Image and Third-Order Signal Rejection

Recall in a previous handout the **example** where a receiver had an IF frequency of $f_{IF} = 30\ MHz$. We desired to demodulate a radio station operating at 100 *MHz*, so we set the LO to a frequency of $f_{LO} = 130\ MHz$ (i.e., high-side tuning).

We discovered that **RF** signals at many **other** frequencies would likewise produce signals at **precisely** the **IF** frequency of 30 MHz—a very serious problem that can only be solved by the addition of a **preselector** filter.

Recall that this preselector filter must allow the **desired** signal (or band of signals) to pass through **unattenuated**, but likewise must sufficiently **reject** (i.e., attenuate) all the RF signals that could create **spurious** signals at the IF frequency.

We found for this **example** that these RF signals reside at frequencies:

10 *MHz*, 15 *MHz*, 30 *MHz*, 80 *MHz*,
160 *MHz*, 230 *MHz*, and 290 *MHz*

Note that the most **problematic** of these RF signals are the two at **80 *MHz*** and **160 *MHz*.**

Q: *Why do **these** two signals pose the greatest problems?*

A: Because the frequencies 80 *MHz* and 160 *MHz* are the **closest** to the **desired** signal frequency of 100 *MHz.* Thus, they must be the closest to the **pass-band** of the preselector filter, and so will be attenuated the **least** of all the RF signals in the list above.

As a result, the 30 MHz mixer products produced by the RF signals at 80 *MHz* and 160 *MHz* will be **likely** be **larger** than those produced by the other problem frequencies—they are the ones most need to **worry** about!

Let's look closer at each of these two signals.

Image Frequency Rejection

We determined in an earlier handout that the radio frequency signal at 160 *MHz* was the **image** frequency for this particular example.

Recall the image frequency is the **other** f_{RF} solution to the (ideal) second-order mixer term $|f_{RF} - f_{LO}| = f_{IF}$!

For **low-side** tuning, the **desired** RF signal is (by definition) the solution that is **greater** than f_{LO}:

$$f_{RF} = f_{LO} + f_{IF} \qquad \text{(low-side tuning)}$$

And thus the image signal is the solution that is **less** than f_{LO}:

$$f_{image} = f_{LO} - f_{IF} \qquad \text{(low-side tuning)}$$

Similarly, for **high-side** tuning, the **desired** RF signal is (by definition) the solution that is **less** than f_{LO}:

$$f_{RF} = f_{LO} - f_{IF} \qquad \text{(high-side tuning)}$$

And thus the **image** signal is the solution that is **greater** than f_{LO}:

$$f_{image} = f_{LO} + f_{IF} \qquad \text{(high-side tuning)}$$

Note for both high-side and low-side tuning, the **difference** between the desired RF signal and its image frequency is $2 f_{IF}$:

$$\left| f_{RF} - f_{image} \right| = 2 f_{IF}$$

This is a **very** important result, as is says that we can **increase** the "distance" between a desired RF signal and its image frequency by simply **increasing** the IF frequency of our receiver design!

For **example**, again consider the FM band (88 MHz to 108 MHz). Say we decide to design an FM radio with an IF of **20 MHz,** using high-side tuning.

Thus, the **LO bandwidth** must extend from:

$$88 + f_{IF} < f_{LO} < 108 + f_{IF}$$
$$88 + 20 < f_{LO} < 108 + 20$$
$$108 < f_{LO} < 128$$

The **image bandwidth** is therefore:

$$108 + f_{IF} < f_{image} < 128 + f_{IF}$$
$$108 + 20 < f_{image} < 128 + 20$$
$$128 < f_{image} < 148$$

Thus, the **preselector filter** for this FM radio must have pass-band that extends from 88 to 108 MHz, but must **also** sufficiently **attenuate** the image signal band extending from 128 to 148 MHz.

Note that 128 MHz is **very** close to 108 MHz, so that attenuating the signal may be very **difficult**.

Q: *By **how much** do we need to attenuate these image signals?*

A: A very **good question**; one that leads to a very important point. Since the image frequency creates the **same** second-order product as the desired signal, the **conversion loss** associated with each signal is **precisely** the same (e.g. 6 dB)!

As a result, the IF signal created by image signals will typically be **just** as large as those created by the desired FM station.

This means that we must **greatly attenuate** the image band, typically by **40 dB** or more!

Q: *Yikes! It sounds like we might require a filter of very **high order**!?!*

A: That's certainly a **possibility.** However, we can always reduce this required preselector filter order if we simply **increase** our IF design frequency!

To see how this works, consider what happens if we **increase** the receiver IF frequency to $f_{IF} = 40MHz$. For this **new** IF, the LO bandwidth must increase to:

$$88 + f_{IF} < f_{LO} < 108 + f_{IF}$$
$$88 + 40 < f_{LO} < 108 + 40$$
$$128 < f_{LO} < 148$$

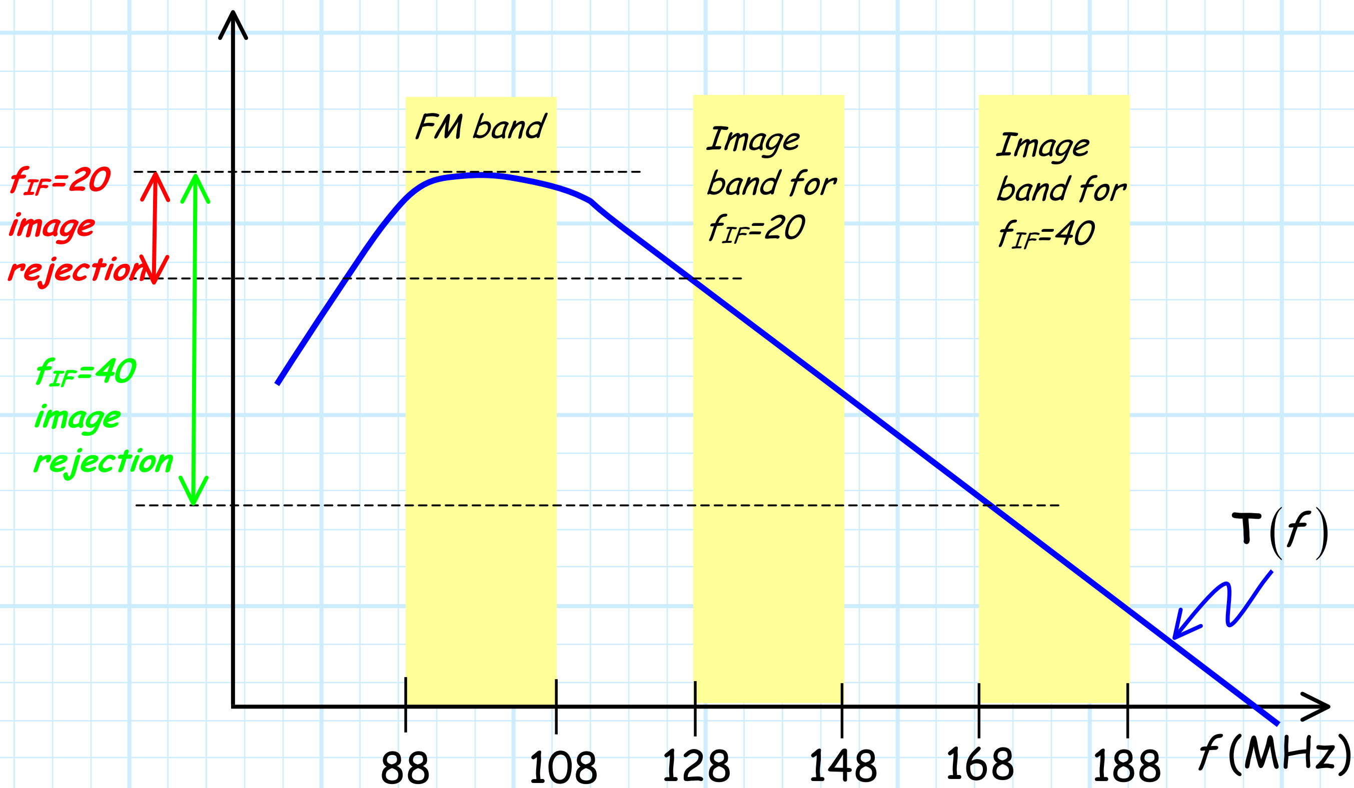
The new **image** bandwidth has therefore **increased** to:

$$108 + f_{IF} < f_{image} < 128 + f_{IF}$$

$$128 + 40 < f_{image} < 148 + 40$$

$$168 < f_{image} < 188$$

Note this image band is now **much** higher in frequency than the FM band—and thus much more **easily filtered**!



The amount by which the preselector attenuates the image signals is known as the **image rejection** of the receiver.

For **example**, if the preselector filter attenuates the image band by at least 50 dB, we say that the receiver has 50 dB of image rejection.

So by increasing the IF frequency, we can **either** get greater image rejection from the same preselector filter order, **or** we can reduce the preselector filter order while maintaining sufficient image rejection.

But be **careful**! Increasing the IF frequency will also tend to increase cost and reduce detector performance.

3rd-Order Signal Rejection

In addition to the image frequency (the **other** solution to the second order term $|f_{RF} - f_{LO}| = f_{IF}$), the other radio signals that are particularly difficult to reject are the f_{RF} solutions to the **3rd order** product terms $|2f_{RF} - f_{LO}| = f_{IF}$ and $|2f_{LO} - f_{RF}| = f_{IF}$.

There are **four** possible RF solutions (two for each term):

$$f_1 = \frac{f_{LO} + f_{IF}}{2} \quad \leftarrow$$

$$f_2 = \frac{f_{LO} - f_{IF}}{2}$$

$$f_3 = 2f_{LO} + f_{IF}$$

$$f_4 = 2f_{LO} - f_{IF} \quad \leftarrow$$

Each of these four solutions represents the frequency of a radio signal that will create a 3rd order product precisely at the IF frequency, and thus all four must be adequately rejected by the preselector filter.

However, solutions f_1 and f_4 will **typically** be the **most** problematic (i.e., closest to the desired RF frequency band). For instance, in our original **example**, the "problem" signal at **80 MHz** is the term f_1 (i.e., $f_1 = 80\ MHz$).

Q: *By **how much** do we need to attenuate **these** signals?*

A: Since these signals produce **3rd order** mixer products, the IF signal power produced is generally much **less** than that of the (2nd order) image signal product. As a result, we can at times get by with as little as **20 dB** of 3rd order signal rejection—but this **depends** on the mixer used.

Q: ***Just** 20 dB of rejection? It sounds like achieving this will be a "**piece of cake**"—at least compared with satisfying the **image** rejection requirement!*

A: Not so fast! Often we will find that these 3rd order signals will be **very close** to the **desired RF band**. In fact (if we're not careful when designing the receiver) these 3rd order signals can lie **inside** the desired RF band—then they **cannot** be attenuated at all!

Thus, rejecting these 3rd order radio signals can be **as** difficult (or even **more** difficult) than rejecting the image signal.

Q: *We found earlier that by **increasing** the IF frequency, we could make the **image rejection** problem much easier. Is there a **similar** solution to improving 3rd order signal rejection?*

A: Yes there is—but you **won't** like this answer! Generally speaking, we can move the 3rd order signals **away** from the desired RF band (thus making them **easier** to filter) by **decreasing** the IF frequency.

This solution of course is exactly **opposite** of the method used to improve image rejection. Thus, there is a **conflict** between the two design goals. It is **your** job as a receiver designer to arrive at the best possible **design compromise**, providing both sufficient image **and** 3rd order signal rejection.

→ Engineering is **not** easy ! ←