AM Receiver with complex signals and channel selection (tuning)

The transmitted AM signal is of the form:

$$s(t) = a(t)\cos(2\pi f_c t + \phi) = A_c[1 + k_a m(t)]\cos(2\pi f_c t + \phi)$$

where ϕ is a constant phase. The AM receiver recovers $m(t)$ from $s(t)$. One method is to recover $a(t) = 1 + k_a m(t)$ and subtract the DC component to obtain $m(t)$.

To show how this is done in software with the USRP and GNURadio Companion (GRC), recall that the USRP source block has a complex output with real and imaginary components $i(t)$ and $q(t)$.

We can write the AM signal $s(t)$ as the real part of a complex signal:

$$s(t) = \mathrm{Re}[a(t)e^{j\phi}e^{j2\pi f_c t}] = \mathrm{Re}[\tilde{s}(t)e^{j2\pi f_c t}],$$

where the complex envelope:

$$\begin{aligned}\tilde{s}(t) &= a(t)e^{j\phi} = a(t)\cos\phi + ja(t)\sin\phi \\ &= i(t) + jq(t)\end{aligned}$$

Thus the USRP source block with frequency set to f_c will have outputs:

$$i(t) = a(t)\cos\phi,\ q(t) = a(t)\sin\phi.$$

To obtain $a(t)$, we take the magnitude of the complex envelope $\tilde{s}(t)$, thus we can write:

$$\begin{aligned}|\tilde{s}(t)| &= |i(t) + jq(t)| \\ &= |a(t)\cos\phi + ja(t)\sin\phi| \\ &= a(t)|\cos\phi + j\sin\phi| \\ &= a(t)\sqrt{\cos^2\phi + \sin^2\phi} = a(t)\end{aligned}$$

This shows that we can recover $a(t) = 1 + k_a m(t)$ regardless of the value of ϕ.

The GRC *Complex to Magnitude* block allows us to obtain the magnitude of the complex envelope by performing the function $a(t) = |i(t) + jq(t)|$.

If there is frequency offset, then $\phi = 2\pi\Delta f t$, but as we have just seen, $|\tilde{s}(t)| = a(t)$ is not affected by the value of ϕ and thus not affected by any frequency offset Δf.

The USRP multiplies the real valued radio frequency signal $s(t)$ by $e^{j2\pi f_c t}$ to generate $i(t) + jq(t)$. This process is called *complex downmixing* and is equivalent to the standard IQ receiver shown in Figure 1.

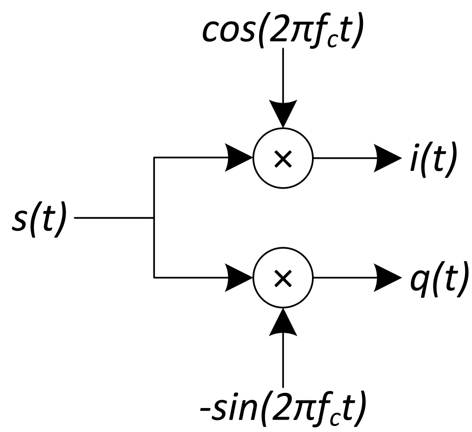

Figure 1 Complex Mixer

Recall:

$$s(t) \leftrightarrow S(f)$$
$$e^{-j2\pi f_c t} s(t) \leftrightarrow S(f + f_c)$$

The spectrum $S(f)$ of the real radio frequency (RF) signal $s(t)$ will be symmetric about zero. After complex downmixing, the resulting signal is complex and the frequency spectrum $S(f + f_c)$ is no longer symmetric about zero.

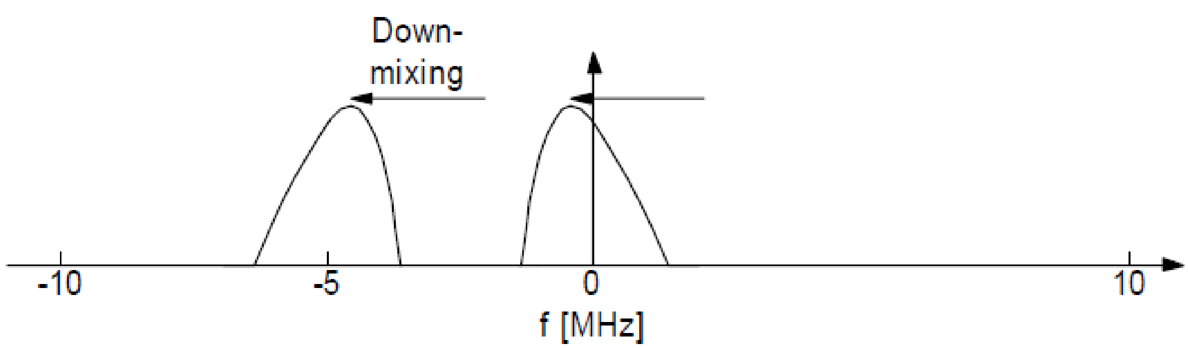

Figure 2 Downmixing

The complex signal output from the USRP source block (or file source block) $i(t) + jq(t)$ is bandlimited to the sampling rate of the USRP source block. The USRP source block output can be recorded to a file and used again at a later time. This file source will have the same sampling rate and bandwidth as the USRP sink block used to record it.

With a sampling rate of 256 kHz and complex samples, the bandwidth will be 256 kHz (because the complex signal spectrum is not symmetric and does not have redundant mirror-image positive and negative frequencies).

AM radio broadcast signals in the medium wave band 530-1600 KHz have a bandwidth of ± 5 KHz and the carrier frequencies (channels) are spaced apart by f_0 =10 KHz in North America (9 KHz elsewhere), e.g. there can be carriers at 710, 720, 730 KHz, etc. AM radio signals in the shortwave bands have carriers spaced by f_0 =5 KHz. AM aircraft channels in the range 108-137 MHz are spaced by 8.33 KHz (25/3).

With a file source sampled at 256 kHz, thus covering a bandwidth of 256 KHz, there can be as many as 25 different AM broadcast signals spaced at 10 KHz.

The AM broadcast signal with carrier frequency $f_c = f_{LO}$ (f_{LO} is set in the USRP source block) will appear at zero Hz after the downconversion (at the USRP source output). Other signals at carrier frequencies $f_c \pm nf_0$ kHz will appear at multiples of $f_0 = 10$ KHz away from zero Hz

We need to create a filter to select the one signal we want (the one with carrier frequency f_c that now appears at 0 Hz). A low pass filter with 5 KHz cutoff frequency will do the job, since all the other signals are centered at frequencies at least 10 KHz away from zero Hz.

To "tune in" (receive) one of the other signals, we can shift the spectrum of the USRP source output by nf_0 KHz by multiplying the complex signal $i(t) + jq(t)$ by $e^{-j2\pi nf_0 t} = \cos 2\pi nf_0 t - j\sin 2\pi nf_0 t$, so that the signal that first appeared at nf_0 Hz now appears at zero Hz.