C. Experimental Examples

1. Measurement of Standing Wave

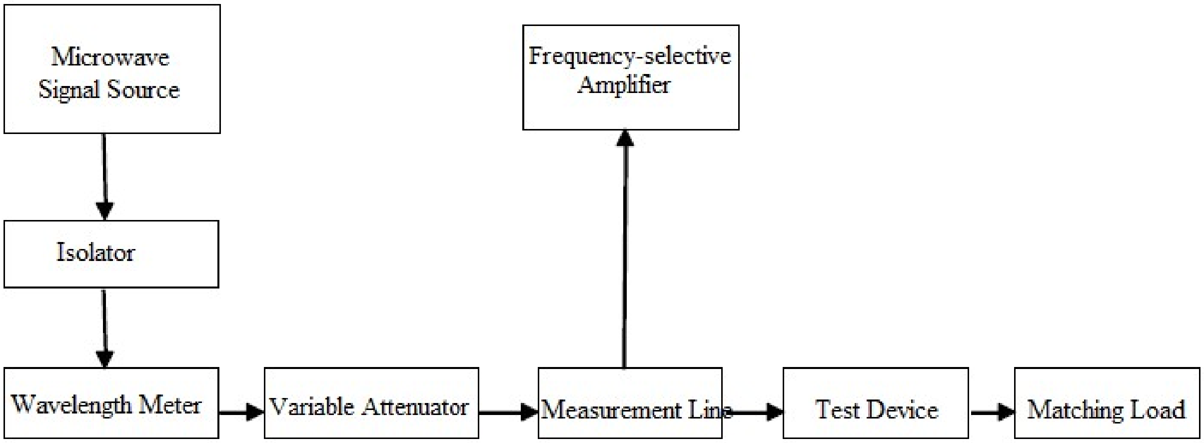

Figure 1 Block diagram of standing wave measurement

1) Set up measurement system per Figure 1.
2) Set the microwave signal source at square-wave modulation mode.
3) Move the probe along the waveguide measurement line until the frequency-selective amplifier gives a certain readout value.
4) Measure intensities I_{min} and I_{max} at adjacent valley and peak of the microwave field in the waveguide measurement line, respectively, using the frequency-selective amplifier.

Since the crystal detector is a square-law detecting device, the standing wave ratio S is given as: $S = \sqrt{I_{\max} / I_{\min}}$.

The intensity distribution of the standing wave field is shown in Figure 2:

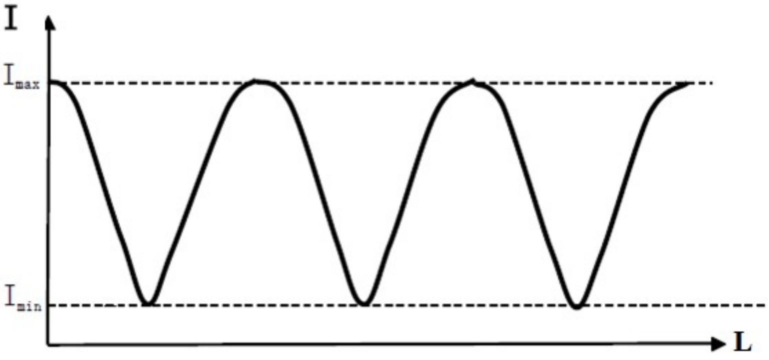

Figure 2 Standing-wave distribution in waveguide

2. Measurement of Large Standing Wave Ratio (optional precise attenuator is needed)

When the standing wave ratio is very large, the level difference between the peak and the valley of a standing wave field is also large. As a result, it is difficult to read out the two levels simultaneously with high accuracy. Moreover, the detecting property of a crystal detector may be also different at two levels of large difference. Therefore, the standing wave ratio cannot be acquired by simply taking the ratio of the two levels. Instead, the power attenuation method should be used as follows:

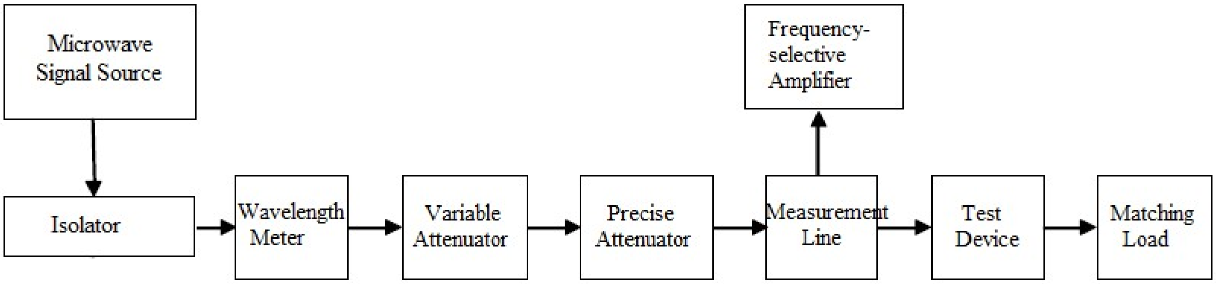

Figure 3 Block diagram of power attenuation method

1) Set up measurement system per Figure 3 and set the precision attenuator at “zero”.
2) Move the probe along the measurement line to a valley location of the standing wave while adjusting the precision variable attenuator until 80% full scale is achieved on the indication meter, and write down the value.
3) Move the probe along the measurement line to a peak location of the standing wave while increasing attenuation amount of the precision attenuator until the same reading is observed on the indication meter. Read the scale of the precision attenuator and transfer the value to A in unit decibel (dB). The measured standing wave ratio is $S = 10^{A/20}$.

3. Measurement of Microwave Frequency

1) Set up measurement system per Figure 1.
2) Connect the detector with meter to the device under test.
3) Measure the frequency of the microwave signal source with the microwave wavelength meter. Turn the micrometer of the wavelength meter while monitoring the reading from the detector indicator until a minimum reading is observed as shown in Figure 4. Now, the wavelength meter is on resonance with the microwave frequency of the microwave source, resulting in an absorption peak as shown in Figure 4. Record the reading on the micrometer of the wavelength meter, and then convert the reading to the corresponding frequency value from the calibration curve.

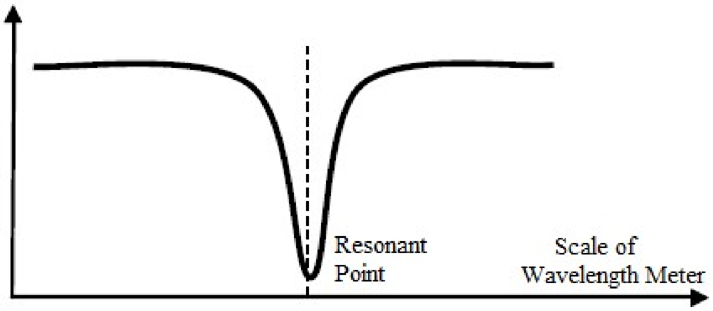

Figure 4 Resonance curve

4. Measurement of Waveguide Wavelength

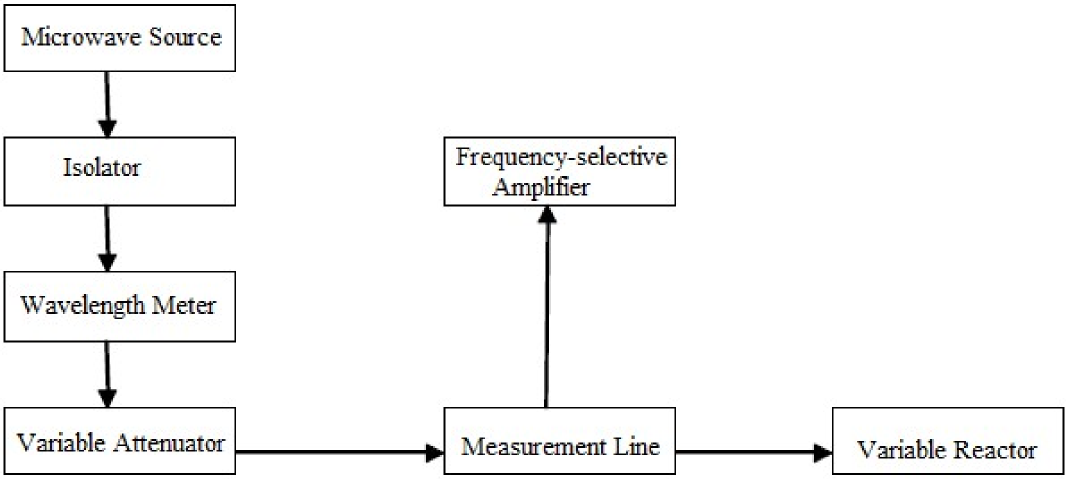

Figure 5 Block diagram of waveguide wavelength measurement

1) Set up measurement system per Figure 5. Since the reflection coefficient of the varactor is close to 1, the superposition of the reflected and incident waves in a measurement line results in an approximately pure standing wave, as shown in Figure 6. If adjacent node positions L_1 and L_2 of the standing wave are measured, the waveguide wavelength λ_g can be calculated as follows

$$\frac{1}{2}\lambda_g = L_2 - L_1$$

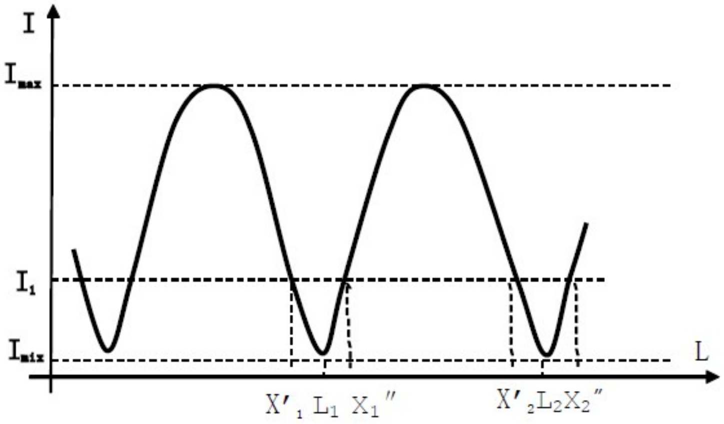

Figure 6 Distribution of microwave field along measurement line

2) To enhance the measurement accuracy of a node location, equal-amplitude method can be used to locate two positions X_1' and X_1'' at amplitude I_1 near a node (I_1 is slightly larger than I_{min}) as shown in Figure 6. Then, the corresponding node location can be determined as

$$L_1 = \frac{X_1' + X_1''}{2}$$

Similarly, $L_2 = \frac{X_2^{'} + X_2^{''}}{2}$. Thus, λ_g can be derived with higher accuracy.

5. Measurement of Microwave Power

Warning: before turning on power, ensure all electric units in Figure 7 are properly grounded, as otherwise the probe of the power meter could be damaged.

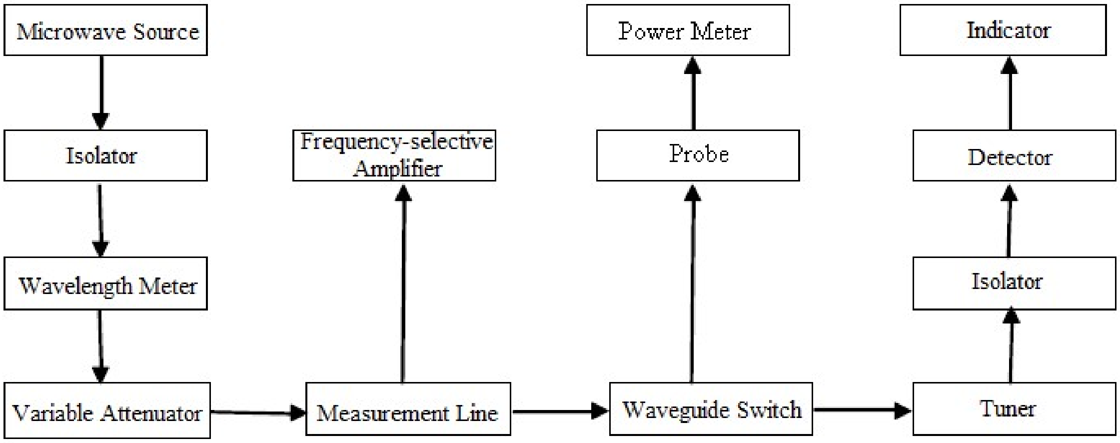

Figure 7 Block diagram of microwave power measurement

1) Measurement of relative power

Turn the waveguide switch to the path of detector. Since the crystal detector is a square-law detecting device, its reading value *I* on the indicator is proportional to the microwave power *P*, i.e. it represents a relative power.

2) Measurement of absolute power

Turn the waveguide switch to the path of power meter. Use the power meter to measure the absolute power.

6. Measurement of Microwave Attenuation (optional precise attenuator is needed)

Definition of attenuation: $A = 10\log(P_1 / P_2)$ in unit of dB, where P_1 and P_2 are the input and output power values of a device under test at matching state.

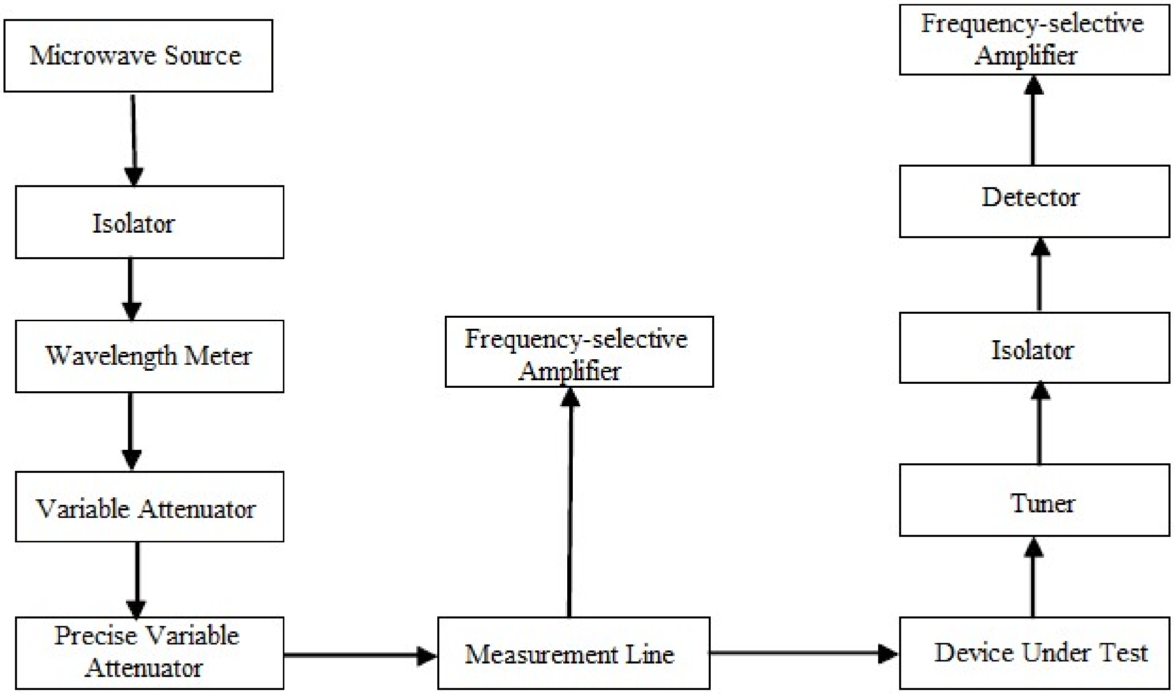

Figure 8 Block diagram of microwave attenuation measurement

1) Direct measurement

   Set up measurement system per Figure 8 and optimize the microwave signal source.

   Before introducing the device under test, adjust the tuner to achieve a matching state between measurement line and detector; then read current reading I_1 from the detector.

   After connecting the device under test, read current reading I_2 from the detector. Since the crystal detector is a square-law detecting device, we have $A = 10\log(I_1 / I_2)$.

2) High-frequency substitution measurement

   Before introducing the device under test, adjust the precision variable attenuator to A_1 with a corresponding reading I from the detector. After introducing the device under test, adjust the precision variable attenuator to A_2 so that the same reading I is restored from the detector. Thus, the attenuation of the device under test can be calculated as $A=A_2-A_1$. This method is more accurate than the direct measurement method, with the measurement accuracy determined by the accuracy of the precision variable attenuator.

   Note: the device under test should match the measurement system.

7. Measurement of ε and tan(δ) of Media

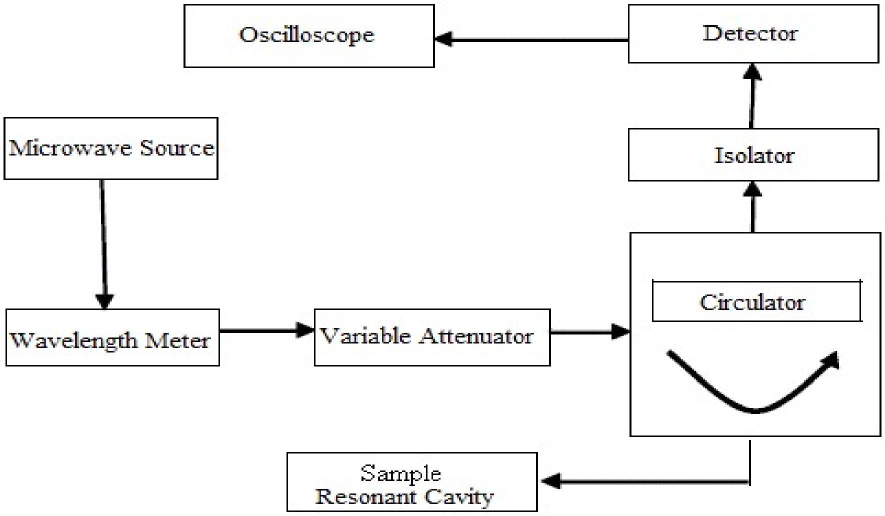

Figure 9 Block diagram of ε and tan(δ) measurements of media

1) Set up measurement system per Figure 9 and set the microwave signal source at sweep mode.
2) Before introducing the sample under test in the resonant cavity, measure the resonance frequency of the sample resonant cavity by varying the sweep range of the signal source while observing the resonance curve of the resonant cavity on an oscilloscope as seen in Figure 10. Then measure the resonance frequency (f_0) of the resonant cavity with the wavelength meter.

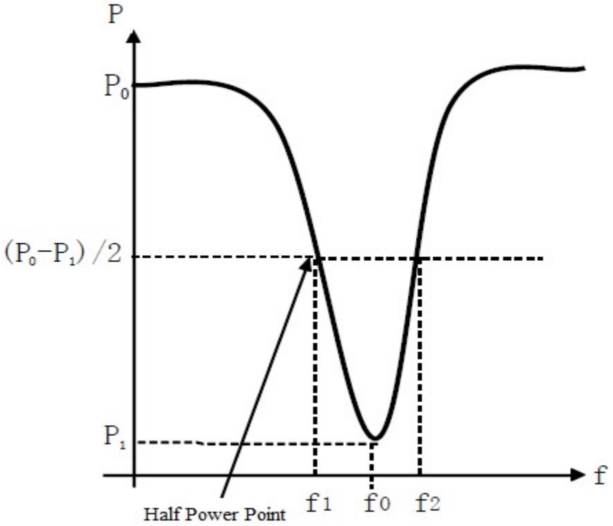

Figure 10 Resonance curve of sample resonant cavity

Use the curve dip on the oscilloscope as the reference point to determine the frequency coefficient K of the horizontal axis of the oscilloscope (i.e. the frequency range of a unit length, represented by MHz/Grid).

First, change the resonance frequency of the resonant cavity while monitoring the shift of the resonance peak on the oscilloscope as ΔL. Next, determine the corresponding frequency change Δf from the wavelength meter. Thus, the frequency coefficient of the oscilloscope is $K=\Delta f/\Delta L$. Normally, K=0.4 MHz/Grid. The half power frequency width of the resonant curve $|f_1 - f_2|$ can be calculated by using K and the half-power points distance $|L_1 - L_2|$.

3) After inserting the sample in the resonant cavity, change the center frequency of the signal source to make the resonant cavity on resonance. Then use the above method to measure the resonance frequency f_s and the half-power frequency width $|f_1' - f_2'|$.

4) Use the following formulas to calculate the quality factor of the resonant cavity with or without sample

$$Q_L = f_0 \big/ |f_1 - f_2|$$

$$Q_L' = f_s \big/ |f'_1 - f'_2|$$

where Q_L and Q'_L are the quality factors of the resonant cavity with and without sample, respectively.

Use the following formulas to calculate the real and imaginary parts of the permittivity of the sample, as well as the tangent value of the loss angle

$$\frac{f_s - f_0}{f_0} = -2(\varepsilon' - 1)\frac{V_s}{V_0}$$

$$\frac{1}{2}\Delta\left(\frac{1}{Q}\right) = 2\varepsilon''\frac{V_s}{V_0}$$

$$\varepsilon = \varepsilon' - j\varepsilon''$$

$$\tan(\delta) = \frac{\varepsilon''}{\varepsilon'}$$

where ε' and ε'' are the real and imaginary parts of the permittivity (ε) of the dielectric sample, respectively; f_s and f_0 are the resonance frequencies of the resonant cavity with and without sample, respectively; and V_0 and V_s are the volumes of the cavity and the sample, respectively.

Note: a frequency sweep signal source is needed to acquire the resonance curve of the sample cavity. If a frequency sweep signal source is not available, the frequency of the signal source will need to be scanned point by point with constant power output.