A Waveform Conversion Circuit Design Used for Square Wave to Sine Wave

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Abstract. As an efficient passive filter, elliptical filter can be used in the waveform conversion module of closed-loop self-excitation circuit based on infrared detectors with steep transition band. In this article, the elliptical filter is designed and used to transform rectangle wave to sine wave by the Advanced Design System (ADS) 2015. After setting the parameters and calculation, the elliptical low-pass filter of seventh-order whose pass band is 0-10.2kHz, ripple in the band is less than 0.3dB and signal suppression is 42.8dB with two notch points. Through the comparison with the fifth-order and seventh-order elliptical low-pass filters, the relationship between the orders is understood, and the requirement of waveform transformation is realized.

1. Introduction
An Application Specific Integrated-Circuit (ASIC) shown in figure 1 is proposed and used to micro-resonant infrared detector for closed-loop self-excitation/detection [1]. The ASIC is composed of the differential amplifier, Gm-Cs filter, quadrature signal generator, charge pump phase-locked loop (CPPLL), waveform converter and automatic gain control (AGC), which are designed for the phase and amplitude conditions required by micro-resonant infrared detector. The CPPLL is composed of frequency and phase detector (PFD), charge-pump (CP), off-chip loop filter, voltage-controlled oscillator (VCO) and dividers [2]. The sinusoidal signal generated by VCO is transformed into a Transistor-Transistor Logic waveform after being divided by the frequency divider for the infrared detector, the waveform conversion circuit must be used to transform the rectangular wave to sine wave. Generally, comparator, integral operation circuit and filter can be used to transform the waveform. When the order of passive filter become higher, the wave distortion can be smaller. In this paper, a passive filter composed of capacitors and inductors is designed and used to transform the waveform. This method is mature and low cost, which can provide reactive power compensation for the circuit in the system, which is more stable and can be produced [3].

2. Design and Analysis of Elliptical Filter Circuit
In all kinds of the passive filters, the elliptical filter can get the steepest transition band, pass band and other ripples, which have the characteristics of attenuation and other fluctuations in both pass band and stop band. The design of this article is the elliptical low-pass filter circuit with the pass band frequency \( f \leq f_p = 10kHz \), the \( f_p \) is reference frequency, reflection coefficient \( \rho = 20\% \) when the attenuation of
$A_p$ is 0.0177 dB attenuation. The stopband frequency range is $f_s$, and $f \leq f_s = 12$ kHz, $A \geq A_s = 20$ dB, the $A_s$ is minimum attenuation of stopband. The design termination resistance is 50Ω. Then normalize the given frequency to obtain $\Omega_s$ which is stopband boundary frequency and the order $n$. After obtaining the center frequency of passband, it can be calculated the geometric symmetrical boundary frequencies.

After using the formulas of elliptical filter and basic formulas, the designed circuit diagram of the fifth-order elliptical filter is shown in figure 2(a), and the simulated results of S-parameter are shown in figure 2(b). The low-pass cut-off frequency is about 11.36 kHz, and the low-pass filter waveform has two notch points about 3.9 kHz and 9.9 kHz. These two transmission notch points have attenuation suppression of -29.9 dB and -31.4 dB, while the stopband suppression of the whole circuit is up to -61.6 dB. Although the elliptical filter with parameters achieves the low-pass effect, the existence of two notch points makes it possible for the frequencies around these two points to be filtered by resonance, so that the waveform transformation of 10 kHz cannot be achieved smoothly [4]. Therefore, it is necessary to improve and optimize the low-pass elliptical filter. $C_1=24.12 \mu F$, $C_2=3.48 \mu F$, $L_2=16.675 \mu H$, $C_3=36.83 \mu F$, $C_4=1.294 \mu F$, $L_4=18.52 \mu H$, $C_5=26.05 \mu F$.

**Figure 1.** The proposed ASIC used for micro-resonant.

(a) The designed diagram of fifth-order elliptical filter

(b) Simulated results

**Figure 2.** Circuit diagram and simulation results of fifth-order elliptical filter.

The central frequency of the circuit structure is determined by the parallel resonance unit, and the resonance frequency can be increased or decreased by appropriately increasing or decreasing the
apacitance or inductance through the formula \( \omega_0 = \frac{1}{\sqrt{LC}} \). When the capacitances or inductances of the parallel resonant unit increase, the resonant frequency decreases obviously, and the waveform moves to the left, but the decrease leads to opposite\[5\]. In fact, if the inductances or capacitances of the series resonant unit are changed, the notch point of the filter structure will move to the left and the bandwidth will be changed accordingly \[6\]. Adjusting the parallel resonance modules and adjusting the series branch modules with \( C_1=22.12 \mu F, C_2=3.48 \mu F, L_2=17.675 \mu H, C_3=36.83 \mu F, C_4=1.294 \mu F, L_4=18.52 \mu H, C_5=22.05 \mu F. \) After the adjustment of series module and parallel module, the simulated results are shown in figure 3.

\[ \text{Figure 3. The simulated results of fifth-order elliptical filter after parameter adjustment.} \]

It can be seen from the figure 3. that the low-pass cut-off frequency is about 10.64 kHz. After changing the parameters, the two notch points of the low-pass filter waveform are about 4.01 kHz and 9.29 kHz, and the two transmission notch points have attenuation suppression of about -38.1dB, while the overall stopband suppression of the circuit increases to -64 dB. Although the simulation results of S-parameters of the fifth-order low-pass elliptical filter are improved after the parameters changing, there are still harmonics that are not suppressed and cannot be effectively output. Therefore, in order to improve the cut-off filter accuracy and reduce the transition band to improve the waveform steepness, it is decided to increase the number of filtering harmonics, that is, to increase the order to \( n=7 \) of the seventh-order elliptical filter\[7\]. The the designed circuit diagram of the seventh-order elliptical filter is shown in figure 4(a), and the simulated results of S-parameter are shown in figure 4 (b). \( C_1=0.02829 \mu F, C_2=0.00663 \mu F, L_2=10.621 mH, C_3=0.03525 \mu F, C_4=0.03702 \mu F, L_4=5.35 mH, C_5=0.02838 \mu F, C_6=0.02569 \mu F, L_6=6.274 mH, C_7 =0.0185 \mu F. \)

\[ \text{Figure 4. Circuit diagram and simulation results of seventh-order elliptical filter.} \]
3. Result of Filter Waveform Transformation

After S-parameter simulation, a seventh-order low-pass elliptical filter with two notch points is obtained, and the transition band drops rapidly. The low-pass filter with \( f_{\text{lp}} = 10.35 \) kHz was obtained. The simulated circuit and result are shown in figure 5.

![Simulated circuit and output waveform](image)

**Figure 5.** Waveform transformation of seventh-order elliptical filter.

The sine wave curve as shown in the figure above can be obtained by transient simulation of the rectangular wave whose input frequency of the seventh-order low-pass elliptical filter is below 10kHz. The circuit can realize the function of rectangle wave to sine wave conversion.

4. Conclusion

In this work, passive fifth-order and seventh-order elliptical low-pass filter are designed and used to transform the rectangular wave to sine wave. After ADS simulations, the fifth-order low-pass elliptical filter and its optimized parameters are compared with the seventh-order structure. The simulation results show that the index of the seventh-order low-pass elliptical filter shows that it can meet the design requirements better. It proves that the relationship between the order and the stability and accuracy of the filter, and realizes the function of converting the pulse to sine wave through the input of TTL signal.

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