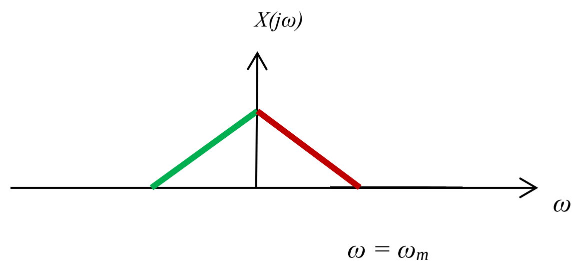
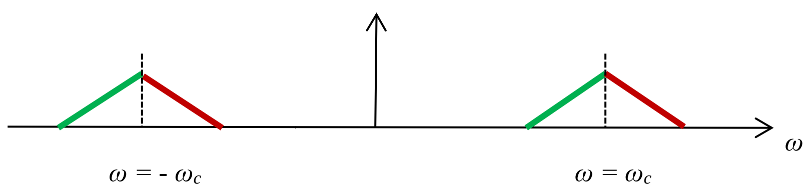
Lecture 9: Speech Scrambling

Consider a speech signal *x(t)* with highest frequency at ω_m. Thus, the spectrum, as illustrated in the figure, is bounded

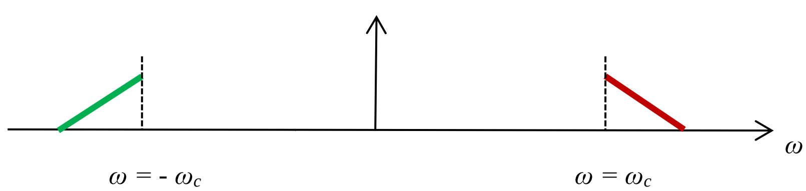
$$\omega \leq | \omega_m |$$



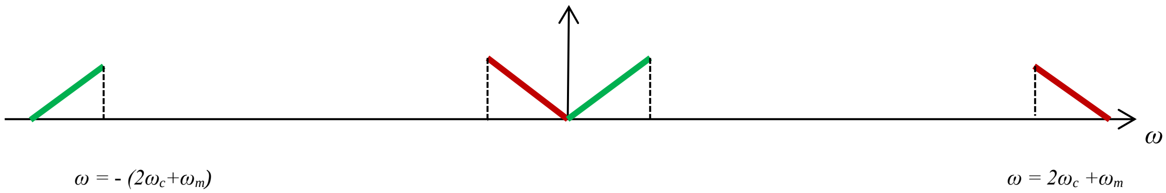
Now, we modulate this lowpass speech signal by $cos(\omega_c t)$. The spectrum is then shifted to $\pm\, \omega_c$.



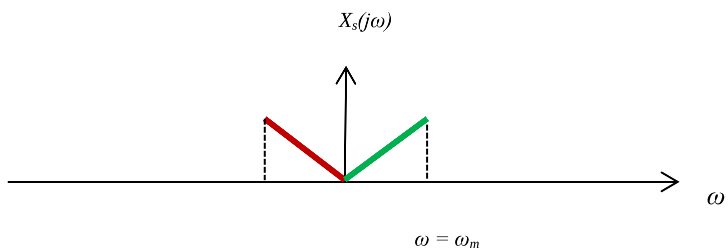
Subsequently, we highpass the modulated signal with the cutoff frequency at $\pm\, \omega_c$. As a result, each of the sidebands loses the low-frequency component. Yet, Hermitian symmetry is retained.



Then we demodulate the highpass signal with $cos((\omega_c+\omega_m)t)$. As a result, the high-frequency sidebands move back into the low-frequency region.



As the last step, we lowpass the demodulated speech signal with a cutoff frequency $\omega = \pm\omega_m$.



The speech scrambling procedure can be summarized in four simple steps:

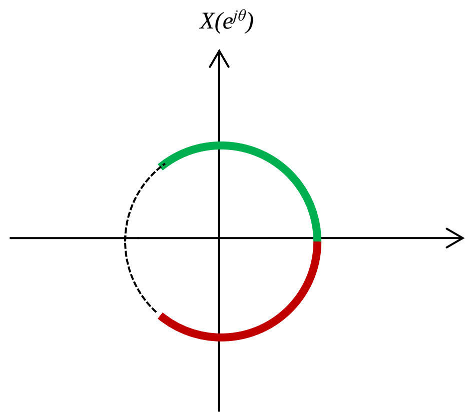
1. Modulation with $cos(\omega_c t)$
2. Highpass with the cutoff frequency at $\pm\ \omega_c$
3. Demodulate with $cos((\omega_c+\omega_m)t)$
4. Lowpass with a cutoff frequency $\omega = \pm\ \omega_m$.

The goal of this procedure is to reverse the order of the spectral distribution of the speech signal. The low-frequency components are shifted to high-frequency range. As a result of the spectral reversal, the contents of the speech become unrecognizable.

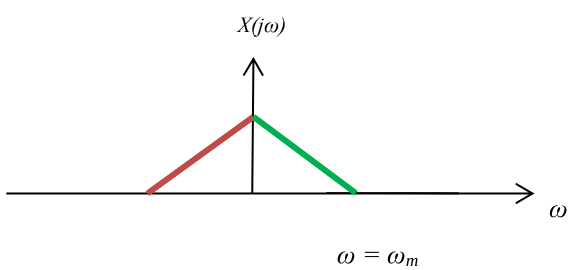
The most interesting feature of the speech scrambling procedure is that the same procedure is used for the recovery. If we describe the secured communication scheme as a locking-keying process, the locking and keying mechanisms for speech scrambling and unscrambling are identical.

Digital speech scrambling

The communication of speech signals is now commonly conducted in the digital form. Thus, the speech scrambling procedure needs to be modified to accommodate. Consider a digital speech sequence $x(n)$. The figure illustrates the *DTFT* spectrum distribution $X(e^{j\theta})$ of the speech sequence.



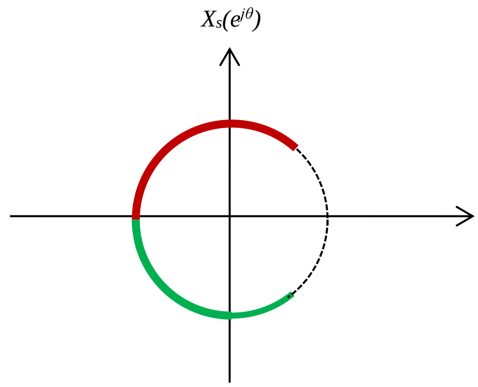
The distribution along the unit circle is equivalent to Fourier spectrum of the analog speech signal.



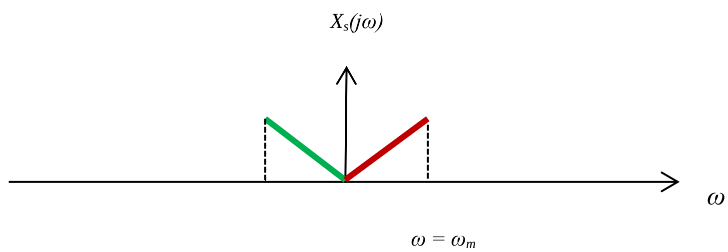
If we modulate the speech sequence by

$$m(n) = exp(jn\pi),$$

this process rotates the *DTFT* spectrum $X(e^{j\theta})$ by π.



This spectral distribution along the unit circle is equivalent to the Fourier spectrum of an analog waveform.



This one-step process achieves the same goal of the speech scrambling that the frequency index system is reversed and speech is no longer recognizable. It greatly simplifies the classical 4-step procedure. In addition, the modulation sequence is in the form

$$m(n) = exp(jn\pi) = (-1)^n$$
$$= \{ \ \ldots +1, -1, +1, -1, \ldots \ \}$$

This means the multiplication by a simple sequence completes the speech-scrambling process, and the recovery procedure is exactly the same.