The Phase Modulator
In
NBFM Voice Communication Systems

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The phase modulator has been a point of discussion as to why it is used and not a frequency modulator in what are called FM communication systems. This paper's goal is to show why a phase modulator is used and not a frequency modulator in the FM communication systems. There are a number of points as to why phase modulators are used and they are probably valid, but this paper will show that to meet technical requirements and efficient operation with a voice response, a phase modulator best meets the situation.

Looking at the characteristics of FM and PM modulators and coming to a conclusion that one is better than the other without considering the system technical requirements can lead to incorrect conclusions. The FM and PM modulators have different characteristics as a function of the input modulation voltage frequency response and they need to be understood for the correct conclusion.

The understanding of why a PM modulator is the modulator of choice will be undertaken by breaking down the elements that make up the system performance. Once the elements are gone over, then the characteristics of these elements will be used to form the conclusion of why the PM modulator is used in FM communication systems.

The discussion breakdown is as follows:

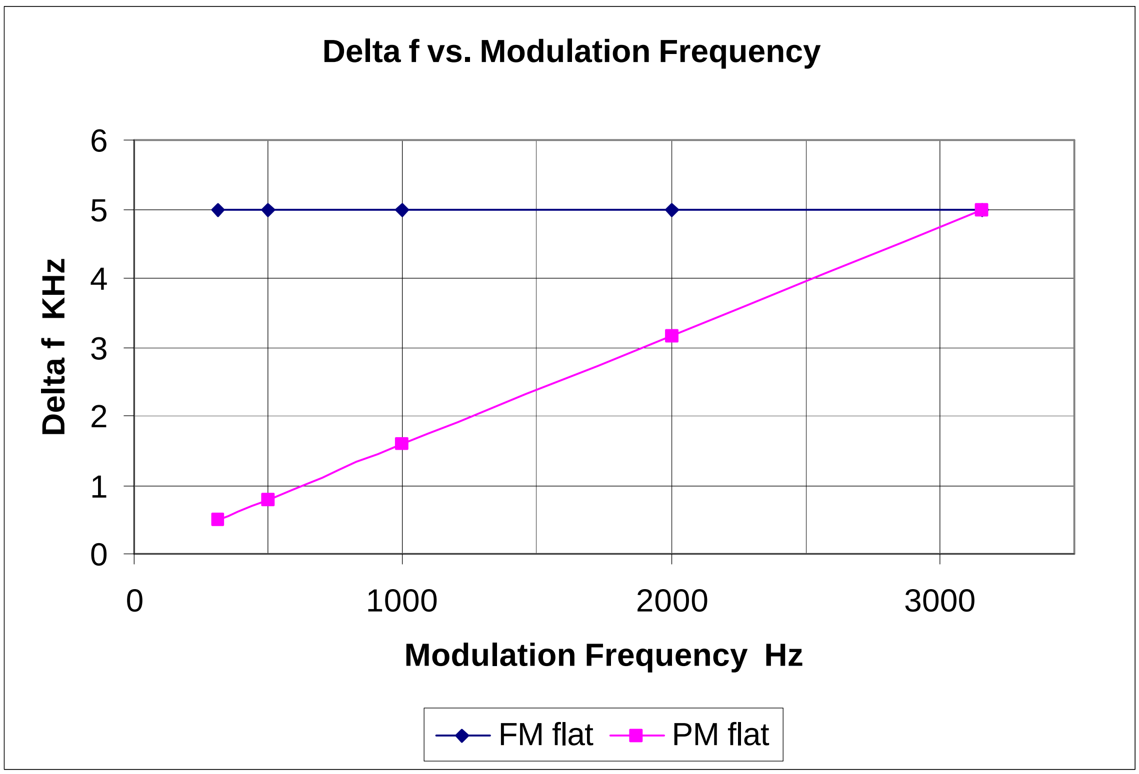
The FM discriminator.
The voice response.
The modulation index.

After the above discussions, the technical requirements will be applied to sort out the reasons for the PM Modulator. Also for this discussion, the PM modulator can be either a phase modulator or a frequency modulator preceded with a pre-emphasis or differentiator circuit making it a phase modulator. The merits, or lack thereof, for phase modulation from a phase modulator or a frequency modulator proceeded with a differentiator circuit is not in the scope of this paper.

The FM Discriminator:

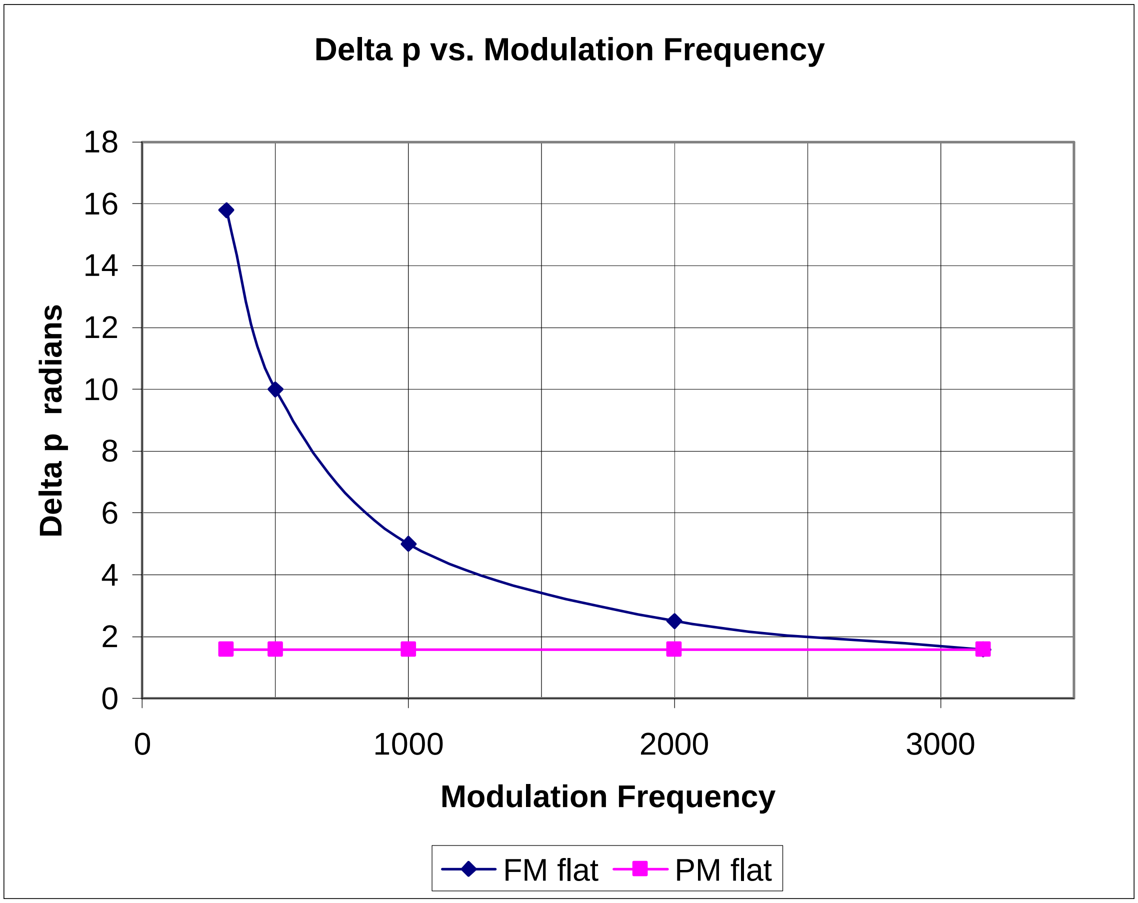
FM receivers have discriminators that convert the incoming rf signals to an audio output. Since FM discriminators demodulate only the delta frequency modulation of the modulated signal (not the phase modulation), the receiver sees only the frequency modulation of the modulated signal. Because the receiver detects only the frequency modulation of the transmitter, the system is properly called an FM system.

Both FM and PM modulators generate modulation that has both a delta-f (deviation) component and a delta-p (modulation index – radians) component (Note: delta-f and delta-p occur simultaneously together and each represent a different aspect of the same thing, angle modulation). The classic plot is that of delta-f as a function of a flat modulation frequency response for both a FM and a PM modulator.



The relationship used for these plots is the classic known relationship between FM and PM for a single tone frequency. The expression is delta-p = delta-f / fm. Delta-p is more commonly recognized as the modulation index. Note that this expression is for a sinusoid steady state modulation frequency.

What appears below is the not so often shown plot of delta-p as a function of a flat modulation frequency response for both a FM and a PM modulator.

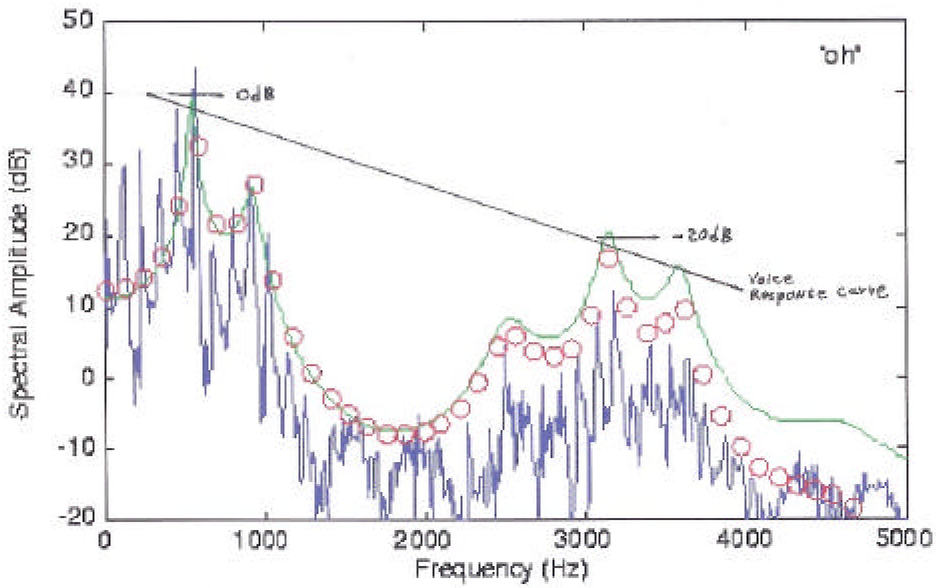


Both plots assumed a max deviation of 5 KHz as the reference. For the FM plots, a flat frequency deviation of 5 KHz for modulation frequencies from 316 to 3160 Hz resulted in a phase deviation from 15.8 to 1.58 radians. And for the PM plots, a flat phase deviation of 1.58 radians for modulation frequencies from 316 to 3160 Hz resulted in a frequency deviation from 500 to 5 KHz, which is shown in the previous delta-f vs. modulation frequency plot. For this paper, deviation is assumed to be + / - (   ) deviation.

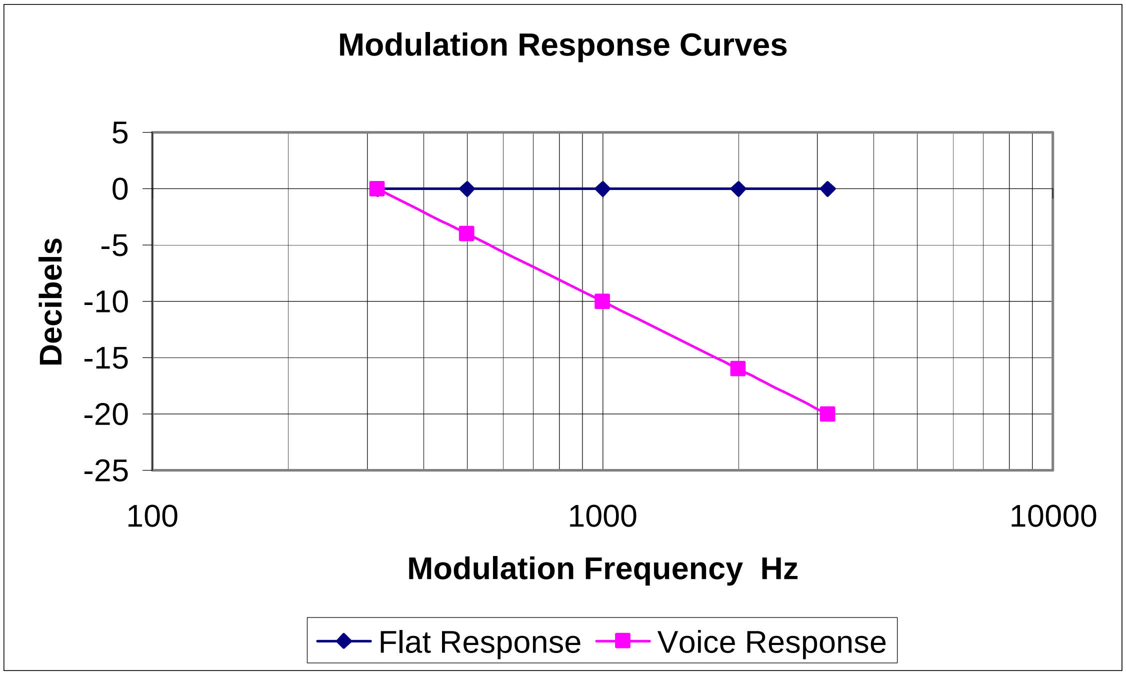
The Voice Response:

Using the results from the flat frequency response would lead to different results and may be fine if the modulation characteristics needed to be a nominally flat response for modulation inputs like music. However the communications system was designed to have the human voice as the modulation input and not music. This requirement brings about the need to analyze the characteristics of the modulators so as to optimize the modulation for the human voice.

The voice spectrum response has characteristics that are, at best, very complex and are what gives everyone's voice a unique sound. However a search of material for the voice spectrum reveals that the general characteristics of voice is a sloping response of 6 dB per octave starting in the 300 to 400 Hz range. This general sloping in response is always present even though the actual spectrum components are very complex.



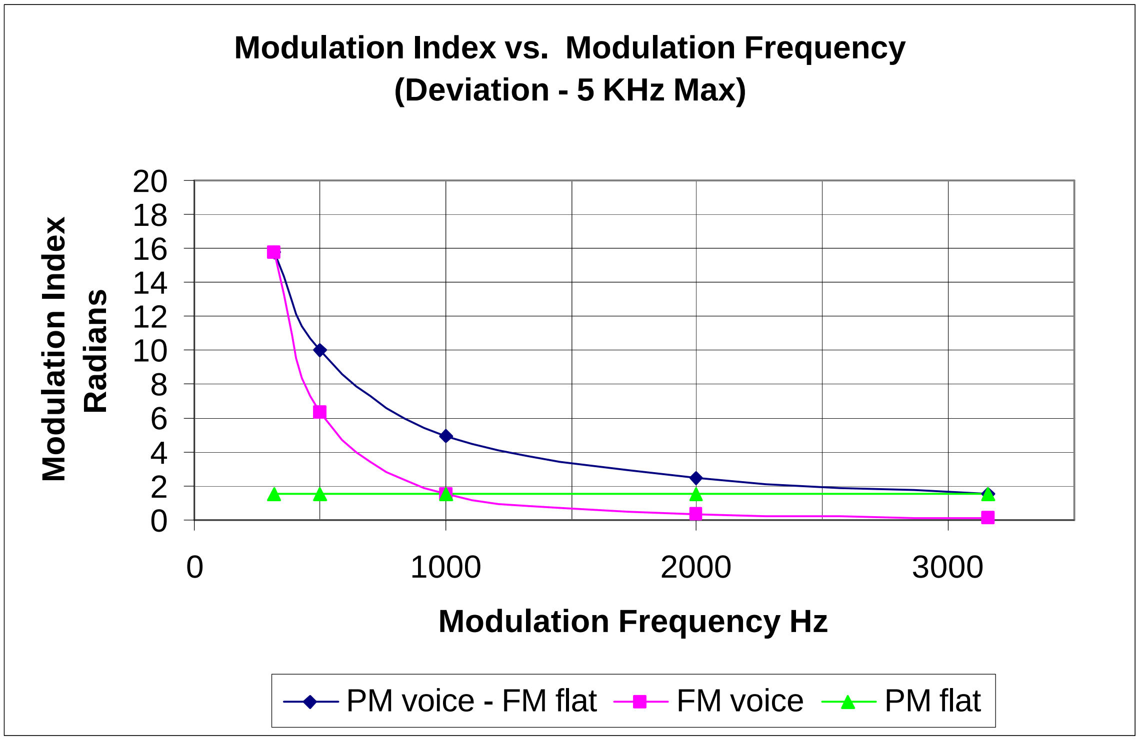
The above plot of the voice response for the word "oh" is very typical of what a human voice spectrum components look like. Thus for the FM communication systems, the modulation input is a voice response that has a 6 dB per octave or 20 dB per decade sloping response. An examination of the audio clipper circuit in a NBFM transmitter will reveal that it operates on the basis that this is the expected input response.



The above plot shows the response in decibels vs. log of modulation frequency for the flat and voice response. These are the modulation response curves used for all the other plots.

The Modulation Index:

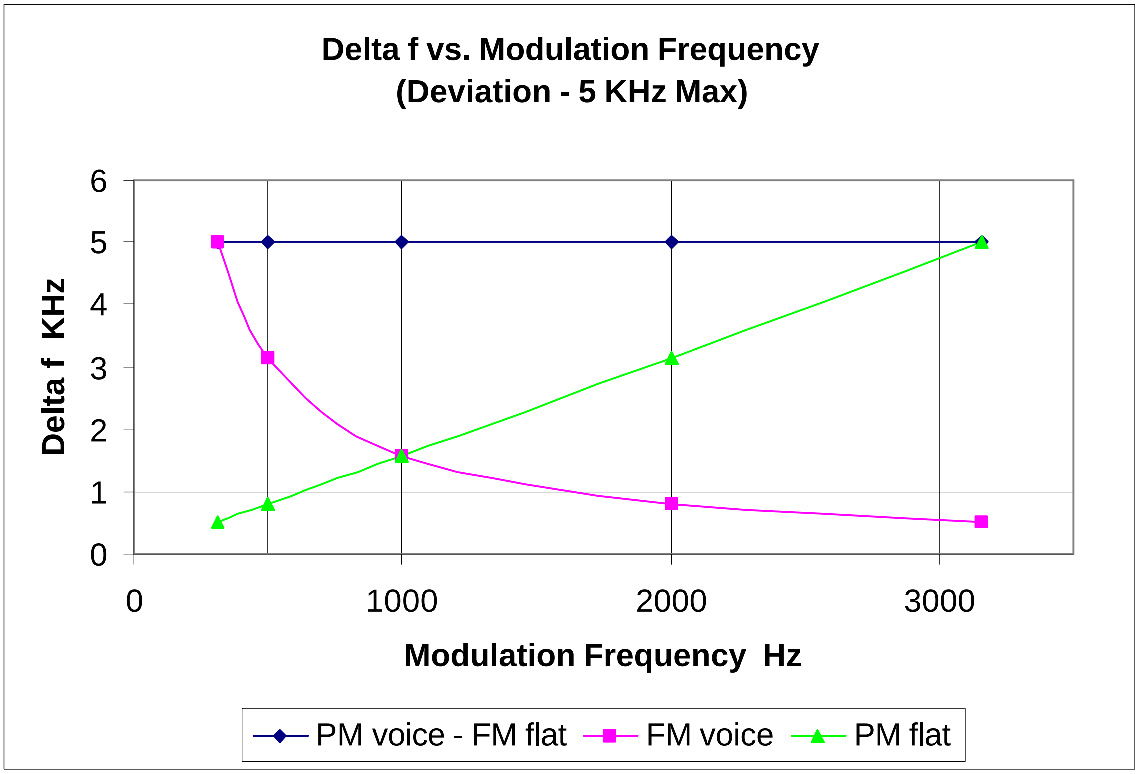
The modulation index is a parameter that is used to indicate the level of modulation relative to the carrier level. Another way to look at it is that the modulation index is how much power is in the sidebands that carry the modulation information and as such, should be as large as possible. For AM modulation, the modulation index is usually stated in percent with 100 % as being the upper limit to avoid distortion. For FM or PM, the modulation index has no upper limit, but just like AM, it is advantageous to keep the modulation index as large as possible. The modulation index for FM or PM does not have the constraint of distortion like AM, but does have a constraint of bandwidth. The modulation index for a FM modulator is determined by the expression of deviation over modulation frequency. The deviation of a FM modulator is proportional to the modulation amplitude. The modulation index for a PM modulator is proportional to the modulation amplitude. Conversely, the deviation of a PM modulator is proportional to the modulator amplitude and frequency. It is very important to note that the modulation index and deviation is very different for FM and PM modulators as function of modulation amplitude and modulation frequency.



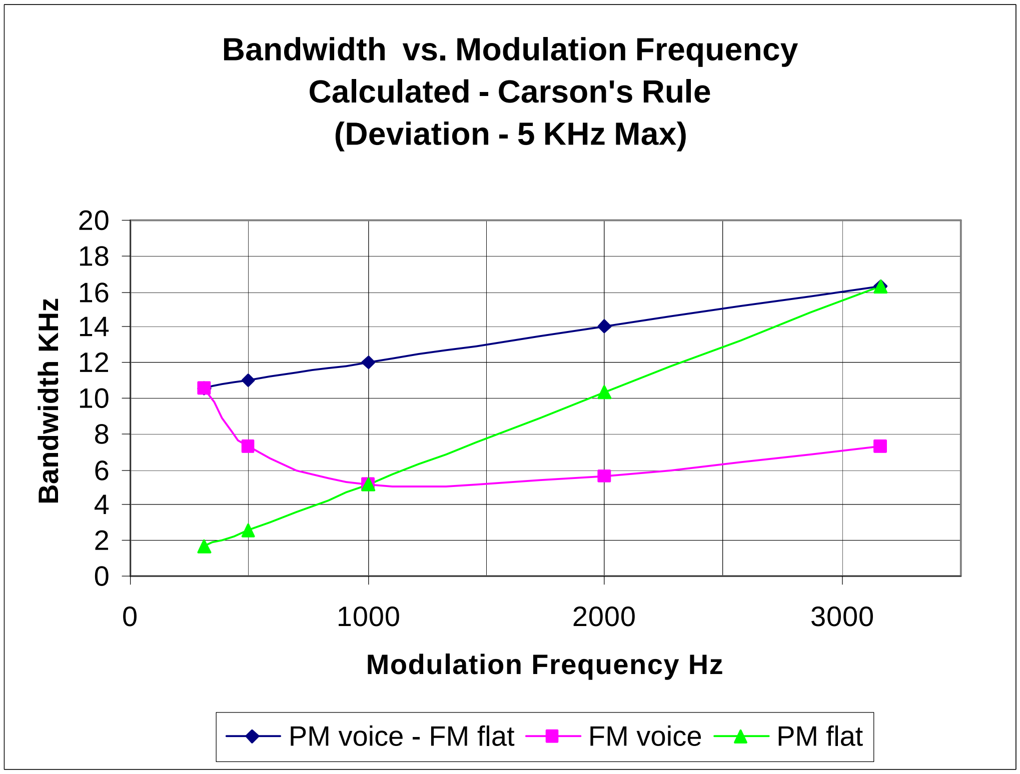
The above plot, of modulation index vs. modulation frequency, was made with the condition that the maximum deviation was 5 KHz. Because the voice amplitude response is a maximum at low frequencies (for this plot, the low frequency is 316 Hz), the modulation index is lower as modulation frequency increases. Note that the overall modulation index for PM voice is higher than FM voice and thus the PM modulator better utilizes the voice response for higher modulation efficiency.

Technical Requirements:

The generally accepted technical requirement in the amateur radio service for NBFM is a maximum deviation 5 KHz and a maximum bandwidth of 15 or 20 KHz. The amateur radio service Part 97.307 emissions standards lists only the modulation index as a requirement. Part 97.307 (f) (1) states: “No angle-modulator emissions may have a modulation index greater than 1 at the highest modulation frequency”.



The above plot of delta-f or deviation vs. modulation frequency shows the classical deviation vs. modulation frequency for the FM and PM with a flat modulation response and the voice modulation response. Note now that the voice response greatly changes the deviation vs modulation frequency curves. With the voice response restricted to a max deviation of 5 KHz, the FM voice deviation lowers with increasing frequency, which accounts for the modulation index being lower. The PM voice response deviation curve now has the deviation as a constant over the modulation frequency range, and as was noted in the modulation index curve, has a higher modulation index for higher modulation efficiency.



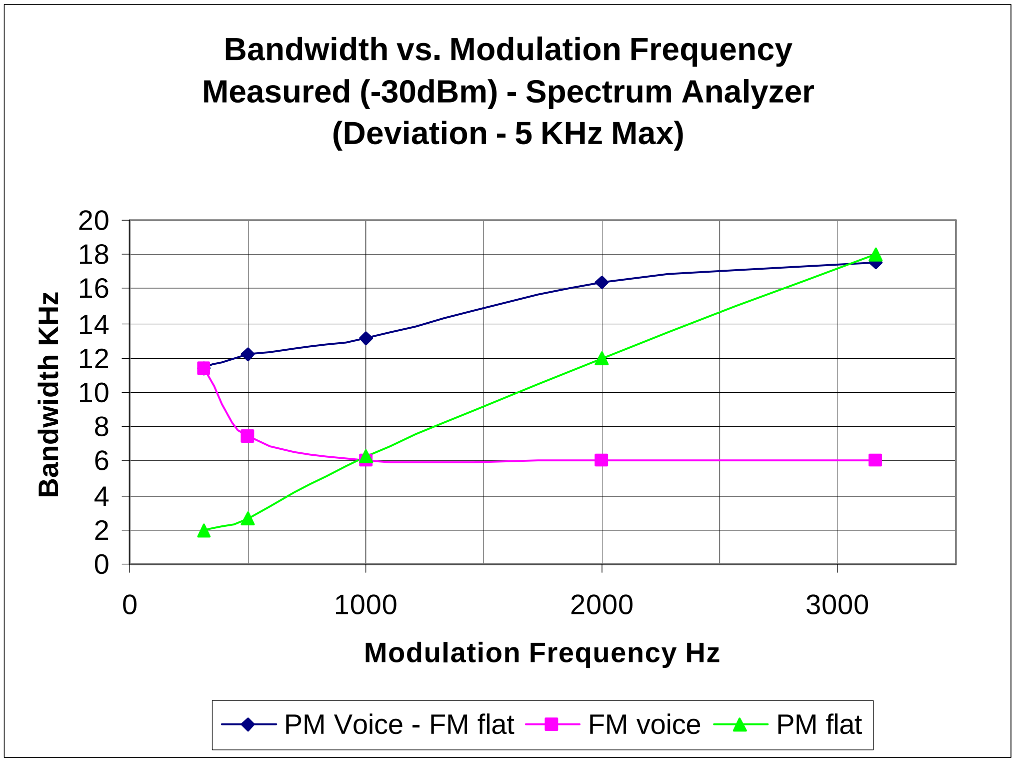
The bandwidth of the transmitted signal is probably one of the most critical of the FCC requirements as well as being a measure of how well a channel is being utilized. A transmitted signal that is narrower than the allowable bandwidth is poor utilization of the modulator and the channel. A signal that is wider than the allowable bandwidth is interference. So the goal is to have maximum bandwidth over the modulation frequencies but not over the required maximum bandwidth. The bandwidth in the above plot was calculated using Carson's Rule of estimated bandwidth. The expression for FM is 2 * (delta-f + fm) and for PM is 2 * fm * (delta-p + 1). The PM voice response curve results in highest bandwidth over the modulation frequency range with the FM voice response curve resulting in a falling off of the bandwidth over the modulation frequency range.

In Conclusion:

The plots of bandwidth, deviation, and modulation index as a function of modulation frequency show that the PM modulator is the best overall choice for NBFM voice communications systems and has been used for decades and is still in used today. Note that a PM modulator for this discussion can either be a phase modulator or a frequency modulator proceeded with a pre-emphasis circuit making it a phase modulator.

Appendix A:

The bandwidth of an FM and PM signals were measured at –30 dBm below the carrier to show how close it is to calculated bandwidth using Carson's rule.



My textbooks did not indicate what the level in dB down from the carrier is for the bandwidth that is calculated using the Carson Rule. My estimation for the bandwidth was –30 dBm below the carrier, which is what I used for my measurements.

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