EEE118: Electronic Devices and Circuits
Lecture IX

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Review

- Considered full wave and bridge rectifiers as an extension to the half wave principle
- Noted that in the full wave circuit the smoothing capacitor is replenished at double the line frequency
- Observed that the output voltage polarity available is only a function of where the reference is placed
- Discussed the differences between three phase and single phase systems more fully.
- Concluded the section on linear power supplies with a review of the circuits.
- Introduced stabilisation and regulation of power supplies.
- Briefly noted the existence of series and shunt regulators
- Discussed the usefulness of the Zener diode as a shunt regulator

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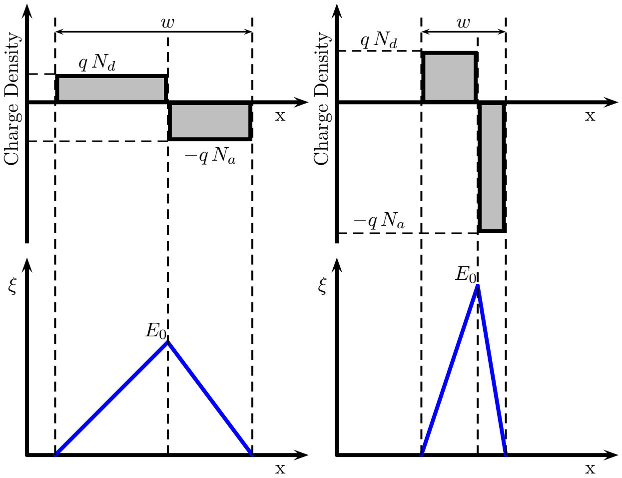
Part 2

- Lecture 9. (Today) A last word on Diode Regulators
- Lecture 10. Small Signals in Diode Circuits & Introduction to Transistors
- Lectures 11. & 12. Transistor Characteristics Graphs & Switching Applications of Transistors
- Lectures 13. & 14. Transistor circuits for Switching AC & Inductive Loads. & Amplifying Applications of Transistors
- Lectures 15. Two Single Transistor Amplifier Circuits & Small Signal Modelling
- Lectures 16 & 17. Operational Amplifiers
- Lectures 18 & 19. Review and Past Exam Run-through.

Outline

Zener Diodes - Impact ionisation

There are more zener diodes with $V_B > 6$ V than $V_B < 6$ V so the Zener effect, which is dominant in the lower voltage devices will be ignored for the moment. A pn diode is designed with a doping level in the P and N type material which will yield the "critical electric field" at a particular terminal voltage. Electric field is measured in V/m so what about the meters? It transpires that the wider the depletion region is the more voltage is required to reach the critical field. Consequently a Zener diode can be designed to break down at a particular voltage by controlling the doping density in the P and N regions. In Si the critical field is approximately 40 V/μm, but it is influenced somewhat by the doping densities. Some high voltage Zener diodes will have a pin structure where an lightly doped intrinsic region is sandwiched between the highly doped P and N regions. This acts to increase the depletion distance requiring a higher voltage to yield the critical electric field.



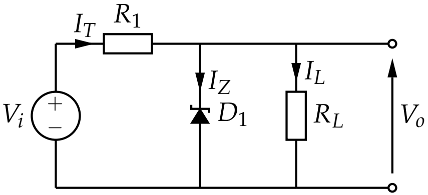
Two pn diodes one with lower doping density (left). Observe that the maximum field E_0, is lower at a given applied voltage in this case than in the higher doping density case (right).

Zener Diodes from a Circuit Perspective

- Since a Zener diode is normally used in reverse bias, it will be assumed that the the cathode will be positive w.r.t anode from now on.
- Zener diodes are only effective regulators if they are biased above their reverse breakdown voltage.
- Once the diode has broken down in a reverse direction, an increase in reverse bias ΔV will lead to an increase in reverse current ΔI
- The ratio of the *small change in V* against the *small change in I* is the dynamic or small signal[1] resistance of the reverse biased diode. It is variable and depends on the biasing conditions. It cannot be computed by dividing the breakdown voltage by the current. It is the change in V and the change in I over a small portion of the breakdown characteristic that is important. dv/di.

[1] small and large signals will be treated fully shortly.

A Zener Diode Shunt Regulator Circuit



In this circuit V_i is the output from any of the rectifier circuits that have been discussed in this course.

- The output voltage V_o will be close to V_B provided the diode is biased above its breakdown voltage. If $V_{C-A} > V_B$ the current is always greater than zero.
- Assume the load current, I_L, is constant but V_i is variable - due to ripple or utility variations.
- A reduction in V_i of ΔV_i will cause a reduction in voltage across R_1 of ΔV_i and hence a reduction in the output voltage.
- However the falling output voltage acts to slightly switch off the Zener diode causing the Zener current, I_Z, to fall by just enough to prevent V_o changing.

- The reduction in the total current I_T due to the falling voltage drop across R_1 is compensated by a similar reduction in I_Z such that I_L (and therefore V_o) are unaffected.
- Similarly if V_i remains constant but I_L changes the increasing I_L tends to lower V_o. A small decrease in V_o tends to switch off the Zener diode slightly, reducing its current and alowing I_L to increase such that V_o remains unchanged.

Design Approach,

- Work out or choose, based on your knowledge of the load, the maximum load current, I_L.
- Choose a Zener diode based on the required output voltage V_o (e.g. BZX55C25 - 25 V)
- Use the diode's manufacturers data sheet to find the minimum current required for proper operation (smallest I_Z that still yields the correct breakdown voltage).

- Consider the conditions that are most likely to cause the regulator to switch off i.e. minimum input voltage and maximum load current; find a value for R_1. The maximum required load current and minimum required Zener current must be able to flow even when the input voltage is at a minimum.

$$\frac{V_{i_{min}} - V_o}{R_1} = I_{L_{max}} + I_{Z_{min}} \tag{1}$$

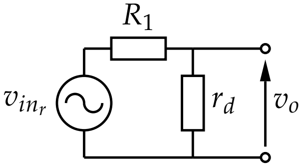
If the value of R_1 is larger than that given by (1), there would be insufficient current under the worst case of input voltage to satisfy the requirements of the load and the regulator. Therefore (1) represents the largest acceptable value of R_1. Of course if R_1 is made smaller than this value its power dissipation will be unnecessarily high.

- Calculate the worst case power dissipation in R_1. (hint: Max input voltage, full load current)
- Calculate the worst case power dissipation in the Zener diode (hint: Max input voltage, no load current). Check the Zener you chose is capable of dissipating the required power, if not select a higher power Zener diode.

Effect on the ripple,

- To calculate the effect of the Zener diode regulator on the ripple an equivalent circuit can be used which models the small changes in Zener resistance that occur to due small fluctuations in the input voltage (or load current).
- If the regulator has been well designed the diode will be broken down in the reverse direction. From the perspective of the ripple signal the diode can be thought of as a small signal (or dynamic) resistance which is equal to the inverse of the slope of the tangent of the breakdown characteristic at the operating point.

In the ripple equivalent circuit only the effect of the small ripple is considered, hence the input is AC. The DC has been neglected.



The output ripple voltage, v_o is obviously a potential division of the input ripple voltage v_{in_r} in the ratio of R_1 and the small signal (dynamic) resistance of the Zener diode. The load resistance (if it is connected) appears in parallel with the dynamic resistance of the Zener and the two may be paralleled using the usual formula. Hence the value of v_o calculated without the load is the worst case ripple voltage. If r_d is lower than R_1 (almost always true) there can be a significant reduction in output ripple. Limitations,

- The voltage is not adjustable.
- The Zener and R_1 may have high power dissipation.
- The dynamic resistance of the Zener is low, but it is not as low as transistor based linear regulators.

Homework 3

It should be possible to fully attempt the Homework 3 now.

It should also be possible to fully attempt the Rectifiers and Smoothing problem sheet.

Signals

In circuits that include active devices (diode, transistors etc.), signals may be considered “large” or “small”.
In this course,

Large Signal

If the signal amplitude is the same order of magnitude as the turn on voltage of an active device the signal is “large”.

Small Signal

If the signal amplitude is much smaller than the turn on voltage of an active device the signal is “small”.

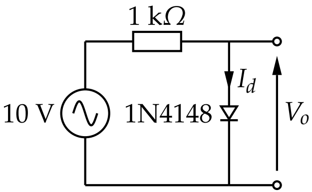
Consider a silicon diode which begins conducting at 0.7 V...

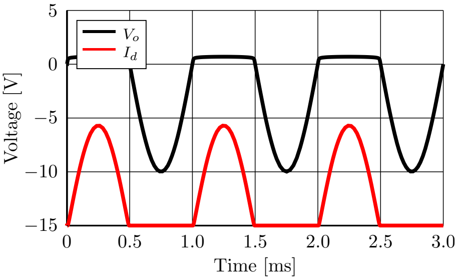
Example of a Circuit with a Large Signal

- The amplitude ("height") of the signal determines how the circuit is analysed.
- If the active devices behave nearly linearly over the range of signal excursion, the circuit can be *linearised* into a single circuit. This means that all the non-linear components (diodes etc.) can be replaced by a single value of dynamic resistance (r_d) which will act on the signal irrespective of the signal amplitude.
- If the active devices behave non-linearly over the range of signal excursion, the circuit may be linearised into several different circuits each having different model parameters (values of didoe dynamic resistance) for each of the the active device(s). The model used will depend on the amplitude of the signal as a function of time.

Typical Conduction State Problem

So far we have looked at conduction or non-conduction only. In the circuit below the diode enters conduction when the 10 V source rises above +0.7 V. Otherwise the diode is not conducting.

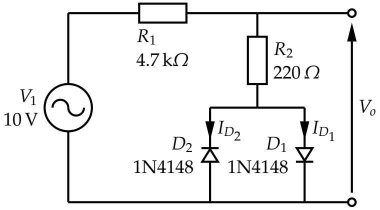


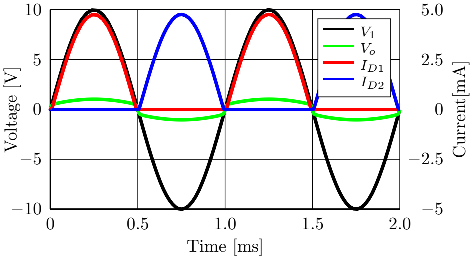


The diode conducts from 0 to 0.5 ms and from 1 to 1.5 ms and again from 2 to 2.5 ms but is not conducting at other times. This can be seen clearly in the current waveform (red).

Conduction State (large signal) Problems with AC Sources

Some circuits are driven by large amplitude signals. Occasionally the circuit conditions vary so greatly depending on the signal that diodes are switched on and off by the effects the signal has on the surrounding circuit. This is sometimes called large signal analysis. Because the signals are sufficiently large to adjust the operating point or quiescent conditions.





What does this circuit do? What applications does it have?

Applications of this Circuit

This is a kind of limiting circuit. It is one of the simplest in a class of wave-shaping circuits.

Description of Operation

The voltage at the output is limited to the sum of the voltage drop of the forward biased diode and the voltage dropped across R_2 due to the current flowing in it. Provided the input voltage is greater than +0.7 V or less than -0.7 V, one of the diodes will be conducting.

Assuming V_1 is a good approximation to Button V_o will sound something like Button .

Increasing the amplitude of the input signal causes the limiting to become more pronounced. Increasing the value of R_1 or reducing the value of R_2 would have similar overall results.

Review

- Reviewed the principle of operation of Zener diodes (impact ionisation).
- Used the device (diode) characteristic to examine the operating point and linearity of a circuit.
- Introduced the Zener diode shunt regulator circuit.
- Provided a method for designing the component values of the regulator.
- Introduced the idea of small signals and large signals.
- Considered the effects of distortion that large signals experience due to the non-linear nature of the diode characteristic with an audio example.

All of this builds towards analysis of transistor circuits.