1 AM Radio Reception

1.1 Chapter 3: Modulated Waveforms - Amplitude Modulation

Notes AM Modulation in a Nutshell:

A high frequency "carrier" wave f_c transports a lower frequency "program" content f_p, i.e., for a simple sinusoidal carrier wave the modulated signal is given by

$$V(t) = [A(1 + \alpha \cos(2\pi f_p t))] \cos(2\pi f_c t)$$

where $\alpha < 1$ is the modulation index. We can pretend that $[\,] = A(\,)$ is equivalent to the amplitude of the modulated waveform, so this makes the amplitude vary over time between $A(1-\alpha)$ and $A(1+\alpha)$. With some trig identities, we can rewrite this as

$$V(t) = A\cos(2\pi f_c t) + \frac{A\alpha}{2}\cos(2\pi(f_c + f_p)t) + \frac{A\alpha}{2}\cos(2\pi(f_c - f_p)t)$$

Thus the sum of three sinusodial waves with frequencies f_c, $f_c + f_p$, and $f_c - f_p$—i.e., the information content of an AM signal is contained within the sidebands of the carrier wave in the frequency domain.

Exploration

- Carrier: 770 internal source—50 kHz, 1 V → Multipler module (MULT) input A
- Program: 33500B—2 kHz, 5 V → SUMMER module input B
- DC VOLTAGE module 5 V → SUMMER input A
- SUMMER output → MULT input B
- MULT output → scope & 770

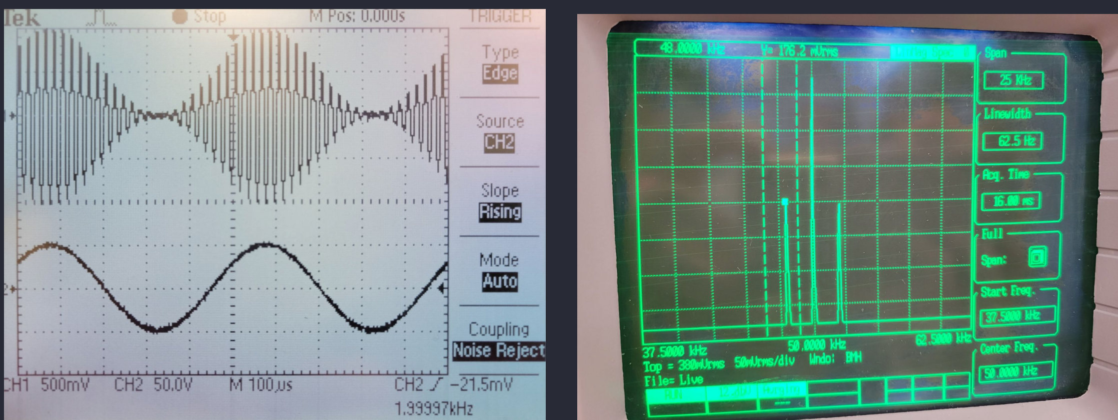


Figure 1.1: Scope (left) with bottom program content and 770 (right) view of AM Modulation of a 50 kHz carrier wave with a 2 kHz program wave.

In Figure 1.1, we see the scope and 770 view of the AM modulation of a 50 kHz carrier wave with a 2 kHz program wave. The scope view shows familiar looking AM modulated waveform, while the 770 clearly shows the carrier frequency at the center and the two sidebands which dictate the frequency of the program content.

Changing content of the two waves

- Increase frequency of program content:
  - The sidebands move further away from the carrier frequency just as the theory predicts $f_c \pm f_p$.

- Change carrier frequency:
  - Moves the 3 peak structure left or right (low freq and high freq respectively) on the 770 (Figure 1.2).
  - The envelope of the modulated waveform remains the same, but the inside oscillations increase as f_c increases.

Figure 1.2: Increasing (right) and decreasing (left) program frequency.

- Program amplitude:
  - Increasing the program amplitude increases the amplitude of the sidebands independent of the carrier amplitude (Fig. 1.3).

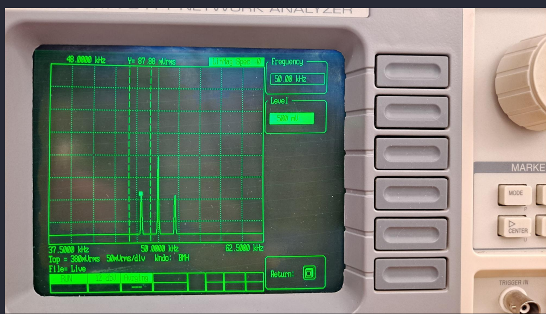


Figure 1.3: Decreasing program amplitude.

- Carrier amplitude:
  - Increasing the carrier amplitude increases the amplitude of the carrier wave independent of the program amplitude (Fig. 1.4).

Figure 1.4: Increasing (right) and decreasing (left) carrier frequency.

- Program content to square wave:
  - There are multiple sidebands at odd multiples of the program frequency.

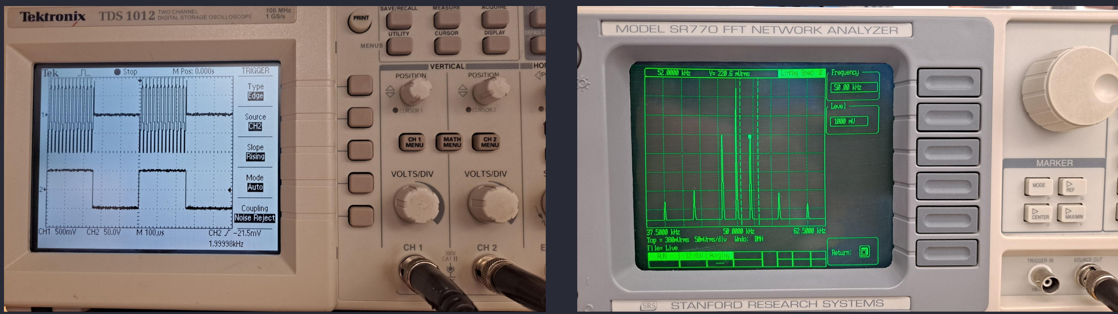


Figure 1.5: Scope (left) with program content in the bottom and 770 (right) view of AM Modulation of a 50 kHz carrier wave with a 2 kHz square wave program wave.

Why $\alpha < 1$? The multiplier ouputs a scaled product of the two input signals

$$V_{\text{out}} = \frac{V_A V_B}{10}$$

for inputs with voltage ± 10 V, and frequency lower than 1 MHz. Thus for 5 V DC input from the summer with the program signal gives

$$\begin{aligned} V_{\text{out}} &= (5V + P\cos(2\pi f_p t))(A\cos(2\pi f_c t))/10 \\ &= \frac{5A}{10} V \left(1 + \frac{P}{5V}\cos(2\pi f_p t)()\right)\cos(2\pi f_c t) \end{aligned}$$

So the waveform has a modulation index $\alpha = \frac{P}{5V}$. In our first case (Fig. 1.1), $P = 5V$ so $\alpha = 1$, Here the scope clearly shows the two distinct frequencies that make up the AM waveform—i.e., the envelope matches the program content shown simultaneously below, and the carrier frequency is resolved in the small oscillations within the envelope.

When we increase $\alpha \to 2$ (Fig. ref here), the program content is overmodulated or *distorted* which makes it hard to extract out the program content from the modulated waveform.

Chapter 11: AM Radio Reception

Notes

- Since AM radio signals are roughly 540-1600 kHz, i.e., 500-200 m wavelength, the EM waves are pretty uniform and can be received by our simple electrical wire antenna connected to an LC-resonant circuit.
- The LC-resonant slighly tunes the frequency range into a narrow band of frequencies, which can be changed by adjusting the number of inductors we put in series (Fig. 1.5).
- Downcoversion: Before we narrow the frequency search range, we can first use downconversion to bring the high frequency AM signals to a lower frequency range provided by the High-Frequency (HF) Mixer module.
  - Local-oscillator (LO) source: Using the 33500B, we set the LO frequency so that the difference between the LO and the AM signal is in the range of our 770 (100 kHz). e.g., for target radio station (RF) 850 kHz, setting the LO to 770 or 930 kHz will output a 80 kHz difference frequency from the HF mixer. It will also ouput and sum & difference frequencies from other radio stations which we must filter with the IF output.

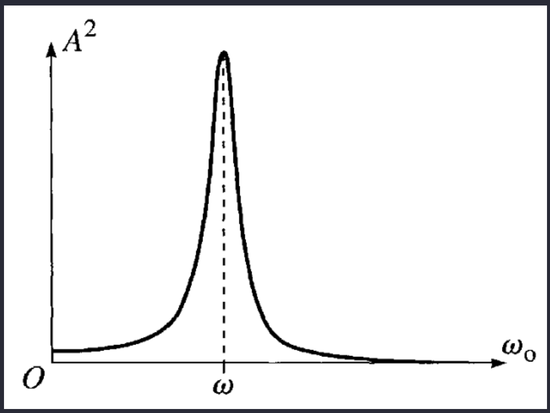
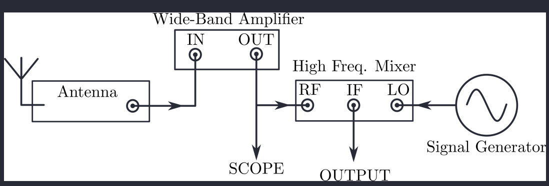


Figure 1.6: Resonant frequency of RLC circuit (Taylor, Classical Mechanics). Our circuit has a broad resonance (rather than sharp) which will receive a band full of AM stations.

  - IF Filter: To create a fixed pass band that only allows the a narrow range of difference frequencies to pass through.

- De-modulation: Turning AM signal into "pure" program content for the Audio Amp. & Speak module.
  - An AM signal waveform has a carrier f_c carrying the program content f_p in the sidebands $f_c \pm f_p$.
  - Tuning the LO frequency to f_c will create a zero difference (or "beat") frequency thus the side bands of the IF are exactly the frequencies of the program content. e.g. for 850 kHz RF, set LO to 850 kHz and the Filter Freq. to 1 kHz.
- Heterodyne/Heterodyning: Shifting one frequency range to another
  - Both Down-conversion and demodulating in this case are examples of heterodyning.



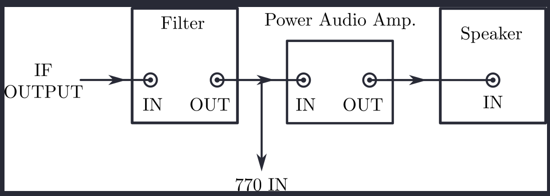


Figure 1.7: Experimental setup for AM radio reception.

Experiment: Finding Radio Stations

- First note a near by radio station we can pick up from St. Louis (Radio Station List). e.g. KFUO $f_{RF} = 850$ kHz.
- Set three inductors in series on the radio antenna circuit (more inductors in series add more inductance and decrease the resonant frequency).
- Radio antenna circuit OUPUT → Wideband Amp $1 \times 1 \times 10$ (10x) or until the signal is visible on the scope
- Wideband Amp OUTPUT → HF Mixer INPUT RF & scope

- 33500B 1 V and Freq. 770 kHz (80 kHz differnce freq.) OUTPUT → HF Mixer (Down-conversion) INPUT LO
- IF OUT → Filter Module 80 kHz; 8 Gain; Band-pass
- Filter OUT → Power Audio Amp. (Adjust gain until you hear noise or signal) & 770 (LOG magnitude, MEASure Spectrum, and Averaging 16 to reduce noise and to have a fast response to the signal) and and note the visualized signal
- Power Audio Amp. OUT → Speaker Module
- Tune the LO frequency to get a strong signal using multiple difference frequency combinations, i.e., For 850 kHz RF, set LO to 930 kHz.
- De-modulate the signal by tuning the LO frequency *exactly* to the Radio station frequency (carrier freq), i.e., the zero beat frequency——e.g. For 850 kHz (KFUO) Radio Station, tune the LO to 850 kHz, the Filter Freq. to 1 or 3 kHz and decrease $Q \to 0.71$

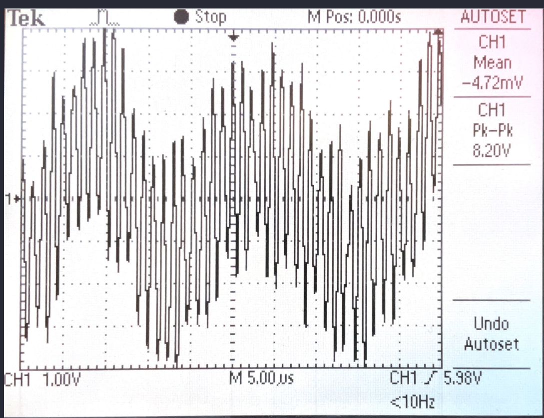


Figure 1.8: TDS 1012 oscilloscope view

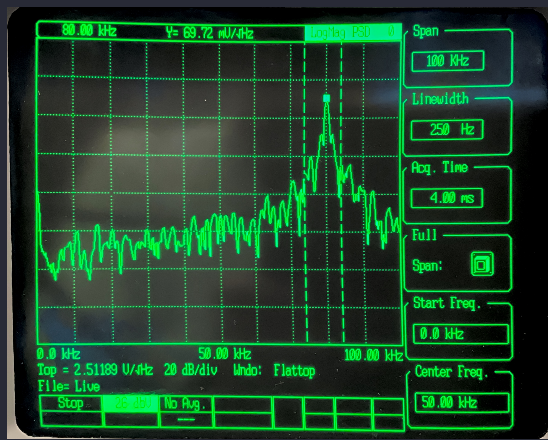


Figure 1.9: SR770 FFT Network Analyzer view

Observations Fig. 1.8 and 1.9 show the oscilloscope and 770 view of the AM radio signal from KFUO 850 kHz

- In the down-conversion step, there is still mostly noise output (and some semblance of program content) from the speaker due to the wide band of the Filter module and the program content being downconverted to the wrong frequency of the original audio signal from the source.
- There are two choices for each difference frequency—e.g. $LO = RF \pm 80$ kHz.

- Changing the LO frequency moves the large amplitude carrier frequency (and its program content) to the or right on the 770 i.e. the target RF frequency will be downconverted to a lower frequency $f_c = f_{RF} - f_{LO} = 850 - 800 = 50$ kHz as shown in Fig. 1.10.

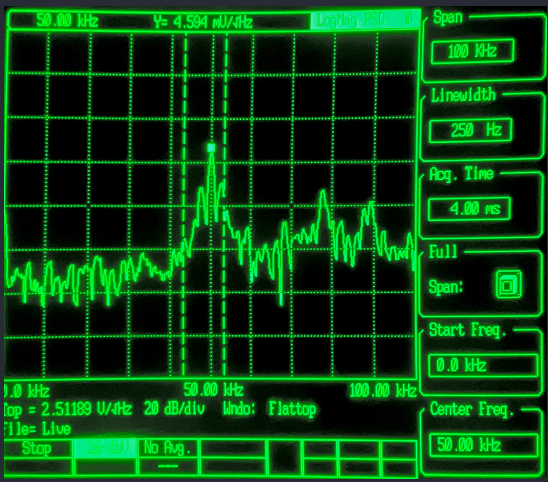


Figure 1.10: Increasing LO frequency.

- Thus de-modulating the signal by tuning the LO frequency to the carrier frequency $f_c = f_{RF} - f_{LO} = 0$ will create a zero beat frequency and the sidebands of the IF will be the program content—i.e. an original audio signal (program content) f_p from the source station is now correctly down-converted by the HF Mixer on the 770 as shown in Fig. 1.11. Furthermore, when a speaker is

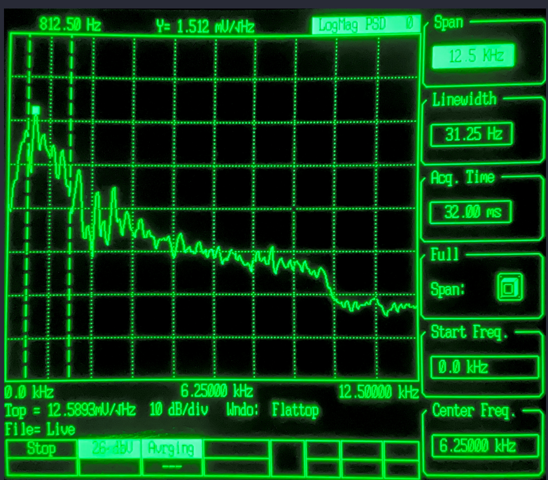


Figure 1.11: De-modulated signal at span of program content. The speaker outputs a sound of a piano and the 770 captures the frequency spectrum of the piano sound (with some noise).

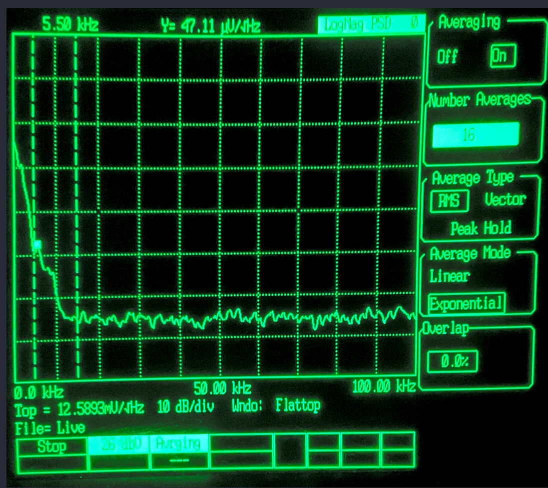


Figure 1.12: De-modulated signal in full span view

talking on the radio station, the 770 captures the frequency spectrum of the human voice in real time showing the resonant frequencies of the human voice (Fig. 1.13).

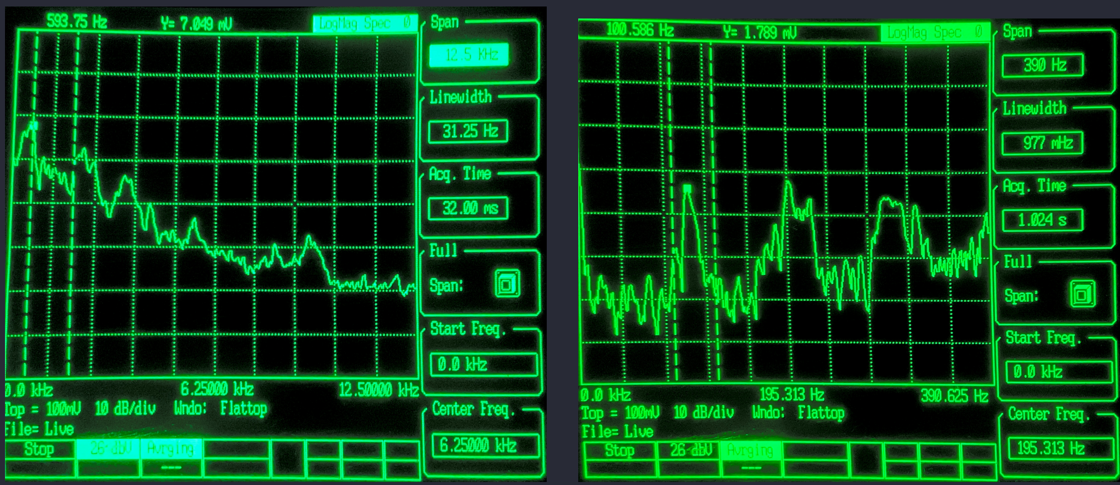


Figure 1.13: Snapshot of De-modulated signal of a human radio voice. 12 kHz span (left) shows high resonant frequencies (Formant) and 390 kHz span (right) shows the lower fundamental frequency (this is a different snapshot of the Radio voice since we can't capture two frequency ranges simultaneously)

The 770 shows, in addition to the fundamental frequency of the human voice, there are high resonant frequencies present in certain vowels (formants); e.g. we can see formants $F_1 = 500$ Hz (fundamental frequency), $F_2 = 2.13$ kHz, $F_3 = 3.375$ kHz in Fig. 1.13 which are characteristic of the human voice.

Source: "Static measurements of vowel formant frequencies and bandwidths: A review", Raymond D. Kent, Houri Vorperian (link)

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Summary

- AM Modulation: Heterodying (Down-conversion and demodulation) can be used to anaylze high frequency AM signals at low frequency ranges and extract the program content of a radio station.
- Further applications: Formants to identify human speech and other audio signals (first step in speech recognition).

  Source: "Formant estimation for speech recognition", L. Welling, H. Ney (1998) link

  doi: https://doi.org/10.1109/89.650308