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MICROWAVE REFLECTOMETER WITH A SINGLE DIRECTIONAL COUPLER

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Abstract. The waveguide setup and the circuit diagram of a microwave reflectometer consisting of one directional coupler and a resonance waveguide slit PIN diaphragm are presented. The operation of the reflectometer is analyzed. Methods for tuning, calibration and accuracy verification are given. The output readings of the reflectometer are independent of parameter instabilities arising in the units.

1. Introduction

The problems related to the exact determination of the reflection coefficient of different microwave components and natural objects have been thoroughly discussed in scientific literature [1–5]. The engineering circuit solutions usually involve reflectometers with two directional couplers — for the incident and for the reflected wave and square law detectors together with an output ratio meter. In some cases where a simpler and a less expensive solution of the reflectometer setup is required, only one directional coupler — for the reflected wave, is used. Special care is taken however to stabilize the microwave generator [3].

A microwave reflectometer with a single directional coupler and a PIN diaphragm is proposed in this paper. The circuit is described, analysis of the operation is made and tuning and calibration methods are given.

2. Reflectometer Circuit and Operation

The block-diagram of the microwave reflectometer is given in Fig. 1. The microwave part consists of a microwave oscillator MWO, an isolator IS and a directional coupler DC for the reflected wave connected in series. A slit diaphragm PIN1 and a square law detector D1 are connected to the auxiliary arm of the directional coupler. A second slit diaphragm PIN2, an impedance transformer IT and the measured microwave load MWL are connected to the output of the directional coupler. The

PIN1 diaphragm is used for amplitude modulation of the signal ($f = 1000$ Hz) and is controlled by the pulse generator PG. The frequency of PG is divided by 32 using a pulse counter PC. The PC output is connected to the PIN2 diaphragm and to the analog switch control ASC. The low-frequency measurement circuit of the reflectometer includes a selective amplifier SA1, a logarithmic transducer LT1, an analog switch AS, a differential amplifier DA1 and a return loss indicator RLI connected in series.

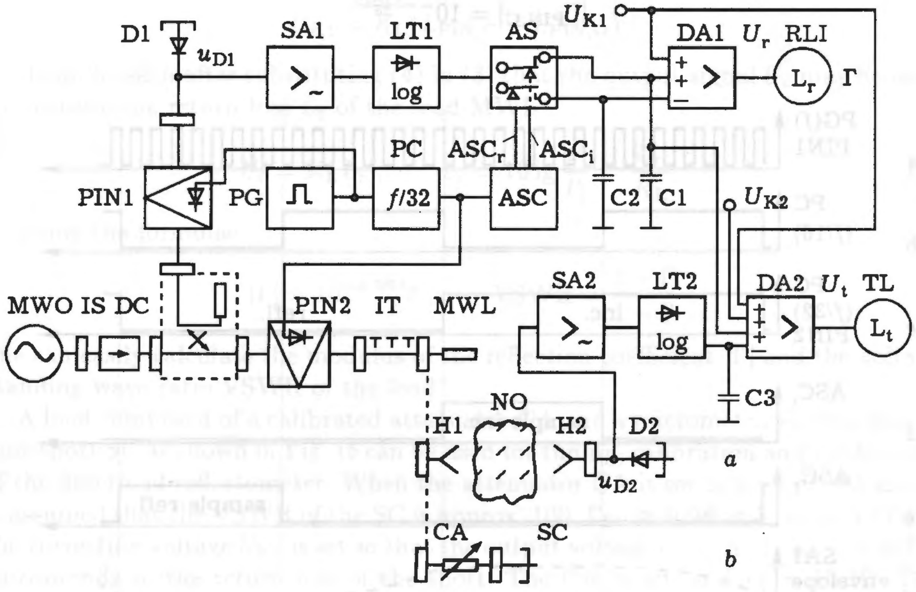

Fig. 1. **Block-diagram of the microwave reflectometer (*a*) circuit for studying the transmissivity of natural objects; (*b*) the load used for tuning and calibration**

Time diagrams of the signals in characteristic points, given in Fig. 2, are used in the analysis of the reflectometer.

An original feature of the proposed scheme is the even and sequential change in the mode of operation of the PIN2 diaphragm (Fig. 2*c*). For zero current ($t = 16\ldots32$ ms) the slit PIN diaphragm is in "open" mode of operation with a low insertion loss $L_{PIN,O}$. In this case the output voltage $U_{D,O}$ after the square law detector D1 is proportional to the reflected power P_r of the load MWL

$$U_{D,O} = K_{WG} K_D P_r 10^{-0.1(C_{DC}+L_{PIN,O})} \qquad (1)$$

where K_{WG} is the waveguide constant, K_D is the transmission coefficient of the detector and C_{DC} is the coupling coefficient of the directional coupler, dB.

In the other mode of operation ($t = 0\ldots16$ ms) current flows through the PIN diode, the slit diaphragm is shortcircuited and the major part of the incident power P_i is reflected. The output voltage $U_{D,C}$ is proportional to P_i in accordance with the relationship

$$U_{D,C} = K_{WG} K_D P_i 10^{-0.1(C_{DC}+L_{PIN,C})} \tag{2}$$

where $L_{PIN,C} = 10 \lg \frac{P_i}{P_{r,PIN,C}}$ is the return loss of the PIN2 diaphragm in the closed state mode "c" and can be expressed with its reflection coefficient

$$|\Gamma_{PIN,C}| = 10^{-\frac{L_{PIN,C}}{20}}$$

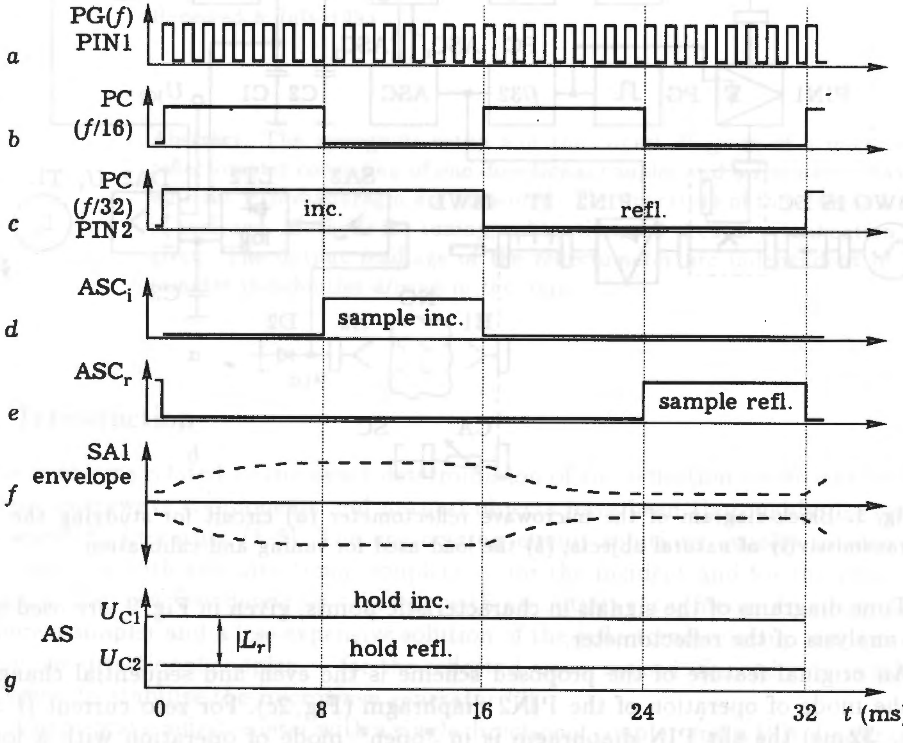

Fig. 2. Time diagrams of selected signals

The signal U_D is amplified by the 1000 Hz selective amplifier SA1. The stationary values (refer to Fig. 2*f*, the envelope) are set after all transients have died out. In the stationary state (t = 8...16 ms and t = 24...32 ms) the amplified signals are processed by the log transducer LT1 using the analog switch control ASC (Fig. 2*d*) and ASC (Fig. 2*e*), respectively The combination of an analog switch AS, its control ASC and the capacitors C_1, C_2 thus functions as a sample-and-hold combination (refer to Fig. 2*g*). The voltages U_{C1} and U_{C2} of the "hold" capacitors are compared in the differential amplifier DA1. The output voltage U_r is proportional to the logarithm of the ratio of the power values applied to the detector D1 in the two operating modes. Using (1) and (2), the voltage U_r can be written as

$$U_r = K_L 10\lg\frac{U_{D,C}}{U_{D,O}} + U_{K1} = K_L\left[10\lg\frac{P_i}{P_r} - L_{PIN,C} + L_{PIN,O}\right] + U_{K1} \quad (3)$$

where $K_L = 0.1$ V/dB is the transfer coefficient of the log ratio meter. The correction voltage U_{K1} in expression (3) can be set to compensate the insertion loss $L_{PIN,O}$ and the return loss $L_{PIN,C}$ of the slit diaphragm PIN2

$$U_{K1} = K_L(L_{PIN,C} - L_{PIN,O})\,. \quad (4)$$

It can be seen after substituting (4) in (3) that the output signal U_r may be used to measure the return loss L_r of the load MWL

$$U_r = K_L L_r\,; \qquad L_r = 10\lg\frac{P_i}{P_r} = \frac{U_r}{K_L}\,. \quad (5)$$

Using the formulae

$$|\Gamma| = 10^{-0.05L_r}\,, \qquad \mathrm{VSWR} = \frac{1+\Gamma}{1-\Gamma}$$

one can easily calculate the modulus of the reflection coefficient $|\Gamma|$ and the voltage standing wave ratio VSWR of the load.

A load composed of a calibrated attenuator CA and a micrometric sliding waveguide short SC as shown in Fig. 1*b* can be used for tuning, calibration and verification of the described reflectometer. When the attenuator CA is set to zero (0 dB) and it is assumed that the VSWR of the SC is approx. 100, $\Gamma_{SC} \approx 0.98$ or $L_{r,SC} \approx 0.17$ dB, the correction voltage U_{K1} is set so that the output voltage $U_r = K_L L_{r,SC} = 0.017$ V corresponds to the return loss of the short. The CA is set to $L_{CA} = 15$ dB. The impedance transformer IT is tuned to reach the output value $U_r = K_L 2L_{CA} \approx 3$ V which corresponds to the double attenuation of CA. Thus the impedance transformer corrects part of the errors due to the finite directivity of DC.

3. Experimental Results and Development of the Methodology

An experimental prototype was designed and developed for studying and verification of the presented measurement principle. It is composed of a Gunn generator (9.5 GHz), a directional coupler with $C_{DC} = 20$ dB and directivity greater than 40 dB, a slit diaphragm 2A506A with $L_{PIN,C} = 1.9$ dB for $I = 7$ mA and $L_{PIN,C} = 1.7$ dB for $I = 12$ mA in closed mode and $L_{PIN,O} = 0.5$ dB for $I = 0$ mA in open mode. The amplitude modulation of the signal in the DC auxiliary arm was realized using a second diaphragm of the same type. The log transducer LT1 has 30 dB dynamic range, which corresponds to a change in U_r from 0 to +3 V. Following the tuning procedure given above a correction voltage $U_{K1} = 0.13$ V was obtained. Correspondence between the measured value in accordance with (5) and the set value $U_r = K_L 2L_{CA}$ was established with a relative error smaller than 3%.

Taking into account that the signals for the incident and for the reflected wave are processed by the same units (DC, PIN1, D1, SA1, LT1), which are parts of the log ratio meter any parameter instability in these units as well as in the microwave generator MWO will therefore have no influence on the final result.

The proposed microwave reflectometer offers an additional possibility for studying the reflection as well as the transmission characteristics of real natural objects NO (Fig. 1*a*), placed between a transmission horn H1 which has replaced the load MWL and a receiving horn H2 with a square-law detector D2 for the transmitted wave. The signal at the D2 output

$$U_{D2} = K_{WG} K_D P_1 10^{-0.1(L_{PIN,O}+L_H+L_t)} \tag{6}$$

is processed by a selective amplifier SA2 for the reduced frequency $f/32$, by a log transducer LT2 and is stored in the capacitor C3. In the expression (6) L_H is the attenuation of the antenna system without a sample and L_t is the attenuation introduced by the object itself. A differential amplifier DA2 makes possible the comparison of the voltages U_{C1} and U_{C3}. The output voltage U_t of the DA2 can be written as

$$U_t = K_L\left[10\lg(K_r U_{D1}) - 10\lg(K_t U_{D2})\right] + U_{K1} + U_{K2} = K_L L_t\,. \tag{7}$$

The requirement for equality of the transfer coefficients of the low-frequency channels for the reflected and the transmitted power $K_r = K_t$ is satisfied. The offset voltage U_{K1} assumes a value corresponding to (4) and the correction voltage $U_{K2} = K_L(C_{DC} - L_H)$ is adjusted to reach $U_t = 0\,\mathrm{V}$ when there is no object NO between the horns. After completing the tuning procedure described above a linear relationship between the output voltage U_t and the attenuation L_t of the microwave energy transmitted through the object is obtained.

4. Conclusion

A microwave reflectometer with one directional coupler has been designed and developed using standard slit PIN diaphragms. The operation of the unit has been analyzed. Formulae for the output signals and for the correction voltages have been obtained. The application of a log ratio meter makes the measurement of the reflection and the transmission characteristics independent of the parameter instabilities in the units of the setup without preliminary stabilization of the microwave power.

References

1. M. Sucher, J. Fox. *Handbook of Microwave Measurements.* (Polytechnic Press, New York 1963).
2. B. O. Weinschel. *Microwave Journal* 12 (1969) 69.
3. Н. К. Бондаренко и др. *Автоматизация измерений параметров СВЧ* (Сов. Радио, М. 1969).
4. G. F. Engen. *The Six Port Reflectometer: An Alternative Network Analyser.* IEEE Trans. MTT 25 (1977) 1070.
5. Б. И. Вичев. *Научные приборы* 26 (1982) 33.