Chapter 1

Introduction

Bandpass filters are employed in many applications such as in a radio-frequency (RF) filter for image rejection or an intermediate-frequency (IF) filter for channel selection of a superheterodyne receiver (Nilsson and Torkelson, 1997) as shown in Figure 1.1, or a double superheterodyne receiver (Nilsson and Torkelson, 1997) as shown in Figure 1.2.

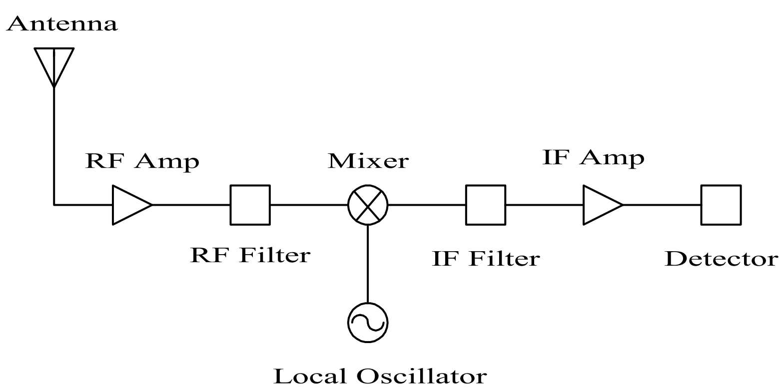

Figure 1.1 Superheterodyne receiver (Nilsson and Torkelson, 1997)

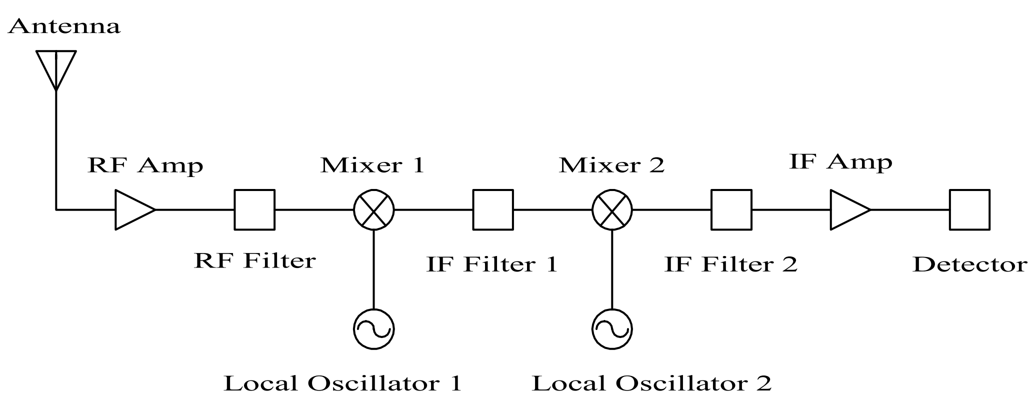

Figure 1.2 Double superheterodyne receiver (Nilsson and Torkelson, 1997)

Requirements of IF bandpass filters for a receiver include high quality (Q) factors, wide dynamic ranges (DRs) and low sensitivities. The quality factor is normally defined as a ratio of the center frequency of the filter to the bandwidth of the filter whilst the dynamic range of a filter is normally defined as a ratio of the square of the maximum signal amplitude to the square of the minimum detectable signal amplitude. In many cases, the minimum detectable signal equals the idle channel noise of the system (Groenewold, 1992). Especially in the case of bandpass filters with a high (Q) factor, dynamic ranges become serious problems because the noise output of bandpass filters appears to be directly proportional to the quality (Q) factor. Therefore the dynamic range of a high Q bandpass filter is inversely proportional to the quality (Q) factor (Groenewold, 1991). Another important parameter is the sensitivity as circuit configurations may be compared for establishing practical utilities in meeting desired requirements. Calculations of sensitivities allow designers to select better circuits or permit conclusions whether a chosen filter satisfies or will keep satisfying the given specifications.

Typically, FM radio receivers require an IF filter set at a center frequency (f_0) of 10.7 MHz based on off-chip devices such as discrete ceramic or surface acoustic wave (SAW) components (Engelen et al., 1999 and Quinn et al., 2000). Advantages of SAW filters include high Q, stable center frequencies and passive elements. As off-chip filters are bulky and consume more power to drive external devices, the need for possible on-chip filters for fully viable integrated receivers has increasingly been motivated (Chung-Yu and Shuo-Yuan, 1997).

Recently, attempts at possible on-chip filters have particularly been demonstrated for 10.7-MHz IF filters based on, for example, switched capacitors (SC) techniques (Quinn et al., 2000; Hernandez-Garduno and Silva-Martinez, 2005; Silva-Martinez et al., 2000;

Hammouda, 2002; Nagsri and Nicollini, 1998 and Nagari et al., 1997), and Gm-C techniques (Tajalli and Atarodi, 2003; Chung-Yu and Chung-yun, 2001; Munoz et al., 2000; Stevenson and Edgar, 1998; and Steyaert and Silva-Martinnez, 1992). Such techniques have, however, repeatedly suffered from low quality (Q) factors from 10 to 55, high total noise from 226 to 707 μV_{rms} and limited dynamic ranges from 58 to 68 dB.

Most Q factors have generally been a function of variables such as a center frequency (Comer et al., 1997 and Ali et al., 2000). For example, the quality factors of some existing Gm-C approaches (Liu and Karsilayan, 2003 and Voghell and Sawan, 2000) have particularly been inversely proportional to the center frequency. Such variable quality factors have been difficult to tune as the variables may vary rapidly and drastically resulting in the need for additional or complicated Q-tunable circuits. In addition, sensitivities of neither the Q factor nor the center frequency at 10.7 MHz have been clearly reported, although sensitivities of the Q factor at other center frequencies have been undesirably a function of the Q factors (Comer et al., 1997 and Ali et al., 2000).

In this dissertation, Chapter 1 provides an introduction to problems addressed to the bandpass filters and provides an outline of the structure of the dissertation. Existing techniques for bandpass filters are reviewed in Chapter 2 with a survey of classification of existing techniques for bandpass filters in both research and commercial products. Chapter 3 proposes a possible system realization of a high-Q bandpass filter followed by two new circuit realizations through new Techniques 1 and 2 of fully balanced, high-Q, wide-dynamic-range current-tunable Gm-C bandpass filters. Technique 1 is relatively simple based on two fully balanced components, i.e. a two-input adder and a low-Q-based bandpass filter. The high quality factor of Technique 1 is approximately equal to a typically high (>100) and constant value of the current gain β, and is, for the first time, no longer a function of variables such as a center frequency. Technique 2 is also relatively simple based on three fully balanced components, i.e. a two-input adder, a low-Q-based bandpass filter and a differential amplifier. The high quality factor of Technique 2 is possible through a tunable bias current. Sensitivities and dynamic ranges (DRs) of the two proposed Gm-C bandpass filters are also included.

Chapter 4 presents simulation and experimental results at 10.7 MHz of both Techniques 1 and 2, in terms of high quality factors, current-tunable center frequencies, low noise performance, wide dynamic ranges, temperature compensations for the center frequencies, temperature compensations for the quality factors, power consumption versus dynamic ranges, and high-frequency performances. Techniques 1 and 2 demonstrate 10.7-MHz, high-Q, wide-dynamic-range current-tunable Gm-C bandpass filters. Comparisons to other 10.7-MHz Gm-C approaches are also included. Finally, conclusions are drawn in Chapter 5.