay effects, as opposed to the amplitude effects.

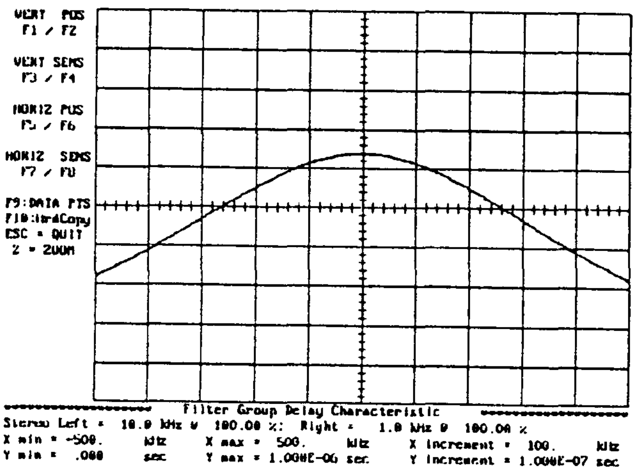

Figure 6. Group Delay Characteristic

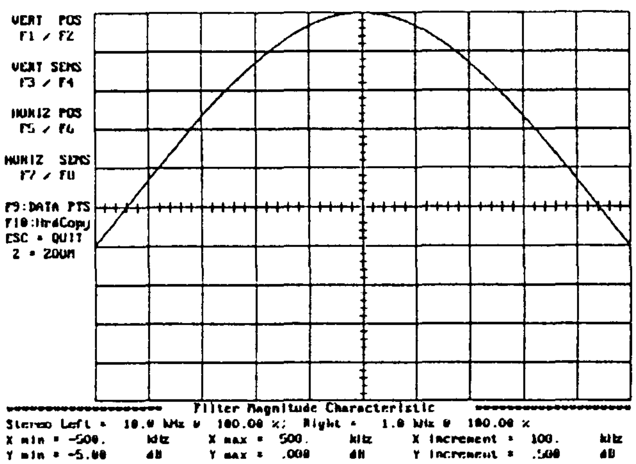

Figure 7. Magnitude Characteristic

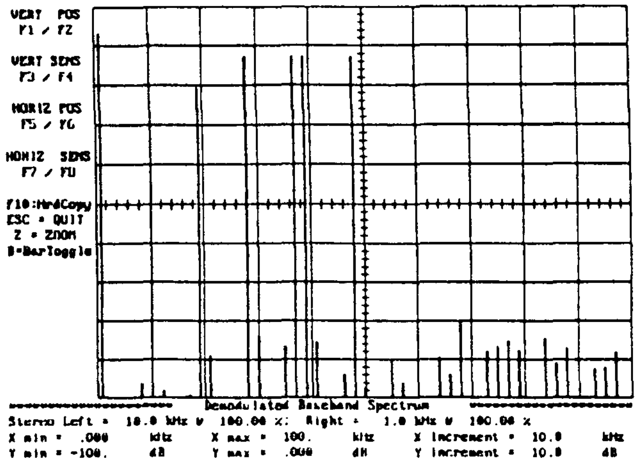

Figure 8. Total Composite Spectrum Effects

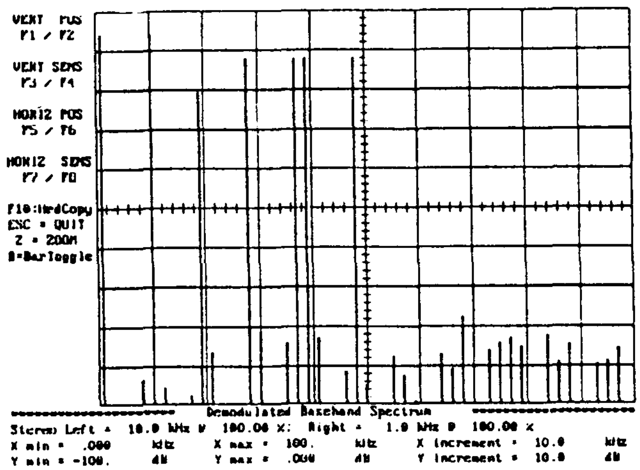

Figure 9. Group Delay Effects Only

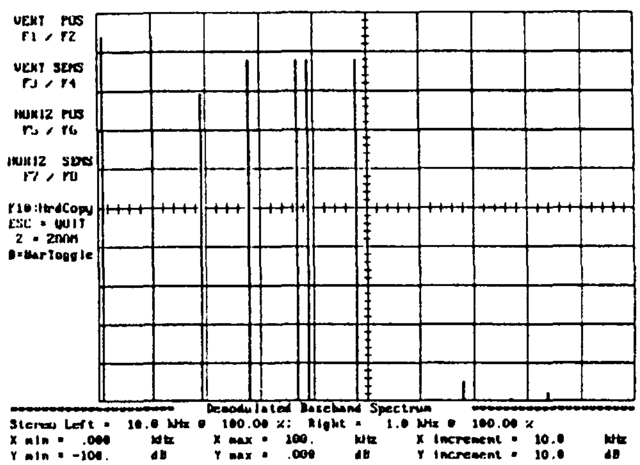

Figure 10. Magnitude Effects Only

FM Subcarriers

FM subcarriers have been growing in importance around the world in the last few years, with Radio Data service gaining in acceptance in Europe and elsewhere. These services rely on low level subcarriers being added to the FM baseband signal above 53 kHz. They are generally 20 dB lower in amplitude than the L+R signal, and thus are susceptible to crosstalk.

Typical subcarrier frequencies for SCA are 67 and 92 kHz, and for RDS, 57 kHz. It is easy to see that the distortion products generated in the graphs will cause significant interference to the subcarrier services.

Tuning for minimum crosstalk

As broadcast engineers, we have witnessed an interesting change in the way we tune FM transmitters. Most of us learned to tune for maximum power and maximum efficiency. Then, a few years ago, we learned how to tune for minimum Synchronous AM. However, now we have seen that, in order to minimize the effects of group delay on our baseband signal, we must find a way to tune for group delay symmetry.

FM broadcast transmitter RF power amplifiers are typically adjusted for minimum synchronous AM (incidental amplitude modulation) which results in symmetrical amplitude response. This will assure that the transmitter's amplitude passband is properly centered on the FM channel. The upper and lower sidebands will be attenuated equally or symmetrically which is ASSUMED to result in optimum FM modulation performance. This will be true if the RF power amplifier circuit topology results in simultaneous symmetry of amplitude and group delay responses.

Actually, symmetry of the group delay response has a much greater effect on FM modulation distortion than the amplitude response. Tuning for symmetrical group delay will cause the phase/time delay errors to affect the upper and lower sidebands equally or symmetrically. The group delay response is constant if the phase shift versus frequency is linear. All components of the signal are delayed in time, but no phase distortion occurs.

The tuning points for symmetrical amplitude response and symmetrical group delay response usually do NOT coincide, depending on the circuit topology. Therefore, simply tuning for minimum synchronous AM (symmetrical amplitude response) does not necessarily result in best FM modulation performance.

Measurements taken on a typical FM transmitter as well as computer simulations showed that tuning the RF power amplifier for symmetrical group delay response resulted in minimum distortion and crosstalk. It confirms that group delay response asymmetry causes higher FM modulation distortion and crosstalk than amplitude response asymmetry. Therefore, RF power amplifier circuit topologies that exhibit coincidence of symmetrical amplitude and group delay responses will result in a better overall FM modulation performance. The transmitter should be tuned for symmetrical group delay response which results in best FM modulation performance rather than symmetrical amplitude response which results in minimum synchronous AM.

All optimization should be done with any automatic power control (APC) system disabled so that the APC will not chase the adjustment in an attempt to keep the output power constant. The transmitter should be connected to the normal antenna system rather than to a dummy load. This is because the resistance and reactance of the antenna will be different from the dummy load and the optimum tuning point of the transmitter will shift between the two different loads. The tuning sequence is:

Initial Tuning And Loading

The transmitter is first tuned for normal output power and proper efficiency according to the manufacturer's instruction manual. The meter readings should closely agree with those listed on the manufacturer's final test data sheet if the transmitter is being operated at the same frequency and power level into an acceptable load.

Input Tuning And Matching

The input tuning control should first be adjusted for maximum grid current and then fine tuned interactively with the input matching control for minimum reflected power to the driver stage. Note that the point of maximum grid current may not coincide with the minimum reflected power to a solid state driver. This is because a solid state driver may actually output more power at certain complex load impedances than into a 50 ohm resistive load. The main objective during input tuning is to obtain adequate grid current while providing a good match (minimum reflected power) to the coaxial transmission line from the driver. In the case of an older transmitter with a tube driver integrated into the grid circuit of the final amplifier, the driver plate tuning and the final grid tuning will be combined into one control which is adjusted for maximum grid current.

Output Tuning

The output tuning control adjusts the resonant frequency of the output circuit to match the carrier frequency. As resonance is reached, the plate current will drop while both the output power and screen current rise together. Under heavily loaded conditions this "dip" in plate current is not very pronounced, so tuning for a "peak" in screen current is often a more sensitive indicator of resonance.

Amplifiers utilizing a folded half wave cavity will display little interaction between output tuning and output loading because the output coupling loop is located at the RF voltage null point on the resonant line. Quarter wave cavities will require interactive adjustment of output tuning and output loading controls, since changes in loading will also affect the frequency of the resonant line.

Output Loading

There is a delicate balance between screen voltage and output loading for amplifiers utilizing a tetrode tube. Generally there is one combination of screen voltage and output loading where peak efficiency occurs. At a given screen voltage, increasing the amplifier loading will result in a decrease in screen current, while a decrease in loading will result in an increase in screen current. As the screen voltage is increased to get more output power, the loading must also be increased to prevent the screen current from reaching excessive levels. Further increases in screen voltage without increased loading will result in a screen overload without an increase in output power.

Automatic Power Control Headroom

Automatic power control (APC) feedback systems are utilized in many transmitters to regulate the power output around a predetermined set point with variations in AC line voltage or changes in other operating parameters. Most modern FM broadcast transmitters utilize a high gain tetrode as the final amplifier stage with adjustment of the screen voltage providing fine adjustment of the output power.

For each power output level there is one unique combination of screen voltage and output loading that will provide peak operating efficiency. If the screen voltage is raised above this point without a corresponding increase in loading, there will be no further increase in power output with rising screen voltage and screen current. If the screen voltage is raised without sufficient loading, a screen current overload will occur before the upward adjustment in power output is obtained. To avoid this problem, it is a good idea to tune the transmitter with slightly heavier loading than necessary to achieve the desired power output level in order to allow for about 5% headroom in adjustment range. The output loading can be adjusted for a "peak" in output power of 5% over the desired level and then the screen voltage can be reduced enough to return to the desired level. This procedure will allow headroom for an APC system controlling screen voltage and will result in about a 1% compromise in efficiency, but it will assure the ability to increase power output up to 5% without encountering a screen overload.

Centering the Passband

A simple method for centering the transmitter passband on the carrier frequency involves adjustment for minimum synchronous AM. If the bandpass is narrow or skewed, increasing synchronous amplitude modulation of the carrier will result. A typical adjustment procedure is to FM modulate 100% at 1 kHz and fine-adjust the transmitter's grid tuning and output tuning controls for minimum 1 kHz AM modulation as detected by a wideband envelope detector (diode and line probe). 1 kHz is used as the FM modulating frequency rather than 400 Hz so that the audio highpass filter in the audio analyzer can be used to eliminate the AC line frequency related asynchronous component from the synchronous AM component. It is helpful to display the demodulated output from the AM detector on an oscilloscope while making this adjustment. Note that as the minimum point of synchronous AM is reached, the demodulated output from the AM detector will double in frequency to 2 kHz, because the fall-off in output power is symmetrical about the center frequency causing the amplitude variations to go through two complete cycles for every one FM sweep cycle. It should be possible to minimize synchronous AM while maintaining output power and efficiency in a properly designed power amplifier.

Effect of Transmitter Tuning on FM Sidebands

The higher order FM sidebands will be slightly attenuated in amplitude and shifted in time (group delay) as they pass through the final amplifier stage. These alterations in the sideband structure that are introduced by the amplifier passband, result in distortion after FM demodulation at the receiver. The amount of distortion is dependent on the available bandwidth versus the modulation index being transmitted. For a given bandwidth limitation, the distortion can be minimized by centering the passband of the amplifier around the signal being transmitted. This will cause the amplitude and group delay errors to affect both the upper and lower sidebands equally or symmetrically. Tuning an amplifier for minimum plate current or for best efficiency does not necessarily result in a centered passband. One way to center the amplitude passband is to tune the amplifier for minimum synchronous AM modulation while applying FM modulation to the transmitter. Since the circuit topology of most transmitters exhibits a difference in tuning between the symmetrical amplitude response and the symmetrical group delay response, FM modulation performance can be further improved by tuning for symmetrical group delay rather than for minimum synchronous AM. The symmetrical group delay tuning point usually does not coincide exactly with the symmetrical amplitude tuning point and falls between the point of minimum synchronous AM and the point of maximum efficiency.

The transmitter may be tuned for minimum intermodulation distortion in left-only or right-only stereo transmissions. Stereo separation will also vary with tuning. For stations employing a 67 kHz SCA, transmitter tuning becomes very critical to minimizing crosstalk into the SCA. Modulate one channel only on the stereo generator to 100% with a 3.5 kHz tone. This will place the lower second harmonic (L-R) stereo sideband within 2 kHz of the 67 kHz SCA. Activate the SCA at normal injection level without modulation on the SCA. Tune the transmitter for minimum 2 kHz output from the SCA demodulator. This adjustment can also be made by listening to the residual SCA audio while normal stereo programming is being broadcast.

A more sensitive test is to tune for minimum even order harmonic distortion which will result in a symmetrical group delay response and will optimize distortion, separation, and crosstalk.

The latest generation of power amplifiers have been designed to operate without compromising subcarrier performance. By providing broadband matching circuits, adjustment of these transmitters for optimum FM modulation performance (minimum distortion, minimum crosstalk, maximum separation, etc.) is very repeatable and stable. The field adjustment techniques are listed below in ascending order of sensitivity:

1. Tune for minimum synchronous AM noise.
2. Tune for minimum IMD in the left or right channel only.
3. Tune for minimum crosstalk into the unmodulated SCA subcarrier.
4. Tune for minimum even order harmonic distortion. (symmetrical group delay)

In any of these tests, the grid tuning is frequently more critical than the plate tuning. This is because the impedance match into the input capacitance of the grid becomes the bandwidth limiting factor. Even though the amplitude response appears flattened when the grid is heavily driven, the group delay (time) response has a serious effect on the higher order FM sidebands.

Optimum tuning versus efficiency

VHF amplifiers often exhibit a somewhat unusual characteristic when tuning for maximum efficiency. The highest efficiency operating point does not exactly coincide with the lowest plate current because the power output continues to rise on the inductive side of resonance coming out of the dip in plate current. If the amplifier is tuned exactly to resonance, the plate load impedance will be purely resistive and the load line will be linear. As the output circuit is tuned to the inductive side of resonance, the plate load impedance becomes complex and the load line becomes elliptic instead of linear since the plate current and plate voltage are no longer in phase. Apparently best efficiency occurs when the phase of the instantaneous plate voltage slightly leads the plate current. This effect is believed to be caused by the non-linear gain characteristics of the power amplifier tube operating on an elliptic load line.[1]

Summary

FM broadcast signals are significantly affected by asymmetrical group delay response. This effect is most pronounced in SCA and RDS subcarriers. Careful tuning of the transmitter can minimize the distortion, and maximize the performance of these services.

Acknowledgements

The author wishes to thank the Engineering Department of Broadcast Electronics and Quantics, Inc., in particular, Geoff Mendenhall, Mukunda Shrestha, Ed Anthony, and Dave Hershberger, without their assistance, this paper would have been impossible.

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