

Technical Column: Dielectric Measurement Using Split-Cylinder Resonator

EMlabs

E-mail : info@emlabs.jp

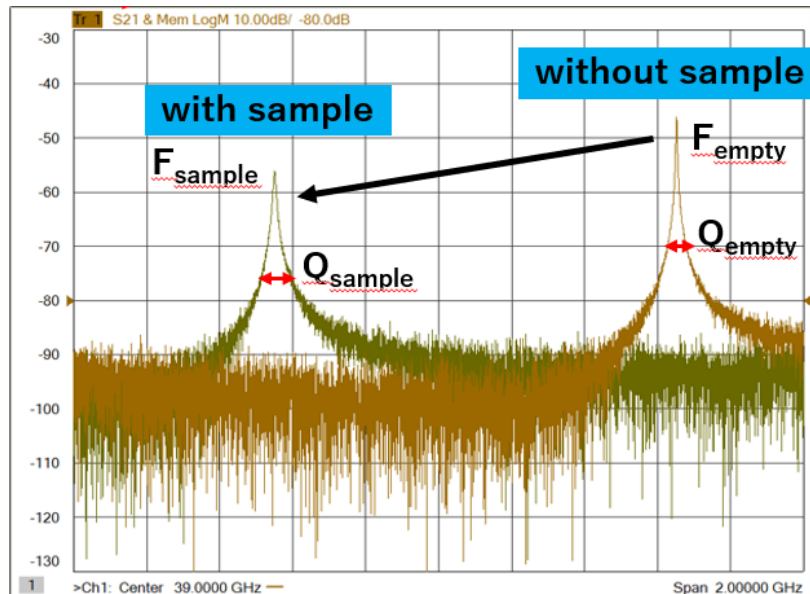
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Introduction

In recent years, electronic devices used in fields such as 5G/6G communications, high-speed servers, and automotive radar have required performance in frequency ranges exceeding 100 GHz. For the design of substrates and packaging materials used in these devices, accurate evaluation of dielectric constant and dielectric loss tangent (dissipation factor) is indispensable. The split-cylinder resonator has become a standard method for dielectric measurement in the 10–80 GHz band, widely used internationally, providing highly accurate and reproducible results.

1. Measurement Principle

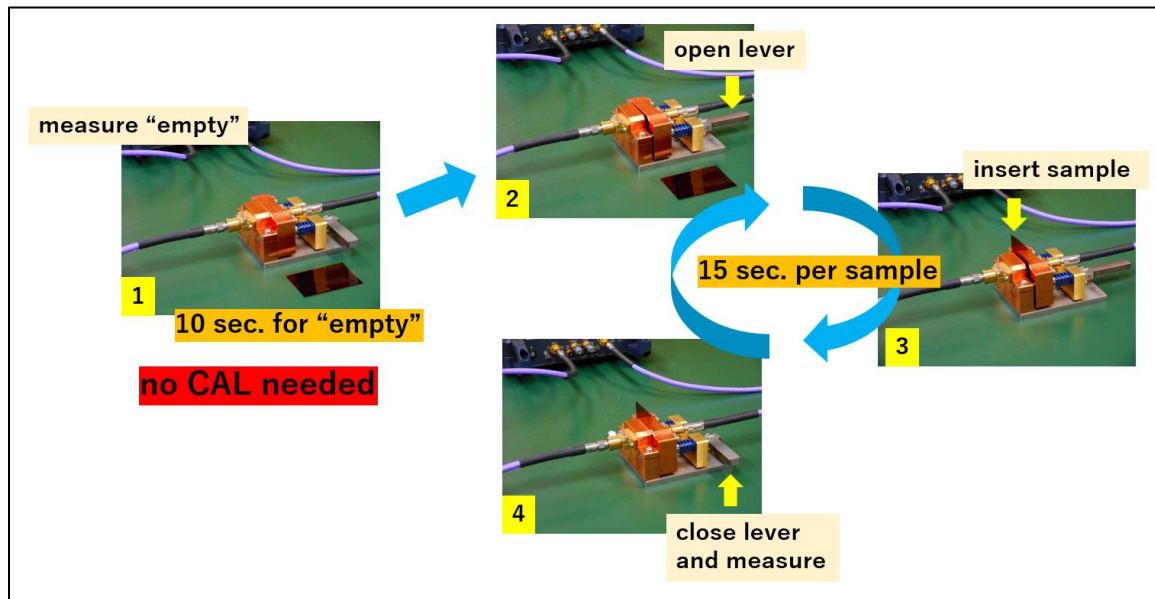
The split-cylinder resonator consists of a metallic cylinder vertically divided, with a film-shaped sample inserted between the halves. Electromagnetic waves are resonated inside the cylinder, and by analyzing the shift in resonance frequency and Q-factor, the dielectric constant (ϵ') and dielectric loss tangent ($\tan\delta$) can be determined (Fig. 1). The $TE_{01\delta}$ mode is typically used, which has strong electric field distribution parallel to the sample, enabling high-sensitivity measurement of thin films.



【Fig. 1: Resonance shift illustration. Comparing resonance with and without sample allows determination of dielectric constant.】

In principle, dielectric constant ϵ' is derived from the frequency shift $\Delta f/f_0$, and loss tangent $\tan\delta$ from the Q-factor change ($1/Q$). When metallic foils are used, the Q-factor reduction can also be applied to evaluate surface conductivity, capturing the skin effect at millimeter-wave frequencies.

Figure 2 shows the resonator setup and procedure. A notable feature is the ultra-fast measurement speed: one sample can be measured in just 15 seconds.

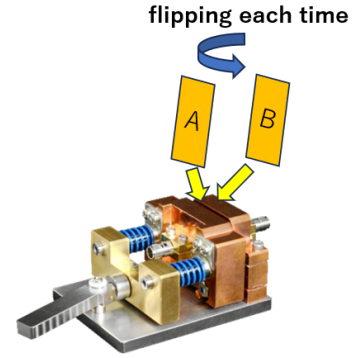


【Fig. 2: Split-cylinder resonator setup and measurement procedure】

2. Features of the Split-Cylinder Resonator

- World-class precision
- Standard deviation of dielectric constant ≤ 0.0006 , dissipation factor ≤ 0.000003
- Measurement time as short as 15 seconds per sample, allowing efficient evaluation of many materials
- Covers 10–80 GHz range by replacing resonators for each frequency
- Can be combined with temperature and humidity chambers for environmental evaluation

COP film (flipping the sample each time)				
	28GHz Dk	40GHz Dk	28GHz Df	40GHz Df
Meas 1-A	2.36965	2.35451	0.000716	0.000755
Meas 2-B	2.36980	2.35486	0.000724	0.000751
Meas 3-A	2.36968	2.35440	0.000723	0.000753
Meas 4-B	2.36973	2.35466	0.000714	0.000748
Meas 5-A	2.36950	2.35381	0.000718	0.000752
Meas 6-B	2.36968	2.35376	0.000722	0.000753
Meas 7-A	2.37036	2.35367	0.000717	0.000752
Meas 8-B	2.37012	2.35412	0.000716	0.000760
Meas 9-A	2.37007	2.35382	0.000720	0.000755
Meas 10-B	2.37012	2.35420	0.000716	0.000754
Average	2.36987	2.35418	0.000719	0.000753
St Dev	0.00028	0.00042	0.000003	0.000003



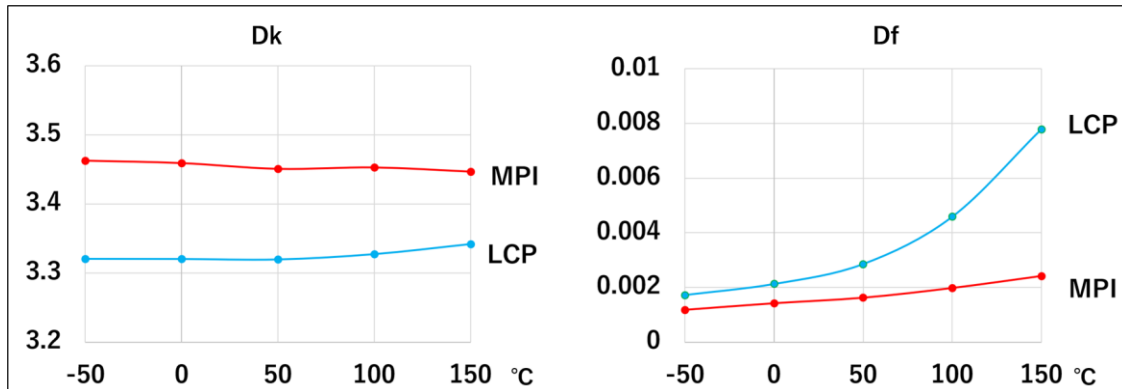
【Table 1: Example of reproducibility with repeated measurements at 28 and 40 GHz showing remarkably low deviation (standard deviation of Df = 0.000003).】

3. Application Examples

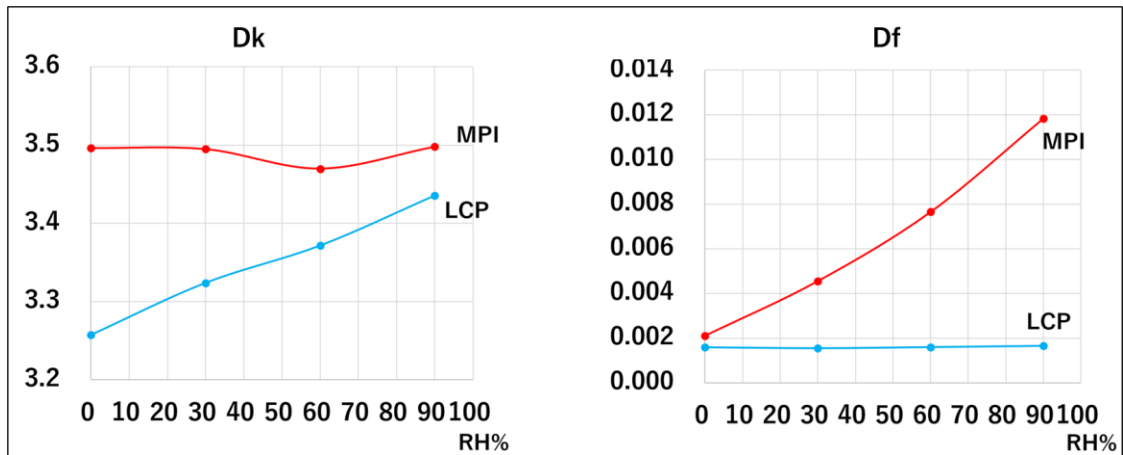
The split-cylinder resonator is widely used to evaluate dielectric properties of substrate and thin-film materials. Materials such as MPI and LCP, important in 5G transmission boards, high-speed servers, and automotive radar, exhibit characteristic environmental dependencies. MPI, known for high hygroscopicity, shows clear differences in dielectric loss between dry and humid states, while LCP exhibits strong temperature dependence with noticeable dielectric constant variation as temperature increases (see Fig. 3).

Humidity dependence is also significant, with pronounced dielectric variation observed under changing humidity at 25 °C (see Fig. 4).

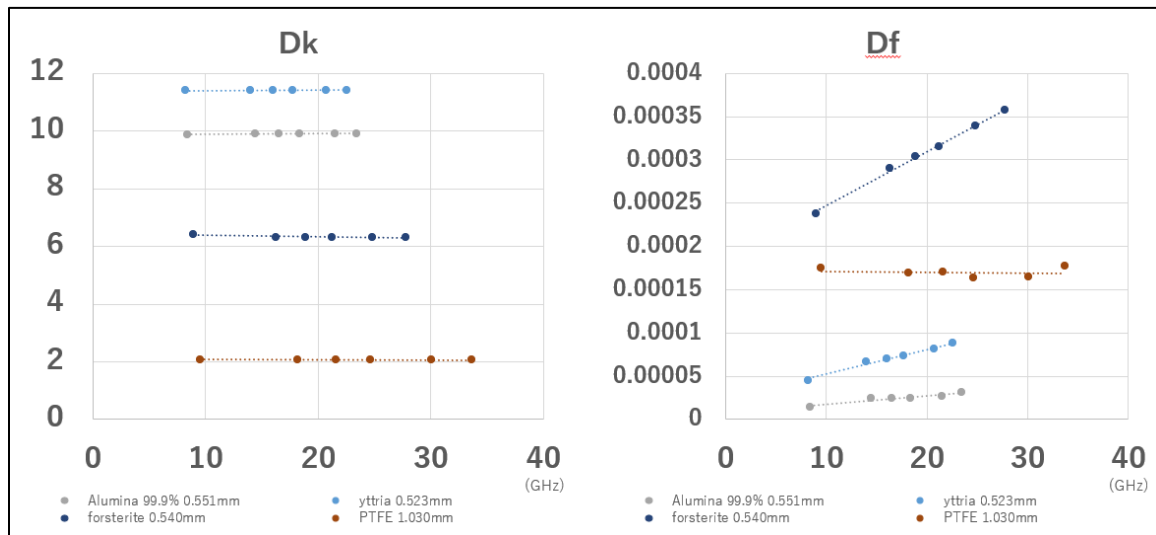
Even ultra-low-loss ceramics such as alumina, with dissipation factors on the order of 10^{-5} , can be measured with stability (see Fig. 5), making this method indispensable for millimeter-wave circuits and high-frequency filter designs.



【Fig. 3: Temperature dependence of dielectric properties (MPI, LCP films)】



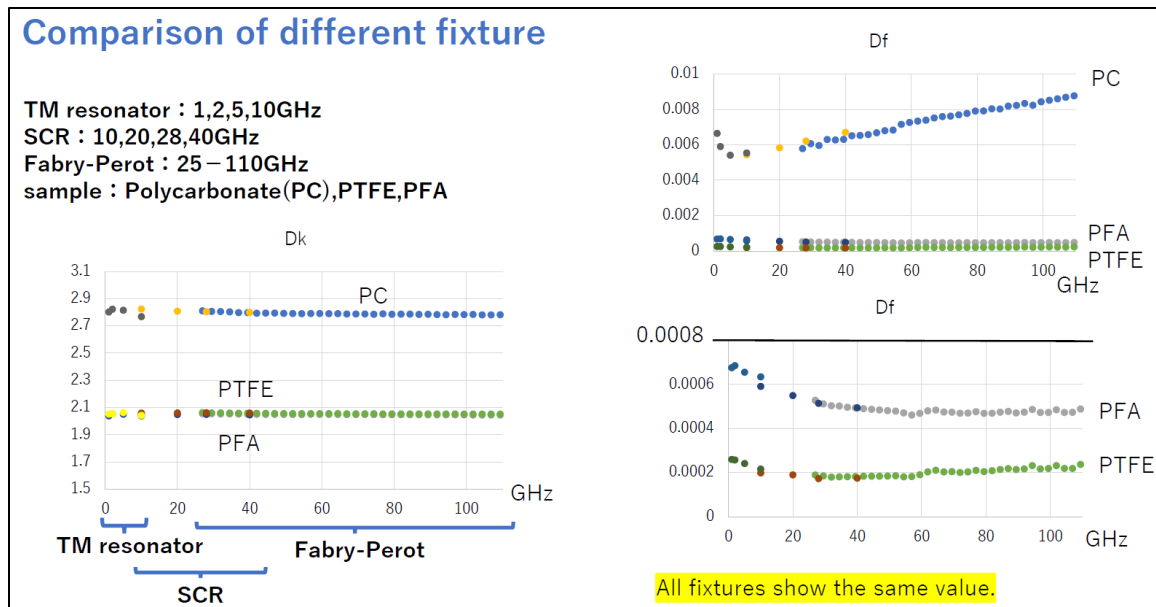
【Fig. 4: Humidity dependence at 25 °C】



【Fig. 5: Measurement examples of ultra-low-loss ceramics and PTFE】

4. Comparison with Other Methods

The split-cylinder covers 10–80 GHz. For low-loss material measurement, other complementary methods include cavity resonators (1–10 GHz) and Fabry-Perot resonators (25–330 GHz). Cross-validation across these methods ensures reliability of measurement results (Fig. 6).



【Fig. 6: Measurement comparison of polycarbonate, PTFE, and PFA using split-cylinder, cavity resonator, and Fabry-Perot resonator. Results show strong correlation.】

5. Key Points in Instrument Selection

Performance of split-cylinder resonators depends heavily on design and manufacturing accuracy, meaning even similar-looking instruments can yield very different results. When selecting equipment, the following criteria should be emphasized:

- Availability of reproducibility data
- Stable presentation of frequency characteristics
- Ability to measure ultra-low-loss materials ($\tan\delta < 0.0005$)
- Cross-correlation with other methods (Fabry-Perot, cavity resonator)
- Minimal variance when performing self-measurement

Failure to ensure these may lead to presenting incorrect measurement values to customers, undermining design reliability. Conversely, selecting an appropriate system secures long-term technical advantage.

Conclusion

The split-cylinder resonator by EM Labs is recognized as an international standard tool for dielectric measurement in the millimeter-wave band, serving as a true “compass” for materials evaluation. With its precision, speed, and ease of use, it enables anyone to obtain reliable data, contributing directly to the advancement of high-performance electronic devices.