Chapter 1

Introduction

1.1 Motivation and Background

In any system that interfaces with the real world, the quantity which processed is always contaminated with noise and interferes. A filter is usually used to reject the surrounding interferes and unwanted noise. Though we are living in a digital age, any system that interfaces with the real world is the analog world, use continuous time filter. A typical digital processing system is shown in Figure 1.1

The physical quantity to be processed is converted to an electrical signal via a transducer. This signal is then converted to a digital signal via an ADC and further processing by the digital signal processor (DSP). According to Nyquist theory and to avoid aliasing, the input signal must be band limited before the A/D conversion. This is achieved by low-pass filters (anti-aliasing filter) that control the bandwidth of the signal which is half the sampling rate of the ADC. The processed digital signal coming out of the DSP is converted back to an analog signal via a low-pass reconstruction filter. Both the anti-aliasing filter and the reconstruction filter are analog filters operating in continuous-time.

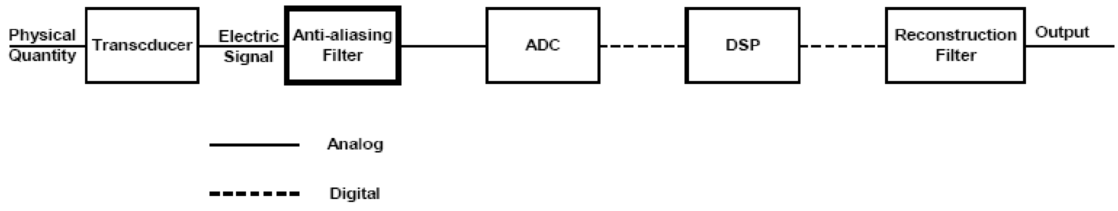

Figure 1.1 A Typical DSP System

The term continuous-time is somewhat confused with term sampled-data. Sampled-data filters do not work with the digital representation of the signal samples, as digital filters do. Thus these filters are discontinuous in time but continue in processed data values. The best example is switched-capacitor filters. Due to the sampling operation involved, continuous-time anti-aliasing filter and reconstruction filter are still needed in those kinds of switched-capacitor systems. Table 1.1 summarizes the properties of the filter categories.

Table: 1.1 Comparison of different types of Filter

	Digital	Sample-Data	Continuous-Time
Time Sample	Discrete	Discrete	Continuous
Data Sample	Discrete	Continuous	Continuous
Need Anti-Aliasing and Reconstruction Filter	Yes	Yes	No
Required Mathematical Transform	Z-Transform	Z-Transform	S-Transform (Laplace)

Filters can be also categorized according to the relative size of the elements used with respect to the wavelength of the signal into two categories: distributed and non distributed filters. In a non-distributed (lumped) filter, the physical dimensions of the used elements (resistance, inductance, or capacitance) are negligible compared to the wavelength of the signal. Thus they are considered as simple elements corresponding to physical element. This is in contrast to the distributed filter, in which the physical elements have dimensions comparable to the wavelength of the fields associated with the signal.

The main focus of this research is the design issues of high frequency continuous time integrated filters. High frequency continuous-time filters have been widely used, in cases where speed and low power dissipation are prime concern. Those applications, as shown in Figure 1.2, include video signal processing [1], hard-disk drive read channels [2], loop filters for phase-locked loops [3], and radio frequency wireless communication systems [4].Using digital filters is not feasible for high frequency applications because they are very power hungry at high frequencies, i.e., powerά $f_{CLK} \frac{(V_{DD}^2)}{2}$. Switched capacitor filters can have good linearity and dynamic range properties but its ability to process high frequency signals due to the sampling operation is limited. The sampling frequency should be chosen larger than the filter bandwidth to avoid inaccurate filter frequency response. That requires the use of operational amplifiers (Op-Amps) with very wide bandwidths, to provide proper settling, demanding large currents; it is required that the unity gain frequency of the used operational amplifier must be at least five times larger than the clock frequency used. Thus continuous-time filters became the only option in these types of applications. Continuous-time filters include two main categories: passive filters and active filters. A passive filter include among its elements resistors, capacitors, inductors, transformers. If the elements of the filter include amplifiers or negative resistances, this is called active.

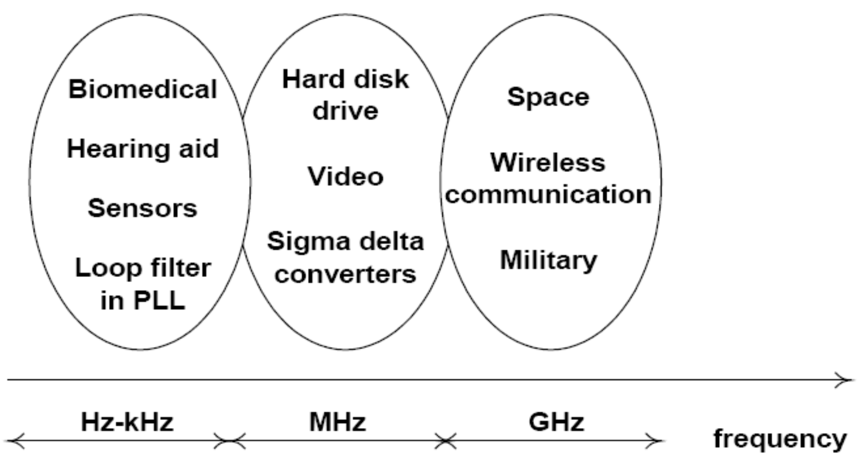

Figure 1.2 Applications of Filter

Active-RC filters have been widely used in low-frequency applications for a long time [5-16]. Discrete active-RC are filters also successful substitutes for passive-RLC filters at low audio frequencies for reasons of size and economy. However, they were found less suitable for high-frequency applications and fully integrated implementations due to the high frequency limitations of op-amps and the large chip area requirements of resistors. Consequently, many alternative active filter circuit topologies have been developed to overcome these drawbacks, for example the popular switched-capacitor filter.

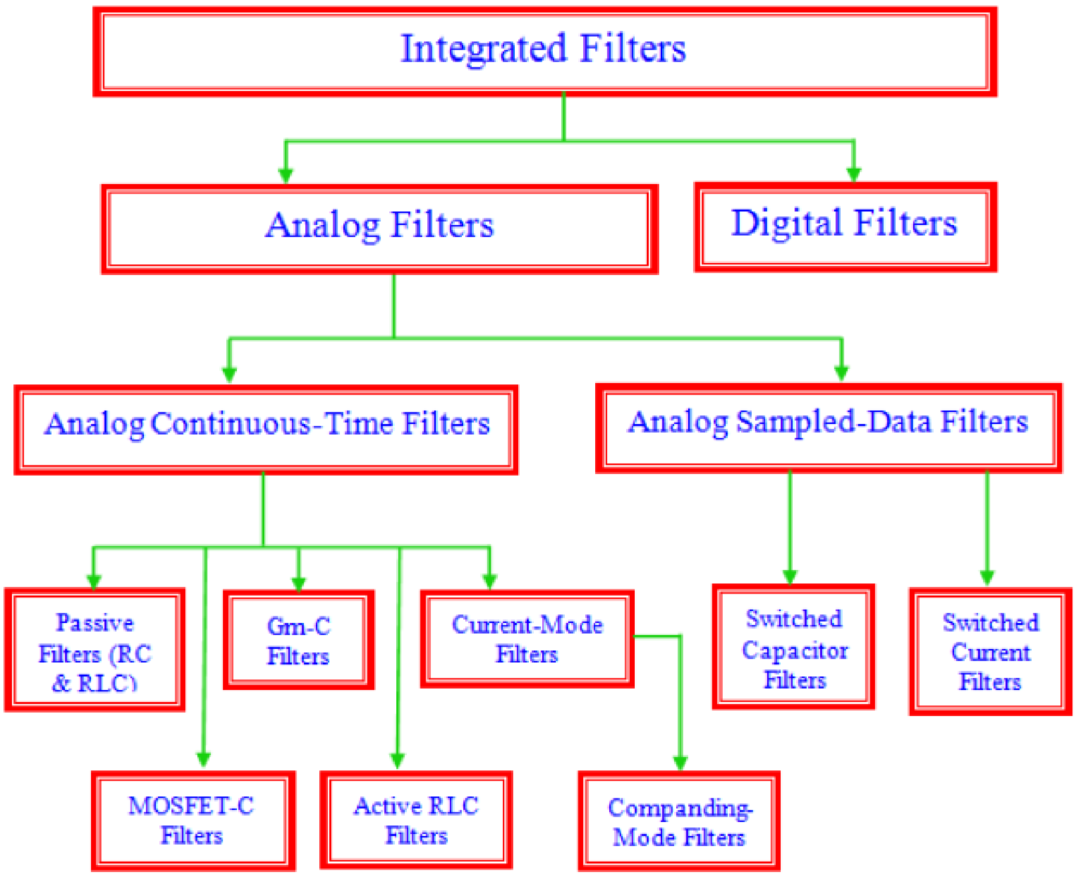

Figure 1.3 Classification of Integrated Filter

In switched-capacitor filter structures, MOS switches and capacitors effectively replace the resistors in active-RC filter structures. Nowadays, switched-capacitor filters can be fully integrated using all available IC technologies especially CMOS. In addition, precision frequency response is achievable without on-chip tuning, and high dynamic range can be achieved. However, they are still not suitable for very high frequency applications due to the sampling mode of their operation, which would require very high clock speeds, along with the use of extra continuous-time (CT) input anti-aliasing filters and output smoothing filters.

CT filters based on the operational transconductance amplifier (OTA) (also referred to as V-I converter, transconductor, or transconductance amplifier) and capacitors, the so-called OTA-C, or gm-C, filters have received the greatest interest and attention in recent research [17-20]. OTA-C filters offer advantages over traditional active-RC filters in terms of design simplicity, high frequency capability, electronic tunability, suitability for monolithic integration, reduced component count, and potential for design automation. Although OTA-C filters are primarily aimed at high frequency operation (up to GHz range), they are also suitable for applications at low frequencies. Also, fully integrated OTA-C filters have been widely used in communication systems. The performance of a filter relies strongly on the circuit components, filter structure, design methods, and IC technology used. In particular, different circuit components and IC technology can result in very different performances for the chosen filter topology. The design of a high performance OTA-C filter is a complex task. It must simultaneously optimize different requirements, such as operating frequency range, power consumption, noise and dynamic range, sensitivity to device variations and fabrication tolerances, chip area, and cost. A number of IC technologies such as Bipolar, BiCMOS, and CMOS [21-29], GaAs, etc have been used for integrated filter design.

In most practical CT filters, an on-chip automatic tuning system is incorporated to overcome performance degradation due to device variations,fabrication tolerances as well as the effects of parasitics, temperature, and environment changes. Moreover, using the right filter structures can also reduce sensitivity. Low supply voltages have adverse consequences for active filter design. As the supply voltage shrinks, the linear signal range of the active devices also decreases. Consequently, the available dynamic range (defined as the ratio of maximum over minimum signal level) is reduced. The minimum signal is restricted by noise, which is generated by active devices and resistors, and does not show a corresponding reduction at lower supply voltages.

Motivated by the rapidly growing mobile and wireless communication market, fully integrated filters for very high frequency and low power consumption have received worldwide attention. The most important filters for fully integrated high frequency applications are perhaps the OTA-C filters, which have been widely utilized. Design of high-order OTA-C filters based on the cascades of biquads, LC ladder simulation, and multiple loop feedback (MLF) methods have been explored. OTA-C filters also have significant limitations. Good overall linearity of the transfer function of OTA-C filters is only achievable with highly linearized OTAs. Increased linear range will unavoidably decrease the available range of transconductances of the OTAs at a given supply voltage, and increase OTA noise. As with other types of active filter, errors in the desired filter response may occur at high frequency, due to excess phase caused by device and layout parasitic at high frequencies. In common with other integrated filters, errors in filter response may be caused by device tolerances, process, and temperature and bias effects. Overcoming this problem requires the use of on-chip tuning circuits in most applications.

1.2 The role of IF filters in wireless receivers

Nowadays, wireless receivers for mobile phones mainly utilize the super-heterodyne structure to achieve good selectivity and to avoid the problem of DC offset in homodyne (Direct-down) receivers. IF band pass filters are then needed for the channel selection and Filtering. A simple block diagram of a wireless receiver is shown in Figure1.4. Most transceivers still use external filters such as surface acoustic wave (SAW) filters for IF filtering. The advantages of using external filters, especially SAW filters, are their high Q, stable center frequencies and no extra power is needed for operation. But in order to drive the 50Ω input impedance of these off-chip filters, much power (hundreds of mW) has to be supplied for the drivers. More noise is coupled into the external connections too. This motivates the design of monolithic receivers with on-chip filters to avoid the extra power consumption for driving the 50Ω load and also to minimize noise coupling.

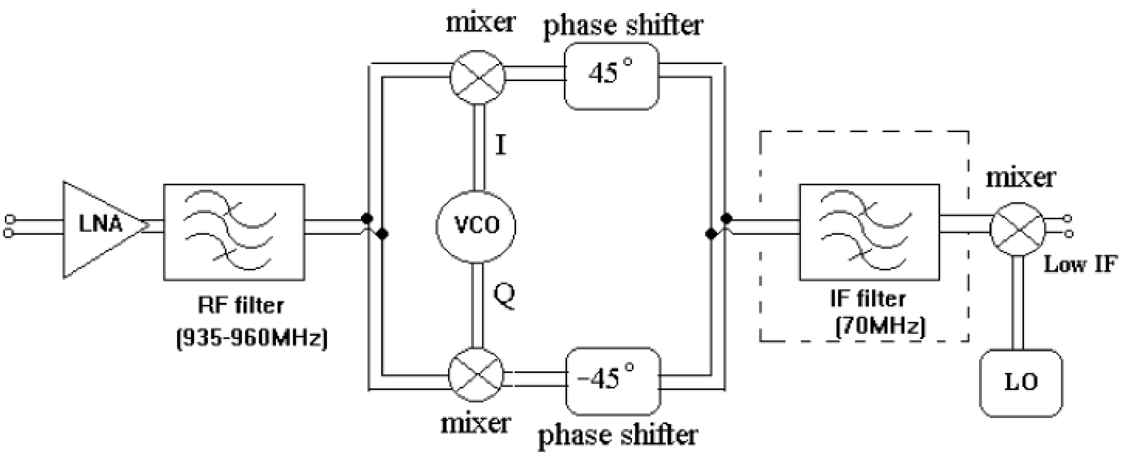

Figure 1.4 Basic Structure of Superhetrodyne Receiver

1.3 Scope of Work:

Today's transceivers employ a number of discrete filters; take up a large portion of space, and increasing the transceiver's overall size. To reduce the size, these filters need to be integrated on the same Silicon. In addition to area reduction, filter integration offers other advantages. The cost of an RF transceiver will be reduced because fewer external components will be required. Power dissipation will also be reduced, as RF signals do not need to travel off-chip thru package pins to an external filter. Signals traveling off-chip need to drive the large capacitances associated with the package pins and printed-circuit board and hence cause additional power consumption. In addition, integrating filters on-chip reduce the number of pins and thus the package can be smaller and less expensive. Finally, filter integration offers increased design flexibility. Also, filter impedance, which is typically 50 ohm to match the external standard, can be chosen during the design process to optimize RF performance.

Continuous-time filters implemented with transconductance amplifiers and capacitors known as Gm-C Filter or OTA-C Filter is best to design Intermediate Frequency (IF) filters in RF Receivers. Rapidly growing Mobile and Wireless communication market, fully integrated filters for very high frequency and low power consumption applications have received considerable attention. In most practical Continuous-time filters, an on-chip automatic tuning system is incorporated to overcome performance degradation due to device variations and fabrication tolerances as well as the effects of parasitics, temperature, and environment changes.

The scope of this research project involves research studies to realize CMOS Folded Cascode OTA and Implement on chip High frequency gm-C IF Filter for Dual Band (FM Band and GSM Band). The design is characterized to layout level based on TSMC 0.18 μm process technology.

1.4 Organization of Thesis

The thesis mainly concentrates on the design of Gm-C IF filter for Dual Band Receiver. The implementation of fully integrated, high-selectivity filters operating at tens of MHz provides benefits for wireless transceiver design, including chip area economy and cost reduction. The Operational Transcondutance Amplifier-Capacitor (OTA-C) technique is a popular technique for implementing continuous time filter and is widely used in many applications.

Chapter I give a very brief introduction about classification of integrated filter and role of IF in wireless receiver.

Chapter II discusses the background of analog continuous time filters. In this chapter, receiver architectures are briefly reviewed and requirements of continuous time channel selection filters are discussed. The most popular continuous time filters are briefly introduced and design requirements are also discussed. This chapter provides a general review of CMOS OTAs. Three types of CMOS OTAs with different input/output configurations were described first, followed by current trends on high frequency, high linearity, and low power CMOS OTAs.

Chapter III discusses the basics of analog circuit design. The fundamental small-signal models and hand-calculation formulas are presented. Also, some important performance metrics in analog design are discussed.This chapter introduces Operational Transconductance Amplifiers (OTA), their different topologies, N-channel and P-channel differential amplifier, used in folded cascode OTA, with its small signal equivalent and parasitic capacitance. Practical folded cascode OTA is designed in TSMC 0.18μm CMOS technology and its pre-layout and post layout simulations are carried out. Cascode current mirror base folded cascode OTA simulation is carried out for getting large input-output swing.

Chapter IV focuses on the Gm-C IF filters for dual band (FM and GSM). First order and second order filter are designed with analysis. Because OTA-C filters are based on integrators built from an open-loop transconductance amplifier driving a capacitor, they are typically very fast but have limited linear dynamic range. This chapter presents the design of a dual band band-pass channel selection IF filter to be used in a direct conversion receiver for FM band and GSM band. Gm-C IF filter for dual band is designed in the TSMC 0.18μm CMOS technology and pre layout and post layout simulation is carried out. A unique Analog-Digital automatic tuning system is also implemented.

Finally, Chapter V summarizes the main contributions and summary of this research work with future enhancements