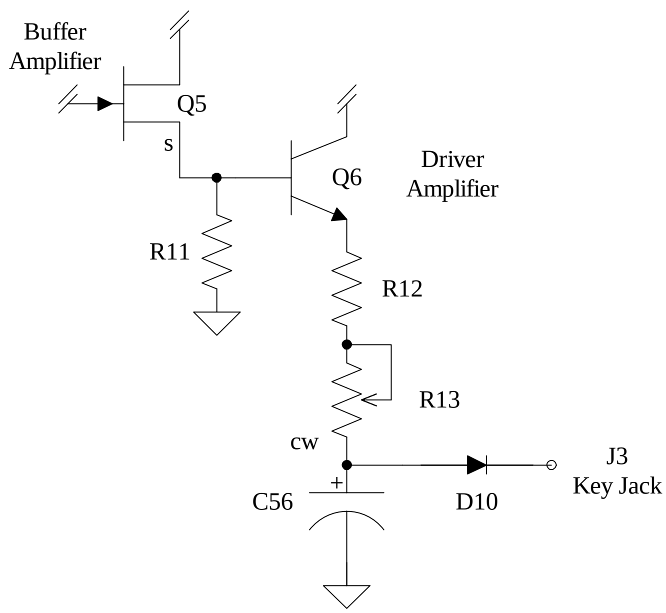
Lecture 29: Decreasing Channel Bandwidth by Using CW. Key Clicks

The text has previously mentioned that it's important for the transmitter not to turn on or off too quickly. For example, C56 in the Driver Amplifier is used to gradually turn off the transmitter:



In this lecture, we will see that by gradually turning off (and on) the transmitter, **much** less bandwidth is required for each CW "channel." (A channel is the contiguous frequency spectrum needed for clear communications.)

To understand this, first consider transmitter pulses with no rise or fall time:

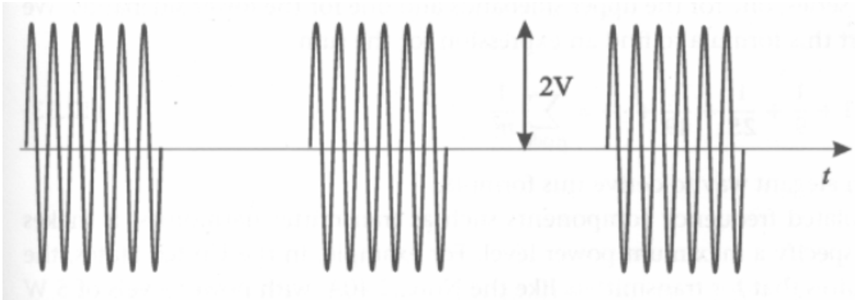


Figure 12.8. Transmitter pulses with zero rise and fall times.

This waveform is really the time domain product of the high frequency carrier

$$V_c(t) = 2\cos(\omega t) \text{ V}$$

and a pulse train of frequency f_k. From equation (B.22) with $V_m = 1$, the Fourier series expansion of this keying waveform is

$$V_r(t) = \frac{1}{2} + \frac{2}{\pi}\left[\cos(\omega_k t) - \frac{\cos(3\omega_k t)}{3} + \frac{\cos(5\omega_k t)}{5} - \cdots\right] \quad (12.30)$$

Multiplying these last two equations and simplifying gives:

$$V_r(t) = \cos(\omega t) +$$
$$\frac{2}{\pi}\left[\cos(\omega t - \omega_k t) - \frac{\cos(\omega t - 3\omega_k t)}{3} + \frac{\cos(\omega t - 5\omega_k t)}{5} - \cdots\right] +$$
$$\frac{2}{\pi}\left[\cos(\omega t + \omega_k t) - \frac{\cos(\omega t + 3\omega_k t)}{3} + \frac{\cos(\omega t + 5\omega_k t)}{5} - \cdots\right]$$

which is (12.31).

Now, let's compute the average power contained in each frequency harmonic. Using $P = |V|^2/(2R)$, normalizing to $R = 1$ Ω and defining $f = f_c \pm n f_k$ where f_c is the carrier frequency:

***n* (harmonic #)**	**P_n (power wrt total = 1 W)**
0	$\frac{1}{2}(1)^2 = -3.01 \text{ dB}$
±1	$\frac{1}{2}\left(\frac{2}{\pi}\right)^2 = -6.93 \text{ dB}$
±2	Not present
±3	$\frac{1}{2}\left(\frac{2}{3\pi}\right)^2 = -16.48 \text{ dB}$
±4	Not present
±5	$\frac{1}{2}\left(\frac{2}{5\pi}\right)^2 = -20.91 \text{ dB}$
⋮	⋮

A plot of this spectrum is shown in Fig. 12.9:

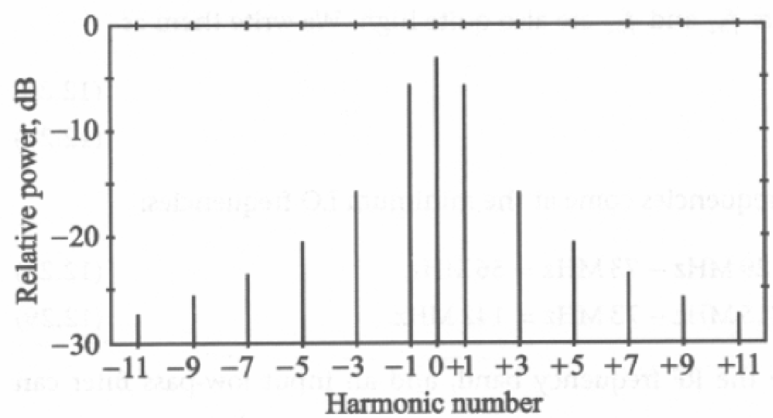


Figure 12.9. Spectrum for a keyed transmitter with zero rise and fall times, in dB relative the total power.

The FCC requires that for QRP transmitters (those 5 W and less), the spurious radiation must be ≥ 30 dB below the carrier (dBc).

However, for keying transmitters such as the NorCal 40A, there are many spurious components. While most, or all, of them may be reduced 30 dB from the carrier, the sum of these may cause a problem for another person's receiver.

Consequently, for keying-type "sidebands" a more appropriate transmitter specification is the channel bandwidth required so that the average power contained in **all** frequency components outside of the channel is 30 dB below the carrier.

This quantity can be easily computed. From (12.31), the total average power (computed in the frequency domain) is:

$$P = \frac{1}{2} + 2\frac{1}{2}\left(\frac{2}{\pi}\right)^2 \left[1^2 + \left(\frac{1}{3}\right)^2 + \left(\frac{1}{5}\right)^2 + \cdots + \left(\frac{1}{n}\right)^2 + \left(\frac{1}{n+2}\right)^2 + \left(\frac{1}{n+4}\right)^2 + \cdots\right] \text{ W}$$

where n is an odd and positive integer. The extra factor of 2 accounts for the average power in both the upper and lower sidebands.

Simplifying gives

$$P = \underbrace{\frac{1}{2}}_{\substack{\text{power}\\ \text{in carrier}}} + \frac{4}{\pi^2}\left(\underbrace{1 + \frac{1}{9} + \frac{1}{25} + \cdots + \frac{1}{n^2}}_{\text{power in harmonics } 1\to n} + \underbrace{\frac{1}{(n+2)^2} + \frac{1}{(n+4)^2} + \cdots}_{\text{power in HO harmonics}}\right) \text{ W}$$

Imagine that harmonics up to and including n are needed for the channel. Then p, which we'll define as the total average power in HO harmonics relative to the carrier for *either* the upper or lower sideband, is

$$p = \frac{2}{\pi^2}\left[\frac{1}{(n+2)^2} + \frac{1}{(n+4)^2} + \cdots\right] \qquad (12.34)$$

There is no additional factor of 2 here since we're looking only at one sideband.

If n is large, we can evaluate p with the approximation:

$$p \approx \frac{2}{\pi^2}\frac{1}{2}\int_n^\infty \frac{dx}{x^2} = \frac{1}{\pi^2}\left(-\frac{1}{x}\right)\Bigg|_n^\infty = \frac{1}{\pi^2 n} \qquad (12.35)$$

The factor of one-half is present in this expression since we have only odd harmonics in the keying waveform [see (12.30)].

From (12.35), we find that

$$\boxed{n \approx \frac{1}{\pi^2 p}} \qquad (12.36)$$

This result allows us to approximately compute the number of harmonics needed for one sideband of a keying waveform so that the average power contained outside the channel relative to the carrier is p.

For example, imagine we wish to determine the number of keying harmonics (i.e., the channel width) required so that the total average power transmitted outside this channel is 30 dB smaller than that transmitted within the channel. Then,

$$p = -30 \text{ dBc} = 0.001 \Rightarrow \; n = 101$$

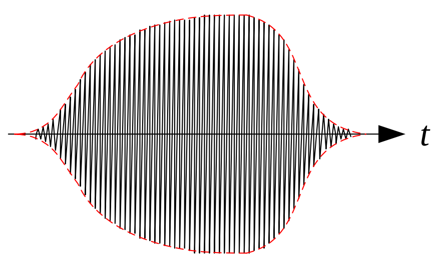
using (12.36). If we next assume a 10-Hz keying rhythm, then the bandwidth needed for this communication channel is

$$\text{BW} = 2 \cdot 101 \text{ harmonics} \cdot 10 \frac{\text{Hz}}{\text{harmonic}} \approx 2 \text{ kHz.}$$

This is a pretty large bandwidth and it's needed if we require that the keying waveform rise and fall instantaneously. (For comparison 2 kHz is the BW needed for a SSB voice channel.)

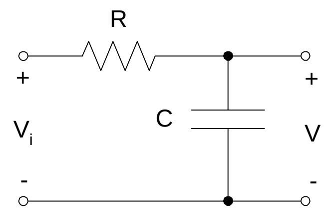
Decreasing Channel Bandwidth for CW

The BW required for a CW channel can be greatly reduced ($\approx$10x) by introducing a rise and fall time to the transmitter keying pulses:



This waveform is the product of carrier and keying waveforms. However, the Fourier series expansion of this waveform is more complicated than the one we considered earlier ($\tau = 0$).

Your text has a clever method for computing the average power in the harmonics using the RC network in Fig. 12.10(b):



From this circuit:

$$\frac{V}{V_i} = \frac{1}{1 + j\omega\tau} = \frac{1}{1 + jn\omega_k\tau} \qquad (12.37),(12.38)$$

where $\tau = RC$ and n is the keying-harmonic number.

Your text uses this frequency response as well as the carrier waveform to solve for the average power **outside** the channel relative to the carrier to be

$$p \approx \frac{1}{3\pi^2 n^3 \left(\omega_k \tau\right)^2} \qquad (12.42)$$

For p = -30 dBc as before:

$$n \approx \left(f_k \tau\right)^{-2/3} \qquad (12.44)$$

Some commercial transmitters use τ = 3 ms. Then with f_k = 10 Hz this gives

$$n \approx 10 \text{ harmonics} \qquad (12.45)$$

Hence,

$$\text{BW} = 2 \cdot 10 \text{ harmonics} \cdot 10 \frac{\text{Hz}}{\text{harmonic}} = 200 \text{ Hz}$$

This is the BW per channel needed for CW communications when the keying waveform has rise and fall times equal to 3 ms.

This BW is 10x smaller than without the rise and fall characteristic. A huge improvement.

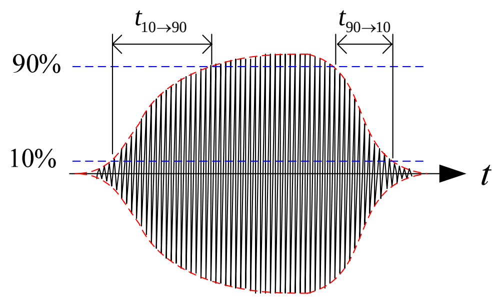
Key Clicks

The IF Filter BW in the NorCal 40A is approximately 400 Hz. Consequently, a 200-Hz CW channel can easily pass through without significant distortion.

A roughly 200-Hz channel is common for CW communications. Operators will space themselves a few hundred Hz more than this from other CW “QSO’s” to avoid interference.

However, if there is a transmitter turning on and/or off too quickly, operators on nearby frequencies will hear clicking sounds that will interfere with their QSO. These are called key clicks.

In Prob. 30, you will measure the output signal produced by your NorCal 40A when it is transmitting. This output will have the smoothed keying waveform shown earlier in this lecture:



Previously in this course, we have characterized the rise and fall times of waveforms in terms of the time t_2. This works only for exponential waveforms.

In the case of non-exponential waveforms, such as the keying waveform above, it is customary to use different definitions of rise and fall times:

- The rise time in terms of $t_{10\to 90}$: the time it takes the modulated waveform to go from 10% to 90% of its final value, and
- The fall time in terms of $t_{90\to 10}$: the time it takes the modulated waveform to go from 90% to 10% of its initial value.