Microwave Substrate Dielectric Constant Estimation Using Dielectric Resonator Oscillator

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***Abstract* - This paper presents a simple method for determining relative dielectric constant of microwave PCB substrates without involving relatively expensive equipment. Microstrip oscillator with elongated feedback arms is etched on a substrate being measured. Dielectric resonator is moved and aligned along feedback arms in different positions. Each position which result in build up of oscillation is marked on PCB surface. Distance between marks is then measured and used to calculate relative dielectric constant.**

I. Introduction

Relative dielectric constant **Er** and substrate thickness **H** are important values required for designing of microstrip structures. Dielectric constant value usually provided by substrate manufacturer. For generic FR4 substrates this value is unknown. Engineers often use filter response measurement method [1, 2] to estimate unknown **Er** value for particular frequency. Such measurement require use of vector network analyzer (VNA) and designing of test filter structure. Filter response is strongly dependent on resonating element dimensions. Dimensions are obtained using mathematical modeling and by observation of simulation results. But it is well known that simulation results and experiment results may have significant differences. Altogether traditional approach tends to be error prone or impossible to implement by inexperienced microwave engineer.

In this paper, alternative method for estimation of dielectric constant is described. This method does not require expensive measurement equipment and sophisticated mathematical modeling. Example measurement of generic FR4 material at center frequency **F=10.288 GHz** is provided to confirm validity of proposed method.

II. Dielectric Constant Estimation

A. Microstrip oscillator structure

To measure wavelength in dielectric simple parallel feedback oscillator structure with elongated feedback arms is used. Basic structure configuration is shown on Fig.1. Any active device with sufficient gain at center frequency of dielectric resonator DR may be used. Active device connected to elongated microstrip lines ML1 and ML2. In case of using conditionally stable active amplifier ML1 may be terminated with 50 Ohm resistor to prevent unwanted oscillations. Output from ML2 is connected to microwave mixer or frequency meter (prescaler). Dielectric resonator DR is freely positioned between microstrip lines ML1 and ML2.

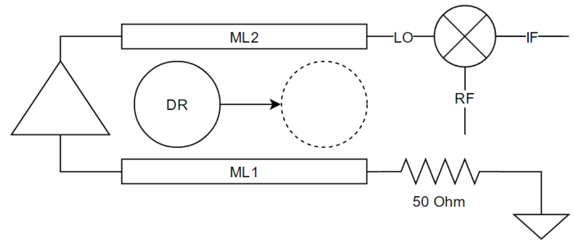

Fig.1 Microstrip oscillator structure

B. Measurement procedure

By moving DR along feedback lines we repeatedly find points where both phase and amplitude balance conditions are satisfied (Barkhausen criterion). Such points are marked on PCB surface with permanent marker. Because signal travels through both arms ML1 and ML2, 360° phase delay obtained every λ/2 (180°) of wavelength in dielectric (Fig. 4).

Oscillation buildup could be detected using simple microwave mixer. RF port of mixer is not necessary to be connected to any source of signal. IF port may be connected to earphones through operational amplifier circuit. Working oscillator is easily distinguished by presence of strong audible noise amplified from IF output signal. More precise results may be obtained if ML2 output is connected to microwave frequency counter (or prescaler circuit to reduce costs).

C. Passive FET mixer as microwave signal detector

Usually discrete microwave mixers are made of Schottky diodes. Simplest configuration possible is single ended diode mixer. Alternatively, passive FET mixer [3] could be used, allowing use of same active device for mixer and oscillator.

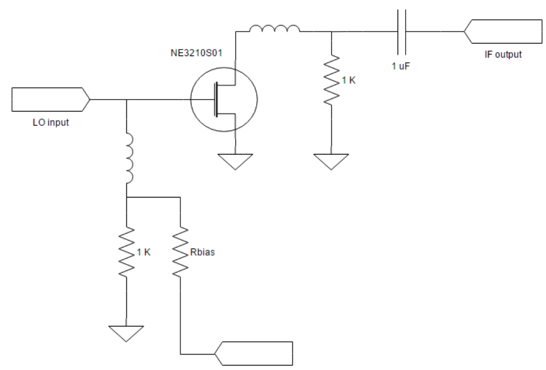

Fig.2 Passive FET mixer (without RF input)

III. Experimental Results

Experimental prototype was build on a generic FR4 substrate with thickness **H=1.0mm**. Dielectric resonator center frequency is **F=10.525 GHz**. Oscillator prototype is shown on Fig.3.

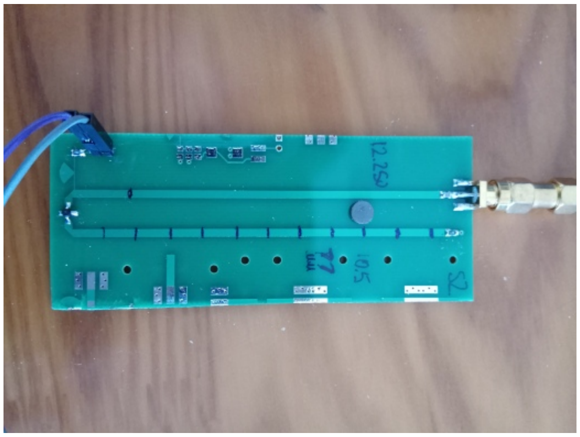

Fig.3 Microstrip oscillator prototype

Total of 11 dielectric resonator positions was found. Those positions are marked across lower microstrip line (Fig. 4) and divide it into 10 segments. Distance between first and last mark is approximately 77mm. Approximate half wavelength value is calculated to be $\lambda/2$ = 7.7 mm.

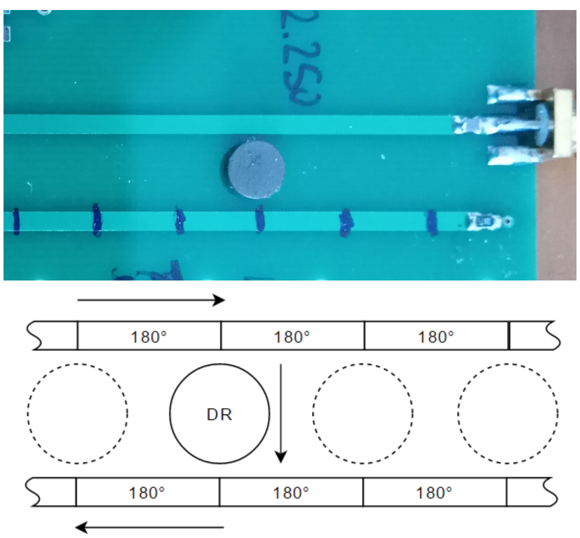

Fig.4 Dielectric resonator positioned at oscillation buildup point

TABLE 1. SUMMARY OF EXPERIMENTAL SETUP

DR center frequency	F_1 = 10.525 GHz (datasheet)
DRO measured frequency	F_2 = 10.288 GHz (measured)
Estimated Er values	Er_1 = 4.1 , Er_2 = 4.5
Substrate thickness	H_{SUB} = 1.0mm
Microstrip line widths	W = 1.8 mm
Active device	NE3210S01
Active device biasing (Vgs=0)	R_d=39 Ohm, V_{dd}=5V
Prescaler	HMC363 (divide by 8)
Frequency counter	Generic model up to 2.7 GHz

Active device used is NE3210S01 FET transistor. This device is conditionally stable over wide frequency range if properly grounded and terminated with 50 Ohm load at input and output in common-source configuration.

Dielectric constant estimated for dielectric resonator center frequency F_1 = 10.525 GHz and wavelength λ=15.4mm is Er_1 = 4.1.

To obtain more precise value prescaler circuity incorporating divide-by-8 HMC363 integrated circuit was used (Fig. 5). Measured frequency of oscillation is F_2 = 1.286*8 =10.288 [GHz]. Updated dielectric constant estimated value is Er_2=4.5.

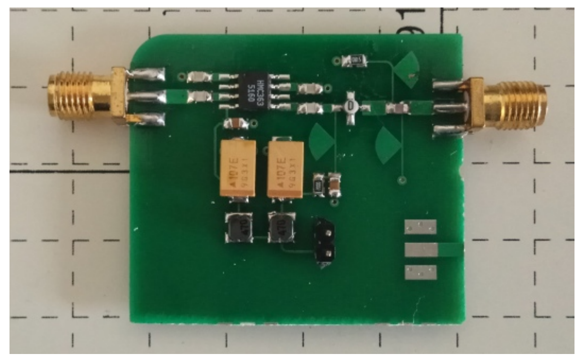

Fig.5 Frequency prescaler

IV. Conclusion

Presented method of dielectric constant measurement provides repeatable results and acceptable performance. Increasing number of half-wavelength segments may improve precision of wavelength measurement but require use of active device with higher gain. Main value of this method is that it allows instantly obtain phase information at certain frequency, requiring only two FET transistors. This method may be useful for DRO design, series fed patch antenna array design and other applications. Further studies may be performed to improve and investigate this method.

References

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