Harmonic Mitigation using Chebyshev Low Pass Filter for 30-50 MHz Frequency Range

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Abstract: Harmonic is one of the main factors that degrade the signal quality and this is a serious problem faced by the power amplifier in its working. These are introduced into the power amplifier due to the nonlinearities of the active element such as transistor in the power amplifier. Therefore the mitigation of harmonics is essential under these circumstances. This paper presents the design of a Chebyshev low pass filter using LC components for the mitigation of harmonics for a frequency range 30-50MHz. Advanced Design System is used for simulation purpose. The obtained results show that Chebyshev low pass filter rejects the harmonic frequencies successfully with a stopband rejection of -24dB.

***Index Terms* – Harmonics, Harmonic mitigation, Nonlinearities, Chebyshev low pass filter, Stopband rejection.**

I. INTRODUCTION

The demand for Radio Frequency spectrum has increased with the evolutions in radios, communications and radars and become commercialized for different applications like mobile communications, television and radio communications, a clean radiation spectrum is a must for each radio transmissions. This has to be ensured by the RF front end of each radio transmitters. The RF front end section includes power amplifiers and they introduce harmonics to the signal and these harmonics are an integer of whole number multiple of the operating frequencies and causes serious impurities in the spectrum. Therefore mitigation of harmonics is essential under these situations.

Passive filters have low cost, simple design and high reliability than active filters. The Chebyshev low pass filter passes the fundamental frequency and attenuates the higher harmonic frequencies. Chebyshev filters have better rate of attenuation beyond passband than Butterworth filters. This paper presents the design of a Chebyshev low pass filter using LC components for the mitigation of harmonics for a frequency range 30-50MHz.

II. CHEBYSHEV LOW PASS FILTER DESIGN

Chebyshev filters or equiripple filters have a steeper roll-off and more passband ripple than Butterworth filters. The analytic form of the squared magnitude function is defined by

$$|H(j)| = \frac{1}{1+\varepsilon^2\, {T_n}^2\left(\frac{\omega}{\omega_p}\right)} \qquad (2.1)$$

where ε is the ripple factor, $T_n(x)$ is the Chebyshev polynomial of degree n and ωp is the passband edge frequency.
Closed form expressions for the Chebyshev polynomial are given by

$$T_n\,(x) = f(x) = \begin{cases} \cos(n\cos^{-1}x)\,, & |x| < 1(Stopband) \\ \cosh(n\cosh^{-1}x)\,, & |x| > 1(Passband) \end{cases} \qquad (2.2)$$

These polynomials can be defined by a recursion formula:

$$T_n\,(x) = 2xT_{n-1}(x) - T_{n-2}(x), n > 1 \qquad (2.3)$$

where $T_0(x) = 1$ and $T_1(x) = x$. The order of the Chebyshev filter is given by the equation:

$$n \ge \frac{\cos^{-1}\left(\frac{\sqrt{A^2-1}}{\varepsilon}\right)}{\cos^{-1}\left(\frac{\omega_S}{\omega_p}\right)} \qquad (2.4)$$

where A is the user-defined stopband attenuation parameter, ε is the ripple factor, ω_s is the stopband edge frequency in rad/sec and ω_p is the passband edge frequency in rad/sec. The user-defined stopband attenuation parameter and ripple factor is given by the equation:

$$A = 10^{0.05A_s} \text{ and } \varepsilon = \sqrt{10^{0.1A_p} - 1} \qquad (2.5)$$

where A_s is the minimum stopband attenuation in dB, A_p in the maximum passband ripple in dB. The two types of LC Ladder networks for Low pass filters are Pi and Tee Section. Pi section prototype starts with a shunt element, whereas Tee section starts with a series element. At the beginning of the circuit $g_0 = 1$ is defined as generator resistance or capacitance. The last element at the end is defined as g_{n+1} which is the load resistance if g_n is a shunt capacitor and load conductance if g_n is a series inductor. The type of the prototype used in the design of the Chebyshev Low pass filter is Pi section as in Figure 2.1

The Chebyshev low pass filter prototype element values are given by the following equations:

$$g_0 = 1 \qquad (2.6)$$

$$g_1 = \frac{2a_1}{\gamma} \qquad (2.7)$$

$$g_k = \frac{4a_{k-1}a_k}{b_{k-1}g_{k-1}}, k = 2,3, \dots \dots n \qquad (2.8)$$

$$g_{n-1} = \begin{cases} 1, if\ n\ is\ odd \\ coth^2\left(\frac{\beta}{4}\right), if\ n\ is\ even \end{cases} \qquad (2.9)$$

g_1 and g_k are the capacitor or inductor element values. The coefficients β, γ, a_k and b_k can be calculated from the following equations:

$$\beta = ln\left[\coth\left(\frac{\alpha_{dB}}{17.372}\right)\right] \qquad (2.10)$$

$$\gamma = \sin\left(\frac{\beta}{2n}\right) \qquad (2.11)$$

$$a_k = \sin\left(\frac{(2k-1)\pi}{2n}\right), k = 1,2, \dots \dots n \qquad (2.12)$$

$$b_k = \sin\left(\frac{2k\pi}{n}\right), k = 1,2 \dots \dots n \qquad (2.13)$$

where α_{dB} is the passband ripple in dB. The number 17.372 is rounded from the exact value 40/ln (10). The low pass filter element values are given by

$$L_k = \frac{Z_0 g_k}{\omega_c} \text{ and } C_k = \frac{g_k}{Z_0 \omega_c} \qquad (2.14)$$

where Z_o is the characteristic impedance in ohm and $\omega_c = 2\pi f_c$ is the angular frequency in rad/sec, f_c is the cut-off frequency of the filter in Hz.

III. Result And Discussions

In this paper, 30-50 MHz band passes up to 50 MHz with passband ripple -0.1 dB and start offering rejection from 50 MHz (cut-off frequency) with a stopband frequency of 60 MHz which offers a rejection around -24dB. The Chebyshev low pass filter has been simulated in Advanced Design System (ADS). Table-4.1 shows the requirements for this research.

Table 4.1: Requirements

Pass band Frequency, ω_p	30-50 MHz
Stopband Frequency, ω_s	60 MHz
Pass band Ripple	-0.1 dB
Stopband Rejection	-24 dB
Filter Order, n	9

Table-2 shows the inductor and capacitor values used in this schematic design.

Table 4.2: Inductor and capacitor values

Inductor	$L_1 = L_4$	$L_2 = L_3$	L_5
Values	229.60 nH	257.31 nH	-

Capacitor	$C_1 = C_5$	$C_2 = C_4$	C_3
Values	76.119 pF	135.89 pF	140.40 pF

Fig-3.1 shows the schematic design for ADS simulation and Fig-3.2 shows the ADS simulation results and observations.

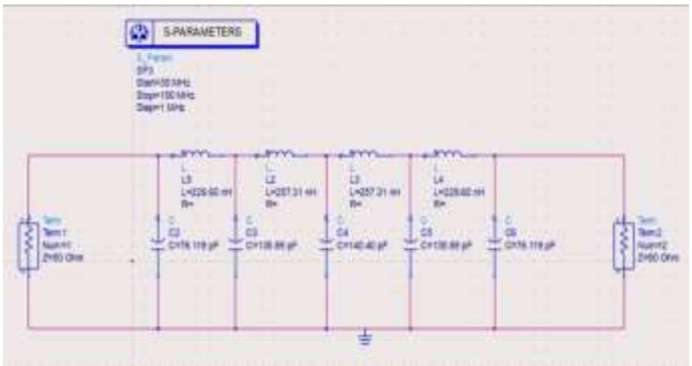

Fig-3.1: Schematic Design

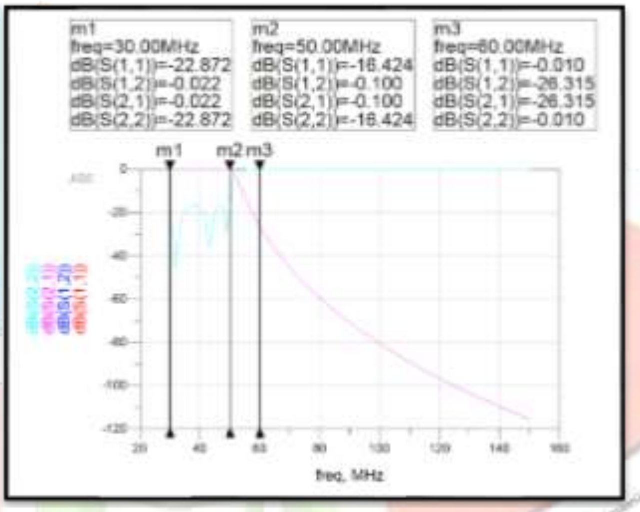

Fig-3.2: Simulation result

Here the color cyan represents the Chebyshev filter response and the color magenta represents the Low pass filter response. From the plot, it is clear that the signal is passed up to the cut-off frequency, 50 MHz and beyond the cut-off frequency, known as harmonic frequency, 60 MHz, the signal is rejected with a stopband rejection of -24 dB.

IV. CONCLUSION

In this paper, the design of a Chebyshev low pass filter using LC components for the mitigation of harmonics for a frequency range 30-50MHz was presented. The Chebyshev Low pass filter successfully passes the signal up to 50 MHz with a passband ripple of -0.1 dB. Then start offering rejection from 60 MHz, known as harmonic frequency with a stopband rejection of -24dB. The obtained results meet the IEEE 519 recommended harmonic standards.

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