EE5331

Demodulation and Demodulators

We'll discuss both analog and digital demodulators. Just keep in mind our objectives; i.e., achieve minimum noise and distortion (or minimum bit error rate), and achieve some optimum spectral efficiency.

Amplitude Modulation

If we assume the modulating signal, \( m(t) \),
lies in the range of -1 to +1 then we can express AM mathematically as

\[
\sqrt{1 + m(t)^2} \cos(\omega \tau)
\]

we can recover \( m(t) \) in this case by obtaining the absolute value of the signal, i.e., via peak detection.

This gives \(|1 + m(t)|\).

Removing the dc term gives \( m(t) \).
$R_L, C_L$ are adjusted to minimize droop between cycles and yet to faithfully reproduce $m(t)$. Effect of overfiltering, effect of underfiltering.
Ideally, the diodes in these circuits behave as pure switches. However, we know diodes turn on and off gradually. Using a Taylor series approximation, we have

$$i_d = k_0 + k_1 u_d + k_2 u_d^2$$

Given $u_d = A\left[1 + m(t)\right] \cos 2\pi ft$

Hence, $i_d = k_0 + k_1 A\left[1 + m(t)\right] \cos 2\pi ft$ +

Desired term

$+ k_2 A^2 m(t) + \frac{k_3 A^2}{2} \left[m(t)\right]^2$ +

$\frac{k_3 A^2}{2} \left[1 + m(t)\right]^2 \cos (4\pi ft)$
Consider the following circuit:

For $R_u$ small we will see more nonlinear response than if $R_u$ is large. Also, if the modulation index is small less distortion results. One additional problem with envelope detection has to do with performance as a
function of signal level. At higher signal levels, the S/N performances of envelope and coherent demodulators are about the same. However, for weaker signals, coherent demodulation offers superior performance over envelope demodulation. Coherent AM demodulation is one major step in performing
coherent demodulation is in obtaining (retrieving) the carrier needed for demodulation. It needs to be coherent with the carrier of the AM signal being demodulated. Fortunately, for AM the demodulation signal is already present. It simply needs to be appropriately processed to be used for demodulation.
Since the recovered output may still be somewhat noisy, a better result may be obtained using a PLL circuit.
Modulated signal input

Phase Detector → Loop Filter

VCO

Phase shift

Recovered carrier

With the recovered carrier demodulation is done as

\[ [1 + m(t)] \cos(2\pi f_c t) \]

follows:

\[ [1 + m(t)] \cos(2\pi f_c t) = \left[ 1 + m(t) \right] (\frac{1}{2} + \frac{1}{2} \cos(4\pi f_c t)) \]

Recovered carrier
Envelope detection does not allow us to retrieve the modulating information, $m(t)$, in this case. Here, coherent demodulation is usually the method of choice. However, coherent demodulation requires a signal that is in phase with the rf carrier. That is, with the signal having the form $m(t) \cos \omega t$, \[\]
we can obtain

\[ m(t) \cos(w_{rt}) \cos(w_{rt}) = m(t) \left[ \frac{1}{2} + \frac{1}{2} \cos 2w_{rt} \right] \]

and obtain \( m(t) \) by low pass filtering and multiplication.

It is not desirable to transmit the carrier separately. We would rather like to retrieve the carrier from the signal \( m(t) \cos w_{rt} \) and use that.
to demodulate the signal, we cannot phaselock an oscillator directly to the signal due to the zero crossings of \( m(t) \) which cause the carrier to go from + to - (causing discontinuities in phase or phase reversals). We can, however, square the signal and low pass filter to retrieve a signal with
One method of DSB demodulation.
A much more efficient circuit for DSB demodulation is the Costas Loop:

\[ \frac{1}{2} m(t) \cos(\omega_c - \omega_R) t \]

At 1 we have:

\[
m(t) \cos(\omega_R t) \cos(\omega_c t) = m(t) \frac{1}{2} \left[ \cos((\omega_R - \omega_c) t) + \cos((\omega_R + \omega_c) t) \right]
\]
At (2) we have
\[
m(t) \sin(w_c t) \cos(w_R t)
= \frac{1}{2} m(t) \left[ \sin[(w_c + w_R) t] + \sin[(w_c - w_R) t] \right]
\]

\[
\epsilon(t) = \frac{1}{4} \left[ m(t)^2 \cos[(w_R - w_c) t] \right] \sin[(w_c - w_R) t]
= \frac{1}{2} \left[ m(t)^2 \sin[2(w_c - w_R) t] \right]
= \frac{1}{2} \left[ m(t)^2 \sin[2\theta] \right] \leftarrow \text{lock}
\]

As long as the LO signal remains locked and free
of excessive phase noise, the S/N from the DSB demodulator is the same as that at high levels as that from an envelope demodulator. At all levels it is the same as AM output from a coherent demodulator. A substantial advantage of DSB over AM regards the input
power required for a particular output S/N. The required input power for DSB is much lower since the carrier is eliminated (or at least greatly reduced).

**SSB demodulation**

Here again we require the use of coherent demodulation. However, we'd like to keep
noise outside of the signal frequency from degrading performance. Notice that the simple scheme shown below will pass unwanted noise and signal from the USB directly to the output.

\[
A \cos(2\pi(fr-f_s)t) \rightarrow \ast \rightarrow B \cos(2\pi ft) \rightarrow X \cos(2\pi(fr-f_s)t)
\]

\[
B \cos(2\pi ft) \\
= AB \left( \frac{1}{2} \cos 2\pi ft + \frac{1}{2} \cos(2\pi(fr-f_s)t) \right)
\]
One method for SSB demodulation first mixes down to a reasonable IF and then places a sharp filter around the desired sideband.

\[\text{IF} \quad \text{Input signal is in LSB}\]

Preselect filter

\[\text{IF of } f_{lo_1}, \quad \text{USB, LSB}\]

The circuit for demodulation is as follows.
\[ f_{lo2} \text{ should ideally be at the frequency and phase of the missing carrier. However, SSB has two principal uses: (1) speech transmission where phase} \]
errors are undetectable and frequency errors up to about 50 Hz are nearly undetectable to most users; and (2) transmission of frequency-multiplexed digital data channels where recovery of frequency and phase of the individual data channels is accomplished in the data demultiplexer and demodulator.
Single-sideband demodulation can also be done using an image rejection mixer where the local oscillator frequency is set to be the same frequency and phase of the missing carrier.

**VSB demodulation**

VSB techniques are used where it is necessary to
send low frequencies. Mainly this is used for television broadcasting. Sufficient carrier is included so that envelope demodulation techniques can be used. AFC circuits can be used to adjust the carrier to the proper spot in the IF band.
Phase demodulation

Assuming we have a signal of the form $a \cos(\omega t + \phi(t))$, we can retrieve the information by using a suitably designed mixer or multiplier with low pass filter at the output.

\[
\begin{align*}
&\text{acos}(\omega t + \phi(t)) \\
\Rightarrow &\quad -ab\sin(\phi(t)) \\
\Rightarrow &\quad b\sin\omega t \\
\text{(Ref. 10)}
\end{align*}
\]
Notice that we have

\[ ab \cos(\omega t + \phi(t)) \sin(\omega t) \]

\[ = -ab \sin(\phi(t)) \]

\[ -\sin(2\omega t + \phi(t)) \]

removed by LPF.

For small phase changes the output \( \equiv -ab \phi(t) \)

A simple circuit to accomplish both the mixing and LPF functions is as shown.
Notice that the input signal amplitude must be constant for this circuit to retrieve the information properly. In the practical situation $a$ varies with...
noise and as the link propagation characteristics vary. That is, \( a = a(t) \). Hence, it is usually desirable to limit the signal amplitude to remove (reduce) variation in \( a \). Another shortcoming of the simple product-type phase demodulator is wrt phase variation; \(-90^\circ \leq \phi(t) \leq 90^\circ\) to prevent ambiguous outputs.
Also, for linear recovery
- $-30^\circ \leq \phi(t) \leq 30^\circ$ unless a
linearizing circuit is used.
A digital circuit technique
can extend $\phi(t)$ to nearly
$\pm 180^\circ$. Here, square waves
are used for both input
and reference signals.

\[ \text{Phase-modulated IF input} \]

\[ \text{Reference Schmitt Trigger Monostable Multivibrator} \]

\[ \text{CD} \]

\[ \text{Reset Flip Flop Out} \]
Notice that the output has the form
\[ A \theta \]
Area provides measure of phase difference.

[For best results the reference signal should be 180° wrt the input signal at 0° phase point.]

Many phase demodulators are now implemented via DSP techniques.
In this case data are collected as complex I+Q signals. Then processing is done to retrieve the information.

Phase can be retrieved as

\[ \phi(t) = \tan^{-1} \frac{Q}{I} \]
The processor must keep track of signs for I and Q to select the appropriate magnitude and sign for \( \Phi(t) \). Notice that the effects of amplitude variations are removed in finding \( \Phi(t) \). Instead of mixing down to baseband, it is now possible in many cases to digitize
directly at the IF frequency. Specialized types of filtering (that can't be done with analog circuits) are possible in this case. One common application of this type of phase demodulator circuit is for QPSK techniques used in modern digital cellular systems.
More on this later.

**FM demodulation**

Consider PLL approach. Limited FM input

![ PLL diagram ]

Travis Discriminator approach

![ Discriminator diagram ]
Each LC circuit has a response of the form:

\[
\text{Amp.} \quad f
\]

\[
\text{Phase} \quad f
\]
Stagger-tuning