Introduction

As we have seen, receiving systems can be very complex, requiring carefully designed filters, amplifiers, and mixer stages in addition to other more specialized circuitry. Consequently, they can be relatively expensive. Receivers are typically designed to operate over a specific portion of the electromagnetic spectrum, but sometimes a need arises to detect signals outside the frequency range for which a receiver was originally designed. Instead of purchasing or assembling a new receiver, a downconverter can be added to an existing receiver. As shown in Figure 1, a downconverter simply translates a signal from a higher frequency to a lower one. (Upconverters are similar circuits that do the opposite.) An input band-pass filter attenuates signals outside the desired range, the mixer performs the frequency translation, and a circuit called a diplexer follows the mixer. Many mixers, especially diode rings mixers, work best when the IF port is terminated in a specific impedance (usually 50 Ω) at all frequencies, not just at the IF. If the termination impedance at the frequency of a spurious signal is not 50 Ω, then the circuit balance of the mixer could be disturbed, which in turn might lead to additional spurious output signals. A diplexer circuit provides the required wideband termination by directing the IF energy to the output of the downconverter and directing spurious signals and unwanted mixer products to a matched load. The use of diplexers is not limited to downconverters. Most well designed receiving systems employ diplexers after each mixer stage.

In this lab exercise you will design one type of diplexer circuit and then assemble a PC board for a diode ring mixer and the diplexer you designed. The mixer/diplexer board will be combined with the band-pass filter you assembled in a previous lab exercise to form the front end of a simple aircraft band receiver.

The group assignments for this lab exercise are the same as those for the previous one.

![Figure 1. Block diagram of a basic downconverter.](image)
Theoretical Background

The design of a wideband termination for a mixer circuit is complicated by the fact that the IF signal needs to pass through the IF filter while at the same time the spurious products (signals) must be kept out of the IF subsystem. This means that the IF signal and the spurious signals have to follow two separate signal paths. A diplexer is designed to direct signals in one frequency range along one signal path and signals at all other frequencies along another path. The latter path usually ends in a simple 50-Ω resistor, where the spurious signal energy is dissipated.

In the case of a downconverter, the design of the diplexer is simplified somewhat because it has to pass only low-frequency signals and terminate all signals above the that range. In a superheterodyne receiver, by contrast, it is usually necessary to pass signals that lie within a narrow range of frequencies (the IF) and terminate all signals above and below that range. This requirement calls for a triplexer, a circuit that provides three possible paths, two of which end in 50-Ω resistors. Hence, a band-pass/low-pass/high-pass filter combination is required (band-pass for the IF; low-pass and high-pass for everything else). In a downconverter a low-pass/high-pass combination is all that is required.

Figure 2 might help to clarify the concept. The output of a mixer contains not only the desired signal but also spurious products at frequencies outside the desired range. All of these signals have to be terminated in an impedance of 50 Ω. In principle, a buffer amplifier with an input impedance of 50 Ω at all frequencies could be used ahead of the IF strip instead of a diplexer, but amplifiers that exhibit constant input impedance over a wide range of frequencies can be difficult and/or expensive to design and construct. The amplified RF energy could also cause intermodulation problems in the following stages. Instead, a low-pass filter with a cut-off frequency above the desired range directs the desired signals to the IF subsystem. A high-pass filter with the same cut-off frequency directs the spurious signals to a 50-Ω resistor. Not all mixer designs require diplexers or triplexers, and even those that perform better with them can be used without them if the resulting degradation in performance is acceptable.

Figure 2. Diplexer block diagram. The small triangle symbol at the bottom of the resistor indicates a connection to the ground node.
The diplexer circuit does not usually have to be complicated. The simple circuit shown in Figure 3 performs adequately in most cases. The input impedance $R_{IF}$ of the IF subsystem combines with the inductor $L$ to form a low-pass response, and the termination resistor $R_t$ and capacitor $C$ form a high-pass response. The design goal is to make sure that the input impedance $Z_{in}$ of the combined LPF/HPF circuit is 50 $\Omega$ at all frequencies and that the cut-off frequencies of the filters are the same (or close) and appropriate for the design goals. These two constraints determine the two unknowns (the values of $L$ and $C$) in the diplexer circuit.

![Figure 3](image_url)

**Figure 3.** Simple diplexer circuit suitable for use in a downconverter. Resistor $R_t$ is a physical resistor that serves as a termination for spurious signals. Resistor $R_{IF}$ represents the input impedance of the IF subsystem.

**Experimental Procedure**

Your deliverables for this lab exercise will be an assembled mixer/diplexer PC board and the documentation specified below. The documentation is due in BRKI 368 at 4:00 pm on Friday, April 11, 2014. Grades will be quantized as indicated next to each item.

- Design a suitable diplexer for your downconverter by finding appropriate values for $L$ and $C$ in Figure 3. Assume that $R_{IF} = R_t \approx 50$ $\Omega$ and that the desired cut-off frequency for both the low-pass response and the high-pass response is around 1 MHz (the exact frequency is not critical). Briefly but concisely explain your design procedure in your documentation.

  **Item #1 [0, 5, 10, 15, 20%]:** Copy of diplexer design process.

- Assemble the mixer/diplexer on the printed circuit board that will be provided to you using SMA board-edge connectors and a Mini-Circuits TUF-1 mixer. Be extremely careful when you mount the mixer; it is easy to install it backwards. Consult the data sheet (especially the top/bottom view diagrams) and think twice before soldering it into place. Make sure your lab partner(s) agrees with the intended orientation of the device on the board. Don’t forget to include the termination resistor $R_t$. The diplexer circuit should use SMT components for $L$, $C$, and $R_t$, since it has to be effective well above the aircraft communication band (roughly 120-130 MHz). However, if an SMT inductor of the correct value is not available, a small toroidal inductor can be used instead.

  **Item #3 [0, 20, 40%]:** Assembled mixer/diplexer circuit board.
• Use an Agilent N9310A signal generator as a local oscillator for the downconverter. Connect the generator to the LO port, and adjust its output level to +7 dBm (as specified in the TUF-1 data sheet) and its frequency to around 126 MHz. Connect the coupled-resonator filter you assembled during the previous lab exercise to the RF input of the mixer/diplexer.

• A second signal generator will serve as the RF signal for the initial tests. An Agilent E4438C or another Agilent N9310A should be available for this purpose. Set the second generator to produce a signal near 126 MHz at a power level of around −50 dBm. Once the RF signal level has been adjusted, apply it to the input of the downconverter (the combined filter and mixer/diplexer boards). You might need to press the “RF Output” button on the signal generator to obtain a signal.

• Connect the output of the diplexer to the Agilent N9320A spectrum analyzer’s input port. Set the frequency range of the analyzer to 0 to 10 MHz or so with resolution and video bandwidths (RBW and VBW) of 10 or 100 kHz, depending on which gives the most satisfactory performance. While adjusting the frequency of the RF signal, note where the mixer output products appear and how they change when the RF signal frequency is varied. Also, determine whether the diplexer seems to be performing as designed. That is, verify whether or not mixer output products above 1 MHz are being attenuated. If it is not working properly, check to make sure that all components have been placed on the PC board correctly, that the solder connections are good, and that there are no solder bridges anywhere.

• Set the RF signal frequency so that it is about 20-40 kHz away from the LO’s frequency, and raise the RF signal level from −50 dBm to around 0 dBm or perhaps higher while monitoring the spectrum analyzer. As the RF signal strength rises, note the appearance of any new mixer output products. Do the products appear at the high-order IMD frequencies $|mf_{LO} \pm nf_{RF}|$, where $m$ and $n$ are integers?

• When the downconverter is operating properly, demonstrate it to the instructor.

**Item #3 [0, 10, 20, 30, 40%]:** Demonstration of working downconverter.

• Now connect the output of the downconverter to the Icom R8500 receiver tuned to about 300 kHz and set for AM demodulation. (You will have to share the R8500, or everyone can listen to one group’s system.) Remove the function generator that served as the RF signal, and replace it with an antenna. Tune around and try to pick up some air traffic signals!

**Group Assignments**

The randomly generated groups for this lab exercise are listed below:

- Walls-Selevan
- Kwiatkowski-Opalinski
- Collins-Swaim
- Hoolachan-Goesseringer

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