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Schemes for recording nanosecond high-power microwave pulses by detectors on hot carriers

*A.I. Klimov**

Institute of High Current Electronics SB RAS, Tomsk, Russia
**klimov.1955@inbox.ru*

Abstract. The paper considers two schemes for detecting nanosecond high-power microwave pulses by detectors on hot carriers, with the source of the bias voltage pulse located near the detector and at a distance. The corresponding detector calibration schemes are analyzed.
Key words: hot carrier detector, scheme of measurement, scheme of calibration.

1. Schemes of measurements and schemes of calibration

To detect high-power microwave pulses [1] with a duration from a few to tens of nanoseconds, detectors [2–4] are used based on the effect of a decrease in the mobility of carriers in a semiconductor upon absorption of microwave energy. The detectors use *p*-type Ge or *n*-type Si crystals. Examples of two circuits that can be used in measurements are shown in Figs.1 and 2. In all the circuits below, the active resistance of the conductors is assumed to be negligible for simplicity.

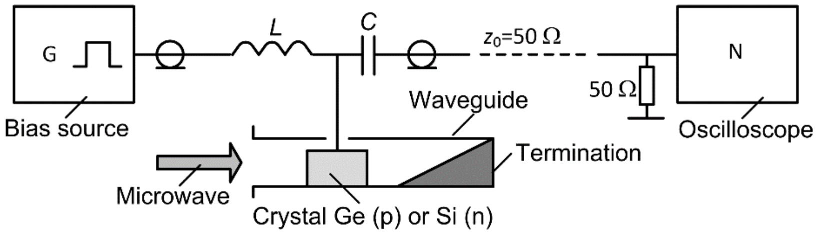

Fig1. Scheme of measurement with a bias source next to the detector.

The design of the detector includes a section of a standard rectangular waveguide with an absorbing load at the end (termination). Inside the waveguide the semiconductor crystal is fixed on a wide wall. In the both schemes, a bias voltage pulse with an amplitude U_0 and a duration significantly exceeding the duration of the microwave pulse is supplied to the crystal from a pulse generator through the inductance L. This voltage sets the steady current I_0 in the crystal and the crystal initial resistance R_0: $U_0 = I_0R_0$. When a microwave appears in the waveguide, a time-dependent increase in the crystal resistance $R(t)$ occurs, which is determined by the microwave power $P(t)$.

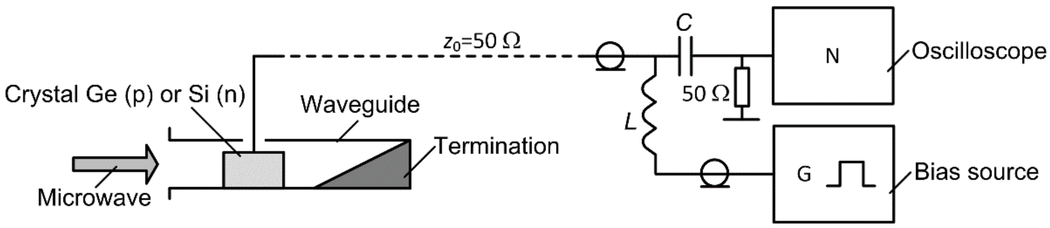

Fig.2. Scheme of measurement with a bias source remote from the detector.

Under the condition $L/R >> \tau$, where τ is the duration of the microwave pulse, and R_{max} is the maximum resistance of the crystal, the current through the crystal during the microwave pulse remains constant and equal to the initial value I_0.

The output signal of the detector is determined by the registration circuit and depends on the voltage increase on the crystal:

$$\Delta U\left(t\right)=\frac{R\left(t\right)-R_0}{R_0}U_0. \tag{1}$$

It is this signal that is observed in the circuit shown in Fig.1 when the bias source is near the detector. The bias signal U_0 at the cable input is suppressed by capacitance C. The useful signal $\Delta U(t)$ is filtered by this capacitance and, according to the experimental conditions, is transmitted over a cable, usually several tens of meters long, which exceeds the signal length in the cable, to a remote oscilloscope for recording. The characteristic impedance of the cable is equal to the input impedance of the oscilloscope, the matching mode is performed and there is no wave reflected from the input of the oscilloscope. This scheme also corresponds to the detector calibration scheme. The only difference is that the microwave pulse in the calibration procedure is supplied from a special magnetron oscillator [3], the pulse duration is much longer and amounts to hundreds of nanoseconds, and the oscilloscope is located next to the detector being calibrated. A long cable is not needed.

In the scheme presented in Fig.2, the bias source is a cable length away from the detector, near the oscilloscope. The measurement conditions are different from the calibration conditions. The bias voltage is applied across the crystal through the long cable.

In the steady state, it can be assumed that the voltage U_0 on the crystal is equal to the sum of the voltage U_{0in} of the incident wave and the voltage U_{0ref} of the reflected wave:

$$U_0=U_{0in}+U_{0ref}$$

where U_{0in} and U_{0ref} are

$$U_{0ref}=\frac{R_0-z_0}{R_0+z_0}U_{0in},\ U_0=U_{0in}+\frac{R_0-z_0}{R_0+z_0}U_{0in}=\frac{2R_0}{R_0+z_0}U_{0in},$$

$$U_{0in}=\frac{R_0+z_0}{2R_0}U_0,\ U_{0ref}=\frac{R_0-z_0}{2R_0}U_0.$$

When the crystal is exposed to a microwave power, the reflected signal is:

$$U_{ref}\left(t\right)=\frac{R\left(t\right)-z_0}{R\left(t\right)+z_0}U_{0in}=\frac{R\left(t\right)-z_0}{R\left(t\right)+z_0}\frac{R_0+z_0}{2R_0}U_0.$$

The useful signal that passes through the filter capacitance C in the matched mode to the oscilloscope is:

$$\Delta U\left(t\right)=U_{ref}\left(t\right)-U_{0ref}=\frac{R\left(t\right)-R_0}{R_0}\frac{z_0}{R\left(t\right)+z_0}U_0. \tag{2}$$

This expression is different from expression (1) and shows that the measurement conditions are different from the calibration conditions. Compliance is possible only under the condition $R(t) << z_0$ that can significantly limit the measurement limits of the microwave pulse power amplitude.

The problem of calibration as applied to the measurement scheme shown in Fig.2 can be solved if filter capacitance C is excluded from the calibration scheme (Fig.3).

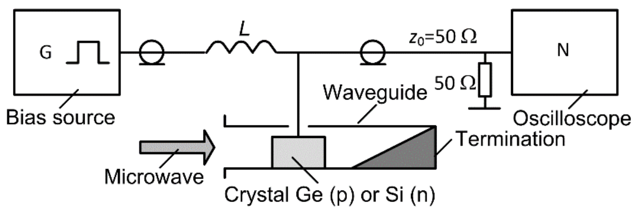

Fig.3. Calibration scheme corresponding to the Fig.2 measurement scheme.

In this case, with a steady-state bias pulse, the bias source is loaded on the parallel-connected crystal resistance R_0 and the cable input impedance, which is equal to z_0 in the matched mode. The bias source current is:

$$I_0 = \frac{R_0 + z_0}{R_0 z_0} U_0.$$

The complete signal at the cable input, which will be recorded by the oscilloscope is:

$$U(t) = \frac{R(t) z_0}{R(t) + z_0} I_0 = \frac{R(t) z_0}{R(t) + z_0} \frac{R_0 + z_0}{R_0 z_0} U_0 = \frac{R(t)}{R_0} \frac{R_0 + z_0}{R(t) + z_0} U_0$$

Expression for the useful signal,

$$\Delta U(t) = U(t) - U_0 = \frac{R(t) - R_0}{R_0} \frac{z_0}{R(t) + z_0} U_0,$$

corresponds exactly to the expression (2), which refers to the measurement scheme of a high-power nanosecond signal using the circuit shown in Fig.2. The bias signal can be eliminated by appropriate processing the calibration results.

2. Conclusion

Thus, in this work, two schemes for detecting nanosecond high-power microwave pulses are analytically considered. In both schemes, the detector is located in the wave field of the microwave oscillator. In one of the schemes, the source of the bias voltage pulse is located near the detector. In another scheme, the bias source is located near the oscilloscope, remote from the detector by the length of the signal cable, which registers the detected signal. It is shown that the first scheme fully corresponds to the detector calibration scheme. For the correct use of the second circuit, calibration must be performed without a capacitance filtering the detected signal. In both cases, the characteristic impedance of the cable must be equal to the input impedance of the oscilloscope.

3. References

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