Pulse Properties of S-TEAM Detectors

1. Scope

This Application Note pertains to S-TEAM low-power microwave detectors (DM), directional detectors (DD) and bidirectional detectors (BD). It is not directly applicable to power sensors (PS) and bidirectional power meters (BPM).

2. Theory

A simplified equivalent circuit for a diode detector is shown in Fig. 1. Looking into its input 1–1', the detector exhibits the reflection coefficient Γ_d. This reflection coefficient does not significantly vary with input power because:

– in low-power detectors, there is a lossy linear network inserted between the detector input and its internal diode;

– in directional and bidirectional detectors, the diode is very loosely coupled to the main transmission line.

The detectors are well matched (typically, $|\Gamma_d| < 0.13$, i.e. VSWR < 1.3), and hence in most practical applications, we can assume $\Gamma_d = 0$.

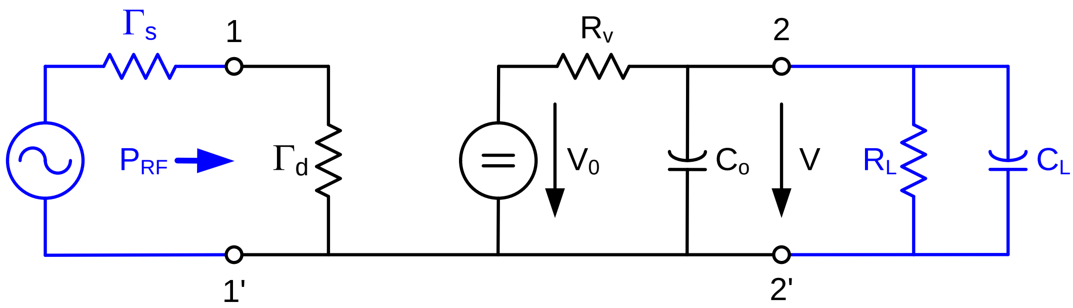

Fig. 1. Simplified equivalent circuit for a diode detector connected to a source with reflection coefficient Γ_s. The DC output load consists of a parallel combination of R_L and C_L.

Looking into its DC output 2–2', a diode detector behaves approximately as a voltage source with open-ended output voltage V_0, internal resistance R_v (often denoted *video resistance*) and internal output capacitance C_o. Generally, V_0 is a nonlinear function of input microwave power P_{RF}, diode temperature, and also load resistance R_L.

Suppose the detector is fed from an ideal square-modulated microwave signal. If the detector output is loaded by a resistor R_L in parallel with a capacitor C_L, the output pulse rise time will be

$$t_r = \left[\ln(10) - \ln(1/0.9)\right]\tau \approx 2.2\tau \quad (1)$$

where τ is time constant, given by

$$\tau = \frac{R_v R_L}{R_v + R_L}(C_o + C_L) \quad (2)$$

Often, a substantial portion of C_L is the capacitance of a cable interconnecting the detector and the instrumentation. The capacitance per meter C_1 of a coaxial cable with characteristic impedance Z_0 is

$$C_1 = \frac{\sqrt{\varepsilon_r}}{Z_0 c_0} \quad (3)$$

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where ε_r is the effective relative permittivity of the cable dielectric and c_0 = 2.99792458×10^8 m/s is the speed of light in free-space. For commonly used cables, C_1 is about 100 pF/m.

The detector fall time is typically about twice the value of the rise time (because of the increased effective value of R_v).

If the load capacitance C_L cannot be lowered, then the rise and fall times can still be reduced by decreasing the load resistance R_L. The penalty, however, is reduced output voltage V, which is governed by the equation

$$(4) \qquad V = V_0 \frac{R_L}{R_v + R_L}$$

where V_0 is the open-ended output voltage (corresponding to $R_L >> R_v$).

Some of the detectors have a more complicated internal structure and the outlined theory is even more of an approximation. Still, with the numerical data in Section 3, a reasonable estimate of pulse rise and fall times can be obtained. Nevertheless, an experimental verification is always desirable.

2.1 Calculator

To estimate the rise and fall times for arbitrary load conditions, use the attached Excel calculator (**DetPulseProp.xlsx**). Examples for the standard DM211 detector and the fast DM212 detector are shown in the following table:

Detector Pulse Properties	**Unit**	**DM211**	**DM212**
Detector internal resistance R_v	ohm	**9000**	**250**
Detector internal capacitance C_o	pF	**22**	**22**
Load resistance R_L	ohm	**33000**	**33000**
Load capacitance C_L	pF	**150**	**150**
Time constant τ	ns	1216	43
Rise time t_r	ns	2672	94
Fall time t_f	ns	5345	188
Relative output voltage V/V_0	%	79	99

3. S-TEAM Detectors

Based on the types of diodes used, there are two classes of S-TEAM detectors:

- Standard detectors
- Fast detectors

Standard detectors use zero-bias Schottky diodes (ZBSD) and are not designed to have fast-pulse capabilities. Still, rise and fall times well below 1 μs can be achieved.

Fast detectors use tunnel diodes (TD) with very low internal resistance R_v, and, consequently, can achieve rise times below 100 ns. Another advantage is their superior temperature stability. Compared to standard detectors, the nonlinearity of their transfer curves is more pronounced, and hence their output voltage is limited to lower values compared to the standard detectors.

3.1 Low-Power Detectors

The list of the S-TEAM low-power detectors with their typical internal resistances R_v and internal capacitances C_o is presented in the table below. The value of R_v in general depends on the signal level. The values provided below assume the output voltage on the order of tens of millivolts. To reduce the overall rise and fall times, if possible, decrease the detector load capacitance C_L, e.g. by shortening the output cable. Alternatively, one can decrease the load resistance R_L; however, this comes at the expense of lowering the output voltage, as explained above.

Model	Type	Band	R_v (Ω)	C_o (pF)
DM211 DM213	Standard	900/2450 MHz	9000	22
DM212 DM214	Fast	900/2450 MHz	250	22
DM311 DM313	Standard	5800 MHz	6000	22
DM314	Fast	5800 MHz	220	22

3.2 Directional Detectors

Directional detectors employ internal filtering, thus modifying the values of R_v and C_o.

Model	Type	Band	R_v (Ω)	C_o (pF)
DD111 DD131	Fast	2450 MHz	250	1500
DD112 DD132	Standard	2450 MHz	8000	1500

3.3 Bidirectional Detectors

There exist the following device types based on the bidirectional detector structure:

- Basic bidirectional detectors (i.e., with no internal signal conditioning)
- Bidirectional detectors with internal output amplifiers (providing e.g. 0 – 10 V output)
- Bidirectional power meters (treated in a separate section)
- Coaxial magnetron launchers (CMLD)

Bidirectional detectors, similarly to directional detectors, employ internal filtering, thus modifying the values of internal output resistance R_v and capacitance C_o.

3.3.1 Basic Bidirectional Detectors and Coaxial Magnetron Launchers

Model	Type	Band	R_v (Ω)	C_o (pF)	t_{rd} (μs)
BD111 BD211 BD131	Fast	2450 MHz	225	1000	0.5
BD112 BD132 BD214	Standard	2450 MHz	10200	2000	45
BD122 BD142	Standard	2450 MHz	10200	24	0.54
CMLD	Standard	2450 MHz	10200	24	0.54

Here t_{rd} is the detector *internal* rise time, obtained from (1) using $\tau = R_v C_o$.

3.3.2 Bidirectional Detectors with Internal Amplifiers

This bidirectional detector type is a cascade of a basic detector and an operational amplifier in each of its two channels. The amplifier's output resistance R_{oa} is about 100 Ω and its output capacitance C_{oa} is about 4300 pF.

In this case, three different rise times come into play:

1. Detector internal rise time t_{rd}, as listed in the above table.
2. Amplifier rise time t_{ra}, which is defined by parallel RC combination in its feedback path. For the used values R = 47 kΩ and C = 3300 pF, the amplifier rise time is t_{ra} = 340 μs.
3. Output circuit (load) rise time:

$$t_{rL} = 2.2 \frac{R_{oa} R_L}{R_{oa} + R_L} \left(C_{oa} + C_L \right)$$

If one of the three rise times (t_{rd}, t_{ra}, t_{rL}) clearly dominates over the rest, this will be the overall detector rise time. If two rise times are comparable, one of them multiplied by an empirical factor can be used as the result. As seen, t_{rd} is the lowest and can be disregarded. Then, approximately:

$t_r = t_{rL}$ if $t_{rL} \gg t_{ra}$

$t_r = t_{ra}$ if $t_{rL} \ll t_{ra}$

$t_r = 1.5 \times t_{ra}$ if $t_{rL} \approx t_{ra}$ (rule of thumb)

3.3.3 Bidirectional Power Meters

S-TEAM bidirectional power meters are standard bidirectional detectors with amplifiers and internal microcomputers providing digital correction of transfer curve nonlinearity and temperature dependence. The power meters are not intended for pulsed applications. Their effective time constant is indirectly determined by the sampling duration setting. Internal hardware rise time (≈ 10 μs) is not a limiting factor. Please consult BPM documentation for sampling control parameters. The above also holds for the microwave power sensor PS112.