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High Frequency and Broadband Coupling Characteristics of Filter Circuit Based on Low Voltage Power Lines

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Abstract

The low voltage power line has some advantages, for example, wide application, connecting fastness and economy. Power line communication technology is becoming a hot research area. Coupling filter circuit is the key link of power line communication. In this paper, a 1MHz-30MHz high frequency and broadband coupling circuit which consists of filter, coupling capacitor, isolation transformer was designed. This circuit can be used to test the input impedance, noise characteristics, and attenuation characteristics of channel. Designed the Butterworth band-pass filter, through simulation, got the amplitude frequency characteristics, and proved the feasibility of the filter. According to the working frequency, selecting the suitable coupling capacitor with band-pass filter and isolation transformer constituted the coupling circuit. In this paper, chose the 50Hz and 15MHz AC signal as contrast signals to simulate and got the two signals' simulating results. The results show that the coupling circuit has isolation effect of the 50Hz industrial frequency signal, instead the 1MHz-30MHz signals can have no distortion to couple to the electric network.

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Keywords: low voltage power line; carrier communication; broadband filter; coupling circuit;

1. Introduction

The author is studying the project of "the research of OFDM group strategy based on wavelet in low power line high speed digital signal transmission". The project is based on coal mine underground. In

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order to get the transmission characteristics underground, it needs to build a coupling circuit model. The power line communication (PLC) realizes data transmission and information exchange by the existing power network, it doesn't need to lay special communication lines. Signal coupling is the important part in PLC communication.

In [1], used "complex-coupling-technology" of combining "electromagnetism-coupling" to "RC-coupling", designed a narrowband coupling circuit with the center frequency of 470KHz, realized 50Hz signal isolation, improved the coupling efficiency. In [2], the working frequency in PLC is about from 1MHz to 30MHz. In [3], different cables have different transmission characteristics, different occasions also have different frequency range, usually the used frequency in visit domain (the last mile) is 1-10MHz, in indoor network it is 10-30MHz. The circuit, in [1], is not suitable for high frequency broadband PLC. A band-pass filter with 1MHz-30MHz has been designed in [2], it also mentioned that the filter can be used in PLC, but it is a pity that there were no special measures and circuits being designed in [2].

In [4], it has analyzed which filter is more suitable for PLC. There are LC filter, RC active filter, Mechanical filter, etc. It shows that the filter is required small volume, light weight, low price, well stability and high frequency. RC active filters have good filtering properties, but it is often used in low frequency circuits because of the operation amplifier limiting. It is hard to find a broadband and high frequency operation amplifier. The mechanical filters have good properties, but the high price doesn't fit for PLC communication.

The paper starts to build the filter circuit model, then the butterworth band-pass filter which frequency band is 1MHz-30MHz is designed, and the suitable components are selected to build the hardware circuit . Finally the simulation experiment is done.

2. Building filter circuit model

2.1. Butterworth low-pass filter designing

The process of special band-pass filter designing is:

- The normalized low-pass filter was designed
- The low-pass filter by impedance transformation and frequency conversion was designed
- The low-pass filter was converted into band-pass filter
- Selecting the appropriate components

First a low-pass filter was designed, and then according to the low-pass filter, the band-pass filter was designed. The designed band-pass filter parameters are: the lower cut-off frequency $f_1 = 1MHz$, and the upper cut-off frequency $f_2 = 30MHz$, band width $BW = 29MHz$, center frequency $f_0 = \sqrt{f_1 \times f_2} = 5.477MHz$, characteristic impedance $Z = 50\Omega$. In cording to above filter parameters. The low-pass filter is designed in figure 1.

The parameters of Frequency conversion are: $M = 2 \times \pi \times 29 = 182.12$, $L^{'} = L \times K^{-1} = 10.98nH$, $C^{'} = C \times K^{-1} = 5.49nF$.

And then the parameters of impedance transformation are: $K = 50$, $L^{''} = L^{'} \times K = 549\ nH$, $C^{''} = C^{'} \times K^{-1} = 0.1nF$.

Third-order Butterworth low-pass filter circuit with cut-off frequency $29MHz$ is showed in figure 2.

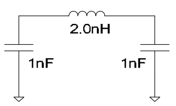

Fig. 1. The normalized low-pass filter

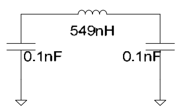

Fig. 2. Third-order Butterworth low-pass filter

2.2 Butterworth band-pass filter designing

The equivalent conversion circuits about low-pass filter converts into band-pass filter in table 1.

Table. 1. Low-pass filter converting into band-pass filter equivalent conversion circuit.

	Inductance	Capacitor
Low-pass branch		
Band-pass branch		
Components value	$C = \frac{1}{\omega_0^2 L}$	$L = \frac{1}{\omega_0^2 C}$

From table 1 we know: The inductance in low-pass circuit equivalents capacitance and inductance series in band-pass circuit, inductance was unchanged; the capacitance in low-pass circuit equivalents capacitance and inductance parallel in band-pass circuit, capacitance was unchanged. According to the equivalent transformation can get the band-pass filter circuit. In order to enhance the stability of circuit, improve common mode rejection radio, and eliminate the distortion in the circuit, the circuit was converted into the whole symmetric circuit in figure 3.

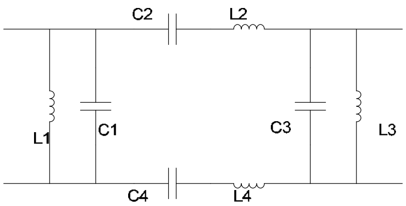

Fig. 3. Whole symmetric circuit

Here: $L1 = L3 = 8.45uH$, $L2 = L4 = 0.27uH$, $C1 = C3 = 100\,pF$, $C2 = C4 = 3.12nF$

2.3 Components choice

According to above band-pass filter designing high-frequency Ceramic capacitors with $400V$ compression are selected, which values are: $C1 = C3 = 100\,pF$, $C2 = C4 = 3.0nF$. Inductances are selected MURATA filtering inductances, which values are: $L1 = L3 = 8.2uH$, $L2 = L4 = 0.27uH$.

2.4 Filter simulation

Third-order Butterworth filter transfer function [6] is:

$$H(S) = 1/(S^3 + 2S^2 + 2S + 1) \quad (1)$$

Then according to low-pass filter and band-pass filter conversion relations, Butterworth band-pass filter with center frequency $1rad/s$ transfer function is:

$$H(S)=\frac{S_n^3}{Q^3S_n^6+2Q^2S_n^5+(3Q^3+2Q)S_n^4+(4Q^2+1)S_n^3+(3Q^3+2Q)S_n^2+2Q^2S_n+Q^3} \tag{2}$$

Here: $S_n = S\times\omega_0^{-1}$, $\omega_0 = 2\pi\sqrt{f_1\times f_2}$, $Q=\omega_0\times\omega_{BW}$, $\omega_{BW} = 2\pi\times BW$.

Putting $S_n = S\times\omega_0^{-1}$ into (2), transfer function of band-pass filter with center frequency $34.4\times10^6 rad/s$ is:

$$H(S)=\frac{S^3}{\frac{Q^3}{\omega_0^3}S^6+\frac{2Q^2}{\omega_0^2}S^5+\frac{3Q^3+2Q}{\omega_0}S^4+(4Q^2+1)S^3+\omega_0(3Q^3+2Q)S^2+2\omega_0^2Q^2S+Q^3\omega_0^3} \tag{3}$$

Characteristic impedance of the designing filter is 50Ω , and simulation diagram is in figure 4.

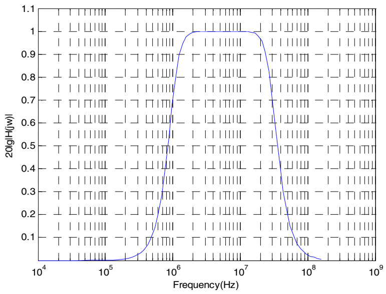

Fig. 4. Simulation result

3. Coupling circuit model

The difficult problem with power line communication is to eliminate the $50Hz$ industrial frequency signal. The band-pass filter has solved the problem well. Next problem is how to select proper coupling capacitor and isolation transformer. According to transformer stability, practicability and price, finally the network transformer HS16-102 is selected as isolation transformer. The final circuit with band-pass filter, isolation transformer and coupling capacitor is in figure 5.

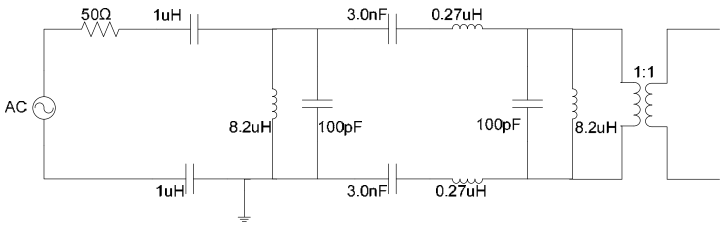

Fig. 5. Final circuit

In this paper, we selected 50Hz/220V AC signal and 15MHz/220V AC signal as reference to simulate, obtained two signal coupling results, figure 6. (a), figure 6. (b). Red line represents original signal, orange line represents coupling result.

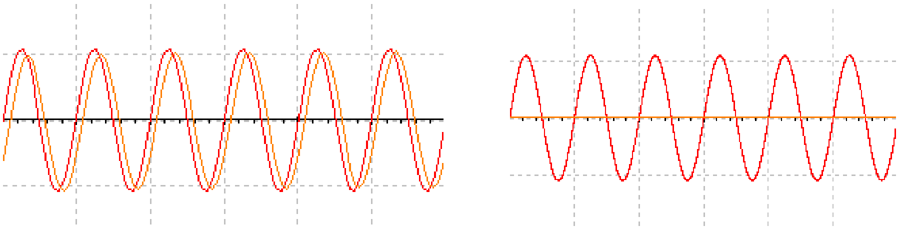

Fig. 6. (a) 15MHz signal coupling result ; (b) 50Hz signal coupling result

From the figures, 50Hz ac signal has been filtered completely, however 15MHz ac signal through absolutely, so the coupling circuit meets the design requirements.

4. Summary

Virtual simulation results show that the coupling circuit is suitable for low-voltage power line communication and reaches communication circuit requirements. 1MHz-30MHz signals with almost no distortion coupled to power line network. This circuit can not only couple signals but also can be used to test channel noise characteristics, signal attenuation characteristics, and channel impedance characteristics, which are necessary to research in power line communication. The next step is to put into project measurement stage, perfect the circuit in practice, in order to realize the best result.

Acknowledgements

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