CTCSS Modulation
And
The LC Phase Modulator

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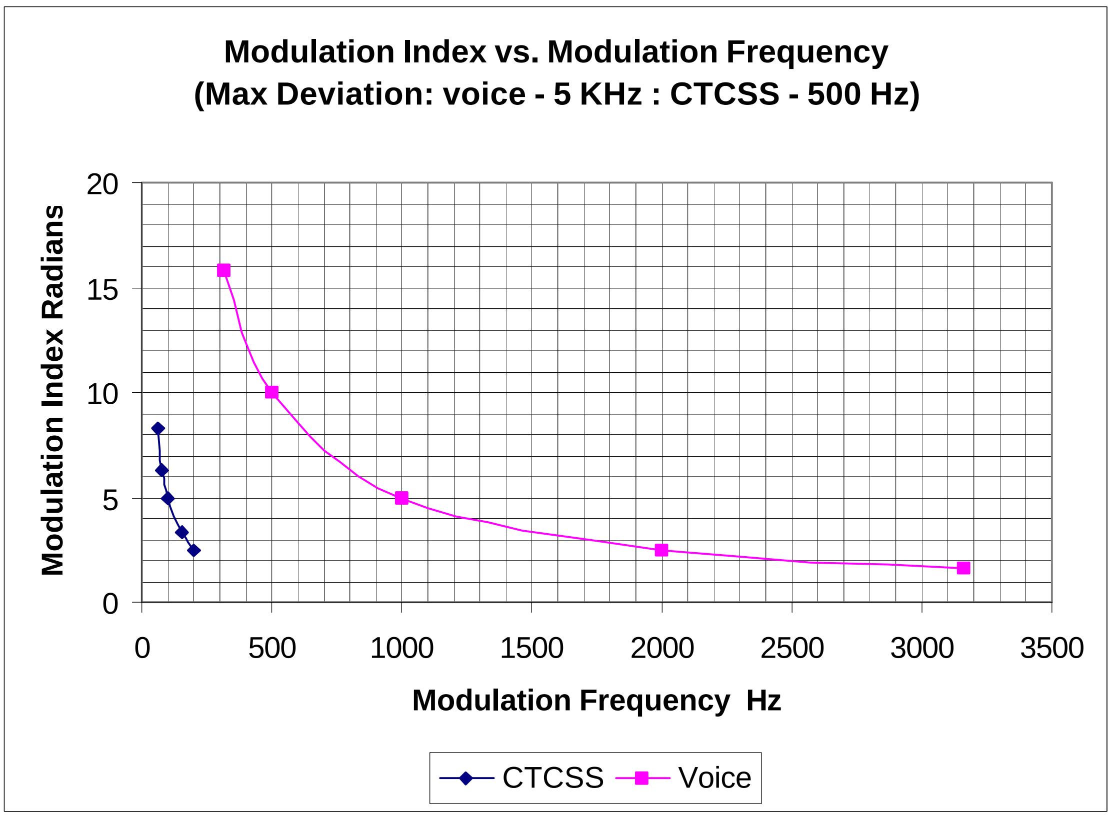
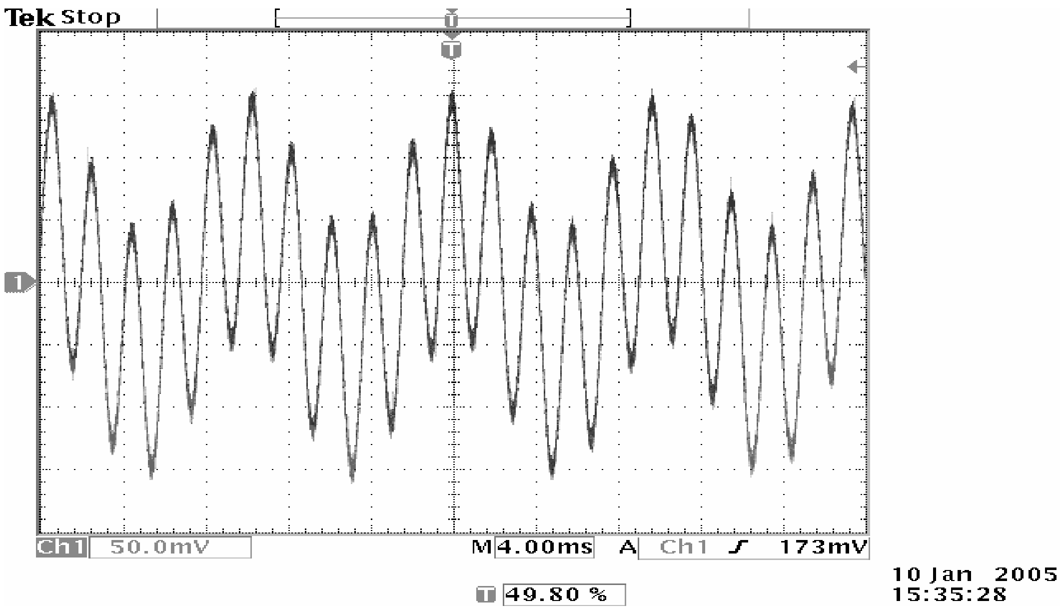
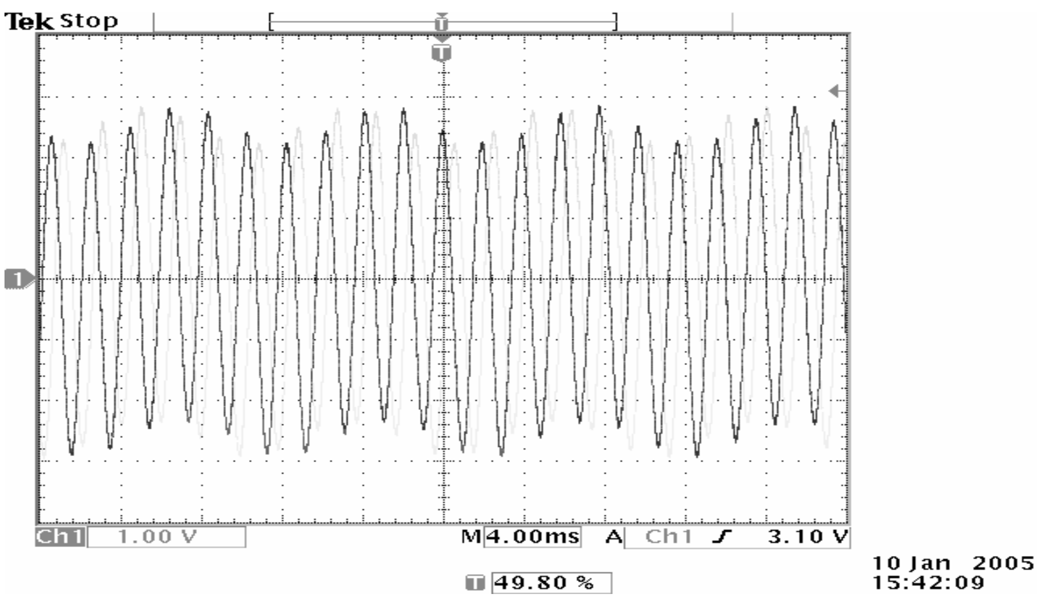
CTCSS modulation of a LC phase modulator has been used successfully in FM communications systems and from a practical point of view works well. However those who would like a higher quality voice modulation, may notice that the LC phase modulator has some voice quality degradation when the CTCSS tone is combined with the voice response. The reason for voice quality degradation with higher distortion is that the modulation index for CTCSS tones is in the same range as the voice response (sloping 6 dB per octave) and results in distortion products in the modulator itself due to nonlinear (tan x) phase shift curve. Note that modulation input level to a PM modulator is directly proportional to the modulation index.



The above plot of modulation index shows the comparable levels of modulation index for voice response and CTCSS. The CTCSS frequency range shown is from 60 to 200 Hz. For example, the voice frequency of 500 Hz, and the CTCSS frequency of 100 Hz, results in a 2 to 1 ratio of modulation levels.

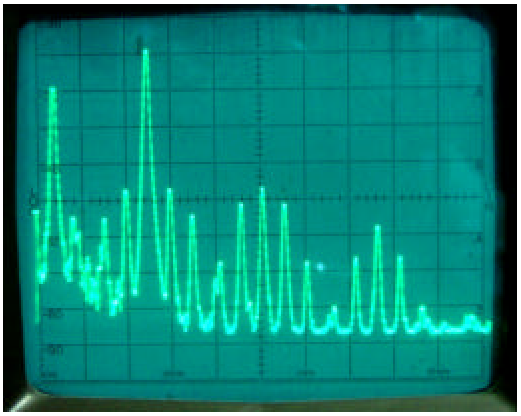


The above scope trace is the time domain view of the 500 Hz and 100 Hz tones as applied to the PM modulator. One may note that the deviation level of CTCSS is nominally a tenth of the voice deviation, so why this 2-to-1 ratio? The reason, of course, is that modulation index is related to deviation divided by the modulation frequency.

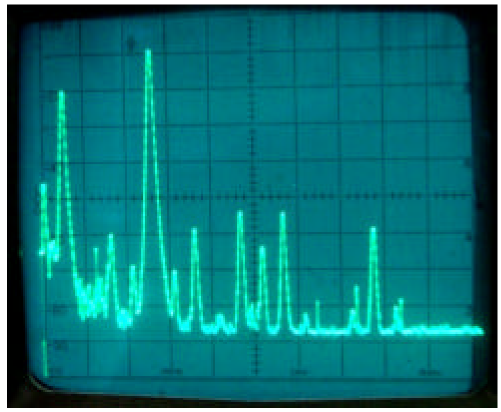


The above scope trace is the time domain view of the 500 Hz and 100 Hz tones as detected by the FM discriminator. The amplitude of the 100 Hz tone is a tenth of the 500 Hz tone, as expected.

The levels of distortion products are not particularly high and normally are not an issue for the communication system. However for higher quality applications, they may be an issue.



Plot of GE 450 MHz Exciter



Plot of GE 450 MHz Exciter with external design LC modulator.

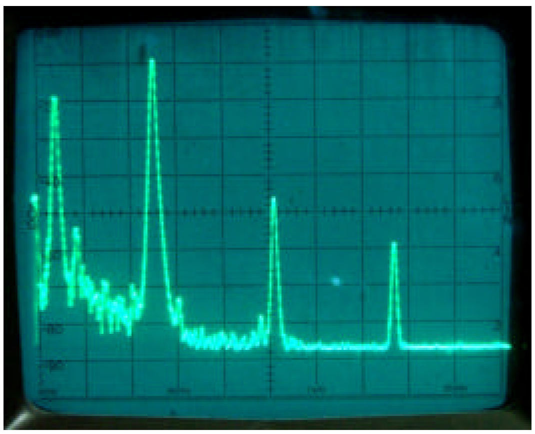
The plots shown are 10 dB per division and the frequency sweep is from 0 to 2 KHz. The resolution bandwidth of the HP3580A spectrum analyzer was 10 Hz. The 500 Hz tone is at about –10 dB with the 100 Hz tone at –20 dB. The 100 Hz tone is not down 20 db from the 500 Hz tone as is present at the output of the FM discriminator, because the plots were made at the de-emphasis (200 Hz corner) output. As can be noted, the distortion products looks like AM modulation of the 500 Hz tone and its distortion products at 100 Hz intervals and are generally 40 dB below the 500 Hz tone.

To eliminate the distortion, isolation of the voice and CTCSS tones is required. This is not possible with a single stage LC phase modulator. Two possible solutions are another LC phase modulator stage for the CTCSS tones or FM modulate the oscillator with the CTCSS tones.

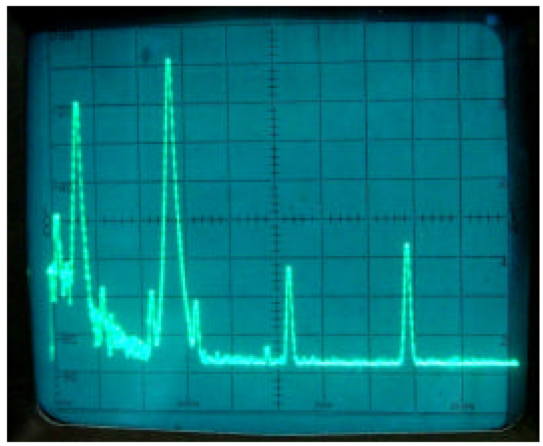
Of note is that CTCSS tones are a FM response with a required constant deviation over the CTCSS tone frequency range. Thus CTCSS is like a separate sub-tone channel with the voice response being the other channel. So the best case is for the voice channel to be PM and the CTCSS channel to be FM. The isolation with an additional phase modulator stage will meet the isolation requirement; however, it does not have constant frequency deviation over the CTCSS frequency range unless the amplitude is correspondingly changed to maintain constant deviation.

In the case of the GE 450 MHz exciter, the channel element (ICOM) has a temperature compensation circuit that shifts the frequency of the crystal for frequency stability as a function of temperature. The TC circuit is estimated to be able to pull the crystal about +/- 5 PPM. One PPM is about 12 Hz in this case.

Looking at the deviation requirement of +/-500 Hz and dividing by 36, the oscillator needs to shift only +/-14 Hz, which is well within the ability of the GE ICOM channel element (the element was a 2C version). Since the deviation is only about 1 PPM, it leaves room for the TC circuit to perform its function. A test was done by connecting a tone generator to the temperature compensation pin through a 1uF film capacitor with the result of no distortion products on the 500 Hz tone due to the 100 Hz tone. The modulation voltage level to TC pin was 60 mV at 100 Hz. A test was also done using a two LC phase modulators in series with the same result.



Plot of GE 450 MHz exciter with FM modulation of the CTCSS tone.



Plot of GE 450 MHz exciter with 2nd stage PM modulation of the CTCSS tone.

The above plots show the elimination of the distortion products with the isolated modulation of the 100 Hz CTCSS tone from the 500 Hz voice tone.

In conclusion, the intent of this paper was to show how the additional distortion products came about when CTCSS and voice is applied to a single stage LC phase modulator. Also that the 100 Hz CTCSS tone distortion products on the voice tone can be eliminated with a additional phase modulator stage or by FM'ing the oscillator. It is beyond the scope of this paper to show specifics of how to accomplish the isolated modulation means in different PM exciters.

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