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Design and analysis on micro-strip wide stop-band low-pass filters

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ABSTRACT

Microwave filter is an important gadget in the microwave circuit; it can exert great impact on the whole microwave circuit. Now that people call more for the band allocation of electromagnetic wave, band resources become more finely allocated; the use of handheld mobile devices also have a higher expectation—high performance, low cost, miniaturization—for microwave devices, thus the micro-strip filter, a kind of microwave filter, comes into being with its high performance, low cost, small size and easy processing. Microwave low-pass filter are normally used in the front of the system to block the high frequency signals and protect circuit in the back; high attenuation over a wide stop-band frequencies is not only a hotspot of current research on microwave low-pass filter but also the attention of people. This paper analyzes the application of micro-strip low-pass filter and is to design a low-pass filter with a wide stop-band and a fast decay speed. The paper is to design elliptic function low-pass filter with serial structure and parallel structure respectively; the design with and parallel structure is to be converted into micro-strip filters by employing the high-low impedance equivalent method and increasing the range of stop-band; the design with and parallel structure is made with hairpin cascade structure. Through the simulation calculation in HFSS, the paper is to design a 4 GHZ low-pass micro-strip filter with the reflection coefficients S11 being smaller than -12 db while the S21, smaller than -30 db.

KEYWORDS

Wide Stop-band; Elliptic function; Serial Structure; Parallel Structure.

INTRODUCTION

The most widely used gadget in the modern communication system, measuring system and radar systems is microwave filter, the core of the microwave circuit; the quality of microwave filter can greatly influence the performance of these systems[1]. Low pass filter is a common frequency selective element which is to suppress the high frequency signals and receive the low frequency signal, thus suppressing signal interference. In the application of low-pass filter, people are expecting stop-band broadening and insertion loss reducing while, in the design process, microwave filter embraces with high performance, low cost, miniaturization[2].

Due to the characteristics of distributed parameter element, there exists a parasitic pass-band inevitably in micro-strip filter. In the application, micro-strip filter need to suppress high harmonics so that the filter with a wider stop-band is always a hotspot of research[3].

Early in 1980, Yakinoma, together with some other researchers, has designed high-low impedance parallel coupled resonator filter which suppress the high harmonics by adjusting the ratio of coupling line impedance and non-coupling line impedance. In this way, parasitic pass-band can be moved away from the pass-band frequency range, suppress the harmonics, and finally broaden the filter stop-band. In this paper, the hairpin resonator structure is a high-low-impedance-based resonator in the shape of a hairpin. Hairpin resonator, due to compact structure, smaller size, lighter weight and reduced cost, has a better electronic property than the pectinate line inter-digital filter and the parallel-coupled line micro-wave filter; also, it has a lower insertion loss and higher frequency stability[4].

This paper studies the application of wide stop-band micro-strip low-pass filter, pays special attention to the elliptic function low-pass filter and design a low-pass filter with wide stop-band and fast decay speed in two ways: the series structure needs taking in multimedia inter-digital structure to extend its impedance while the parallel structure, converting into a hairpin resonator structure based on equivalent method, needs hairpin cascade structure to make wide stop-band and minimized sized, low-pass filter possible.

BASIC DESIGN THEORY

This research analyzes the elliptic function low-pass prototype; due to attenuation of reactance network of finite elements is a smooth curve and no changes would happen at a certain frequency, so it is impossible to make a filter embracing ideal filtering ability and the filter must be a continuous function but absolutely not with cutoff frequency mutations[5]. The filters used in everyday life are usually designed by approximating to the ideal filter frequency response curve.

After normalization, elliptic function of low-pass prototype is:

$$L_A(\omega) = 101g[1 + \varepsilon F_n^2(\omega)] \quad \textbf{(1)}$$

When n is an odd number:

$$F_n(\omega) = sn[\frac{nK_1}{K} sn^{-1}(\omega, k), K_1] \quad \textbf{(2)}$$

When n is an even number:

$$F_n(\omega) = sn[K_1 + \frac{nK_1}{K} sn^{-1}(\omega, k), K_1] \quad \textbf{(3)}$$

K=K (k) and K1=K (k1) is the integrations of k and k1 respectively, which adopts the elliptic function of the first kind. Therefore, in the pass-band, equiripple exists and transmission zero can be introduced into a certain frequency range, thus increase the out-of-band isolation index[6]. Figure 1 is the frequency-response curve of elliptic function filter.

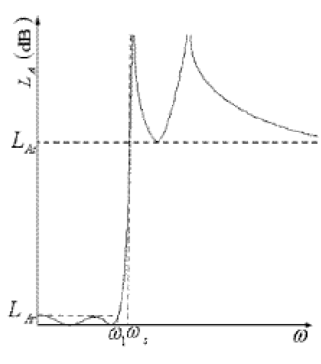

Figure 1 : Frequency-response curve of elliptic function filter

The elliptic function filter has a broader impedance range and better frequency choices; with suitable micro-strip coupling structure equivalent to the elliptic function can broaden impedance and suppress harmonic waves, which is the prototype the author chooses for this research.

DESIGN OF LOW-PASS FILTERS

According to the above theory, the design of a 4 GHZ low-pass micro-strip filter, need bandwidth of 4 GHZ, insertion loss being less than 1 dB, in-band ripple being less than 0.5 dB, reflection coefficients S_{11} being smaller than -12 dB, S_{21} being less than 30 dB and the out-of-band suppression in the range of 4.5 to 14 GHZ.

The lumped parameters filter in the elliptic low-pass design prototype has two structures: one is serial structure, meaning that the first components is series inductance which is equivalent to a high impedance line; the other one is parallel structure, meaning the first components is the shunt capacitance which can be equivalent to a hairpin resonator structure. In this paper, the author is to get micro-strip filter with two structures respectively, and than discusses the two's decay speed, miniaturization and wide stop-band.

Elliptic function low-pass filters with serial structure

This cell design employs high impedance line Z_h = 100, low impedance line Z_l = 20, substrate with relative dielectric constant Er = 3.66 and thickness H = 0.508 mm, the loss tangent TanD = 0.004, and the thickness of copper layer T = 0.035 mm.

To broaden filter stop-band and restrain parasitic pass-band, the author needs to add stop-band with impedance in the structure without affecting the in-band characteristics. Some researchers introduce multi-digital structure into the traditional coupling micro-strip low-pass filter; by doing this, the in-band characteristics are uninfluenced while the parasitic pass-band is effectively restrained and the stop-band expanded[7]. Multi-digital structure can be regarded as a combination of high impedance line inductance and high band-stop lines. The structure, the equivalent circuit and the frequency-response curve is shown in Figure 2.

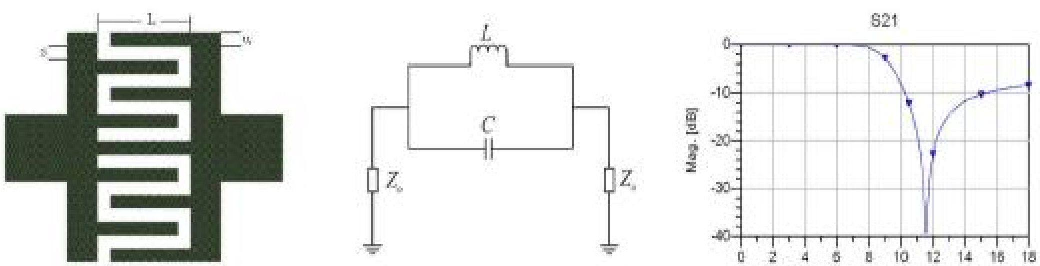

Figure 2 : Multi-digital structure, the equivalent circuit and frequency response

Figure 3 shows the resonance frequency change with the change of L in the multi-digital structure. The result is: a fixed impedance line width w = 0.2 mm, gap width s = 0.2 mm, multi-digital length L = 1.5 mm, 2 mm and 2.5 mm. respectively.

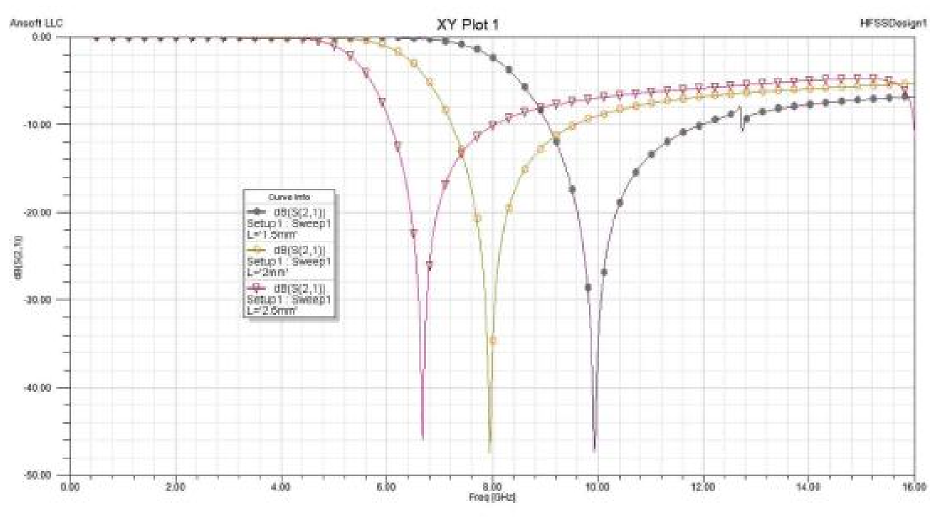

Figure 3 : Resonance frequency change with change of l in multi-digital structure

From Figure 3,it's clear that the larger L is, the lower the resonant frequency becomes. This is because the increase of lengths of multi-digital structure would lead to increase of inductance and capacitance in its equivalent structure, thus decreasing the resonant frequency.

In HFSS, the author carries on a simulation calculation in a 3D simulation model established based on size (See in Figure 4). The author adds two multi-digital structures on both sides of the filter to restrain a parasitic pass-band of more than 10 GHz and then analyzes the influence of the length L of multi-digital structure on the resonant frequency. If selecting L being 1.3 mm and 1.6 mm respectively, then the author gets the results that the objective function set in Optimetrics is optimized, so are the variables. Optimization of variables' length does not change the width of them, so impedance of each section of transmission line does not change in this process. After many times of optimization calculation, the author gets the following results (See in Figure 5).

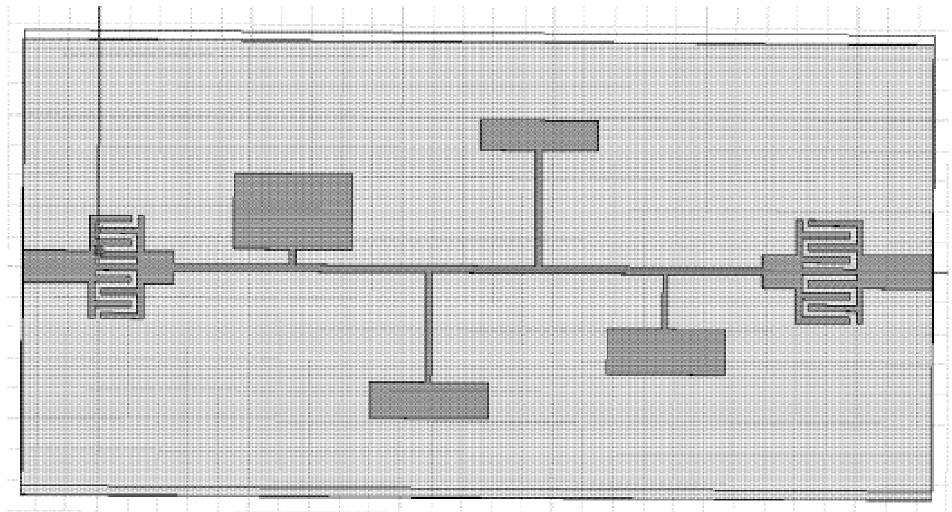

Figure 4 : Model after introduction of multi-digital structure

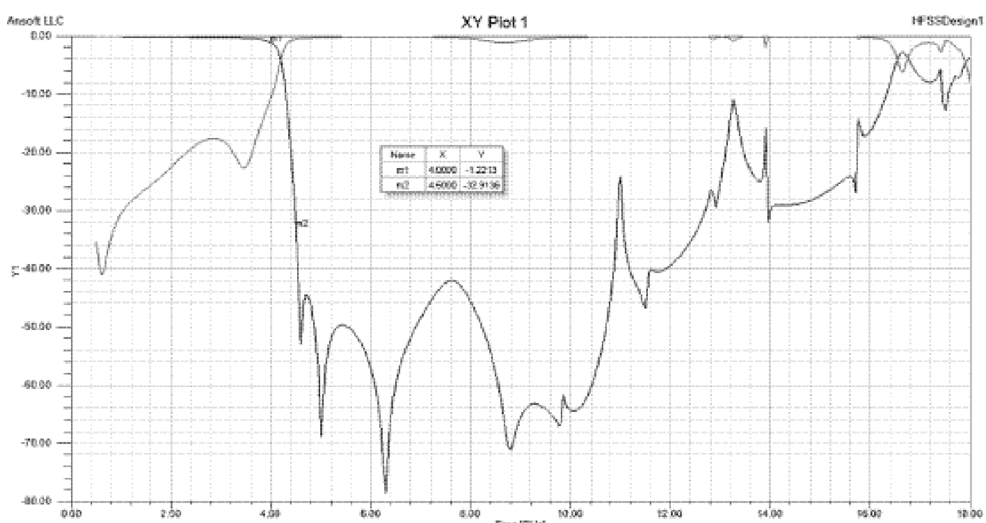

Figure 5 : Results of simulation calculation after introduction of multi-digital structure

From Figure 5, it is clear that, after the introduction of multi-digital structure refers to the structure, the in-band characteristics remain the same; attenuation remained unchanged at 4.5 GHz, the parasitic pass-band is effectively restrained with a degrees from more than 40 db or from to 10.8 GHz or from more than 20 db to 13 GHz. Therefore, multi-digital structure only affects the quality of filter near the resonance frequency; also, the interaction of two multi-digital structures in different sizes can restrain the broadening of harmonic component, which is helpful for the simplification of the design process.

Obviously, introduction of two multi-digital structures still do not meet the the requirements of stop-band range, so more of this structures need to be introduced. In the end, after the introduction of two multi-digital structures on both ends of filter, the results of simulation calculation meet the design requirements. Its structure is shown in Figure 6; simulation results as shown in Figure 7:

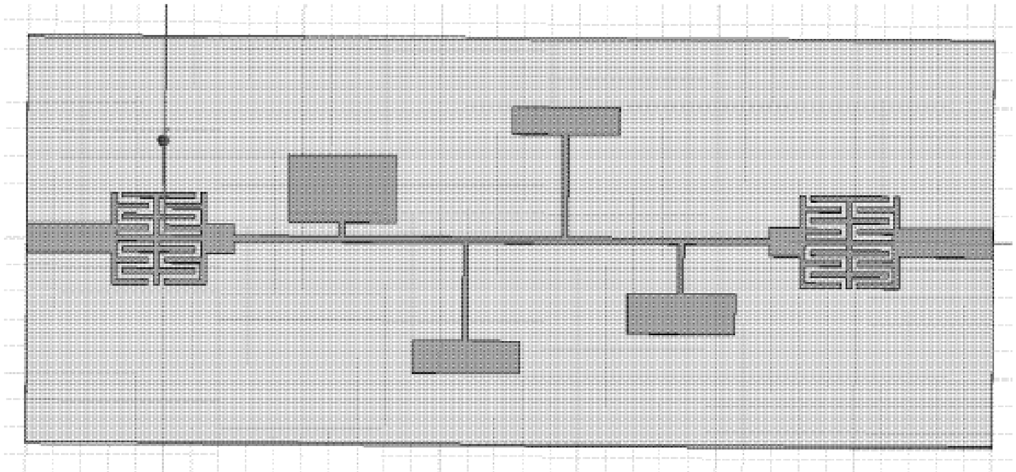

Figure 6 : Model after introduction of four multi-digital structures

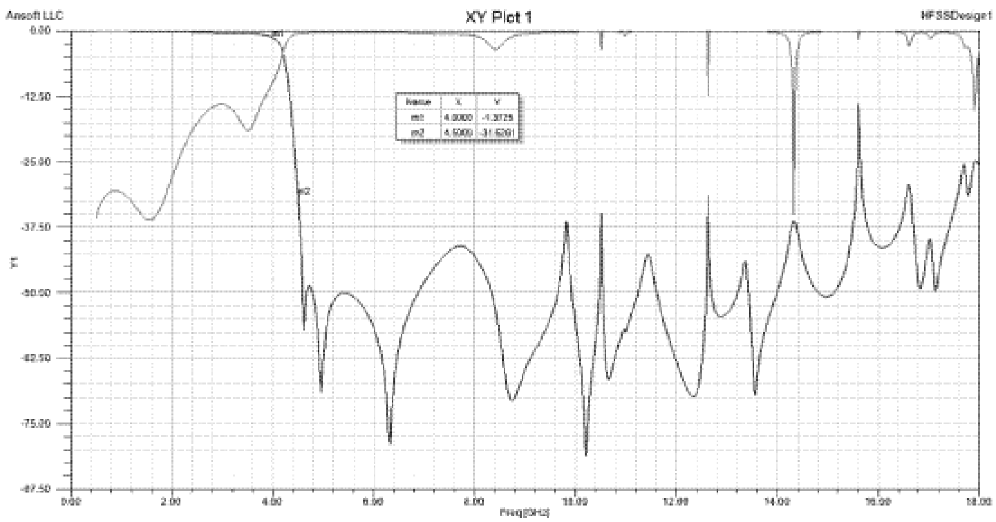

Figure 7 : Simulation results after introduction of four multi-digital structures

From Figure 7, it is clear that, within the 4 GHz band-pass, in-band ripple is smaller than 0.5 dB; insertion loss is smaller than 1 dB; reflection coefficients S_{11} is smaller than -12 dB and S_{21} is smaller than 30 dB within 4.5 ~ 15.5 GHz. After introduction of multi-digital structures, the micro-strip filter occupies a larger area. in the design, the four multi-digital structures' total length is about 6.4 mm, smaller than one fifth of the entire length of the dielectric substrate. Therefore, it's safe to say that the introduction of the multi-digital structures only exerts a slight influence on the area and that simulation results meet the design requirements.

Elliptic function low-pass filters with parallel structure (hairpin cascade structure)

Figure 8 shows the hairpin resonator and the frequency-response curve. This kind of impedance features small size, simple and compact structure, limited design parameters, easy design and a frequency-response band-stop and has a good harmonic suppression ability. Now it has been widely used in the design of wide stop-band filters[4].

Analysis of hairpin resonator structure

Hairpin Resonator structure has the following main design parameters: high impedance line length L and width of Lw, low impedance line length of a and width of b as well as the gap width g. Here is one by one to study the effect of various parameters on the resonant frequency.

This unit adopts Er = 3.66 the relative dielectric constant of substrate, its thickness H = 0.508 mm, loss tangent TanD = 0.004, T = 0.035 mm copper layer thickness. 3 d model is set up, in HFSS simulation.

First of all, to make the length of a low impedance line a = b = 2.6 mm, 1.5 mm, width slit width between g = 0.2 mm, high impedance line of line of Lw = 0.3 mm wide, changing the length of the high impedance line L = 9.2 mm, 9.6 mm and 10 mm. The simulation curve as shown in figure 9:

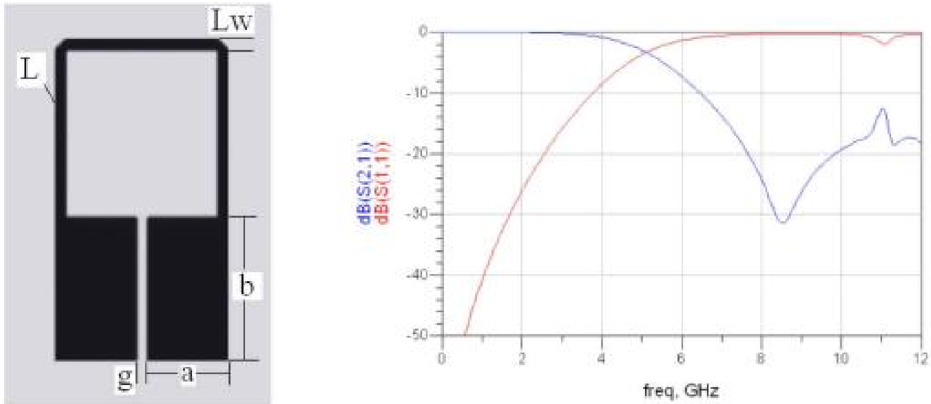

Figure 8 : Hairpin resonator and the frequency-response curve

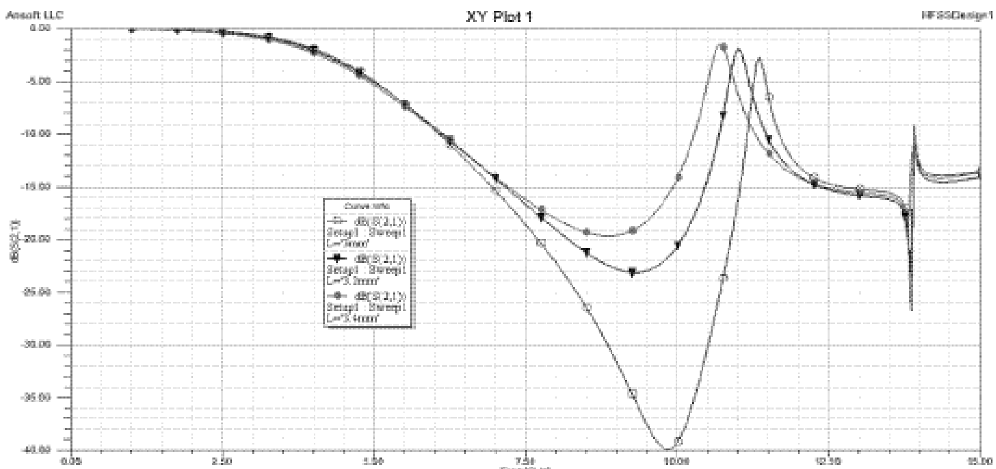

Figure 9 : Influence of high impedance line length l on the resonance frequency

By the figure can be seen that when L increases when the length of the high impedance, the resonance frequency of the circuit is reduced. This is because the high impedance line length increases, the equivalent inductance Ls increases, but at the moment, capacitance basic remains the same, which leads to reduces the frequency of the resonant circuit. Then, make a = 1.5 mm, b = 2.6 mm, g = 0.4 mm, L = 9.2 mm, change the line width of Lw of high impedance line = 0.3 mm, 0.4 mm and 0.5 mm. The simulation curve is shown in figure 10:

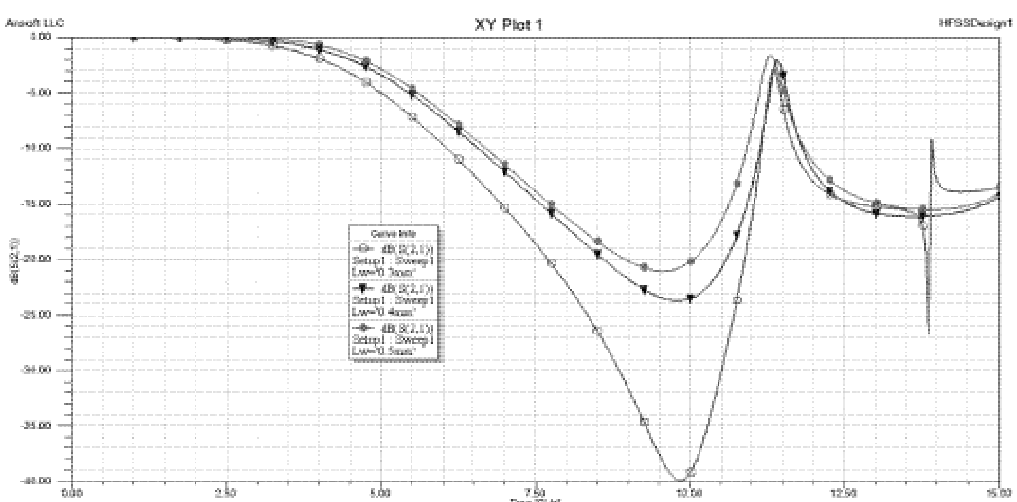

Figure 10 : Influence of high impedance line width of lw on the resonance frequency

From above can be concluded that with the increase of the line width of Lw of high impedance line, circuit resonance frequency decreases, but the cutoff frequency of the circuit will be improved. Mainly high impedance lines width increases, the main reduce the equivalent circuit inductance Ls, but also makes the equivalent shunt capacitance Cs is increased, the circuit resonance frequency and the influence of cut-off frequency cannot be ignored.

Make a = 2.6 mm, L = 9.2 mm, Lw = 0.3 mm, g = 0.2 mm change the width of the low impedance line b = 2.4 mm, 2.5 mm and 2.6 mm. The simulation curve is shown in Figure 11.

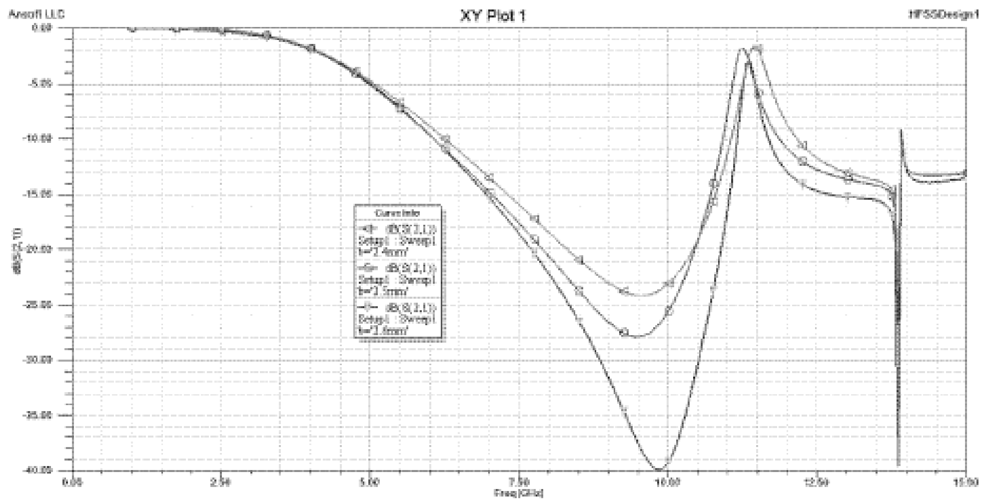

Figure 11 : Influence of low impedance line width b on the resonance frequency

By drawing on see, when b increases, the resonance frequency of the circuit is reduced. This is because the increase of low impedance line width, which is equivalent to increase the equivalent capacitance of the Cp, thus reduce the resonance frequency of the circuit. Make a = 1.5 mm, b = 2.6 mm, L = 9.2 mm, Lw = 0.3 mm, change the gap width between g = 0.2 mm, 0.3 mm and 0.4 mm. The simulation curve as shown in Figure 12:

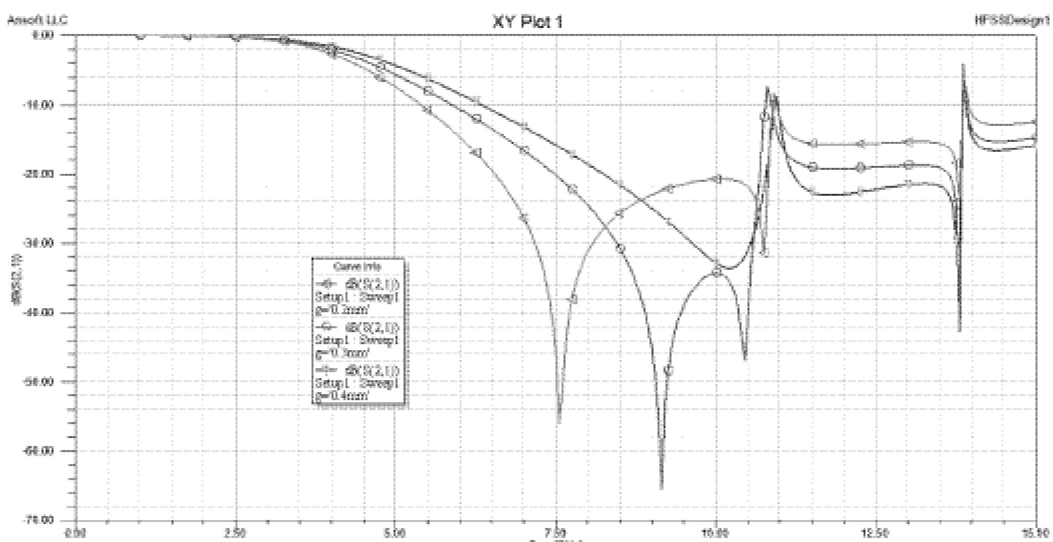

Figure 12 : Influence of middle gap width g on the resonance frequency

See by the graph, the middle gap width g increases, the circuit of the resonance frequency increases, the increase is mainly due to the gap width, the coupling capacitance Cg will decrease, so the resonant frequency of the circuit will increase.

Design of low-pass filter with hairpin structure

According to the design requirements, the 3 d simulation model is established in the HFSS, slopes couplet hair card designed six low-pass filter, as shown in Figure 13, at the ends of the resonator cables for the characteristic impedance of 50 transmission lines. Set the solving mode for the driving of HFSS, set up the port for wave port incentives, set the frequency sweep range to 0.1 GHz ~ 18 GHz, frequency sweeping method for the rapid frequency sweep, solving the center frequency is 4 GHz, mesh adaptive way to use the system default. Using HFSS Optimetrics function of optimization design, as the optimization variables is more involved, and the range of values of each variable is large, using HFSS provides five kinds of optimization algorithm of any a kind of hard to directly get the optimization goal. When choosing optimization algorithm, therefore, consider using the algorithm of multiple combination way, after a lot of optimization calculation, finally get the optimization simulation results as shown in Figure 14.

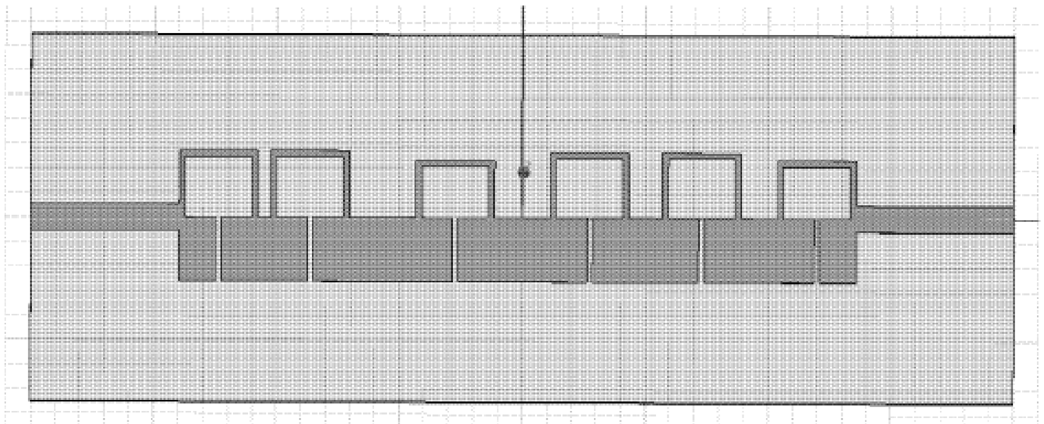

Figure 13 : level 6 cassette filter structure

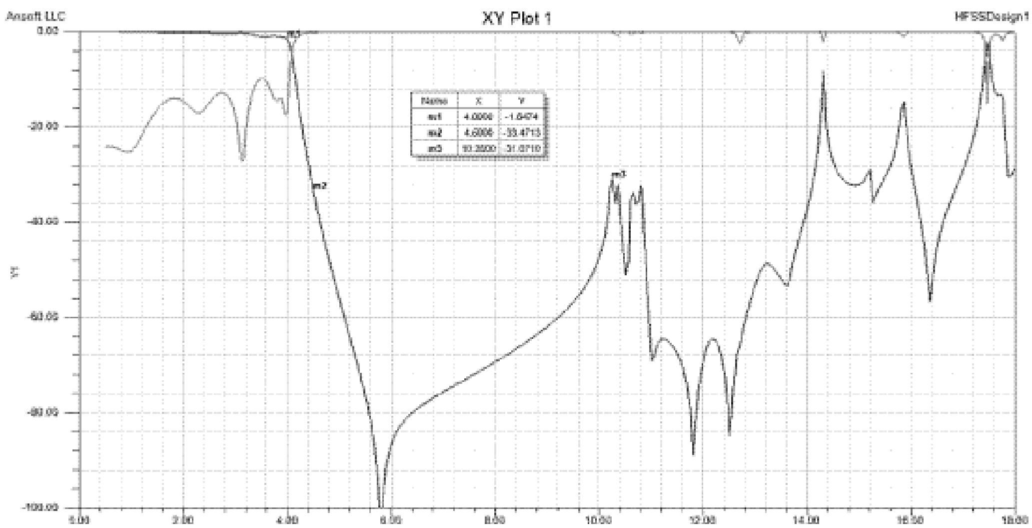

Figure 14 : 6 cassette filter frequency response

Can be seen in the figure, 6 cassette resonance structure at 4.5 GHz attenuation to - 30 db below, within the scope of 4.5 to 14 GHz inhibition are reached below 30 db. Visible six slopes of the hairpin resonator, the transition is very steep, is also very effective in harmonic suppression, meet the requirements of the design, has a certain practical value.

Compared the above two kinds of the method of using elliptic function filter design of micro-strip filter: high and low impedance equivalent series elliptic low-pass filter, and sending card low-pass filter. We can see that the high and low impedance equivalent series of elliptic function low-pass filter can directly reflect the elliptic function more steep attenuation characteristics, but in terms of harmonic suppression than sending card structure; And cassette low-pass filter has more advantage in harmonic suppression, but to achieve fast attenuation characteristics need to increase the series of resonator.

CONCLUSION

This paper focuses on the design of 4 GHZ low-pass filter which has a steep transition zone and a very wide range of micro-strip stop-band low-pass filter and which is based on two normalized structures of the elliptic low-pass filter. Firstly, the author uses equivalent method to convert the design with and parallel structure into micro-strip filters which has a perfect transition zone but bad harmonic suppression ability; by increasing the range of stop-band cascade structure, the design can embrace the characteristic of wide stop-band and fast decay speed. Secondly, make the elliptic function filter with parallel structure as a hairpin resonance structure which has good harmonic suppression ability; with hairpin cascade structure, the author makes the miniaturized, wide stop-band low-pass filter. With the continuous development of high-performance substrate materials, the application of microwave planar circuits has also been extended with higher frequency and wider range, especially micro-strip filters. Therefore, it is predictable that micro-strip filter featuring high performance, low cost and miniaturization will still be a future research focus, which indicates that filter with higher standard and higher performance will come into being and make the world a more colorful place.

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