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Carrier Lifetime and Forward Resistance in RF PIN-Diodes

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Never stop thinking

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Page	**Subjects (major changes since last revision)**
All	Document layout change

1 Carrier Lifetime and Forward Resistance in RF PIN-Diodes

This abstract summarizes the fundamentals of RF PIN Diode physics. General design considerations of PIN Diodes are discussed and a measuring method for the carrier lifetime is introduced.

PIN diodes are used as switches or controlled resistors for signals at radio and microwave frequencies. **Figure 1** shows a theoretical sketch of a PIN diode.

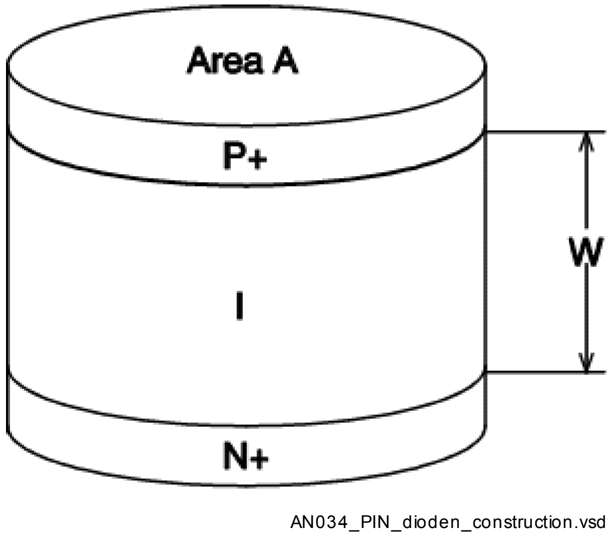

Figure 1 PIN Diode construction

A lightly doped I-region (intrinsic) separates the heavily doped P+ and N+ regions. This forms a capacitor at zero bias:

(1)

$$C_0 = \frac{\varepsilon A}{W}$$

Where:

C_0: capacitance at zero bias

ε: dielectric constant of I-zone material

The intrinsic region has a high resistance which can be calculated at zero bias by the following equation:

(2)

$$r_0 = \frac{\sigma W}{A}$$

Where:

r_0: resistance at zero bias

σ: specific resistance of I-region (dependant on the doping concentration)

In forward bias the injection of carriers from the P+ and N+ region reduces the specific resistance to a level below that obtained from doping alone. The carrier concentration is determined by both injection and recombination processes; recombination is quantified by the term ‘carrier lifetime‘. The resulting resistance for radio frequencies can be approximated by the following equation:

(3)

$$r_f = \frac{W^2}{(\mu_n + \mu_p) \cdot \tau I_f}$$

Where:

r_f: forward resistance for radio frequencies

I_f: forward current

μ_n: electron mobility

μ_p: hole mobility

τ: carrier lifetime

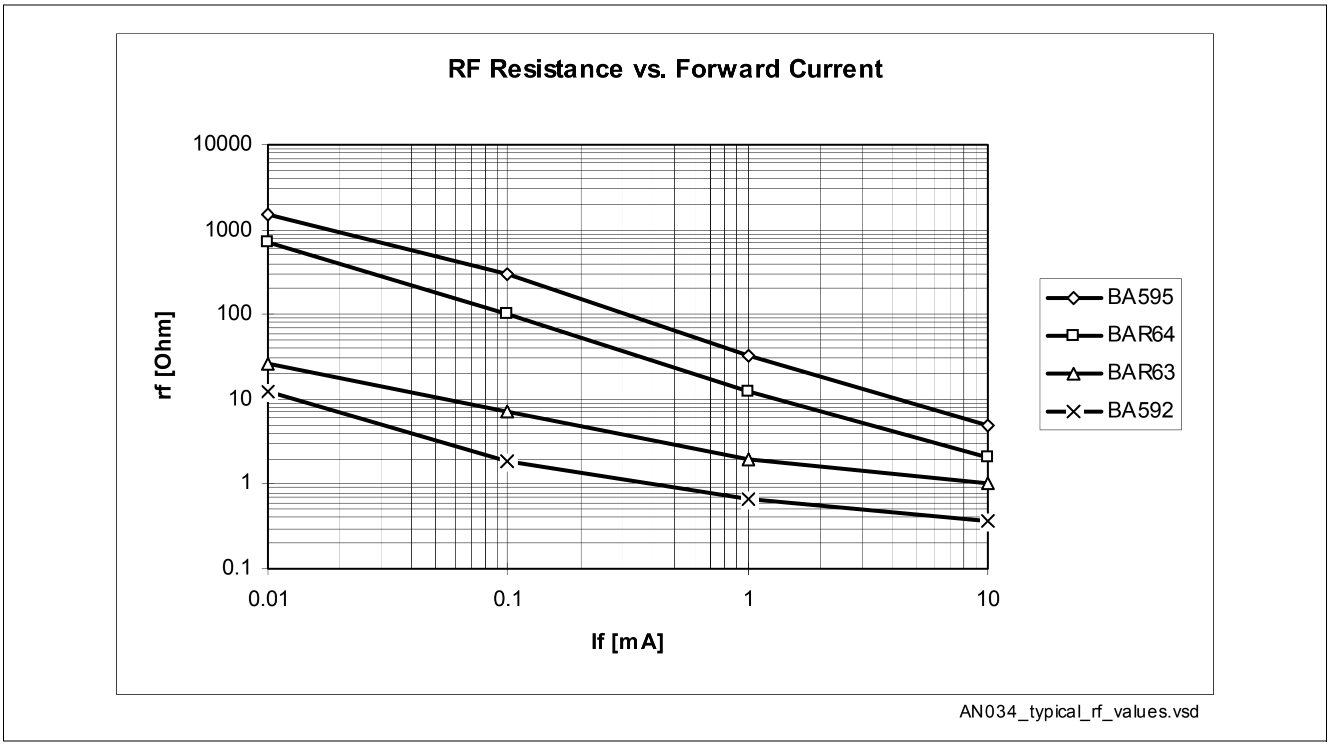

Figure 2 Typical values

To make things more complicated τ is not constant- it decreases with higher I_f - because recombination is facilitated when more carriers are available. Additionally τ is reduced by ‘traps‘(e.g. fold atoms) and border effects around the active I-zone. Refer to **Figure 2** for a typical values of r_f resistances.

Table 1 Overview of diode parameters

	A	W	τ	r_f	C_0
BA595	Medium	High	1600 ns	High	230 fF
BAR64	High	Medium	1400 ns	Medium	300 fF
BAR63	Low	Low	80 ns	Low	300 fF
BA592	Medium	Very low	120 ns	Very low	1200 fF

As a rule of thumb PIN diodes should be operated at frequencies considerably higher than the reciprocal of τ:

$$f \geq \frac{10}{\tau} \tag{4}$$

This avoids non-linear intermodulation and harmonics effects by preventing modulation of the charge carrier concentration.

How can you actually measure the electrical characteristics of a diode? r_f and C_t under bias condition can be obtained by using an impedance analyzer e.g. HP4291. Another test setup gives us the carrier lifetime (**Figure 3**).

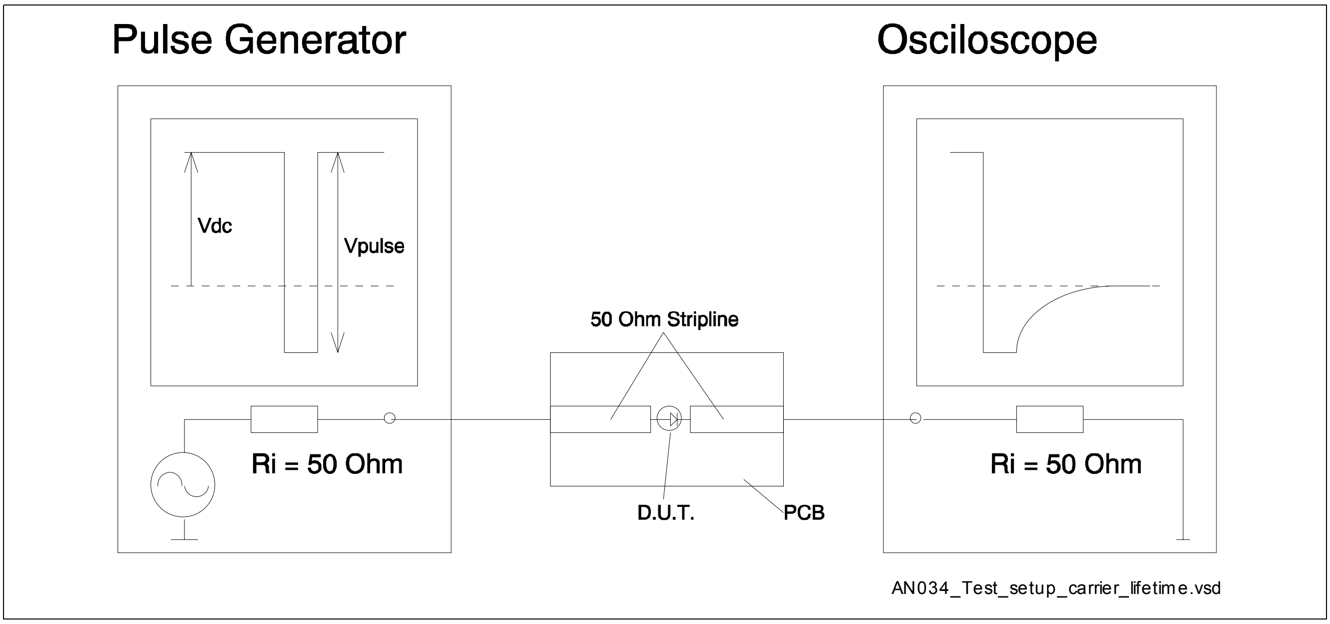

Figure 3 Test setup for measuring the carrier lifetime

The pulse width of the negative pulse from the generator must exceed the expected carrier lifetime. The DC conditions and pulse amplitude should be adjusted to obtain the oscilloscope trace shown in **Figure 4**: in this example I_f = 10 mA (0.5 V across 50 Ω) in forward bias, I_r = 6 mA in reverse bias. The time τ_{rr} (reverse recovery time) measured from the falling slope of the pulse to the time where it reaches 3 mA reverse bias given an estimate for τ, which is due to the following relationship between τ_{rr} and τ:

(5)

$$\tau_{rr} = \tau \ln \cdot \left(1 + \frac{I_f}{I_r}\right)$$

For chosen I_f and I_r the natural logarithm in the equation reduces to 1.

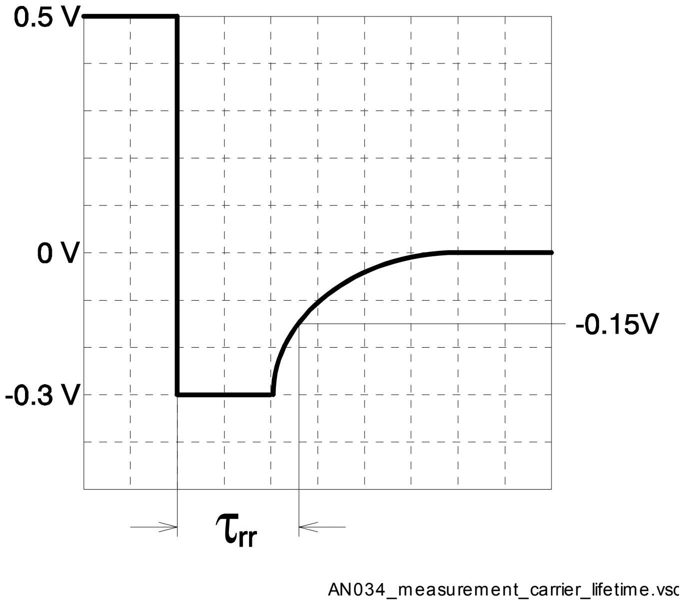

Figure 4 Oscilloscope trace showing the measurement of carrier lifetime