Integrated Circuit FM Receiver using Bipolar Linear Array GA911 Technology

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March 2011

Introduction

Even if FM radio broadcasting is a fundamental means of communication, it can't escape one of the big trends in electronics today: miniaturization. As mobile communication devices are gaining more and more functionalities, people still want to have the option of listening to FM radio on their smart phones or MP3 players. This can only be achieved through the miniaturization of the FM reception process by implementing all its functions into a microchip. This miniaturization process is widely used in the industry, but has not been explored in depth by undergraduate students. In order to appreciate the complexity of such a task, we decided to design an FM receiver in a microchip. To make the project more interesting, we chose to create a user interface facilitating its use.

Background: The Superheterodyne Principle

Our FM receiver follows the Superheterodyne principle which dictates the use of an Intermediate Frequency (IF). The information carried on an FM channel is modulated on a high frequency carrier that propagates through the air. The high frequency carrier is modulated to represent the voltage of the information signal as a varying frequency. One method of demodulating the information signal is to shift this high frequency to a lower one (the IF). This can facilitate circuit design and component selection due to less pronounced Miller effects for transistors and larger values for reactive components in filters. In order to tune to different radio channels, we only have to change the local oscillator frequency to shift the desired channel to the designated IF, allowing the demodulation step to work at a single frequency, regardless of the channel the receiver is tuned to. [2]

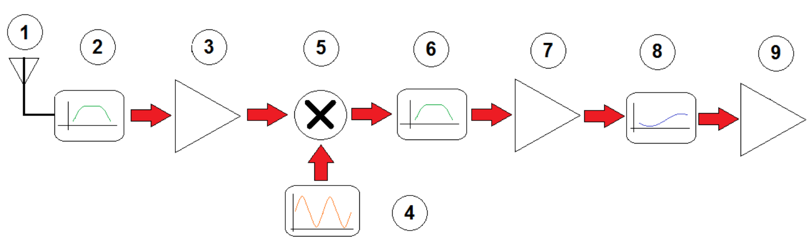

Figure 1: Block Diagram of an FM receiver

Block Functions: 1 Antenna; 2. RF Filter; 3. Low Noise Amplifier; 4. Local Oscillator; 5. Mixer; 6. IF Filter; 7. IF Amplifier; 8. Demodulator; 9. Audio Amplifier

Technology used

The technology used to make the integrated circuit is the Sound Design GA911 2.5 GHz Bipolar Linear Array. In the GA911 technology, all components are pre-placed on an array of 1000 by 2000 microns, and the designer must use a layout editor software to connect these components together to create the desired layout. This technology is more restrictive in many aspects in order to facilitate its use by beginner designers and reduce the manufacturing time. On the downside, this technology limits the designer to the use of the components inside the chip such as resistors (200, 1k, 5k, 10k and 90k Ohms) and transistors (NPN and PNP). The lack of inductors or capacitors inside the chip is an important consideration when designing it. All such components must be placed outside and therefore the input/output pins need to be effectively used. The number of pins for this project is limited by the DIP20 package to 20 per chip.

The technology provided allows for one layer of metal routing only. This metal layer serves as a passage for the signals and voltages to connect transistors and resistors to pads and pins for the creation of a circuit. This brings additional challenges when trying to connect the components together since at no point can two metal lines cross. In addition, various rules concerning the width of the line, the snapping to the grid and the distance between elements are enforced by Sound Design for the manufacturing of the design.

Application of Federal Communications Commission standards

In the USA, the standards for FM radio broadcasting can be found under the "Radio and Television Broadcast Rules" section of the Code of Federal Regulations (CFR) from the Federal Communications Commission (FCC). In Canada, the standards observed are regulated by the "Canadian Radio-Television Telecommunications Commission" (CRTC). Specific sections about FM radio are in sub part B "FM Broadcast stations" under part 73 of title 47. In order to properly receive the broadcast information, it was important to understand the standards used to transmit the information. In this aspect we needed to consider some standards in order to design our FM receiver.

"§ 73.201 Numerical designation of FM broadcast channels
The FM broadcast band consists of that portion of the radio frequency spectrum between 88 MHz and 108 MHz. It is divided into 100 channels of 200 kHz each." [4]

This standard plays a role in the RF filter design, antenna specifications, and local oscillator range. The bandwidth of each channel also defines the bandwidth of our IF filter. This information is key to knowing where to look for the radio channels and shows that without standards, they could be located anywhere.

§ 73.211 Power and antenna height requirements [4]

Station class	*Maximum ERP*	*Reference HAAT in meters (ft.)*	*Class contour distance in km*
A	*6 kW (7.8 dBk)*	*100 (328)*	*28*
B1	*25 kW (14.0 dBk)*	*100 (328)*	*39*
B	*50 kW (17.0 dBk)*	*150 (492)*	*52*
C3	*25 kW (14.0 dBk)*	*100 (328)*	*39*
C2	*50 kW (17.0 dBk)*	*150 (492)*	*52*
C1	*100 kW (20.0 dBk)*	*299 (981)*	*72*
C0	*100 kW (20.0 dBk)*	*450 (1476)*	*83*
C	*100 kW (20.0 dBk)*	*600 (1968)*	*9*

"§ 73.318 FM blanketing interference
Areas adjacent to the transmitting antenna that receive a signal with a strength of 115 dBu (562 mV/m) or greater will be assumed to be blanketed. In determining the blanketed area, the 115 dBu contour is determined by calculating the inverse distance field using the effective radiated power of the maximum radiated lobe of the antenna without considering its vertical radiation pattern or height.
[…]
(a) The distance to the 115 dBu contour is determined using the following equation:
D (in kilometers)=0.394√ P
D (in miles)=0.245√ P
Where P is the maximum effective radiated power (ERP), measured in kilowatts, of the maximum radiated lobe." [4]

This table helped us to have a sense of what is the maximum power we are likely to receive at the antenna given the distance of surrounding transmitters. The FM blanketing area rule more precisely defines the maximal signal strength to be received on the ground.

"§ 73.315 FM transmitter location
(a) The transmitter location shall be chosen so that, on the basis of the effective radiated power and antenna height above average terrain employed, a minimum field strength of 70 dB above one uV/m (dBu), or 3.16 mV/m, will be provided over the entire principal community to be served" [4]

By knowing what is the minimum signal strength that should exist for a radio station to be considered, we are able to define the sensitivity requirements of our receiver. These were used just as a guideline to get an idea of the power available to the front end of our receiver.

"73.317 FM transmission system requirements
(a) FM broadcast stations employing transmitters authorized after January 1, 1960, must maintain the bandwidth occupied by their emissions in accordance with the specification detailed below. […].

(b) Any emission appearing on a frequency removed from the carrier by between 120 kHz and 240 kHz inclusive must be attenuated at least 25 dB below the level of the unmodulated carrier. Compliance with this requirement will be deemed to show the occupied bandwidth to be 240 kHz or less.

(c) Any emission appearing on a frequency removed from the carrier by more than 240 kHz and up to and including 600 kHz must be attenuated at least 35 dB below the level of the unmodulated carrier.
(d) Any emission appearing on a frequency removed from the carrier by more than 60 kHz must be attenuated at least 43 + 10 Log10 (Power, in watts) dB below the level of the unmodulated carrier, or 80 dB, whichever is the lesser attenuation.
(e) Preemphasis shall not be greater than the impedance-frequency characteristics of a series inductance resistance network having a time constant of 75 microseconds. (See upper curve of Figure 2 of § 73.333.)
[51 FR 17028, May 8, 1986]" [4]

Researching this helped us plan how much interference from adjacent channels we needed to consider. This has an importance when designing the RF filter in terms of out of band rejection and Q factor.

The following specifications were adopted to comply with broadcasting standards:

Reception frequency band	88 MHz to 108 MHz
Receiver selectivity (channel spacing)	200 KHz
Receiver sensitivity (minimum signal level)	3,16 mV / meter
Maximum input signal strength	116 dBμ
Maximum interference from adjacent channels	Level of unmodulated carrier – 35 dB

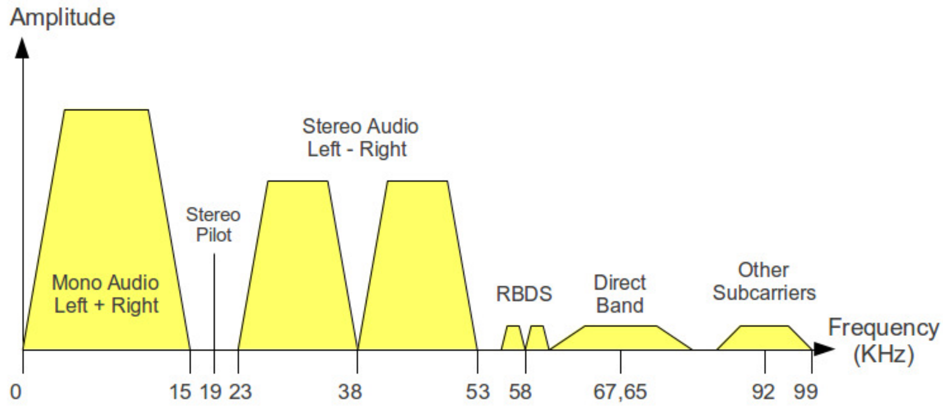

Figure 2: Spectrum of an FM channel

Content of an FM channel

Figure 2 is the spectrum of an FM channel relative to the station frequency [6]. In our FM receiver, we are only interested in the Mono audio component of the signal, which is located in the 0 and 15 kHz range. As can be seen, the spectrum covers a 100 kHz range, but since it must contain a negative frequency component mirrored on to the opposite side, it accounts for the 200 kHz band.

Circuit Description

The RF filter is located just after the antenna. It should select only the FM band (88 to 108 MHz) and reject the signals at other frequencies. This filtered signal is then passed to the RF amplifier. Transistors and resistors suffer from an inherent noise due to the transmission of charge through them. This noise can be broken down into several categories such as thermal, shot, flicker and burst. Because of these occurrences, the Low Noise Amplifier (LNA) should be designed to inject as little noise as possible into the input signal without compromising it [3]. Since this is one of the first stages, any signal and noise appearing at its output will be amplified by each following stage. Noise analysis is therefore very important at this point to ensure a good signal to noise ratio. Some solutions to this problem included adding degeneration resistances to help reduce noise or placing transistors in parallel to help reduce the current flowing through each and thus reduce the transconductance and the base resistance.

The local oscillator used was purchased as a USB controlled kit. A program was designed to communicate with the oscillator to allow for incremental frequency steps as low as 1 Hz. We then used both the LNA output and local oscillator output as inputs for the following stage, the mixer. The Gilbert Cell Mixer is one that uses differential pair inputs to perform the following linear equation:

IF = (RF frequency) - (Local Oscillator Frequency)

The IF is at the heart of the Superheterodyne design, where the frequency of 10.7 MHz is used as a temporary, intermediate stage frequency. All following stages will be designed for this intermediate frequency and so this will put the linearity of the mixer to the test. Since the local oscillator just "shifts" the FM band to the IF, we can shift any radio channel of interest to this IF to demodulate it.

During the mixing process, other frequencies besides the result of the subtraction become present (such as the addition of the above equation as well as harmonics). To remove these unwanted frequencies, a filter is necessary. In our design, we used one that has a bandwidth of 180 kHz centered around 10.7 MHz. This allows one FM channel (that is on the IF) to be passed at a time. We also included in this stage a form of manual gain control. This is to adjust the amplitude of the signal account for differences in channel strengths.

The IF amplifier stage provides even more gain to saturate the signal into a square wave. This is done to preserve the frequency but normalize the amplitude. This is good to remove noise as well as provide a good signal output. This square wave is fed to the quadrature demodulator which contains reactive components tuned to 10.7 MHz. The demodulator is able to mix the incoming signal with a 90 degree phase shifted version of itself to achieve a frequency-to-voltage conversion. This DC voltage will vary depending on the deviation from the IF. [1]

During the designing phase of the circuits, information had to be presented in a universal language in order to be understood by all parties involved. This universal language is made possible by the IEEE Standard 315, which accounts for proper labelling and drawing of pictograms depicting circuit components for electronic schematics. This allowed us to express the functionality and component placement of our system that would be easily understandable by another person in the same domain. By following such a standard in our academic life, the transition to the workplace will be easier as we have learnt proper conventions to communicate with other engineers and technicians.

Conclusion

During this project we experienced the many difficulties that come with the implementation of a chip. We have also learnt a lot about the proper simulation of electronic circuits and troubleshooting, as well as proper design habits and team skills. It has shown us how people today take such a complex device for granted, and that how "just an FM radio", it not just an FM radio. The standards put in place to regulate the many different steps, whether it is for proper understanding of electronic circuits or the proper transmission of news radio, make the whole process possible. It becomes clear that without such guidelines many things today would not be feasible, or be able to work as well as they do.

References

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[6] "Wikipedia– FM Broadcasting". October 2010. http://en.wikipedia.org/wiki/FM_broadcasting