Replacing many RF receivers with only ONE using Channelization

From the early days analog radio receivers to the superheterodyne channelized receivers today many things have changed. Nowadays, different technologies are in use and the capabilities grew immensely. This article will give you a brief overview of the development of radio receivers. Moreover, it will show how using channelization it became possible to use one radio receiver and listen to many different radio stations simultaneously.

By Marija Dimitrijevic, Product Owner NC-10 Channelizer

Shared Communication Medium

In modern telecommunications point-to-point communication medium can be shared between multiple transmitters in various ways. For example, many different telephone calls can be transferred simultaneously via the same wire. In this case, each conversation can be considered as a separate channel on this medium. Another example are traditional TV or Radio stations transmitted through different channels at the same time. Information coming from one of the transmitters is called a channel.

There are multiple ways in which different channels of information can share a medium. Two of the most common ones are Time Division Multiplexing and Frequency Division Multiplexing. In Time Division Multiplexing different sources transmit in different slots of time whereas in Frequency Division Multiplexing, they transmit simultaneously at different RF frequencies. In the remainder of this text we will talk about the case of Frequency Division Multiplexing and frequency channels that this process produces.

Frequency Division Multiplexing

A signal in its original form at the transmitter side is called a baseband signal. This could for example be an audio signal which may take up to 20kHz of bandwidth. However, sending many different signals in baseband form would not be possible since data from different sources would overlap and it would not be possible to distinguish them. A more flexible way of sending data would be through use of different modulations. Modulations use various mathematical formulas to translate baseband signal to a signal centered at a carrier frequency of a, for example, radio station. The result of this is a frequency channel.

Modulated signal takes specific bandwidth around the carrier frequency, depending on modulation type. Some of the commonly used modulations for audio signals are AM (amplitude modulation) and FM (frequency modulation). Each country has an authority that takes care of the frequency regulations. They determine at which carrier frequency stations' data can be transmitted and make sure that different stations are not overlapping. For example, in USA FM stations take space between 87.8MHz and 108.0 MHz. This band is divided into 101 channels, each 0.2MHz wide.

Principles of Radio Receivers

Radio receiver is an electronic device that receives radio waves using an antenna and converts them to alternating currents. The desired information is then extracted from this current. The receiver uses analog filters to separate the desired radio frequency signal from other signals picked up by the antenna. Analog filter is followed by an amplifier used to increase signal power and finally demodulation is done. Information obtained in this way can be sound, images or data.

In various industries radio receivers can be used to acquire different types of information. For easier understanding of the topic, in the remainder of this text we will focus on radio receiver's functionality known in consumer electronics. This implies receiving and reproducing sound from radio broadcasting stations (AM or FM).

As explained in introduction, specific channel of interest, for example an FM radio station is transmitted at some carrier frequency and takes specific bandwidth. It is transmitted together with many different channels of information, all at different carrier frequencies. In order to be able to play the radio station, we need to do steps mentioned in transmitting phase in reverse order. That means that signal first needs to be translated from higher frequency to the baseband. Next step is demodulating it so that it can turn back to its original form.

Frequency Tuning

In order to simplify the explanation, let's talk about an example. Let us observe the hypothetical FM broadcasting scheme given in Figure 1. Every station takes 200kHz bandwidth but all of them are transmitted at different carrier frequencies. In order to, for example, listen to FM Station 3, what radio receiver needs to do is to obtain its specific 200kHz of information. The process done in early receivers is called tuning and it meant adjusting the frequency of the receiver to the carrier frequency of the channel of interest.

However, due to the lack of components able to do frequency selection besides the antenna itself, bandwidth of the receiver was equal to the bandwidth of the antenna. This meant that receiver would accept many different frequencies and not only the ones between 99.9MHz and 100.1MHz that we are interested in. Hence, receiver would pick up information from all different stations in figure below. This resulted in bad reception since data of interest was overlapping with data from other channels of information.

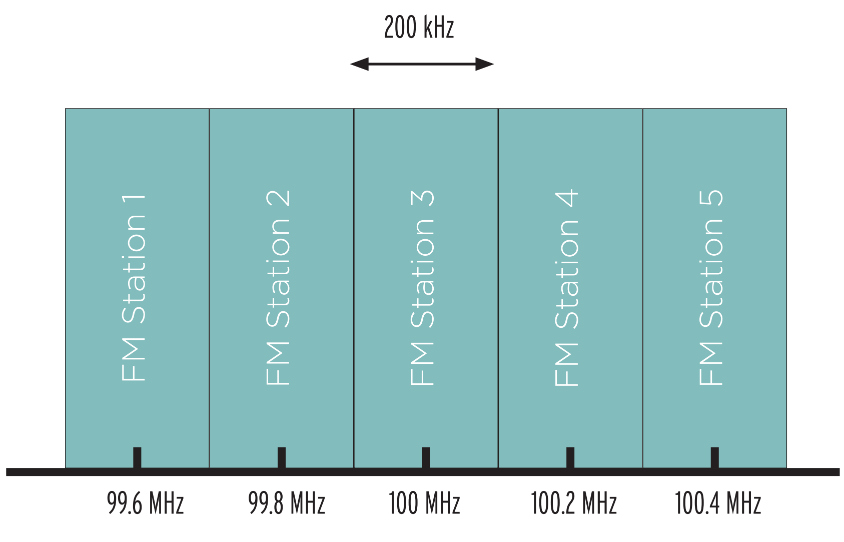

Figure 1 Hypothetical FM Broadcasting Scheme

Tuned Circuit

With the development of tuned circuit, it became possible to extract only the desired channel's frequencies. This was done by placing tuned circuit between antenna and detection system of a receiver. Tuned circuit acted as a bandpass filter. Capacitance and inductance of the circuit were determining the frequency of the tuned circuit. This meant that in order to listen to different stations this bandpass filter would have to change its passband depending on station and its carrier frequency. Result of this filtering would be that frequencies of interest are kept as close to their original form as possible. On the other side, all other frequencies would still be present but with significantly lower amplitudes.

The drawback of this type of receiver was the fact that the channel of interest would remain at high frequency and the higher the frequency is, the more difficult it is to create efficient filters with good selectivity. Moreover, different stations require different filters. Introduction of superheterodyne receivers helped with overcoming these issues.

Superheterodyne Receivers

Many industry radio receivers nowadays use the superheterodyne architecture. Signal centered at some high radio frequency is first "shifted" to a lower frequency, so called Intermediate Frequency. Only after this, processing takes place. It is IF signal that goes through filter and demodulation stages instead of a very high frequency RF signal. With this type of receiver, different radio stations are shifted to the same intermediate frequency. Given that different radio stations have same, standardized bandwidth unique filter can be used to extract only the channel of interest.

Integrated Circuits

Invention of transistors and development of integrated circuits led to the big changes in how receivers work nowadays. Many of the functions previously done by analog electronics are now done using digital circuits on a chip. Different hardware platforms were created for Digital Signal Processing on chip. Some of them include FPGAs, ASICs or dedicated Digital Signal Processors. All of these can execute signal processing operations much faster than general purpose processors (CPU).

Process of receiving radio signal nowadays means that the signal is digitized at Intermediate Frequency. Afterwards, it is bandpass filtered and demodulated in Digital Signal Processing on chip. This type of receiver is also known as Software Defined Radio. It's advantages include the possibility of dynamically changing properties of a receiver with regards to filtering and demodulation type. It is important to say that sample rate of the analog to digital converter is often much higher than the bandwidth of channel of interest.

Digital Signal Processing

To understand additional steps that must be done in digital domain, we will refer to the example described before. Let us assume our Analog to Digital Converter has sample rate of 50MSps. Signal of interest has 200 kHz of bandwidth as mentioned before. After digital filtering is done the amount of data remains the same. However, frequencies belonging to the channel of interest are unchanged and frequencies belonging to other channels will be significantly attenuated. After this, demodulation needs to be done.

There are two ways to do this. One of them is in the chip and other is in windows computer that receives filtered data from the chip. However, this amount of data is extremely high for windows processing and therefore reduction of sample rate needs to be done. This process is called resampling and it changes the sample rate of data in such way that all information of interest is saved and all other information is removed. In our case, resampling would lead to the sampling frequency of 200kHz since this is all that it takes to preserve all information for one FM station. The only thing remaining after this step is demodulation.

Channelization

The process of filtering out the unwanted components of signal from its original form and reducing the sample rate to the minimum required by the signal of interest is called channelization.

Given that the initial sample rate in our example is 50MHz and the extracted channel is 200kHz we reduce the amount of data 250 times. Since this saves us huge amount of processing power on windows side, it is possible to extract more channels using the chip and process them as well.

To be able to process and extract many channels in parallel from a wideband input can be very beneficial for a number of applications such as signal surveillance of communications, radar and GNSS. By using FPGAs thousands of signals can be extracted from a wideband signal in realtime. If capability of streaming the channels to different UDP ports is added, numerous use cases benefit in terms of used hardware.

Simplest example of this scenario would be listening to FM stations. As stated earlier, USA has 101 FM stations and in order to listen to all of them, traditionally, 101 different receivers are needed. If we had one receiver and an FPGA chip capable of channelizing and streamig 101 channels at the same time instead, one receiver would suffice. Hence, hundreds or even thousands of channels can be obtained using only one receiver.