# Thin-film passives in RF/microwave circuits

## *Consistent Q and ESR make thin-film parts an attractive option for design engineers*

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Until recently, most microwave capacitors were based on fired multilayer ceramic technology. In this process, layers of highly conductive electrode metal alloys are interleaved with low-loss ceramic dielectrics in a multilayer fashion until the target capacitance is obtained. The resulting stack is then sintered into a monolithic structure in a high-temperature firing process. This process continues to satisfactorily serve high-power capacitor needs in addition to those in larger value RF capacitors.

On the flip side, the multilayer ceramic process can potentially exhibit variability on a lot-to-lot and inter-lot basis with regard to parameters important to RF designers. Among these parameters are variations in Q factor, ESR, insulation resistance and capacitance variations over the full-specified tolerance range. Though many applications are not negatively impacted by these variations, breakthroughs in thin-film component manufacturing now offer designers an alternative choice for high-frequency microwave components.

The same concepts of thin-film technology used in making semiconductors have allowed the creation of a series of thin-film passive components with extremely tight electrical and physical characteristics. Line width sizes below 1 µm and dielectric layer thicknesses below 100 angstroms are achievable.

In addition to the tight parametric tolerances (inductance and capacitance) gained from tight line widths, several other electrical performance advantages can be optimized. Among these are:

Extremely consistent ESR on a lot to lot and inter lot basis as a result of high-vacuum-electrode deposition processes.Consistent Q and ESR as a result of ultra-pure, low-K dielectrics deposited in a CVD process.Consistent and predictable impedances across wide frequency ranges.Land Grid Array termination capability to reduce parasitics.

The resulting performance advantages of thin-film components can impact a design. In many cases it can reduce the number of components used to achieve a particular circuit function. Not only will the size of the design shrink, but also assembly time and assembly cost decreases while reliability is improved through the use of fewer components. What is more, electrical performance is improved through the use of more electrically consistent parts with lower-loss factors.

## Example: Band-reject filters

A real-world example of this is band-reject filters. A band-reject filter is a circuit designed to block the passage of signals in a specific spectrum of RF frequency while allowing other signals to pass un-attenuated. Other common names are notch filters, bandstop filters or band suppression filters. A common implementation of a band-reject filter is between a power amplifier and matching circuit prior to an antenna.

For example, in a typical application, the narrow notch filter is used to attenuate noise from heterodynes and harmonics unintentionally generated by complex, multiband, wide coverage receivers. The use of a single high-quality thin-film capacitor can essentially replace the use of six components in a twin T design due to thin film's near-ideal characteristics.

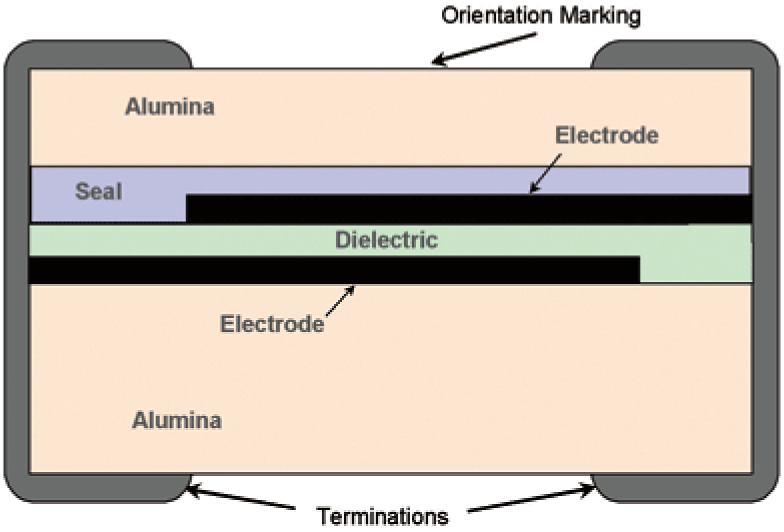

*Fig. 1. Construction of a thin-film capacitor.*

Thin-film capacitors (see *Fig. 1*) have an additional performance advantage not discussed earlier: a single resonant point response due to the fact that the devices use a single-layer dielectric design packaged as a multilayer ceramic capacitor (MLCC). A few of the thin-film capacitor's S21 forward transmission loss characteristic curves are shown in *Fig. 2*

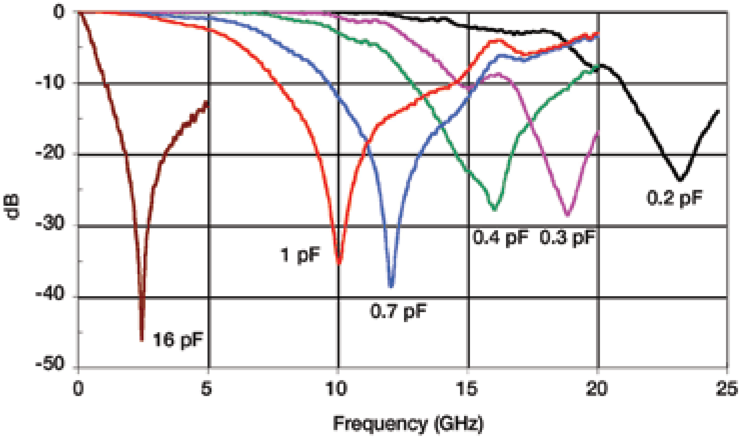

Fig. 2. S21 forward transmission loss characteristics curve.When using a thin-film capacitor, manufacturers can reap the electrical benefits of a single-layer capacitor while being rewarded with the processing ease of an MLCC-type component. A thin-film capacitor's consistent performance impact on electrodes and oxide thickness and quality impact on dielectric K is shown in *Fig. 3*.

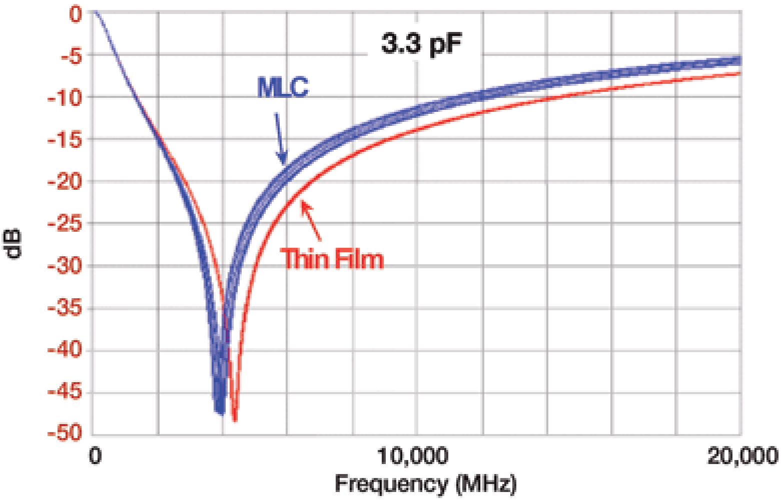

Fig. 3. A thin-film capacitor has an extremely repeatable frequency response compared to MLCCs.

It is also important to realize the limitations of thin-film capacitors used as band-reject filters. Since thin-film capacitors are typically only available in low capacitance values they are limited to relatively high-frequency band-reject filter designs. If dealing with low frequency designs, other filter methods must be utilized typically using high-Q multilayer RF capacitors.

## Thin-film inductors

Thin-film inductors offer many practical advantages over air wound cores (though of course they can not achieve the same Q factors). Thin-film inductors are easier to pick and place in a SMT process than air core inductors. They can easily be processed in the IR, vapor phase and wave processes typically used in today's assembly. Further, they will maintain value through those processes, as well as through handling and through high-vibration environments. Though they can not be tuned in circuit like air cores can, thin-film inductors can be used to replace air cores once an exact inductance value is determined for proper circuit function (assuming the Q factor is acceptable).

As in the case of thin-film capacitors, ESR and loss are dramatically reduced due to line width control and dielectric laydown quality/accuracy. This results in an end product which can be as small as an 0402 package with virtually any inductance value imaginable plus tolerance accuracy as close as 0.05 nH. Further, consistent metalization allows relatively high-current-carrying capability in thin-film inductors – up to 1,000 mA depending on device selected.

An example of thin-film inductor implementation might be in frequency compensation on broadband amplifiers. Previously, a resistor/inductor combination was used. As in the case of thin-film capacitors, the use of a thin-film inductor can reduce the number of components used in the circuit thereby saving size, weight, assembly and cost as well as improving reliability.

Just as thin-film capacitors, thin-film inductors are limited in maximum value.

In particular, a thin-film inductor provides designers with a good solution at extremely high frequencies. A common example is in multi-gigahertz oscillators. At high frequencies, wire-wound inductors may simply not be available, due to the absence of cost effective manufacturing techniques to build such low value wire-wounds.

At this point the designer is left with the choice of creating a low value inductor with serpentine PC board trace designs or choosing a miniature SMT thin-film inductor.

Though a PCB-based solution can be considered low cost, it uses valuable board space, and can vary based upon the PCB supplier. The thin-film inductor will have the same extremely repeatable and consistent frequency response on a lot-to-lot basis and on an inter lot basis as that of thin-film capacitors.

## Other thin-film structures

A variety of other structures have been created with the knowledge and process capability gained in manufacturing thin-film capacitors and inductors. Among these are couplers and harmonic low pass filters.

Miniature SMT couplers are a welcome addition to the designer’s toolbox. These devices provide high directivity, repeatable coupling with low insertion loss. They handle large amounts of power in a PCB footprint as small as 0402 with low profiles. As in the case with other thin-film components their electrical response and consistency on a lot-to-lot and inter lot basis is unmatched. ■