## 2.2 Diode envelope detector (DDE)

### 2.2.1 Theory of mixing

A mixer is traditionally a radio term for a circuit that shifts one signal's frequency up or down by combining it with another signal. A mixer is also a device that blends several audio signals together for example for recording, broadcast or sound reinforcement.

The two types of mixer differ in two important things:

- A mixer makes new frequencies out of the input frequencies
- A audio mixer doesn't make new frequencies

A audio mixer can be seen as a *combiner* that adds two signals. A *mixer* instead multiplies the two input signals. Because mixing combines two energies with each other this process is often called *heterodyning* (Greek for *other* and *power*). To understand the process in a mixer and in a combiner we need two sinusodial signals, $x(t)$ and $y(t)$

$$x(t) = X \cdot \sin(2\pi f_x t) \tag{2.1}$$

$$y(t) = Y \cdot \sin(2\pi f_y t) \tag{2.2}$$

Now we can compute the output of a combiner with adding the two signals

$$x(t) + y(t) = X \cdot \sin(2\pi f_x t) + Y \cdot \sin(2\pi f_y t) \tag{2.3}$$

It is obvious that this process produces nothing new.

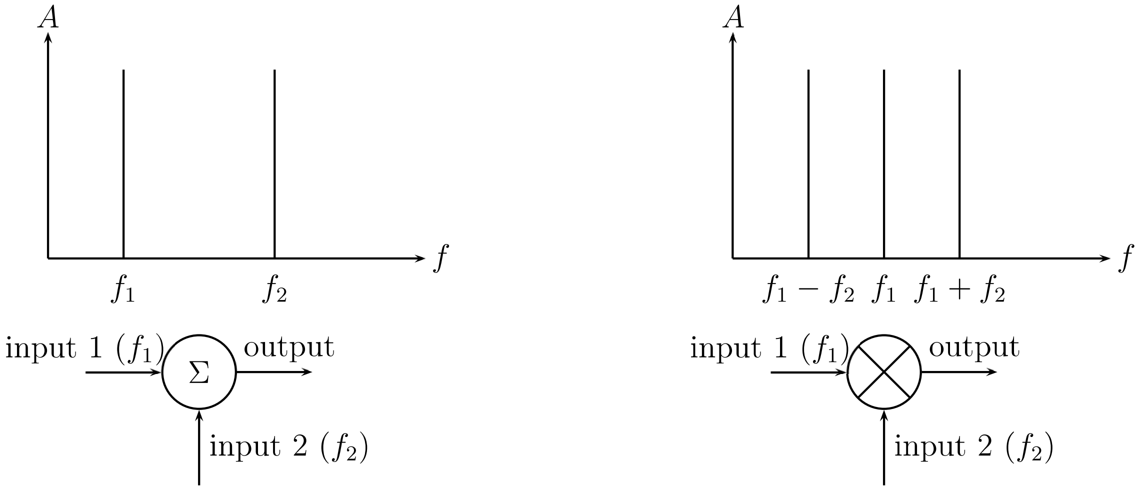
The output of a mixer is computed by

$$x(t) \cdot y(t) = X \cdot \sin(2\pi f_x t) \cdot Y \cdot \sin(2\pi f_y t) \tag{2.4}$$

With the trigonometrically formula $\sin x \sin y = {}^1\!/_2[\cos(x-y) - \cos(x+y)]$ equation (2.4) can be reduced to

$$x(t) \cdot y(t) = \frac{X \cdot Y}{2}\{\cos(2\pi[f_x - f_y]t) - \cos(2\pi[f_x + f_y])\} \tag{2.5}$$

The output of equation (2.5) contains two new frequencies: $f_x - f_y$ and $f_x + f_y$. These two will later be called lower and upper sideband. The following figure shows the spectra of the outputsignal of a mixer and a combiner.



(a) Combiner (b) Mixer

Figure 2.1: Comparison of the spectra of a combiner and a mixer

### 2.2.2 Theory of amplitude modulation

Amplitude modulation is the oldest mean of translating information into radio form and back again. In a amplitude modulated signal the waveform varies in accordance with the frequency of the input signal. Such a system is called a frequency shifting system and the output consists out of

1. Original signal: carrier
2. Information: Message
3. Sum of frequencies: Upper sideband
4. Difference of frequencies: Lower sideband

The spectrum of the AM signal is identical with the signal shown in 2.1(b).

Using the two input signals shown above the AM output can be computed by

$$AM(t) = (U_c + U_m \sin(2\pi f_m t)) \cdot \sin(2\pi f_c t) \tag{2.6}$$

Reducing the equation in the same way as equation (2.4) brings up the four parts inside the AM signal

$$AM(t) = \underbrace{U_c \sin(2\pi f_c t)}_{Carriersignal} + \underbrace{\frac{U_m}{2}\{\cos(2\pi \overbrace{[f_c - f_m]}^{Lowersideband} t) - \cos(2\pi \overbrace{[f_c + f_m]}^{Uppersideband} )\}}_{Information} \tag{2.7}$$

The equation also shows that the information resides entirely in the sidebands of the output signal. Therefore the more energetic the sidebands are the more information energy will be available for the demodulator. How strong the signal is modulated can be computed by using the equation

$$m = \frac{U_m}{U_c} = \frac{A - b}{A + B} \tag{2.8}$$

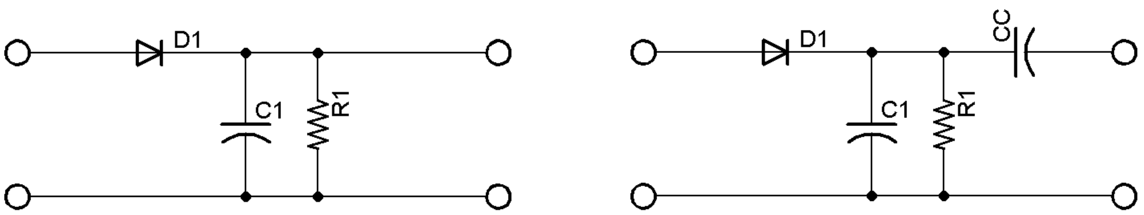
Where $m$ is the modulation index, $U_m = A$ the message amplitude and $U_c = B$ the carrier amplitude. The maximum distortion free modulation is reached when the modulation output just reaches zero at the modulation waveforms negative part. This condition is called 100% modulation and occurs when $U_m = U_c$.

### 2.2.3 AM demodulation with envelope detection

Demodulation is achieved by using another mixer in which the modulated signal is modulated again with the carrier signal. Since the information inside an AM signal resides in the waveform the easiest way to recover it is to use a diode rectifier. In that case such a rectifier is called diode envelope detector.

The nonlinear characteristic of a diode allows the diode ”to multiply”. The multiplication happens due to the rectification of the input signal: It gets multiplied by the carrier. The output waveform is then equal to the information waveform.

Putting a coupling capacitor after the detector removes the dc offset.



(a) Without coupling capacitor (b) With coupling capacitor

Figure 2.2: Standard circuit for diode envelope detector

### 2.2.4 Dimensioning the detector

The diode has to be chosen for the forward and backward voltage. Also the frequency of the diode has to be at least equal to the upper sideband frequency.

The resistor is arbitrary. With the modulation index and the resistor the capacitor can be computed by

$$C \leq \frac{\sqrt{(\frac{1}{m})^2 - 1}}{2\pi R f_m(max)} \tag{2.9}$$

The coupling capacitor has to be chosen just as big that the dc offset is removed. But it is recommandable to choose the size of the coupling capacitor with the impedance of the RC parallel structure inside the diode envelope detector.