Steps for Finding a Junction Diode Circuit Transfer Function

Determining the transfer function of a junction diode circuit is in many ways very similar to the analysis steps we followed when analyzing previous junction diode circuits (i.e., circuits where all sources were explicitly known).

However, there are also some important differences that we must understand completely if we wish to successfully determine the correct transfer function!

**Step 1:** Replace all junction diodes with an appropriate junction diode model.

*Just like before!* We will now have an IDEAL diode circuit.

**Step 2:** Assume some mode for all ideal diodes.

*Just like before!* An IDEAL diode can be either forward or reverse biased.
**Step 3:** ENFORCE the bias assumption.

Just like before! ENFORCE the bias assumption by replacing the ideal diode with short circuit or open circuit.

**Step 4:** ANALYZE the remaining circuit.

Sort of, kind of, like before!

1. If we assumed an IDEAL diode was forward biased, we must determine $i^i_D$--just like before! However, instead of finding the numeric value of $i^i_D$, we determine $i^i_D$ as a function of the unknown source (e.g., $i^i_D = f(v_I)$).

2. Or, if we assumed an IDEAL diode was reversed biased, we must determine $v_D'$--just like before! However, instead of finding the numeric value of $v_D'$, we determine $v_D'$ as a function of the unknown source (e.g., $v_D' = f(v_I)$).

3. Finally, we must determine all the other voltages and/or currents we are interested in (e.g., $v_O$)--just like before! However, instead of finding its numeric value, we determine it as a function of the unknown source (e.g., $v_O = f(v_I)$).
**Step 5:** Determine **WHEN** the assumption is valid.

Q: OK, we get the picture. Now we have to **CHECK** to see if our IDEAL diode assumption was correct, right?

A: Actually, **no**! This step is very different from what we did before!

We cannot determine **IF** $i_D^i > 0$ (forward bias assumption), or **IF** $v_D^i < 0$ (reverse bias assumption), since we cannot say for certain what the value of $i_D^i$ or $v_D^i$ is!

Recall that $i_D^i$ and $v_D^i$ are **functions** of the unknown voltage source (e.g., $i_D^i = f(v_I)$ and $v_D^i = f(v_I)$). Thus, the values of $i_D^i$ or $v_D^i$ are **dependent** on the unknown source ($v_I$, say). For **some** values of $v_I$, we will find that $i_D^i > 0$ or $v_D^i < 0$, and so our assumption (and thus our solution for $v_O = f(v_I)$) will be **correct**

However, for **other** values of $v_I$, we will find that $i_D^i < 0$ or $v_D^i > 0$, and so our assumption (and thus our solution for $v_O = f(v_I)$) will be **incorrect**.

Q: Yikes! What do we do? **How can we determine the circuit transfer function if we can’t determine **IF** our ideal diode assumption is correct??
A: Instead of determining IF our assumption is correct, we must determine WHEN our assumption is correct!

In other words, we must determine for what values of $v_I$ is $i_b' > 0$ (forward bias), or for what values of $v_I$ is $v_b' < 0$ (reverse bias).

We can do this since we earlier (in step 4) determined the function $i_b' = f(v_I)$ or the function $v_b' = f(v_I)$.

Perhaps this step is best explained by an example. Let's say we assumed that our ideal diode was forward biased and, say we determined (in step 4) that $v_O$ is related to $v_I$ as:

$$v_O = f(v_I)$$
$$= 2v_I - 3$$

Likewise, say that we determined (in step 4) that our ideal diode current is related to $v_I$ as:

$$i_b' = f(v_I)$$
$$> \frac{v_I - 5}{4}$$

Thus, in order for our forward bias assumption to be correct, the function $i_b' = f(v_I)$ must be greater than zero.
\[ i_D^I > 0 \]
\[ f(v_I) > 0 \]
\[ \frac{v_I - 5}{4} > 0 \]

We can now “solve” this inequality for \( v_I \):

\[ \frac{v_I - 5}{4} > 0 \]
\[ v_I - 5 > 0 \]
\[ v_I > 5 \]

**Q:** What does this mean? Does it mean that \( v_I \) is some value greater than 5.0V??

**A:** NO! Recall that \( v_I \) can be any value. What the inequality above means is that \( i_D^I > 0 \) (i.e., the ideal diode is forward biased) WHEN \( v_D^I > 5.0 \).

Thus, we know \( v_o = 2v_I - 3 \) is valid WHEN the ideal diode is forward biased, and the ideal diode is forward biased WHEN (for this example) \( v_D^I > 5.0 \). As a result, we can mathematically state that:

\[ v_o = 2v_I - 3 \quad \text{when} \quad v_I > 5.0 \text{ V} \]
Conversely, this means that if \( v_I < 5.0 \) V, the ideal diode will be reverse biased—our forward bias assumption would not be valid, and thus our expression \( v_O = 2v_I - 3 \) is not correct \((v_O \neq 2v_I - 3 \text{ for } v_I < 5.0 \text{V})!\)

**Q:** So how do we determine \( v_O \) for values of \( v_I < 5.0 \) V?

**A:** Time to move to the last step!

**Step 6:** Change assumption and repeat steps 2 through 5!

For our example, we would change our bias assumption and now ASSUME reverse bias. We then ENFORCE \( i_D' = 0 \), and then ANALYZE the circuit to find both \( v_D' = f(v_I) \) and a new expression \( v_O = f(v_I) \) (it will no longer be \( v_O = 2v_I - 3 \) !).

We then determine \textit{WHEN} our reverse bias assumption is valid, by solving the inequality \( v_D' = f(v_I) > 0 \) for \( v_I \). For the example used here, we would find that the IDEAL diode is reverse biased \textit{WHEN} \( v_I < 5.0 \) V.

For junction diode circuits with multiple diodes, we may have to repeat this entire process multiple times, until all possible bias conditions are analyzed.
If we have done our analysis properly, the result will be a valid continuous function! That is, we will have an expression (but only one expression) relating $v_O$ to all possible values of $v_I$.

This transfer function will typically be piecewise linear. An example of a piece-wise linear transfer function is:

$$v_O = \begin{cases} 
2v_I - 3 & \text{for } v_I > 5.0 \\
12 - v_I & \text{for } v_I < 5.0 
\end{cases}$$

Just to make sure that we understand what a function is, note that the following expression is not a function:

$$v_O = \begin{cases} 
2v_I - 3 & \text{for } v_I > 7.0 \\
12 - v_I & \text{for } v_I < 3.0 
\end{cases}$$
Nor is this expression a function:

\[ v_O = \begin{cases} 
2v_I - 3 & \text{for } v_I > 3.0 \\
12 - v_I & \text{for } v_I < 7.0 
\end{cases} \]
Finally, note that the following expression is a function, but it is not continuous:

\[ v_o = \begin{cases} 
2v_I - 3 & \text{for } v_I > 5.0 \\
5 - v_I & \text{for } v_I < 5.0 
\end{cases} \]

Make sure that the piecewise transfer function that you determine is in fact a function, and is continuous!