A Precise and Inexpensive Dielectric Measurement Device

Przemyslaw Korpas[1], Wojciech Wojtasiak[1] and Jerzy Krupka[2]

[1] Institute of Radioelectronics, Warsaw University of Technology, Warsaw, Poland
[2] QWED Sp. z o.o., Warsaw, Poland

Abstract – Split post dielectric resonators (SPDR) are now commonly used for measurements of complex permittivity of many materials. The permittivity of the sample is calculated based on the change in the resonance curve of the loaded and unloaded SPDR. So far, the most precise measurements with such resonators have been performed employing Vector Network Analyzers. There is a large group of SPDR users who are not familiar with microwaves and do not need such robust equipment. QWED has developed an inexpensive, computer-controlled microwave oscillator system that enables quick and automatic measurements of complex permittivity with a dedicated resonator. It is based on the microwave phase locked loop (PLL)-stabilized oscillator intended for *Q*-factor and resonance frequency measurements. A multipoint resonance curve fitting algorithm allows accurate *Q*-factor determination.

Introduction

Over a decade ago, a method of precise complex permittivity measurements with a split post dielectric resonator was developed and reported in [1-3]. The method is based on the change in *Q*-factor and resonance frequency between the unloaded resonator and the resonator loaded with the sample. A typical approach to get parameters of the resonance curve is to use a Vector Network Analyzer – a precise piece of equipment, very common for microwave laboratories. Outside of these microwave laboratories, however there is a large group of SPDR users such as chemists, material scientists, and others who do not have easy access to a VNA. The high price of even a second hand analyzer might be still a significant cost in budget planning. QWED proposes a precise and inexpensive replacement of the VNA, optimized to determine the *Q*-factor and resonance frequency of the most popular SPDRs: 1.1, 1.9, 2.45 and 5 GHz.

The system is based on the PLL-stabilized microwave source with direct digital synthesizer (DDS) generated reference, controlled by a fast 32-bit ARM microcontroller. Power transmitted through the resonator is measured by a wideband logarithmic power detector, and a multipoint resonance curve fitting algorithm enables accurate *Q*-factor extraction. This handy, small sized device (comparable to a 2.5 inch portable hard drive) is connected to the PC computer with a USB cable and does not require any external power. Dedicated control application enables easy results management. The thickness of the sample being tested is the only external information required for the complex permittivity calculation. Use of the computer screen for presentation of results leads to great hardware simplicity, as well as significant cost reduction in beginning to measure the permittivity and losses of dielectrics using SPDRs. The accuracy of the system is better than 1% for permittivity and 2% for losses.

Concept of the System

The main guideline for the system design is as follows: the user should be capable of quickly measuring the *Q*-factor and resonance frequency of an SPDR without complicated calibration, obtaining results as easily and accurately as is possible with a Vector Network Analyzer. The

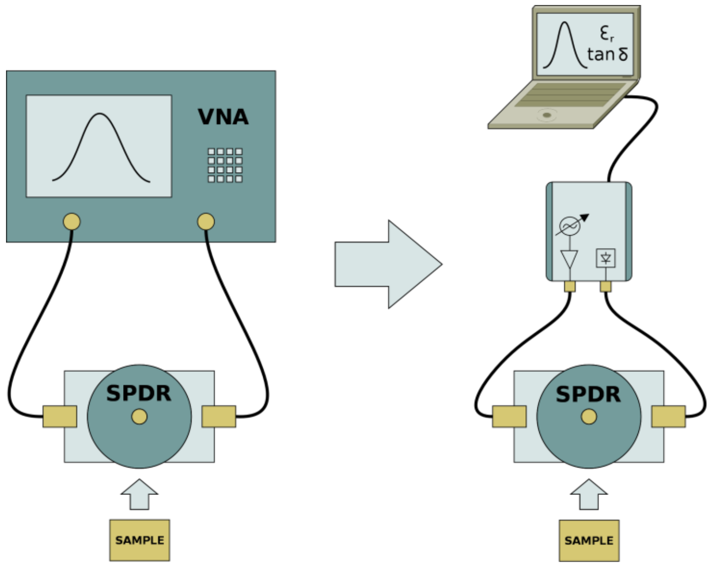

Fig. 1. Concept of the system

simplest method of obtaining the response of the resonator is to measure its transmission ($|S_{21}|$) at several frequency points in a manner similar to a VNA—at each step, one of the resonator's ports is being excited with a monochromatic signal of a known level, and the transmitted power is measured on the second one. Acquired data points presented on the graph are shaped like a Lorenz curve—a typical response of a resonant circuit. The *Q*-factor and resonance frequency are extracted with a curve fitting algorithm. The concept of the system realizing this idea is presented in Fig. 1.

Several simplifications in comparison to the typical VNA had to be made. An empty split post dielectric resonator with very weak coupling (called "unloaded") has a quality factor in the range of ten to twenty thousand, which results in a very narrow 3-dB bandwidth (about 100kHz). Whereas the curve fitting algorithm increases its accuracy with a growing number of considered data points, the transmittance in a 3-dB bandwidth should be measured at a reasonable number of points. On the other hand, a larger number of points slows down the resonator scanning process. To keep sweeping fast, and to keep the frequency step small enough (below 10 kHz), a PLL-stabilized microwave oscillator with a DDS-generated reference has been applied.

Due to the separation required between forward and reflected waves, which are below typical monolithic detector sensitivity, the output power level is not measured except during the initial factory calibration. During $|S_{21}|$ calculation, the output power level is obtained from interpolated calibration data saved previously in FLASH memory. This approach may lead to some errors in absolute transmission value, but should not affect the *Q*-factor value noticeably due to narrow bandwidth of the resonance.

Use of a phase and frequency insensitive detector is another great simplification. In place of complex superheterodyne receiver with narrow bandpass filters, a simple wideband logarithmic power detector from Analog Devices [4] has been used. This single chip allows measurement of power levels between -55 and -5 dBm resulting in a 50 dB dynamic range up to 8 GHz (with slight dependence on frequency). Because the maximum transmittance of the unloaded SPDR is $|S_{21}| \approx -40$ dB (at resonance frequency) and a margin for additional attenuation caused by a lossy sample is required, the range of measured transmittances has been defined

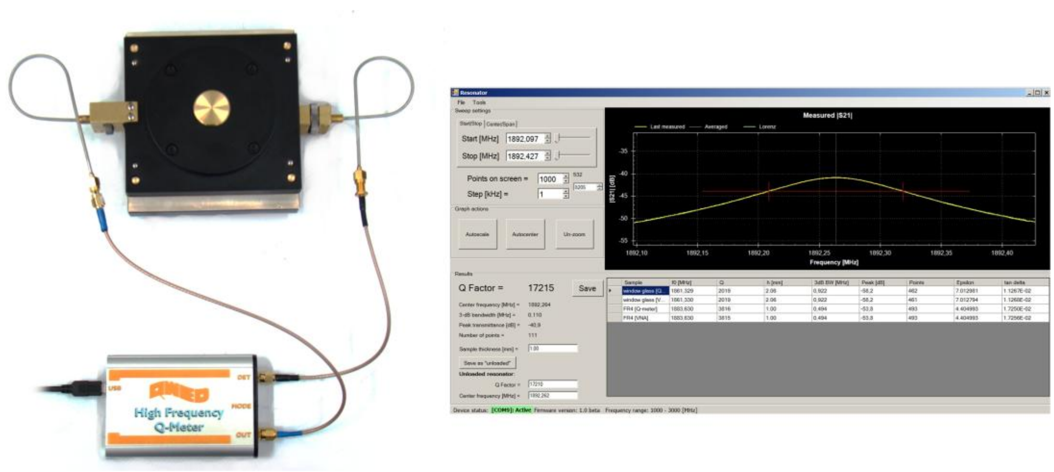

Fig. 2. System running with 1.8 GHz resonator.

between -60 and -20 dB. Due to the detector nonlinearities, a minimum device output power should be not less than 10 dBm.

Such a simple power detector, despite its advantages, has some drawbacks. Proper shielding is crucial due to the proximity of oscillator and amplifiers, which are located on the same printed circuit board—a crosstalk can occur easily as well as interference with external radio signals.

A different kind of problem is specific to the measured object. The response of the resonator consists of many modes that can be excited depending on the signal source frequency. One should keep in mind that typically the output signal of a voltage controlled oscillator (VCO) contains a relevant amount of harmonics (*i.e.*, -10 dBc for the second harmonic), which can excite higher modes in the resonator. Due to the wideband power detector use, the transmittance presented on the computer screen will be distorted in a specific manner: at each frequency, where any harmonics is high enough to go through the resonator, an additional "false" peak might be presented. The only solution is to decrease both: the amount of harmonics and the sensitivity of detector at higher frequencies.

Prototype and Results

The system presented in this paper enables the user to quickly measure the dielectric constant and losses of the sample inserted into the Split Post Dielectric Resonator in the same way as would be done with Vector Network Analyzer. The prototype system running with a 1.8 GHz resonator is presented in Fig. 2. Frequency selective methods of harmonics suppression such as lowpass filters and balanced structure of the output amplifier have been applied to solve problems with higher modes excitation. Output power of 15 dBm at 2.2 GHz with harmonics below -40 dBc have been reached.

Table 1 shows a comparison of the results obtained with the described system to results obtained using a Vector Network Analyzer. Some repeatable difference in resonance frequencies is caused by inaccuracy of the reference clock. This is not a problem as long as the reference is stable because, calculation of the *Q*-factor is based on relative f_0 change only. The overall system accuracy is about 1% for permittivity and 2% for losses. The result is stable in a few seconds after sample insertion, depending on the averaging ratio.

Table 1. Comparison of Results Performed with the System and VNA

Sample	Setup	h (mm)	f_0 (MHz)	Q	ε_r	$\tan\delta$
empty	Q-meter		1892.243	17198	1.000000	0.0000469
	VNA		1892.201	17299	1.000000	0.0000466
glass	Q-meter		1861.329	2019	7.012981	0.011267
	VNA		1861.259	2149	7.014913	0.010503
FR4	Q-meter		1883.630	3816	4.404993	0.017250
	VNA		1883.541	3988	4.416133	0.016279

Conclusion

This contribution describes an inexpensive PC-controlled system that allows easy SPDR-based material parameter measurement. This handy device seems to be a great replacement for a large and expensive Vector Network Analyzer for this kind of application. The optimized system reduces costs and has a performance similar to that of a VNA. Some observed imperfections are still the subject of further improvement.

References

[1] J. Krupka, Maj S., Application of the $TE_{01\delta}$ mode dielectric resonator for the complex permittivity measurements of semiconductors, *Proc. CPEM '86*, pp. 154-155, 1986.
[2] J. Krupka, K. Derzakowski, M.E. Tobar, J. Hartnett, and R.G. Geyer, Complex permittivity of some ultralow loss dielectric crystals at cryogenic temperatures, *Measurement Science and Technology*, vol. 10, pp. 387-392, Oct. 1999.
[3] J. Krupka, A.P. Gregory, O.C. Richard, R.N. Clarke, B. Riddle and J. Baker-Jarvis, Uncertainty of Complex Permittivity Measurements by Split-Post Dielectric Resonator Technique, *J. European Ceramic Society*, vol. 21, pp. 2673-2676, 2001.
[4] Analog Devices, www.analog.com.