IMPROVING FM MODULATION PERFORMANCE BY TUNING FOR SYMMETRICAL GROUP DELAY

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ABSTRACT

FM broadcast transmitters are often tuned for minimum synchronous AM resulting in a symmetrical amplitude response which is *assumed* to minimize FM distortion. This would be true if the RF power amplifier circuit topology resulted in simultaneous symmetry of the amplitude and group delay responses.

Recent research using computer modeling and empirical tests have verified that simply tuning for minimum synchronous AM does *not* result in best FM modulation performance, because the symmetry of the group delay response has a much greater effect on distortion of the FM modulation than the amplitude response.

This paper describes a simple procedure to optimize the FM modulation performance of any FM transmitter by tuning for symmetrical group delay using a broadcast modulation monitor and standard test equipment found in most radio stations.

INTRODUCTION

FM Broadcast Engineers need a simple and effective procedure to tune FM transmitter power amplifier(s) for best FM modulation performance. Over the past several years, procedures for tuning the amplifier(s) for minimum synchronous AM (ICAM) resulting from FM modulation have been used with some success to improve FM modulation performance. This paper explains an alternative tuning procedure that offers further improvements in FM modulation performance. The new procedure involves tuning the amplifier(s) for symmetrical group delay instead of minimum synchronous AM (ICAM). Before getting into this procedure, the terminology needs to be defined.

DEFINITION OF TERMS

Synchronous AM

The perfect FM transmitter would have an absolutely constant output amplitude, regardless of FM modulation or power supply variations. A practical FM transmitter produces an output which varies in amplitude as well as frequency. The portion of the amplitude variation resulting from the FM modulation is called "Synchronous AM".

Synchronous AM, also referred to as Synchronous AM Noise or Incidental Carrier AM (ICAM), is a measure of the amount of incidental amplitude modulation introduced onto the carrier by the presence of FM modulation. Since all transmitters have limited bandwidth, there will be a slight change in power output as the carrier frequency is swept to either side of the center frequency. This change in RF output level follows the waveform of the audio frequency being applied to the FM modulator causing AM modulation in synchronization with the FM modulation. This concept is similar to the slope detection of FM by an AM detector used in conjunction with a tuned circuit. The technical paper entitled "Optimum Bandwidth for FM Transmission"[1] provides further insight into the overall bandwidth required to achieve a given level of FM modulation performance.

Synchronous AM measurements give the station engineer a rough idea of the overall system bandwidth and whether the transmitter is tuned to position the amplitude passband correctly.

Symmetrical Group Delay

Another way in which practical transmitters deviate from the ideal, is the group delay response. Group delay refers to the propagation time delay variations between a group of several different frequency components (FM sidebands) propagating through the transmitter power amplifier(s). Each different frequency component (FM sideband) will pass through the input and output network(s) at a slightly different rate, so that the FM sidebands in the group are not all delayed equally in time, hence the term Group Delay refers to the total time delay variation of the group of FM sidebands. Symmetrical Group Delay refers to a tuning condition that causes the Group Delay (time) variations to be equal above and below the center frequency of the transmitter.

Another way of viewing Group Delay, is to observe the phase shift of each FM sideband passing through the output amplifier(s). If each FM sideband is phase shifted linearly with frequency, the Group Delay (time) will be constant. Constant Group Delay is therefore equivalent to linear phase shift with frequency. A properly terminated piece of transmission line provides constant group delay and linear phase shift. All components of the signal are delayed equally in time and no phase distortion occurs.

FM Modulation Performance

For the purpose of this presentation, FM modulation performance is defined as the overall quality of the FM baseband information transmitted to the consumer. Quality factors include the amount of harmonic distortion, intermodulation distortion, stereo separation, and crosstalk between subcarriers. Factors which are not part of the demodulated baseband include AM signal to noise ratios that do not directly affect FM modulation performance.

LIMITATIONS OF SYNCHRONOUS AM MEASUREMENTS

Synchronous AM measurements are an indirect way of evaluating and optimizing FM performance. Even though synchronous AM measurements are a helpful aid to begin tuning an FM transmitter, these measurements tell only the amplitude response half of the total story. Transmitter tuning also affects the group delay (time) response which changes the relative time delays of the higher order FM sidebands.

FM broadcast transmitter RF power amplifiers are typically adjusted for minimum synchronous AM. This results in a symmetrical amplitude response by centering the transmitter's amplitude passband 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 would be true if the RF power amplifier circuit topology resulted in simultaneous or coincidental symmetry of the amplitude and group delay responses.

The tuning points for symmetrical amplitude response and symmetrical group delay response normally do *not* coincide, depending on the circuit topology of the RF power amplifier. Therefore, simply tuning for minimum synchronous AM (symmetrical amplitude response) normally does not result in best FM modulation performance. The technical paper entitled "The Significance of Power Amplifier Circuit Topology on FM Modulation Performance"[2] provides detailed information about various power amplifier circuit topologies.

Symmetrical Amplitude (Synchronous AM) versus Symmetrical Group Delay Response

A computer simulation called FMSIM[3] was jointly developed by Broadcast Electronics and Quantics Software to explore the effects of the transmitter output network(s) and FM filterplexing systems on FM modulation performance. FMSIM allows the effects of the Amplitude Response to be independently compared with the effects of Group Delay response. The independent evaluation of amplitude versus group delay effects are difficult or impossible to do empirically since the amplitude and group delay responses are inseparable in a real network. The results of these simulations showed that amplitude differences between the upper and lower sidebands of the FM signal have little direct effect on FM modulation performance, while *Group Delay (time)* differences between the upper and lower sidebands have a much more profound effect on FM modulation performance.

Furthermore, the analysis revealed that when the group delay is symmetrical above and below the carrier frequency, the total FM distortion is minimized. In particular, the even order (2nd, 4th, 6th, ...) harmonics of the audio modulating frequency drop out.

Figure-1 shows a spectrogram of baseband distortion products from a power amplifier that is tuned for a symmetrical amplitude response (minimum synchronous AM) with an asymmetrical group delay response. Note that both even and odd order distortion products are visible in the demodulated baseband.

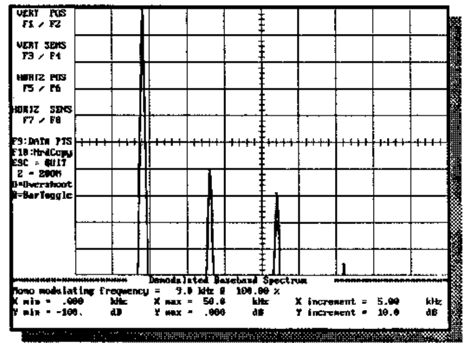

FIGURE-1

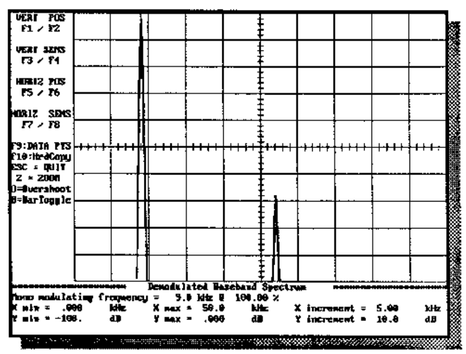

FIGURE-2

Figure-2 shows a similar spectrogram from the same power amplifier that has been re-tuned for a symmetrical group delay response centered on the carrier frequency. Note that only odd order distortion products are now visible. This effect leads to a simple, low cost procedure for tuning the amplifier(s) to this condition without the use of network analyzers or other complicated test equipment.

Tuning for Best FM Modulation Performance

Tuning for minimum synchronous AM is a good starting point, but it is desirable to finish tuning at the symmetrical group delay point. Fine tuning the input and output for minimum even order harmonic distortion will optimize the group delay (time) response.

Tuning the transmitter for minimum even order harmonic distortion will result in a symmetrical group delay response and optimum FM modulation performance. This can be accomplished by: (1) observing the even order harmonics in the demodulated baseband with a spectrum analyzer or by (2) placing an audio bandpass filter (tuned to the second harmonic of the audio modulating frequency) on the input of the audio distortion analyzer.

Most FM stations have an FM stereo modulation monitor with a 19kHz bandpass filter and metering circuitry that is normally used to measure the 19kHz pilot tone injection level. This monitor function can also be used to tune for symmetrical group delay if the transmitter is 100% modulated with a single 9.5kHz monaural tone *without 19 kHz pilot*. The second harmonic distortion produced by transmitter amplifier(s) mistuning will fall within the 19kHz bandpass of the monitor's pilot injection level metering and will appear as if there was a pilot tone present. Tuning the transmitter power amplifier(s) for a minimum pilot injection level indication will null the second and other even order harmonics of the 9.5 kHz modulating tone resulting in symmetrical group delay of the sidebands.

If the FM station does not have a suitable stereo modulation monitor, a simple 19kHz bandpass filter can be inserted between the composite output of the RF to baseband demodulator and the audio voltmeter. The transmitter is then tuned for minimum audio voltage produced by second harmonic distortion.

The passive 19kHz bandpass filter can be purchased from one of the companies shown in the references[4] or it can be easily constructed out of readily available inductors and capacitors[5] according to the schematic shown in Figure-3.

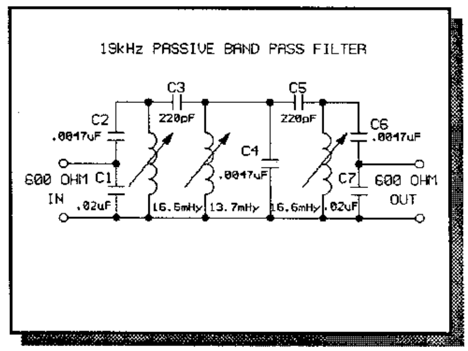

FIGURE-3

Figure-4 shows the amplitude response and insertion loss of the 19kHz bandpass filter illustrated in Figure-3.

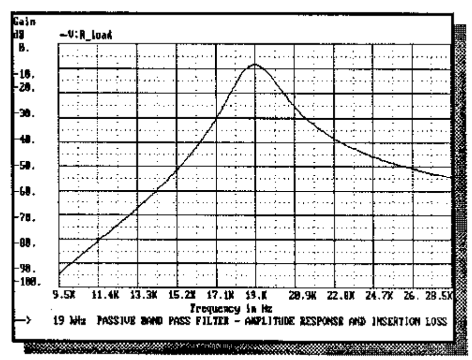

FIGURE-4

The 19kHz filter should have at least 80 dB rejection of the 9.5kHz modulating tone and at least 50 dB rejection of the third and higher harmonics of 9.5kHz.

Be certain that the FM demodulator has good linearity and does not introduce distortion products that would cause the broadcast engineer to mistune the transmitter to compensate for the distortion introduced by the demodulator. Modulation monitors that utilize a pulse-counting discriminator are usually the most dependable for this measurement.

CONCLUSIONS

1. 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. Depending on the circuit topology, the tuning conditions for symmetrical group delay response may not coincide with the symmetrical amplitude response.

2. Simply tuning for minimum synchronous AM (symmetrical amplitude response) does not necessarily result in best FM modulation performance. Best FM modulation performance is always obtained when the system is tuned for symmetrical group delay (time) response.

3. Most FM transmitters will exhibit a significant increase in synchronous AM when tuned for symmetrical group delay response even though this condition results in best FM modulation performance.

4. The symmetrical group delay tuning point usually does not coincide exactly with the symmetrical amplitude tuning point and generally falls between the point of minimum synchronous AM and the point of maximum RF power amplifier efficiency.

5. RF power amplifier circuit topologies that exhibit coincidence of symmetrical amplitude and group delay responses will result in a better overall FM modulation performance.

6. Tests on several FM broadcast transmitters verified that tuning for minimum even order harmonic distortion provided the best FM modulation performance with minimum distortion to the demodulated FM baseband and resulted in symmetrical group delay through the transmitter as measured with a network analyzer. These tests also confirmed the FMSIM prediction that group delay response asymmetry causes higher FM modulation distortion and crosstalk than amplitude response asymmetry.

ACKNOWLEDGEMENT

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REFERENCES

1. "Optimum Bandwidth for FM Transmission". Anthony, Edward J. Broadcast Electronics, Inc. 1989.

2. "The Significance of RF Power Amplifier Circuit Topology on FM Modulation Performance". Shrestha, Mukunda B. Broadcast Electronics, Inc. 1990.

3. "FMSIM", the FM Simulation Program is available from Broadcast Electronics Inc., P.O. Box 3606, Quincy, IL 62301-3606 or Quantics, P.O. Box 2163, Nevada City, CA 95959-2163

4. SOURCES OF 19kHz BPF:

Filtronetics Inc., 6010 Parretta Dr.,
Kansas City MO. 64120,
(816) 231-7375

Torotel Products Inc., 13402 S. 71
Highway, Grandview, MO. 64030,
(816) 761-6314

Belar Electronics Lab Inc.,
119 Lancaster Ave., Devon, PA 19333,
(215) 687-5550

5. 19kHz BPF BILL OF MATERIALS:

C1,C7 = .02uF   C3,C5 = 220pF
C2,C4,C6 = .0047uF
All capacitors are disc ceramic or dipped mica and are available at Radio Shack.
L1,L2,L3 = J.W. Miller #9061 or VLS153