L-C Filters: Past, Present and Future

Here is a review of the development of L-C filters, and a summary of their advantages over other filter types

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Filters are frequency selective circuits or devices that performance valuable functions in electronic equipment. Filter design objectives usually include adequate stopband selectivity without introducing unacceptable passband insertions losses and distortions.

In receivers, filters reject unwanted out-of-band interference and establish sensitivity by defining the front-end noise bandwidth. In transmitters, filters reduce unwanted frequencies (spurii) and suppress transmitter noise at receive frequencies. Filters also reject some of the unwanted mixing products in both receivers and transmitters.

Filters are useful in various multiplexing applications. For example, they can separate audio from video in video transmission equipment. For digital equipment, filters provide anti-aliasing and passband or waveform shaping. Filter realizations below microwave frequencies utilize L-C and alternate technologies. L-C filters are usually ordinary ladder networks, with selectivity typically achieved via reflection rather than dissipation.

The primary objective of this tutorial and quasi-historical article is to provide a panoramic overview of L-C filters that is lucid. It has been limited to a qualitative discussion. Details of specific applications, mathematics and computer usage have not been included.

Historical background

L-C filters (and also equalizers) flourished during the past eras of electronics technology. These circuits have been used in practical applications for eight decades. The original impetus for the creation of L-C filter technology by Zobel [1] was telephony. A related applications was the use of loading coils to improve high frequency response of telephone cables. Prior to about 1950, most L-C filters were designed using the classic method of image parameters.

Modern network synthesis L-C filter design emerged from the works of Foster, Cauer, Darlington, Saal and others. This new design method became popular as a result of technical articles by Weinberg and a landmark paper by Dishal [2]. The work of Dishal introduced dissipation factors and coefficients of coupling to Butterworth and Chebyshev filters realized by modern network design. A famous book on microwave technology by Matthei, Young and Jones [3] provides much basic information applicable to L-C filters. References [2] and [3] paved the way for practical filter design and development at microwave frequencies. Modern network synthesis design of L-C filters became solidified via a handbook authored by Zverev [4] in 1967.

As time went on, competing technologies to L-C became available. Active filters and digital filters were also covered in a more recent handbook by Williams [5]. By this time, the personal computer had become a vital tool in the design, analysis, documentation and manufacture of L-C filters and alternate filter realizations. A quite recent book by Rhea [6] has included newer L-C filter design improvements plus computer simulation and optimization of filters. This book effectively brings the art of filter design into the twenty-first century.

Image parameter design method

The design of L-C filters by the method of image parameters resulted in useful filter circuits. Values of the circuit elements could be obtained via simple formulae with the slide rule. Composite filters used interior constant-k and m-derived full sections terminated by m-derived half sections. This provided filer performances that were quite satisfactory for many applications. In some instances, transforming end sections were used for special impedance matching requirements. Laborious computations of actual filter responses, in the presence of incidental dissipation and lack of image termination, were not usually attempted. Measured data on filter breadboards was used as the criteria for acceptance and the basis of refinements when changes were needed.

With the advent of the personal computer, the responses of image parameter L-C filters could be predicted readily via analysis with ABCD matrices. The effects of constant resistance source/load termination and incidental dissipation were included in the analysis. Filter responses such as VSWR (return loss), amplitude, phase shift, group delay and input/output impedance were attainable in the same way that comparable responses were computer for modern network theory designs.

In some cases, image parameter filters require fewer different circuit elements. This is an advantage for both ease and cost of manufacture. Image parameter design originated the zig-zag filter which employs a minimum number of inductors. The method of image parameters has also proven useful in the design and analysis of certain microwave structures that employ non-commensurate transmission lines.

Modern network synthesis

Modern network synthesis has permitted realizations of many new filter response shapes that have their own advantages and disadvantages. Butterworth amplitude responses are monotonic and are useful in some situations. Chebyshev filter responses ideally provide equal passband amplitude ripples for disspationless filters. In the real world, incidental dissipation usually impairs obtaining equal ripples. Thomson (i.e. Bessel) filters provide monotonic group delay responses. Gaussian filters are useful when transient response is important. These filter responses entail networks that have only poles in their transfer responses. With the introduction of both poles and zeros, the elliptic function filter can be employed. This filter ideally has equal ripples in both passband and stopband amplitude responses.

Response shapes for modern network synthesis designs of ladder networks can be obtained in two ways: the complex frequency plane and the ABCD matrix. Practical filters, conceived via modern network synthesis, are often implemented using various identities and transformations.

In the era of modern network synthesis, the equal element filter has been introduced. This filter has several advantages: fewer different circuit elements, reduced insertion loss due to dissipation and enhanced peak power handling capability. The equal element filter is analyzed using the ABCD matrix.

Starting in the 1960s, a new class of bandpass filters was introduced. These general filters intentionally used bridging couplings between non-adjacent resonators. General filters can be used for elliptic function designs, improved passband group delay responses and simultaneous approximation of amplitude and group delay.

It should be noted that all filters mentioned herein can also be analyzed by nodal analysis.

Competing filter technologies

Prior to about 1950, the primary alternative to L-C filters was crystal filters. Crystal filters, using quartz resonators, continue to fill a niche when very narrow bandwidths require high unloaded Qs that are not realizable by ordinary inductors.

With the advent of solid state devices and integrated circuits (ICs), the practicality of active filters became a reality. the availability of operational amplifiers (opamps) made active filters active filters a viable option below 100 kHz for low power applications. In more recent years, opamps have been available at frequencies as high as the popular communications intermediate frequency bands centered at 70 MHz and 140 MHz. Active filter technology has continued to push upwards in frequency from VHF to UHF.

Other filter technologies have also arrived to compete with L-C filters. Digital filters have become useful building blocks in digital signal processing. As the transition from analog to digital hardware accelerates, digital filters will become more common. They are compatible with circuit integration and equipment miniaturization.

The surface acoustic wave (SAW) filter has taken over some applications from L-C filters, with IF bandpass filters in satellite earth station equipment being a good example. They have the advantages of inherent linear phase, low cost and small size. Unlike quartz crystal filters, SAW filters have been useful for both narrow and wide bandwidths.

Filters from competing technologies are usually fixed tuned without any available adjustments. Some competing filters require DC excitation. They might also be housed in sealed enclosures that are not acceptable to the user. Many L-C filters use adjustable inductive and/or capacitive components that can be "tweaked" by the user to accommodate mismatched source/load impedances, component value variations or other aberrations from the norm.

Technology and market changes

In the past eight years or so, several significant changes have occurred in technology and the electronic marketplace:

1. The Cold War has ended and government markets have eroded. Funding for research and development is much more difficult to obtain.
2. Commercial markets have made unit cost the most important specification. Commercial hardware is also becoming acceptable in some government applications.
3. Surface mounted components have replaced many components with leads.
4. Digital technology is rapidly replacing much analog technology.
5. Many equipment functions are achieved by software rather than hardware.
6. Personal computers have taken over many design and manufacturing chores.
7. Newer applications, such as the many forms of wireless communications, have created major commercial markets for electronics.

Advantages of L-C filters

Despite the inroads of competing technologies, L-C filters retain certain advantages:

1. L-C filters can be breadboarded rapidly by typical users, without being dependent upon external specialists. Vector board circuits can be readily designed, fabricated and tested.
2. L-C prototypes can be modified readily in response to the evolution of specifications for systems and subsystems.
3. L-C filters can be adjusted to optimize the performance of systems and subsystems.
4. L-C filters are useful additions to commercially available test equipment.
5. L-C filters can be used to speed up preliminary developments with subsequent replacement by other types of filters.
6. L-C filters can accommodate voltage and power levels that cannot be handled by other types of filters.
7. L-C filters are passive and do not usually require DC excitation.
8. L-C filter usage at microwave frequencies is compatible with monolithic microwave integrated circuits (MMICs). Improved computer models are available for microwave lumped circuits.

Summary

Although competing filter technologies are replacing L-C filters in many applications, L-C filters are preferable in other applications. There is still a substantial need for L-C filters that will not go away. L-C filter technology also feeds related circuits such as equalizers, impedance matching networks, transformers, shaping networks, attenuators, power dividers, signal samplers, monitor tees, directional couplers, DC blocks and return loss bridges. L-C circuit techniques are also applicable to active circuits such as amplifiers, oscillators, mixers, detectors, frequency multipliers and DC power supplies.

The L-C filter continues to provide the practicing engineer with opportunities to innovate and experiment. As we enter the next century, many of these opportunities will be realized via the personal computer. Nevertheless, the ultimate in professional satisfaction will entail predicting filter performance and determining circuit elements on the computer, building a breadboard or prototype model, and obtaining measured data that correlates experimental data with theory.

The design and development of L-C and other filters is an ongoing learning experience. Each new task can exhibit small or large excursions from prior designs. The quest for technical knowledge will go on as the engineer encounters new and more difficult challenges. ■

References

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This article includes only a minimal bibliography. Many other engineers and scientists have made significant contributions to L-C filter technology. In particular, the outstanding contributions of S. B. Cohn should be noted.

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