IMPLEMENTATION OF FM DEMODULATOR USING CORDIC TECHNIQUE

By

RAGAB ABD-ALLA SALHEEN ZAHYAN

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science
In
Electronics and Electrical Communications Engineering

Faculty of Engineering, Cairo University
Giza, Egypt
September , 2006

IMPLEMENTATION OF FM DEMODULATOR USING CORDIC TECHNIQUE

By

RAGAB ABD-ALLA SALHEEN ZAHYAN

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science
In
Electronics and Electrical Communications Engineering

Supervised by
Prof. Dr. Ameen Mohammed Nassar
Professor of Electronics and Communications Engineering.

Faculty of Engineering, Cairo University
Giza, Egypt
September, 2006

IMPLEMENTATION OF FM DEMODULATOR USING CORDIC TECHNIQUE

By

RAGAB ABD-ALLA SALHEEN ZAHYAN

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science
In
Electronics and Electrical Communications Engineering

Approved by the Examining Committee:

Prof. Dr. Alsayed Mostafa Saad ,Helwan University , Member

Prof. Dr. Abd elhaleem Mahmoud shosha ,Cairo University , Member

Prof. Dr. Ameen Mohammed Nassar , Thesis Main Advisor

Faculty of Engineering, Cairo University
Giza, Egypt
September , 2006

Acknowledgments

First of all I would like to express my deep and sincere thanks to ALLAH, who help me finish this work.

I wish to express my warm thanks to my supervisor Dr. Ameen Nasser who usually helps me from my first steps in the faculty till now and he usually gives me his advices in technical and all other fields.

I wish to thank the R&D department of Bahgat group and EL-Sewedy Electrometer Company for support and tools..

I warmly send thanks to my father's soul.

I warmly thank my mother and my wife.

I also wish to thank everybody who helped me finish this work.

Finally I dedicate this work to my daughters Zinab, Rawan and my son Abd-allah.

ABSTRACT

This work focuses on the design and implementation of FM demodulator using CORDIC algorithm, this is done after digitizing the analogue FM signal in order to do all processing in digital domain to get its advantages like flexibility , easily storing and manipulated of data , reproducibility, ...etc .

The design of FM demodulator using CORDIC gives us the advantages that we don't need to add blocks for bandpass limiter (the effect of amplitude fluctuations of the received FM signal is overcame without building any additional blocks). Also all multipliers are replaced by shift and add operations which yields to a simple design in a small area which means low cost design.

The design of FM demodulator using CORDIC gives a better performance in case of phase shift between transmitter and receiver. Also it gives better performance in case of noisy systems.

All of these give us the facility to add it in many applications like FM radio receivers, digital audio processors, SECAM decoders in digital video processors in analogue and digital TV receivers,.....etc.

The basic research has been carried out in MATLAB.

The VHDL implementation of the CORDIC algorithm, differentiator and all other component is based on the results obtained from the MATLAB simulation.

Mentor Graphics VHDL editor, simulator and synthesizer are used for the demodulator's hardware implementation on Xilinx FPGAs.

TABLE OF CONTENTS

LIST OF FIGURES

Chapter 1

Introduction

1.1 Modulation

Baseband signals produced by various information sources are not always suitable for direct transmission over a given channel.
These signals are usually further modified to facilitate transmission. This conversion (modification) process is called modulation.
In this process, the baseband signal is used to modify (modulate) some parameter of high-frequency carrier signal.

A carrier is a sinusoid of high frequency, and one of its parameters such as amplitude, frequency or phase is varied in proportion to the baseband signal [1].

As mentioned earlier, modulation is used to facilitate transmission.
Some of the important reasons for modulation are [1]:

- Ease of radiation.
- Simultaneous transmission of several signals.
- Effecting the exchange of SNR with BW.

1.2 Frequency modulation FM

One of the most common techniques of modulation in analogue domain is frequency modulation (FM) in which the information signal, Vm (t) is used to vary the carrier frequency within some small range about its original value[1][2].

Here are the three signals in mathematical form:
Information: Vm(t)
Carrier: $Vc(t) = V_{co} \cos (2 \pi f_c t + \phi)$

FM: $VFM(t) = V_{co} \cos (2 \pi [f_c + (\Delta f/V_{mo}) V_m (t)] t + \phi)$

We have replaced the carrier frequency term, with a time-varying frequency.

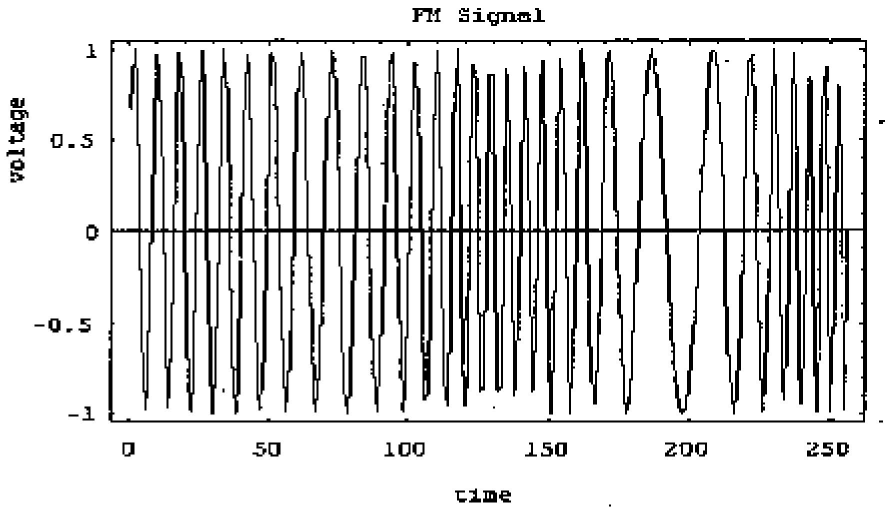

Figure 1.1: Simple FM signal

1.3 FM Spectrum

A spectrum represents the relative amounts of different frequency components in any signal. It's like the display on the graphic-equalizer in our stereo, which has leds showing the relative amounts of bass, midrange and treble [2].

It is a well-known fact of mathematics, that any function (signal) can be decomposed into purely sinusoidal components (with a few pathological exceptions).
In technical terms, the sines and cosines form a complete set of functions, also known as a basis in the infinite-dimensional vector space of real-valued functions (gag reflex).

The shape of the spectrum may be explained using a simple heterodyne argument: when you mix the three frequencies (fc, fm and Δf) together you get the sum and difference frequencies.
The largest combination is fc + fm + Δf, and the smallest is fc - fm - Δf. Since Δf = Δfm, the frequency varies (Δf + 1) fm above and below the carrier.

A more realistic example is to use an audio spectrum to provide the modulation [2]:

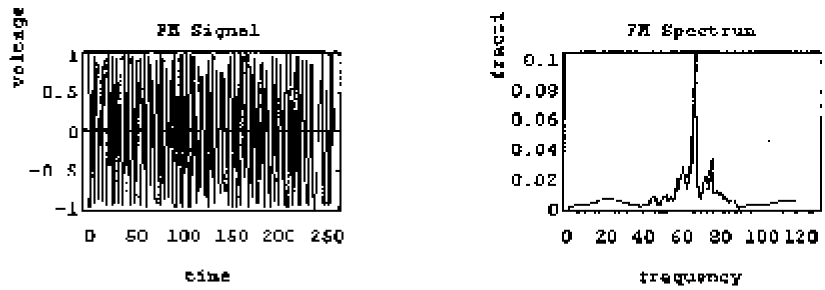

Figure 1.4: The spectrum of an fm audio signal

In this example, the information signal varies between 1 and 11 Hz. The carrier is at 65 Hz and the modulation index is 2.
The individual side-band spikes are replaced by a more-or-less continuous spectrum. However, the extent of the side-bands is limited (approximately) to (Δf + 1) fm above and below [2].

Here, that would be 33 Hz above and below, making the bandwidth about 66 Hz. We see the side-bands extend from 35 to 90 Hz, so out observed bandwidth is 65 Hz.

You may have wondered why we ignored the smooth humps at the extreme ends of the spectrum. The truth is that they are in fact a by-product of frequency modulation (there is no random noise in this example). However, they may be safely ignored because they are have only a minute fraction of the total power. In practice, the random noise would obscure them anyway.

FM radio has a significantly larger bandwidth than AM radio, but the FM radio band is also larger. The combination keeps the number of available channels about the same.

The bandwidth of an FM signal has a more complicated dependency than in the AM case (the bandwidth of AM signals depend only on the maximum modulation frequency).

In FM, both the modulation index and the modulating frequency affect the bandwidth. As the information is made stronger, the bandwidth also grows.

1.5.2 FM Efficiency

The efficiency of a signal is the power in the side-bands as a fraction of the total. In FM signals, because of the considerable side-bands produced, the efficiency is generally high. The conventional AM is limited to about 33 % efficiency to prevent distortion in the receiver when the modulation index was greater than 1. FM has no analogous problem.

The side-band structure is fairly complicated, but it is safe to say that the efficiency is generally improved by making the modulation index larger (as it should be).

But if you make the modulation index larger, so make the bandwidth larger (unlike AM) which has its disadvantages. As is typical in engineering, a compromise between efficiency and performance is struck. The modulation index is normally limited to a value between 1 and 5, depending on the application.

1.5.3 FM Noise

FM systems are far better at rejecting noise than AM systems. Noise generally is spread uniformly across the spectrum (the so-called white noise, meaning wide spectrum) [2].
The amplitude of the noise varies randomly at these frequencies.

The change in amplitude can actually modulate the signal and be picked up in the AM system. As a result, AM systems are very sensitive to random noise. An example might be ignition system noise in your car. Special filters need to be installed to keep the interference out of your car radio.

1.6 FM Demodulation

There are different techniques for realization of fm demodulation in order to get the information signal [1].

The basic idea of FM demodulation can be described as follows

Let: the instantaneous frequency W_i

$W_i * t = W_c * t + K_f * \int_0^t m(t)\,dt$

i.e. $Tx(t) = A\cos(W_i * t = (W_c * t + K_f * \int_0^t m(t)\,dt))$ where Tx is the transmitted signal. When differentiate this signal with respect to time the output will be

$d\,Tx(t)/dt = (dA/dt) * \cos(W_c * t + K_f * \int_0^t m(t)\,dt) +$

$A * (Kf * m(t) + w_c) * (\sin(W_c * t + K_f * \int_0^t m(t)\,dt))$.

When the amplitude of the incoming fm carrier is assumed to be constant the output will be:

$d\,Tx(t)/dt = A * (Kf * m(t) + w_c) * (\sin(W_c * t + K_f * \int_0^t m(t)\,dt))$.

This means that the information becomes in the amplitude of the output signal and then by using envelope detector we can get *m(t)*.

Practically there are different methods in analog and digital domains for FM demodulation.

In next chapter we will introduce the most common methods in more details.

1.6.1 The bandpass limiter

The amplitude of the modulated signal should be constant with respect to time, due to noise in the system the amplitude of the transmitted signal varies with time so, we introduce the bandpass limiter block to ensure that the amplitude of the signal is constant [1][3].

In next chapters we will see that in case of building an FM demodulator using CORDIC there is no need for that block, and this is one of the advantages of the FM demodulator using CORDIC.

At the receiver the higher frequencies must be deemphasised in order to get back the original baseband signal.

The transfer function of the de-emphasis circuit is shown below [4].

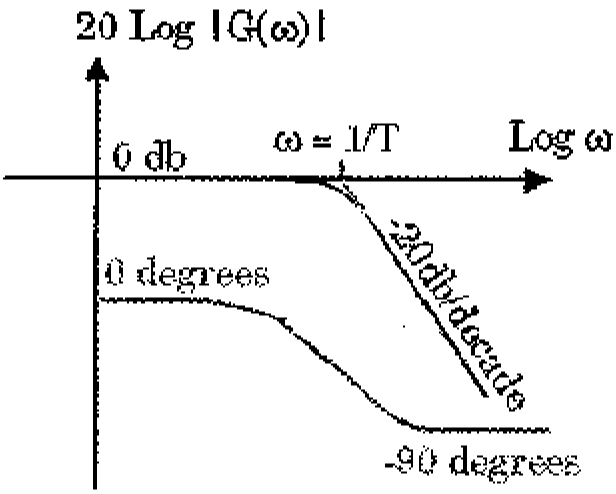

Figure 1.6: Deemphasis transfer function

1.7 Why digital

The question now why we design this demodulator in digital domain although we deal with analogue modulation scheme?
Simply the answer will be the advantages of digital signal processing which are:

-More flexible.
-Often easier system upgrade.
-Data easily stored and manipulated.
-Better control over accuracy requirements.
-Reproducibility.

But the design in digital domain has limitations we should mention it; these limitations may be briefly stated in the following points:

- A/D & signal processors speed:
Wide-band signals still difficult to treat (real-time systems).
-Finite word-length effect.