无线电与电子学专业英语

陆伟良　李　玉　编译

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Lesson 1 The Semiconductor Diode

A semiconductor diode is a two-terminal device containing a single p-n junction. The general circuit symbol for a semiconductor diode is shown in Fig. 1-1, along with its relationship to the p-n structure.

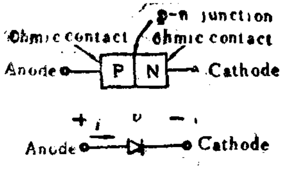

Figure 1-1 Circuit symbol for a semiconductor diode

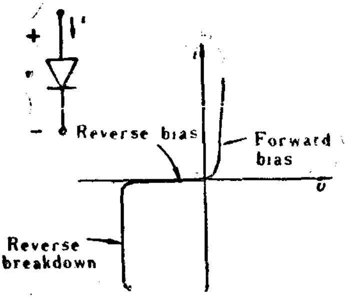

Figure 1-2 Typical diode characteristic illustrating three regions of operation

The v-i characteristic of a typical semiconductor diode is shown in Fig. 1-2.

Generally, diode applications can be classified according to which of the three regions of diode operation (see Fig. 1-2) are used. Switching and rectifying applications involve transitions between the reverse-bias and forward-bias regions. In such applications, care must be taken to choose a diode with a reverse breakdown voltage sufficiently large to prevent undesired reverse breakdown. The reverse breakdown region is employed primarily in voltage reference applications. There, the diode is chosen for the specific value of reverse voltage at which reverse breakdown occurs.

The diode is the first network element we encounter that is strikingly nonlinear in the middle of its normal operating range. Both KVL and KCL① can be used since their validity does not depend on the linearity or nonlinearity of the network elements. However, we must exercise caution in the use of superposition, Thevenin equivalents, and Norton equivalents, because these methods are explicitly restricted to linear networks.

One generally useful approach is to separate the linear network from the nonlinear elements and carry out a graphical solution for the voltage and current in the nonlinear elements. To illustrate the method of graphical solution, let us consider the network shown in Fig. 1-3(a). A single nonlinear element, a diode, is connected to a network of arbitrary complexity, but containing only linear resistive elements and sources. The linear portion of the network may be replaced by its Thevenin equivalent network as shown in Fig. 1-3 (b).②

The first step in the solution is to separate the

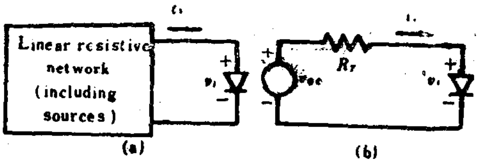

Figure 1-3 (a) General nonlinear network (b) Linear network replaced by Thevenin equivalent circuit

linear network from the nonlinear element, as shown in Fig. 1-4(a). Next, we determine the relationship between v_D and i_D, the v-i characteristic of the nonlinear element, by experimental measurement or from another source such as a manufacturer's data sheet, and ~~plot this relationship~~ as shown in Fig. 1-4(b). The third step in the solution is to find the relationship between v_L and i_L, the v-i characteristic for the linear network. From Fig. 1-4(a), we have

$$v_L = v_{OC} - i_L R_T \qquad (1\text{-}1)$$

where v_{OC} and R_T are the Thevenin equivalent voltage and resistance of the linear network. Equation 1-1 is then plotted on the graph containing the v-i characte-

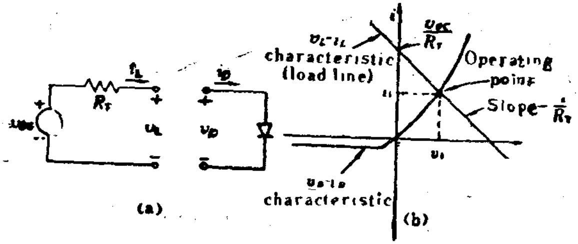

Figure 1-4 Graphical solution to nonlinear networks

ristic of the nonlinear element. Since Eq. 1-1 is a linear relationship between v_L and i_L, the equation plots as a straight line, and only two points on the line need be calculated to determine the entire line. Two convenient points are the intercepts at $v_L = 0$ and at $i_L = 0$ corresponding respectively to a short circuit and an open circuit at the linear network terminals. For $v_L = 0$, Eq.(1-1) yields

$$
\begin{aligned} i_L &= \frac{v_{OC}}{R_T}, \\ v_L &= 0. \end{aligned} \tag{1-2}
$$

whereas for $i_L = 0$ we obtain

$$
\begin{aligned} v_L &= v_{OC}, \\ i_L &= 0. \end{aligned} \tag{1-3}
$$

These points, which are the x-and y-axis intercepts of the line in question, are indicated in Fig. 1-4(b) along with the resulting line. The slope of the line is seen to be $-1/R_T$, so that③ for small values of R_T the line approaches the vertical and for large values of R_T the line becomes horizontal.

If the nonlinear element is connected to the linear network, as shown in Fig. 1-3 (b), then we have the following circuit constraints imposed by the connection:

$$
v_L = v_D = v_1 \tag{1-4}
$$

and

$$
i_L = i_D = i_1.
$$

From Fig. 1-4(b) there is only one point where v_L equals v_D and i_L equals i_D: the intersection of the two

v–i characteristic curves. Thus the required values of v_1 and i_1 must be the values of voltage and current at this intersection point, and can be read directly off the graph.

The linear v–i characteristic plotted in Fig. 1–4(b) is known as a load line, since it represents the locus of all possible loads the linear network can present to the nonlinear element. Also, the intersection v_1–i_1 is often called the operating point or Q-point of the nonlinear element.

If the linear network contains time-varying sources, then the Thevenin equivalent voltage source in Fig. 1–3(a) will be a function of time. However, the Thevenin resistance of the linear network remains a constant, since it is independent of the amplitude of the sources. Thus, the load line of the linear network has a constant slope, $-1/R_T$, but moves parallel to itself in the v–i plane such that④ the voltage axis intercept is always equal to the instantaneous Thevenin equivalent voltage. Since the load line is moving in the v–i plane, its intersection with the nonlinear v–i characteristic also moves, producing the corresponding time variation of voltage and current in the nonlinear element.

If a circuit contains more than one nonlinear element, graphical solutions, while possible, become more complex. First, it is not possible to separate the circuit into a linear part and a single nonlinear element. Thus the network facing a given nonlinear element contains at least one nonlinear element, and the v–i characteristic at its terminals will produce a nonlinear load line. Of course, the intersection of the nonlinear load line with the remaining nonlinear characteristic produces the desired operating point. The difficulty is with the construction of the nonlinear load line. If the network contains only two nonlinear elements, a graphical solution can be obtained with only a modest increase in complexity. For cases with more than two nonlinear elements, the effort required for graphical solutions is seldom justified. For this reason we seek alternate methods of solution to networks with nonlinear elements.

An exponential model for the diode v–i characteristic that is reasonably accurate for many actual diodes.

$$i = I_s(e^{qv/kT} - 1), \tag{1-5}$$

where I_s is the reverse saturation current of the diode and kT/q has the value of 26mV at room temperature. It is perfectly possible to write KVL and KCL in algebraic form incorporating this exponential relation for each diode.

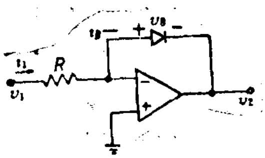

Figure 1–5 A logarithmic amplifier

Figure 1–5 shows an exponential diode (I_S placed next to the diode symbol indicates an exponential diode) used as a negative feedback element around an op-amp. Because of the negative feedback, we presume initially that the op-amp is in the linear region. Since v_+ is zero, we can take v_- as zero also. Therefore the current i_1, which equals the current i_D is given by

$$i_1 = i_D = v_1/R. \tag{1-6}$$

If this current represents a forward bias current for the diode, that is, if i_1 is positive and much greater than the saturation current I_s, we can approximate the complete exponential relation by

$$i_D \approx I_s e^{Qv_D/KT} \tag{1-7}$$

Furthermore, writing KVL from the v_- node to the v_2 node, we obtain

$$v_2 = -v_D \tag{1-8}$$

Finally, substituting for i_D and v_D in Eq. 1-7 yields

$$v_1/R = I_s e^{-qv_L/KT} \tag{1-9}$$

which can be solved to obtain a logarithmic transfer characteristic

$$v_2 = -\frac{KT}{q} \ln\left(\frac{v_1}{I_s R}\right) \tag{1-10}$$

Thus, as long as v_1 is sufficiently positive to supply a current through R much larger than the saturation current I_S, the diode is forward biased into the purely exponential region permitting the construction of an analog circuit that computes the logarithm of an input voltage. Such circuits are widely used in instrumentation.

Note that the logarithmic amplifier of Fig. 1-5 works only for v_1 positive. If v_1 becomes negative, the current i_1 attempts to become negative, but is limited by the small reverse saturation current of the diode. The diode becomes strongly back biased the v_- node voltage becomes negative, and the amplifier output v_2 saturates at the $+v_{cc}$ supply.

An alternate and very useful approach is to represent the nonlinear v-i characteristic in pieces with a set of approximate but linear v-i characteristics, each one valid over a suitably restricted range of voltage and current. As long as we careful to check that the voltages and currents were in the proper ranges, it was possible to represent the nonlinear op-amp with a piecewise linear model.

New Words

semiconductor	['semikən'dʌktə]	*n.*	半导体
classify	['klæːsifai]	*vt.*	把…分类，把…分等级
region	['riːdʒən]	*n.*	区域，地带
rectify	['rektifai]	*vt.*	把…整流，纠正
involve	[in'vɔlv]	*vt.*	包含，包括
transition	[træn'siʒən]	*n.*	转变，变迁
prevent	[pri'vent]	*v.*	预防，阻止
sufficiently	[sə'fiʃəntli]	*ad.*	足够地，充足地

primarily	['praimərili]	*a.*	最初的，原始的
occur	[ə'kə:]	*vi.*	发生，出现
encounter	[in'kauntə]	*v*; *n*.	遭遇，碰见；冲突
strikingly	['straikiŋli]	*ad.*	显著地，惊人地
validity	[və'liditi]	*n.*	效力，合法性
caution	['kɔ:ʃən]	*n.*	谨慎，告诫
explicitly	[iks'plisitli]	*ad.*	明白地
approach	[ə'prəutʃ]	*v.*	靠近，近似
illustrate	['iləstreit]	*v.*	用图说明，图解
arbitrary	['ɑ:bitrəri]	*a.*	任意的，专横的
complexity	[kəm,pleksiti]	*n.*	复杂(性)，复杂的事物
plot	[plɔt]	*n*; *v*.	曲线，标绘图；划分
entire	[in'taiə]	*a.*	完全的，全部的
intercept	[intə(:)'sept]	*vt.*	拦截，相交
correspond	[kɔris'pɔnd]	*vi.*	符合，相当
respectively	[ris'pektivli]	*ad.*	分别地，各自地
slope	[sloup]	*n.*	斜率
vertical	['və:tikəl]	*a.*	垂直的，顶点的
horizontal	[hɔri'zɔntl]	*a.*	水平的
impose	[im'pəuz]	*v.*	强加
parallel	['pærəlel]	*n.*	平行线，对比
instantaneous	[instən'teinjəs]	*a.*	瞬间的
terminal	['tə:minl]	*n.*	末端，终点
seek	[si:k]	*v.*	寻找，追求
reasonable	['ri:znəbl]	*a.*	有理的，明智的
accurate	['ækjurit]	*a.*	准确的，精密的
approximate	[ə'prɔksimit]	*v.*	接近，近似

pure	[pjuə]	*a.*	纯粹的，纯净的
instrumentation	[ˌinstrumen'teiʃən]	*n.*	测试设备
attempt	[ə'tempt]	*v.*; *n.*	企图，尝试
piecewise	['piːswaiz]	*ad.*; *a.*	分段地；分段的

Professional Teminology

semiconductor diode	半导体二极管
two-terminal device	二端器件
p-*n* junction	*p*-n 结
reverse-bias	反向偏置
forward-bias	正向偏置
reverse breakdown voltage	反向击穿电压
network element	网络元件
normal operating range	正常工作区
superposition	叠加
Thevenin equivalent network	戴维南等效网络
Norton equivalents	诺顿等效
linear network	线性网络
nonlinear element	非线性元件
graphical solution	图解法
short circuit	短路
v-*i* characteristic curves	伏安特性曲线
load line	负载线
operating point	工作点
time-varying sources	时变源
reverse saturation current	反向饱和电流

negative feedback element	负反馈元件
op-amp	运算放大器
logarithmic transfer characteristic	对数传递特性
analog circuit	模拟电路
logarithmic amplifier	对数放大器

Expressions

according to	根据，按照，与…相应
depend on	取决于，随…而定
to separate...from...	把…从…中分开
to separate...into...	把…分成
to carry out	实行，执行，实现
be connected to	接到…，与…相连
be replaced by	被…替代
be in question	成为问题，正在讨论中
be indicated in	示于，显示于…中
along with	以及
(be) equal to	等于
for this reason	为此
to substitute for...in...	把…代入到…中
as long as	只要
be limited by	受…限制
a set of	一组

注　释

① both…and… 起连接词作用，作“两者都”，“又……又……”。

② 本句中 as shown in Fig 1-3b 习惯上译为“如图 1-3b 所示”，从语法上讲这是一个关系代词 as 引导的定语从句。在从句中，as 是主语，谓语动词是 is shown，is 被省略。

③ so that 引导为状语从句。表示目的或结果，此处为结果状语从句。

④ such that，such 为形容词，作表语，that 为连接词，引导为结果状语从句。

第一课　晶体二极管

半导体二极管是含有一个 p-n 结的二端器件。半导体二极管的一般电路符号，以及它和 p-n 结构的关系示于图 1-1。

图 1-2 所示是一个典型的半导体二极管的 v-i 特性曲线。

一般来说，二极管的应用可以根据使用时二极管工作的三个区域（见图1-2 所示）来进行分类。作为开关和整流应用时，包括有反向偏置和正向偏置两个区域的转换。在这些应用中，必须注意选择一个反向击穿电压足够大的二极管，以防止不希望的反向击穿。稳压管主要应用于反向击穿区。这时二极管是根据指定的发生反向击穿时的反向电压值来选择的。

二极管是我们所遇到的正常工作区的中间部分为明显非线性的第一个网络元件。在这里 KVL 和 KCL 都是能应用的，因为它们的适用性与网络元件是线性还是非线性无关。然而，我们在使用叠加原理、戴维南等效及诺顿等效时，要非常谨慎，因为这些方法只能用于线性网络。

一种普遍有效的方法，是把线性网络与非线性元件分开，然后用图解法求出非线性元件的电压和电流。为了说明这种图解法，让我们来考虑图 1-3（a）所示的网络。以单个非线性元件，即二极管，接于任意复

杂的网络上，而此网络仅含有线性电阻元件及电源。这个网络的线性部分，可以用它的戴维南等效网络代替，如图 1-3 (b) 所示。

解法的第一步是把线性网络和非线性元件分开，如图 1-4(a)所示。其次一步确定 v_D 和 i_D 间的关系，即非线性元件的 v-i 特性，这可以用实验的方法测出，或者从诸如制造厂所给的技术数据等其他来源得到，并画出曲线如图 1-4(b)所示。解法的第三步，要找出 v_L 和 i_L 之间的关系，即线性网络 v-i 特性。从图 1-4(a) 得

$$v_L = v_{OC} - i_L R_T \tag{1-1}$$

式中 v_{OC} 和 R_T 是线性网络的戴维南等效电压和等效电阻，然后将(1-1)式画在有非线性元件的 v-i 特性曲线的图上。因为(1-1)式是 v_L 和 i_L 之间的线性关系，所以画出图来是一条直线，我们只需要计算出直线上的两个点，就可以确定整个直线。直线与座标轴取 $v_L=0$ 和 $i_L=0$ 的两个交点比较方便，这分别相当于在线性网络的端口处短路和开路。因为 $v_L=0$，从(1-1)式中可求出

$$i_L = \frac{v_{OC}}{R_T},$$
$$v_L = 0. \tag{1-2}$$

而当 $i_L=0$，我们得到

$$v_L = v_{OC},$$
$$i_L = 0. \tag{1-3}$$

这两个点，就是所求的直线在 x 轴和 y 轴上的截距，它们以及由此所得的直线示于图 1-4(b)。直线的斜率可以看出为 $-\frac{1}{R_T}$，因此当 R_T 的值很小时，这条直线接近于垂直，而 R_T 值很大时这条直线变为水平。

如果非线性元件与线性网络连接，如图 1-3(b) 所示，则我们得到由于电路连接所形成的电路约束如下：

$$v_L = v_D = v_1$$

和

$$i_L = i_D = i_1 \tag{1-4}$$

从图 1-4 (b) 看出这两条 v-i 特性曲线只相交于一个点，在该交点：$v_L = v_D$，$i_L = i_D$，因此所求的 v_1 和 i_1 的值，就必是这个交点的电压和电流值，而且能够在曲线图中直接读出。

在图 1-4 (b) 中所画出的这条 v-i 直线，称为负载线，因为它代表线

性网络对非线性元件呈现出的所有可能的负载的轨迹。交点 v_1-i_1 常常称为非线性元件的工作点，或 Q 点。

如果线性网络含有时变源，那么在图 1-3a 中的戴维南等效电源是一个时间函数。然而，线性网络的戴维南电阻保持为常数，因为这个电阻与电源振幅无关。因此，线性网络的负载线具有恒定的斜率 $-1/R_T$，但它在 v-i 平面内平行移动，使得在电压轴上的截距总是等于戴维南等效电压的瞬时值。因为负载线在 v-i 平面内移动，它与非线性 v-i 特性曲线的交点也在移动，从而产生了非线性元件中电压和电流值的相应时间化变。

如果电路含有多个非线性元件，图解法在可能应用时，也变得比较复杂。首先，不可能把电路分成线性部分和单个的非线性元件。于是面对着一个给定的非线性元件后，网络内部至少还含有一个非线性元件，因此，在网络端口处的 $v-i$ 特性曲线将是一条非线性负载线。当然，非线性负载线同另外的非线性特性曲线的交点，就是所要求的工作点。这个方法的困难在于作出非线性负载线。如果网络仅含有两个非线性元件，还可以利用图解法求解，只是增加一定的复杂性。对于两个以上非线性元件的情况，图解法就由于太费力而极少认为是一种好方法。为此，我们就要对具有多个非线性元件的网络寻找别的求解的方法。

二极管的 v-i 特性曲线的指数模型，对于许多实际二极管都是相当准确的。

$$i = I_s(e^{qv/kT} - 1), \tag{1-5}$$

式中 I_s 是二极管的反向饱和电流，kT/q 在室温下的值为 26 mV。这就完全可能将 KVL 和 KCL 写成与每个二极管指数关系式相组合的代数方程。

图 1-5 示指数二极管（一般在二极管符号旁用 I_s 表示指数二级管）用作运算放大器的负反馈元件。因为具有负反馈，所以我们先假定运算放大器工作在线性区。因 v_+ 是零，因此 v_- 也可以认为是零。所以电流 i_1（等于 i_D）由下式求出

$$i_1 = i_D = \frac{v_1}{R}. \tag{1-6}$$

如果这个电流代表二极管的正向偏置电流，即如果 i_1 为正值且比饱和电流 I_s 大得多，则完整的指数关系可用下式来近似表示：