Chapter 6 : DIODES IN TELECOMMUNICATIONS

We used diodes to rectify the a.c. voltage and convert it to a d.c. supply voltage in Chapter 2. We employed the *self-operated switch* property of diodes in that application. When the potential across the diode exceeds the threshold voltage, diode becomes almost a short circuit. Otherwise it remains open. This useful property of diodes is exploited in many applications in telecommunications electronics.

6.1. Diode detector

The AM signal at the output of the second IF amplifier is

$v_{IF}(t) = V_{IF}\,[1 + m(t)]\,\cos(\omega_{IF}\, t)$.

The waveform of this signal is given in Figure 1.5(a) (where m(t) is a sinusoid) and its spectrum for a general modulating signal m(t) is given in Figure 1.12(b). AM demodulation is separating the information signal m(t) from $\cos(\omega_{IF}\, t)$. The simplest and oldest method of doing this is called *envelope detection.* In an envelope detector, the signal is first *half wave* rectified and then low pass filtered. We employ the rectification property of diodes in envelope detection.

A half wave rectifier using an ideal diode and its function on m(t) is shown in Figure 6.1(a). The information signal is assumed to be a sinusoidal test signal

$m(t)= (V_m/V_{IF})\cos(\omega_m\, t)$.

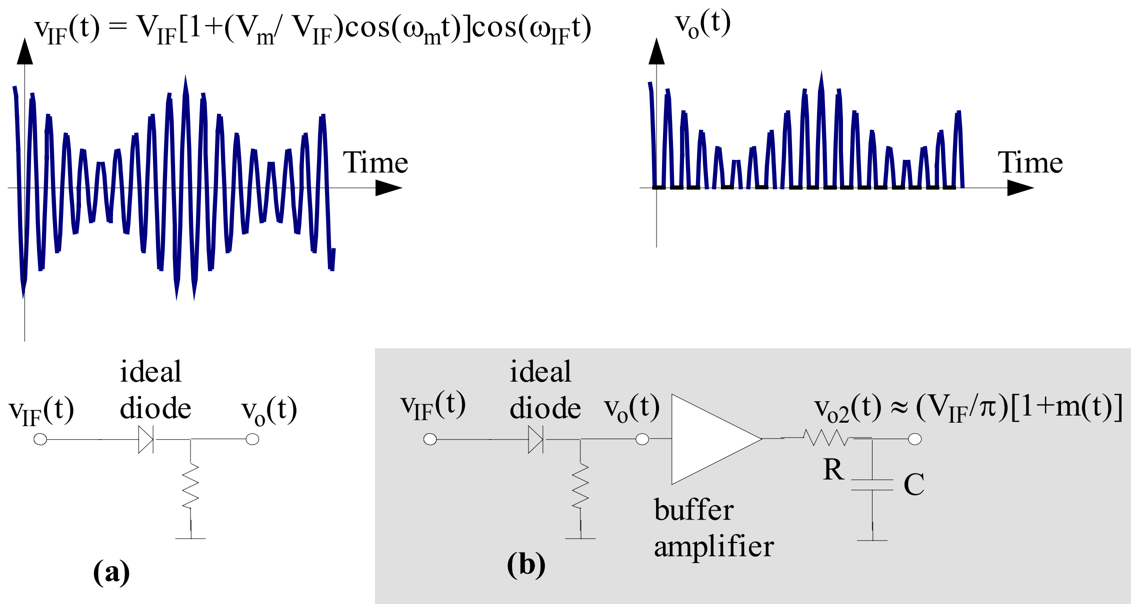


Figure 6.1 (a) Half wave rectifier and waveforms and (b) RC LPF following the rectifier

The IF frequency is always much larger than the modulating signal frequency. Diode rectifies the AM signal and only positive half cycles appear across the resistor. Note that the mechanism is similar to power rectification problem in Chapter 2, except the amplitude varies with respect to time in this case.

Half wave rectified signal can be written as

$v_o(t) = V_{IF}\ [1 + m(t)]\ \{[\cos(\omega_{IF} t) + |\cos(\omega_{IF} t)|]/2\}$.

$s(t) = [\cos(\omega_{IF} t) + |\cos(\omega_{IF} t)|]/2$

is the mathematical expression for half wave rectified sine wave. The shape of s(t) is similar to the one in Figure 2.17. This waveform can also be represented as a linear combination of sinusoids, like the square wave in Section 1.2, as

$$s(t) = 1/\pi + (1/2)\cos(\omega_{IF} t) + (2/3\pi)\cos(2\omega_{IF} t) - (2/15\pi)\cos(4\omega_{IF} t) + (2/35\pi)\cos(6\omega_{IF} t) - \dots$$

$$= a_o + a_1\cos(\omega_{IF} t) + \sum_{n=1}^{\infty} a_{2n}\cos(2n\omega_{IF} t)$$

where a_o is the average value of s(t) and a_1 is the coefficient of the fundamental component. The harmonics in the summation are only even harmonics in this signal. When we substitute this expression for s(t), $v_o(t)$ becomes

$$v_o(t) = (V_{IF}/\pi)[1 + m(t)] + V_{IF}[1 + m(t)] \times \{a_1\cos(\omega_{IF} t) + \sum_{n=1}^{\infty} a_{2n}\cos(2n\omega_{IF} t)\}$$

Spectral structure of $v_{IF}(t)$ and $v_o(t)$ are given in Figure 6.2, for $m(t) = (V_m/V_{IF})\cos(\omega_m t)$. Note that the first term in $v_o(t)$ is $(V_{IF}/\pi)[1 + m(t)]$ and it is the lowest frequency component in the summation. This term is the information signal (plus a d.c. term) and all we must do is to filter out all the other terms using a LPF.

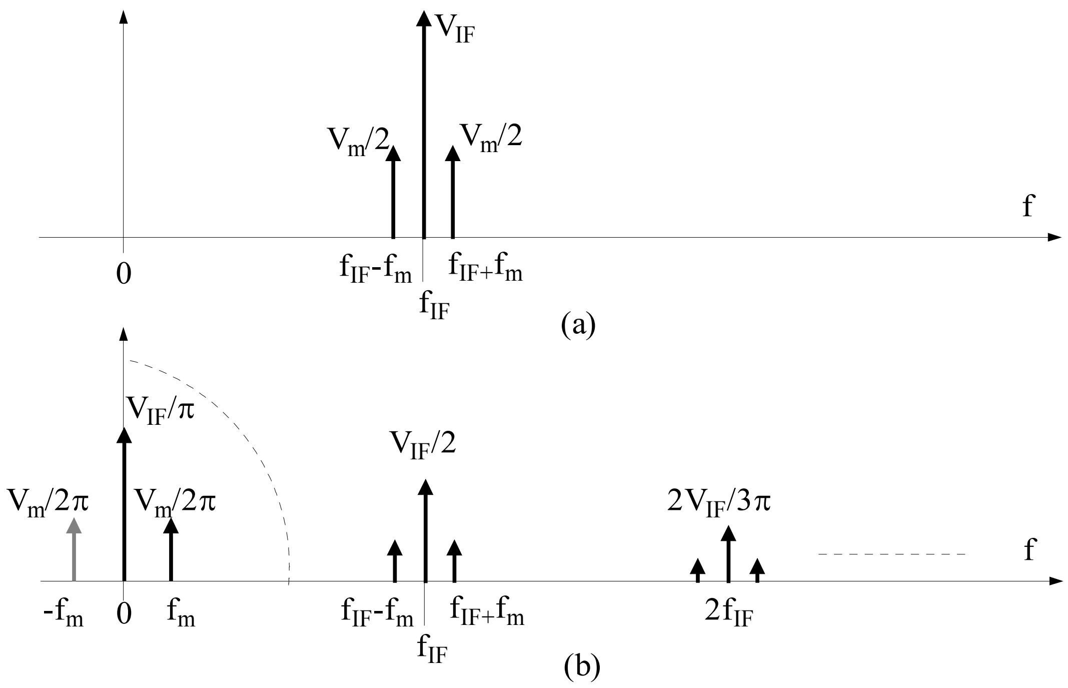


Figure 6.2 Frequency spectrum of (a) $v_{IF}(t)$ and (b) $v_o(t)$

Figure 6.1(b) shows how $(V_{IF}/\pi)[1 + m(t)]$ can be obtained from $v_o(t)$. The amplifier serves as a buffer in this circuit and isolates the capacitor of the BPF from the diode. The rectified voltage $v_o(t)$ appears intact at the output of the amplifier. Amplifier output is like a voltage source and hence $v_o(t)$ is fed into the RC LPF. With a properly chosen cut-off frequency, LPF eliminates all frequency components except the low frequency ones. This is an *ideal* envelope detector configuration.

The simple envelope detectors are not implemented using a buffer amplifier, in practice. The capacitor of the LPF is connected directly across the diode as shown in Figure 6.3. Without a buffer amplifier, the capacitor loads the diode. When diode is *on*, the capacitor charges up through the *on resistance* of the diode. When it is *off*, the capacitor discharges through parallel resistance R. The time constants in two cases are different. This situation arises because of the nonlinear nature of the diode.

Voltage across the capacitor $v_o(t)$ follows the envelope with some ripple as in the case of power rectification. Here we are not allowed to increase the capacitance, hence the time constant RC, indefinitely. RC must be chosen such that the capacitor can discharge fast enough and its voltage can follow the minimum slope of the envelope, $-V_m\omega_m$ (V/sec).

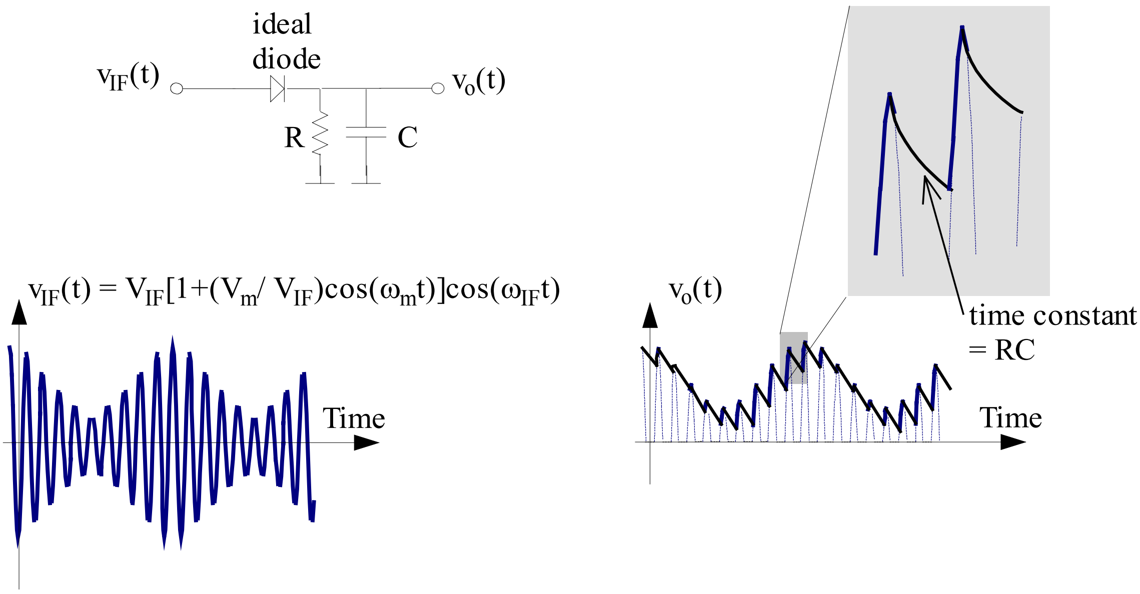


Figure 6.3 Envelope detector

Otherwise the detected envelope signal suffers from what is known as *failure-to-follow distortion* or *diagonal distortion*. This upper limit on RC causes ripple on the detected waveform, particularly during the up-sloping phases of the envelope, in envelope detectors. This is shown in the shaded box in Figure 6.3.

6.1.1. Real diodes in envelope detectors

We use a fast signal diode 1N4448 in the envelope detector of TRC-10. 1N4448 is a low cost silicon diode, which is very commonly used in low power applications. Real diodes have threshold voltage V_o, which has adverse effects on the detected signal.

Assume that we replace the ideal diode in Figure 6.1 with a real diode, like 1N4448. To keep the discussion simple, let us model the diode by piece-wise linear model of Figure 2.16(a). The operation of the rectifier of Figure 6.1 with a real diode is shown in Figure 6.4.

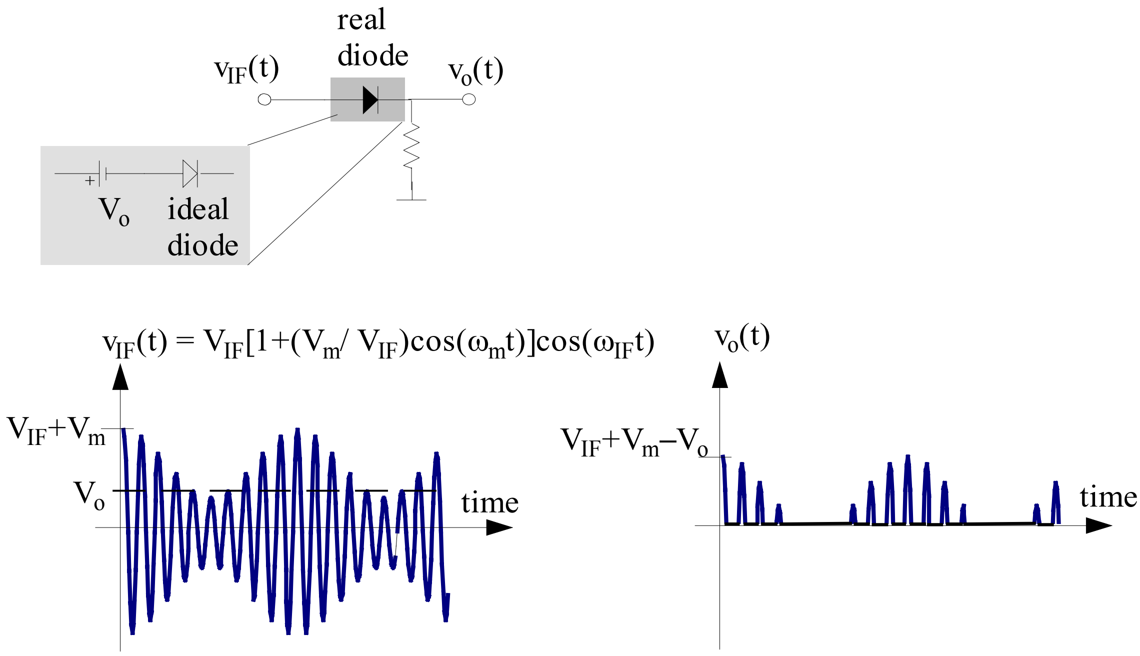
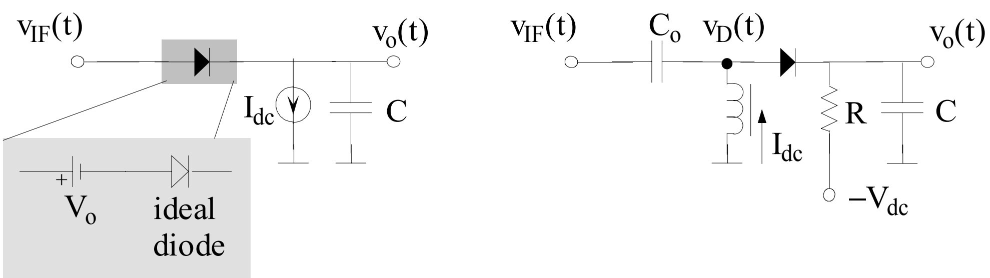


Figure 6.4 Rectifier with a real diode

The diode conducts only after the voltage across its terminals exceeds the threshold voltage V_o. V_o can be taken as 0.6 volts approximately for 1N4448, in which case the detected envelope of a $v_{IF}(t)$ of, for example, 2 V pp amplitude is severely distorted. This is a very important limitation, which is illustrated in Figure 6.4.

We overcome this problem in electronics by few precautions. Consider the circuit in Figure 6.5(a). The d.c. current source sets the average diode current to I_{dc} at all times. The diode is *on* even when $v_{IF}(t)$ is zero. This also means that the d.c. voltage across the capacitor $v_o(t)$ is $-V_o$, since the average value of $v_{IF}(t)$ is zero. The output voltage $v_o(t)$ can follow the envelope down to very low positive input voltage levels.



(a) (b)

Figure 6.5 Envelope detector with a real diode compensated for V_o; (a) equivalent circuit and (b) implementation

This preconditioning of a diode by forcing a d.c. current to flow through it is called *biasing*.

We implement this solution in electronics by the circuit given in Figure 6.5(b). Here the d.c. current source is implemented by a large resistor R connected to a negative voltage supply, $-V_{dc}$. The value of I_{dc} is $(V_{dc}-V_o)/R$. The return path of the d.c. current is the inductor, keeping the d.c. component of $v_D(t)$ at zero. As far as d.c. circuit is concerned, we must maintain that the d.c. current $(V_{dc}-V_o)/R$ is insensitive to variations of other parameters in the circuit, such as V_o and the *on* resistance of the diode. This requirement enforces the choice of a large R and $V_{dc} >> V_o$. The a.c. circuit must experience a high impedance at this node (the current source terminal impedance is infinite), which also means that R must be large compared to other prevailing a.c. circuit impedance.

We employ a *large* capacitor C_o in series with the diode to block the d.c. component of the diode current. C_o presents virtually zero impedance to $v_{IF}(t)$ and hence $v_{IF}(t)$ appears directly across the *large* inductor. All high frequency components of diode current pass through C_o. Inductor is virtually open circuit for all frequency components at and above ω_{IF}.

6.2. TX/RX switch

The communication mode of TRC-10 is *simplex*, which means that we use the same frequency channel both for transmission and for reception. During the transmission, TX output amplifier must be connected to the antenna, and the frequency channel must be occupied by our transmitter signal. The antenna must be switched to the receiver input while listening. The TX/RX switch in TRC-10 does this electronic switching.

The switching property of diodes is enhanced when they are used with appropriate biasing. Consider the circuit in Figure 6.6.

Assume that $v_{in}(t)$ is the RF signal that must be switched on and off the load R_o. The current source is a d.c. source, and it can take on two levels, I_{dc} and $-I_{dc}$. When we want to switch the diode *off*, we set the current source to $-I_{dc}$. The I_b is set to I_{dc} in order to switch the diode *on*.

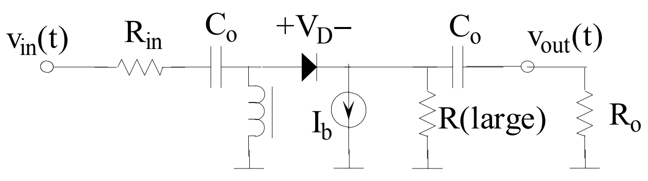


Figure 6.6 A diode switch circuit

The two capacitors block the d.c. current, and forces it to flow either through the diode and the inductor, or through the large resistor R. On the other hand, the capacitors exhibit low impedance path to RF signals. The inductor provides a short circuit path for the d.c. current to ground, hence keeping the anode of the diode at zero d.c. potential at all times.

The circuit behavior for $I_b = -I_{dc}$ is shown in Figure 6.7(a). the current direction is opposite to that of diode, and the only path it can pass is through the large resistor R. I_{dc} develops a potential of $I_{dc}R$ across R, which reverse-biases the diode. The diode voltage is

$v_D(t) = v_{in}(t) - I_{dc}R$.

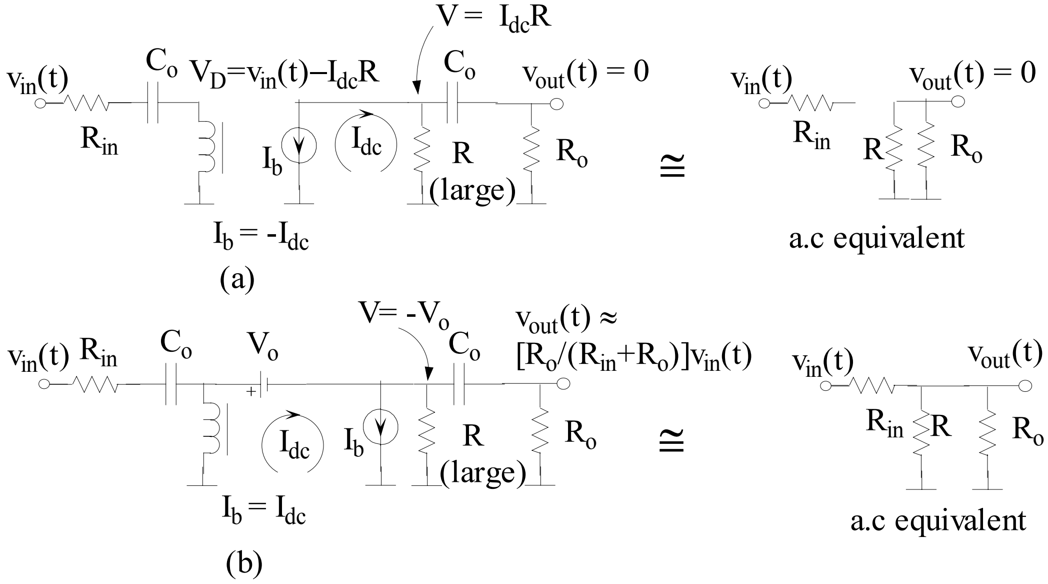


Figure 6.7 Diode switch circuit when (a) $I_b = -I_{dc}$ and (b) $I_b = I_{dc}$

As long as the amplitude of $v_{in}(t)$ does not exceed $I_{dc}R$, the diode is OFF and $v_{out}(t) \approx 0$. The value of I_{dc} and R must be determined to satisfy this condition.

When $I_b = I_{dc}$ the d.c. current flows through low impedance path of the inductor in series with the diode. The diode is turned on and the input voltage is switched on to load. Diode remains on as long as the minimum current (negative) $\{[v_{in}(t)-V_o]|_{min}\}/(R_{in}+R_o)$ is less than I_{dc}.

6.2.1. Diode biasing

Diode V-I characteristics is useful to discuss the current bias and diode switching on a quantitative basis. Consider a generic case of $R_{in} = R_o = 50\ \Omega$ and the power that must be delivered to the load is 100 mW, in the circuit depicted in Figure 6.6. Assuming that $v_{in}(t)$ is sinusoidal (this is always a good assumption for narrow band signals like the signals in TRC-10), the amplitude of $v_{in}(t)$ becomes 6.3 V, i.e.

$v_{in}(t) = (6.3\ \text{V})\cos(\omega t)$.

In the following example, we shall first find the required bias current I_{dc} by making certain assumptions and then check whether these assumptions are correct, with $v_{in}(t)$ as input .

The switching diode is 1N4448. Assuming that the piecewise linear model is valid, the RF current i(t) through the diode is

$i(t) = v_{in}(t)/(R_{in}+R_o) = (63\ \text{mA})\cos(\omega t)$.

The total diode current becomes

$i_D(t) = I_{dc} + i(t) = I_{dc} + (63\ \text{mA})\cos(\omega t)$.

Peak-to-peak swing of $i_D(t)$ is 2×63 mA=126 mA. I_{dc} must be such that $i_D(t)$ is always positive. This sets a minimum value of 63 mA for I_{dc}. Let us choose I_{dc} = 65 mA.

We can apply this current on the V-I characteristics of 1N4448 to find the diode voltage $v_D(t)$ and output voltage $v_{out}(t)$, as shown in Figure 6.8.

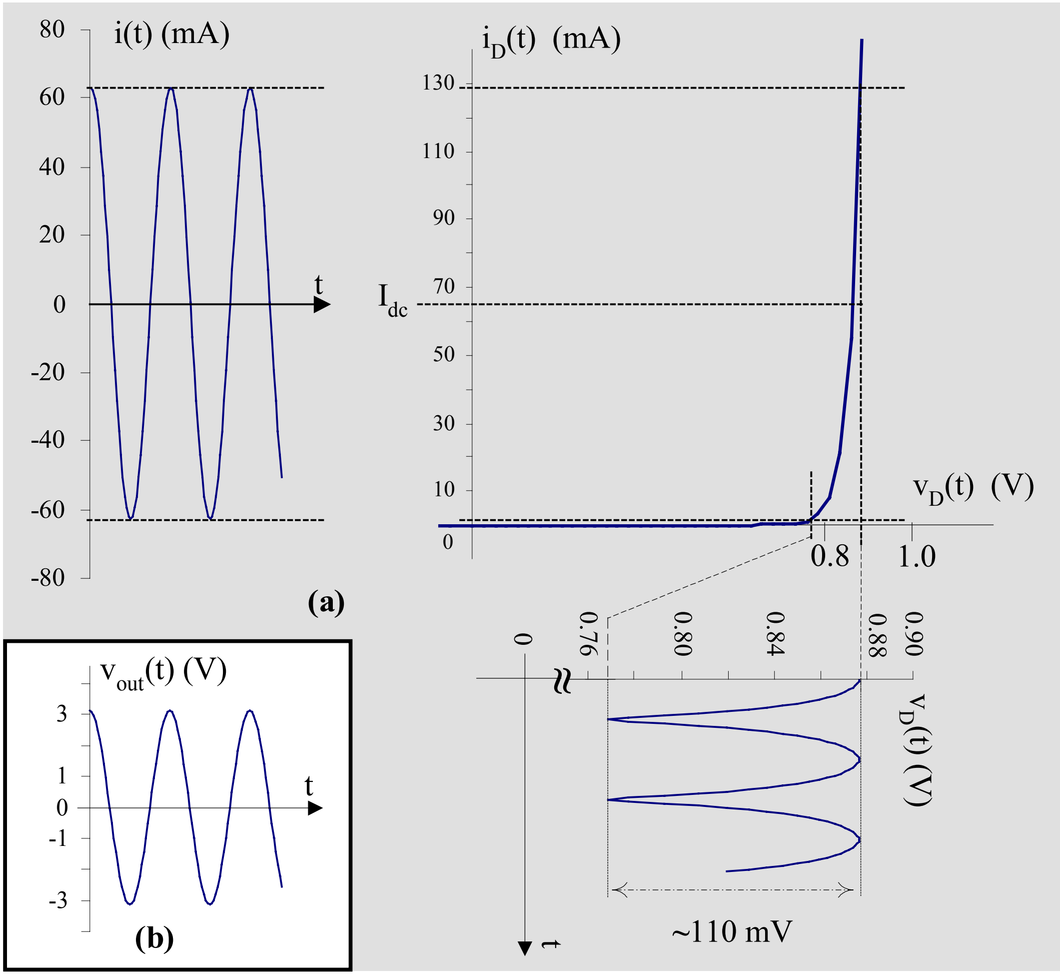


Figure 6.8 Diode biasing (a) diode characteristics and diode voltage and (b) output signal

Once I_{dc} *biases* the diode so that *the average current through it is 65 mA*, whatever the other parameters may be, the diode operates with $i_D(t)$ confined in a range between approximately 2 mA and 128 mA. This is delineated in Figure 6.8(a). This input current yields a diode voltage variation between 0.77 V and 0.88 V. The $v_D(t)$ waveform is severely distorted.

However, if we calculate $v_{out}(t)$ as

$$v_{out}(t) = v_{in}(t) - i(t)R_{in} - v_D(t)$$

at every point in time, we obtain the waveform shown in Figure 6.8(b). This signal looks like a perfect sine wave, because the distortion in it is limited to the distortion in $v_D(t)$. $v_D(t)$ is a 110 mV p-p signal. The p-p amplitude of $v_o(t)$ is 6.25 V, which is almost the same as found from *assumed* RF current i(t), $v_o(t) = i(t) \times R_o =$ (3.15 V)$\cos(\omega t)$. The diode and the circuit functions almost like an ideal switch.

It is obvious that the equivalent circuit in Figure 6.7(b) is a very good one. It models the biased diode switch operation very well.

6.2.2. PIN diode switch

1N4448 performs very well as a switch, as we have seen in the example of Section 6.2.1. Let us now examine the *power budged* of this switch. The RF power delivered to the load is 100 mW. Another 100 mW is dissipated on the source resistance. Hence the switch handles a total of 200 mW RF power.

On the other hand, 1N4448 requires 65 mA bias current to operate. The threshold voltage V_o of 1N4448 at this average current level is about 0.88 V, as can be seen in Figure 6.8(a). 65 mA passing through 0.88 V makes 57 mW power dissipation.

We are dissipating 57 mW to switch 100 mW of RF power! This 57 mW dissipation can grow to a significantly higher level when the implementation requirements of the current source I_b is also considered.

A better approach is to use *PIN diodes* instead of signal diodes. “PIN” refers to the semiconductor structure of the diode. These diodes have three layers of semiconductor material, **P**-type/**I**ntrinsic (un-doped)/**N**-type, as opposed to two layer **P**/**N** of other diodes like 1N4448.

PIN diodes cannot be switched on and off quickly. Applying a forward voltage or a bias current activates the semiconductor current carrying mechanism in all diodes. When this voltage or current is removed diode stops conduction. PIN diodes require certain amount of time before this current carrying mechanism stops.

MPN3404 (or BA479) is a PIN diode. The datasheet is given in the Appendix. The *minority carrier life-time* of such PIN diodes is few microseconds (4 µseconds for BA479). This means that while the diode is on, if we reverse the current or the voltage across it for a brief period sufficiently less than this life-time, diode does not turn off. It remains in conduction. Half a period at 30 MHz is 1/60 µs, which is very short compared to minority carrier life-time.

This property of PIN diodes allows us to use them with small bias currents, in power switching applications.

TRC-10 uses two PIN diodes in a configuration shown in Figure 6.9.

R56 is the output resistance of TX output amplifier. C72, C75 and C76 are d.c. blocking capacitors, which isolate the switching circuit d.c. wise and provide a low impedance (virtually zero impedance) path for the RF signals.

S2 is a DPDT manual switch. It has a pair of switches, with independent contacts, operating in parallel. When the center tap of the first switch, S2/1, is connected to +15 V supply, TRC-10 transmits. S2/1 is the one shown in Figure 6.9. The other one, S2/2, is in the 16 MHz oscillator circuit. When the center tap of S2/1 is connected to –15 V, TRC-10 receives. The functions of S2 are:

- During reception:
  1. D8 is turned ON and D7 is turned OFF, antenna is connected to RX;
  2. 16 MHz oscillator module (discussed in Chapter 7) is turned OFF by shutting down its power supply;

- During transmission:
  1. D7 is turned ON and D8 is turned OFF, antenna is connected to TX;
  2. 16 MHz oscillator module is turned ON.

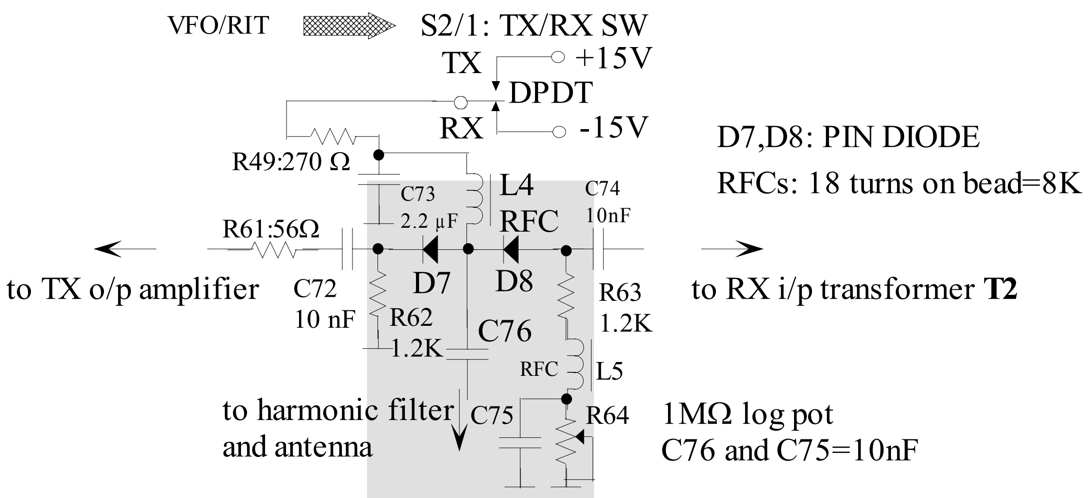


Figure 6.9 TX/RX switch circuit

The part of the circuit shaded in gray has two functions. One function is the *RF gain* adjustment performed by 1 M potentiometer R64. The other function is TX/RX RF switch. RF gain adjustment is discussed in Section 6.2.2. For the following discussion of RF switch function, assume that the center tap of R64 is all the way up and RFC L5 is grounded.

Figure 6.10 gives a clarified view of RF switch circuit.

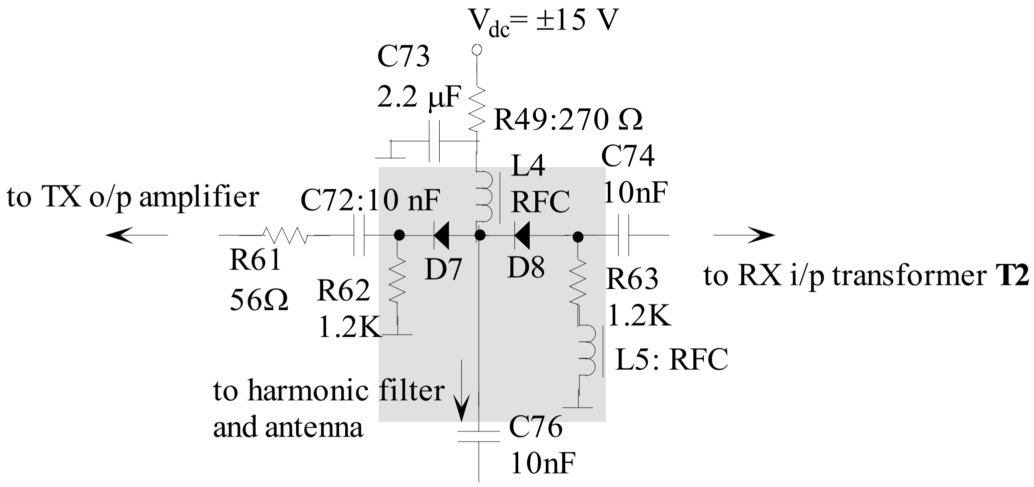


Figure 6.10 TX/RX RF switch circuit

Few mA of bias current is sufficient to keep the PIN diode in conduction. However bias current in diodes has another effect: we can control the value of the ON resistance R_D of the diode by changing the bias current. The variation of R_D with respect to bias current is given in the data sheet of MPN3404. ON resistance of the diode is only 0.7 Ω at 10 mA forward current (5 Ω for BA479).

For good switching of circuits with termination resistances of about 50 Ω as in our case, R_D must be as low as possible. Otherwise a significant voltage drop occurs on the diode. We choose the minimum, approximately 1 Ω at 10 mA of bias current.

When V_{dc} is set to +15 V, d.c. bias current flows through R49, L4, D7 and R62. L4 is an inductor and short circuit d.c. wise. Similarly C73 is open circuit for the bias current. Hence the bias current is approximately (+15 V)/(R49+R62), or 10 mA, ignoring the turn-on voltage V_o of D7. This current sets the ON resistance of D7 to 1 Ω and The RF signal at TX output amplifier is connected to harmonic filter through a 1 Ω resistor.

The d.c. voltage at the node between D7 and D8 is now $(+15\text{ V}-V_o)\times[R62/(R49+R62)] + V_o$, or 12.4 V. D8 is completely reverse biased and its only effect in the circuit is a small *junction capacitance* that appears between its terminals. This capacitance is given in the data sheet as 0.5 pF approximately. The RX input is effectively isolated from the TX output, which is helpful to protect and avoid saturation at RX mixer input.

When transmitters are switched on to the antenna abruptly, the instant power rise causes emissions at frequencies other than the intended one. This is a kind of spurious emission, which lasts for only few tens of microseconds. They produce clicking sounds at the output of the receivers of other receivers operating at other bands. C73 and R49 are included into the circuit to slow down the initial build up of bias current when TRC-10 is switched to TX. When V_{dc} is switched to +15 V, C73 charges up from –15 V with a time constant of R49×C73 = 0.6 ms. Bias current rises up to 10 mA in about 2.4 ms (four times the time constant), hence allowing the emitted signal power to increase gradually.

When V_{dc} is set to −15 V, d.c. bias current flows through L5, R63, D8, L4 and R49. The bias current D8 is 10 mA, again. The RF signal at the antenna is connected to RX input via a 5 Ω resistor. D7 is reverse biased and TX output is isolated from the antenna and RX, in this case.

6.2.3. RF gain control

Wireless telecommunications have many aspects. One of the implications of the word "tele" is that the communicating parties can be very far away from each other in some occasions and they can be very close to each other (just next door), in others. This type of use imposes a strong requirement on receivers, related to received signal strength. The received signal power from a nearby TX and a far away TX can differ by 80-90 dB, while still remaining within the limits of a receiver. A wireless receiver must be able to cope with received signals of such diverse strength.

Attenuating the strong RF signals just after the antenna is one of the measures to this end. TRC-10 employs a manual RF gain control (rather attenuator). This attenuator makes use of the controllable R_D property of PIN diode D8, and the potentiometer R64. RF gain control circuit is shown in Figure 6.11.

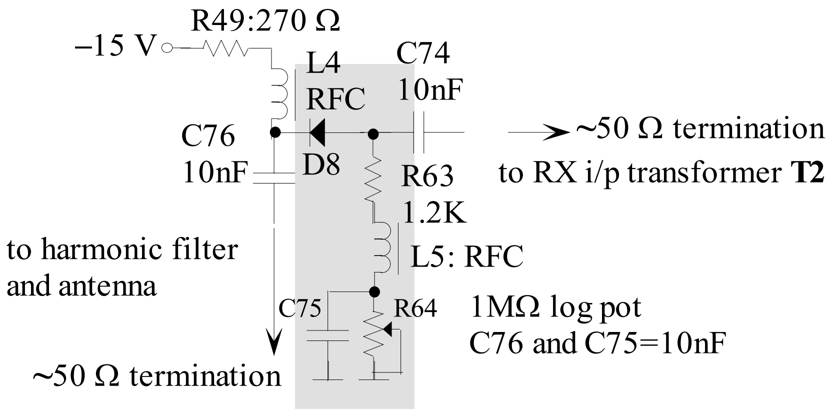


Figure 6.11 RX RF attenuator

C75 is a by-pass capacitor, which provides a very low impedance path for RF signals and by-passes R64 for RF. C75 keeps R64 always out of the RF path, which is particularly useful to decrease the TX signal break through during transmission.

C75 is open circuit for d.c. 1 M potentiometer is in the bias current path during reception. Bias current of D8 during reception is

$(15 \text{ V}-V_o)/(R64+R63+R_D+R49)$,

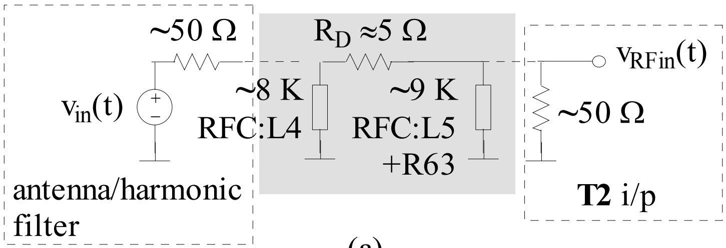
where V_o and R_D are the threshold voltage and the on resistance of D8, respectively.

When R64 is at its minimum, which is zero ohms, the analysis of the circuit is as given in Section 6.2.2. Bias current is about 10 mA and R_D is about 1 Ω.

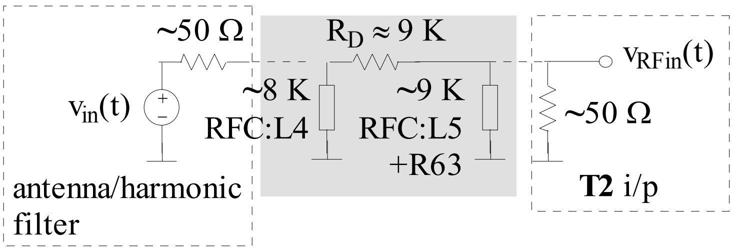
When R64 is at its maximum, 1 M, the bias current is approximately (15 V-V_o)/(1M), or 14 μA. R_D at this forward current level is large for PIN diodes, in the order of 10K.

L5 is added in series with R63 to increase the RF impedance of the current bias path. Both L4 and L5 provide impedance of about 8 K at 16 MHz.

With above considerations, the RF equivalent circuit the attenuator during reception is given in Figure 6.12.



(a)



(b)

Figure 6.12 Equivalent circuit of RX RF attenuator at 16 MHz; (a) 10 mA bias current and (b) 14 μA bias current

6.3. Audio gain control

Referring back to Figure 6.5(b), the output voltage of the envelope detector is

$$v_o(t) = V_{IF} [1 + m(t)] - V_o,$$

with possibly some ripple on it. The LPF formed by R and C effectively filters out almost the entire ripple, which is an RF component. $V_{IF}[m(t)]$ is the detected information signal. We amplify this signal using TDA7052A and feed it to the loudspeaker, as discussed in Chapter 2. The d.c. part $V_{IF} - V_o$ in $v_o(t)$ also carries an important information about the communication channel. V_{IF} is a scaled version of the amplitude of the RF signal delivered by the antenna.

Wireless communication channels have peculiar properties, particularly at HF band. One such effect is called *fading*. The received signal amplitude changes occasionally in time rather slowly, due to propagation mechanisms that take place in HF band. This variation usually has a period more than few tens of seconds. When listening to the receiver output under fading, one gets the feeling that the voice slowly *fades* out and then comes back. This can be quite disturbing.

We use the d.c. component of detected signal to compensate fading effect in TRC-10. "V_{IF}" is used to control the gain of TDA7052A, such that as the received signal amplitude *fades out*, the gain of the amplifier is increased. Similarly, as received signal comes back, gain decreases. The loudspeaker amplifier is shown in Figure 6.13.

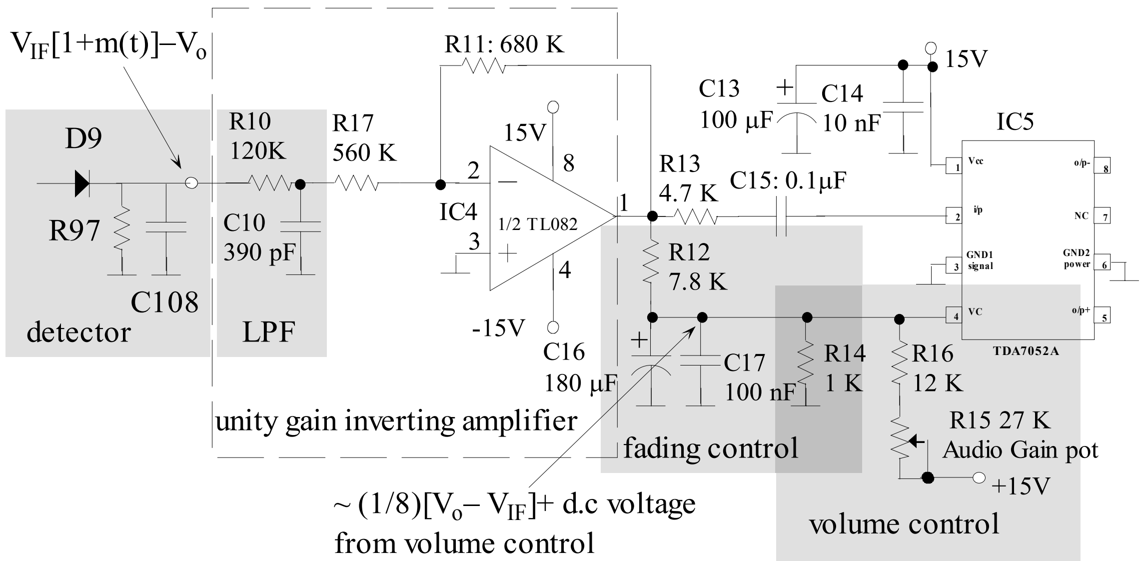


Figure 6.13 Audio gain control circuit

R12 and the parallel combination R14//(R15+R16) together with C16+C17 filters $v_o(t)$, to provide approximately (1/8) $[V_o - V_{IF}]$ only to the pin 4 of TDA7052A. the volume control potentiometer R15 and R16 superimposes a d.c. voltage on (1/8) $[V_o - V_{IF}]$, such that potential across pin 4 varies approximately between $0.4 - (1/8)V_{IF}$ and $1.1 - (1/8)V_{IF}$ volts d.c. Once the R15 is adjusted for a comfortable volume level, the sound volume remains stable at that level. If the RF signal amplitude fades, V_{IF} falls and the voltage across pin 4 increases. The gain of TDA7052A increases, in turn.

6.4. Bibliography

The ARRL Handbook has a chapter on modulation and demodulation (Chapter 15) and information on diodes that we discussed in this chapter (p.8.17).

Biasing is a fundamental topic in electronics and every electronics text devotes a significant space for it. Also detection is covered by all communications textbooks. P.J. Nahin's *The Science of Radio* (2nd Ed., Springer-Verlag New York, Inc, 2001) is an excellent book on introductory Telecommunications. A classic text, *Communication Circuits: Analysis and Design* by K. K. Clarke and D. T. Hess, gives a very good account of envelope detectors, although it is rather advanced and somewhat seasoned.

6.5. Laboratory Exercises

Envelope detector

1. The detector circuit of TRC-10 is given in Figure 6.9.

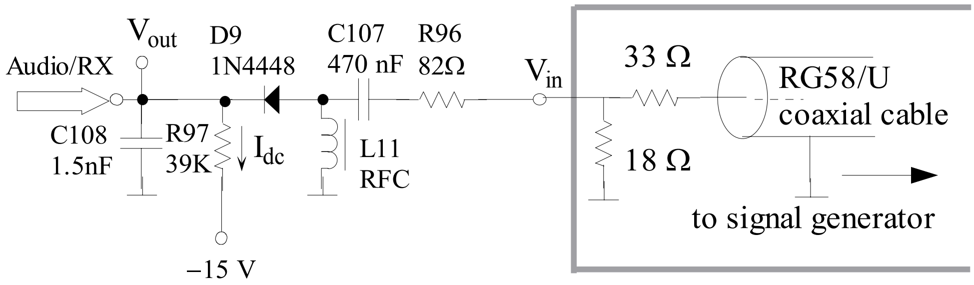


Figure 6.14 TRC-10 envelope detector

Calculate the bias current I_{dc} in this circuit. Find out the threshold voltage V_o of 1N4448 for this bias current. You can do this by examining the data sheet of 1N4448. The graph of “V_F -Forward Voltage” vs “I_F -Forward Current” reveals this information. Record this voltage. What is the threshold voltage if the bias current is 1 mA? (See problem 1 of this chapter.)

2. Wind 17-18 turns on RFC core to make L11. Take care while winding and stripping the leads, etc. as you did in the previous inductors. Install the components C107, L11, D9, R97 and C108 and solder them. Install R96 such that IC13 side is not connected and solder the C107 side. Check all connections both visually and using an ohmmeter.

   Switch the power on. Using your multimeter, measure the threshold voltage V_o, across the anode and cathode of the diode. Does it agree with what you have found from the data sheet?

   Measure the voltage across C108, V_{out}. How does it compare with V_o? Switch the power off.

3. Mount and solder 33 Ω, 18 Ω resistors and the coaxial cable, with a BNC connector on one end, to the free end of R96 as shown in Figure 6.14 in gray bracket, using ground plane construction technique. Connect the coaxial cable to the signal generator. Switch the signal generator on. Set the signal generator to AM signal with 10 V p-p amplitude and 50 % modulation, to obtain

   $(2.5V)[1+0.5\cos(2\pi f_m t)]\cos(2\pi f_{IF} t)$,

   where f_m is 1 KHz and f_{IF} is 16 MHz. Connect the probe of channel 2 of the scope to signal generator output across 18 Ω resistor in the attenuator circuit. Observe the waveform on the scope.

   Calculate V_{in}, ignoring the loading of R96.

4. Switch the power on. You will hear a high pitch sound. This sound is the detected 1 KHz modulation signal. Adjust the volume pot to a comfortable level.

   Connect the probe of channel 1 of the scope to V_{out}. Adjust the scope to observe approximately 0.8 V p-p 1KHz sine wave. Measure and record the amplitude of V_{out}, and minimum and maximum ripple on the signal.

   Connect a probe to IC6 output. Is there any ripple?

5. Decrease the signal generator output amplitude gradually, while both watching IC6 output and listening the sound. Adjust the scope and the volume pot as necessary. Record the input amplitude levels where you can no longer see the signal and where you can no longer hear the signal, separately. Calculate V_{in} for these levels.

6. Set the signal generator output back to 5 V p-p. Vary f_m between 500 Hz and 10 KHz and measure the IC6 output amplitude. Chose the number of measurements and measurement frequencies adequately. Find the –3 dB frequency. Switch the power and equipment off.

7. Remove 33 Ω, 18 Ω resistors and the coaxial cable. Remove excess solder. Place the free end of R96 into its place and solder.

8. Set up the input part of the circuit in Figure 5.26 (i.e. two 1.5 K and the 56 Ω resistors, and the coax.), and check that the entire RX/IF section and loudspeaker amplifier chain works. Signal generator output amplitude must be low. 10 mV to 50 mV p-p is sufficient. Describe how you performed this test and record your observations. Do not forget that now you have the very narrow band IF filter on the way. You must tune the signal generator frequency to the center frequency of IF filter. All probe connections must be made to the OPAMP outputs only.

   Desolder and remove the two 1.5 K resistors, 56 Ω resistor and the coaxial cable at the input. Remove the excess solder from the copper surface using your desoldering pump. Install and solder C94 and C95.

   TX/RX switching circuit

9. Make the two RFCs L4 and L5, like you made L11. The circuit diagram of TX/RX switching circuit is given in Figure 6.9. Install and solder L4, L5, R49, R62, R63, C73, C74, C75, D7 and D8. Make sure that the polarities of the diodes are correct.

   Install and solder the 2-pin PCB jack J21 for 1 M R64. Install and solder the 3-pin PCB jack J22 for S2/1 TX/RX switch.

   Check all connections.

10. R64 is a 1 M *logarithmic potentiometer*. When its knob is set to approximately the mid point of the range, the resistances on either side are not equal in these *log-*

pots. One of them is approximately $(1\ E6)^{\alpha}\ \Omega$, where α is a positive number less than one. For this pot, α is about 0.8 and $(1\ E6)^{\alpha}\ \Omega$ is about 70 K, approximately. Find out which side pin is on the high resistance side. Short circuit that pin to the center pin by soldering a small piece of wire to those two pins on the pot.

Cut two 20 cm pieces of insulated construction wire. Strip a 5 mm of insulation from each end. Connect and solder one wire to *low* impedance side pin. Solder the other wire to one of the two shorted pins. Fit a 2-pin PCB plug to the other two leads of the wires.

Fit the plug into the jack J21 and check that the contacts are properly functioning.

Carefully mount R64 on the panel. Fit its knob. Collect and tie the wires together and guide it along the side of the tray tidily, from the panel to the jack.

11. S2 is a DPDT “ON-ON” switch. It has two switches operating in parallel. Each switch has three pins. The normal position of S2 is such that the center (floating) pin is connected to one of the side pins, in each switch. This side pin is RX pin in each switch, so that when the switch is left alone TRC-10 remains in RX mode. When the switch is toggled, center pin contacts the other side pin. This pin is TX pin.

    Identify the center pins, the RX pins and TX pins on each switch, using a multimeter.

    Cut three 20 cm pieces of insulated wire for each switch (six altogether). Strip a 5 mm of insulation from each end. Solder a wire to each contact of S2. In this exercise, we connect only S2/1. S2/2 switch is connected to the PCB in the exercises of Chapter 7. Collect the three wires from S2/2 together, wind them into a coil and tie them.

    Before fitting a 3-pin PCB plug to the wires of S2/1, check the PCB jack J22 pins. +15 pin on the jack must correspond to TX pin on the plug. The pin connected to R49 on the jack must correspond center pin on the plug, and –15 on the jack to RX on the plug. Fit the wires to the plug carefully.

    Fit the plug into the jack J22 and check that the contacts are properly functioning.

12. Make sure that C72 is *not* connected yet. Switch the power on. In this exercise, we perform the d.c. test of the switch circuit without any signal in it.

    Connect your multimeter across R62 and measure the d.c. voltage across it, when S2 is thrown to TX mode. Calculate the current passing through R62. This is the bias current of D7. Record these values.

    Measure the d.c. voltage across D7, with S2 again in TX mode. Record this voltage. From the data sheet of PIN diode, find the threshold voltage and R_D corresponding to the current you measured. Compare this voltage with the one you measured. Record all your work and observations.

Let S2 be in its normal position (i.e. RX mode). Measure the d.c. voltage across R63 with R64 set to minimum, to midpoint and to maximum. Calculate the bias current of D8 for these three cases. Find out the threshold voltage and R_D corresponding to these bias currents.

Switch the power off.

13. We assumed that approximately 50 Ω terminates all three ports of the TX/RX switch circuit. The RX port provides the input to RX mixer. SA602A has input impedance of 1.5 K, nominally. Actually this input impedance varies significantly with frequency, and we expect it to be less than 1.5 K. T2 transformer is a matching transformer. We use a T25-10 toroid, for this transformer.

    Low loss, high permeability transformer materials are not available at 30 MHz. We use a core made of low loss inductor material, mix-10 of Micrometals. This transformer is wound as an *auto transformer* in order to reduce the leakage flux. Figure 6.15 shows the structure of T2.

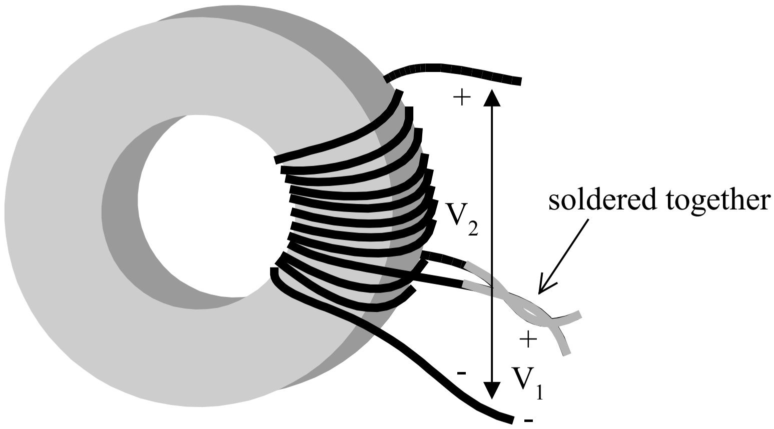


Figure 6.15 T2 auto transformer

The first four turns of the secondary winding and the primary winding are the same, and two coils are electrically connected in this auto transformer. The secondary winding has eight more turns, making a turns ratio of 4:12.

Wind the transformer using an appropriate length of 0.2 mm diameter wire. Wind the turns tightly. You can try a *trifillar* winding to reduce leakage flux, if you wish. Refer to ARRL Handbook for multifillar windings. You can also ask the lab technician to describe how to make it and show you one.

Install and solder T2.

14. The RX input circuit is given in Figure 6.16.

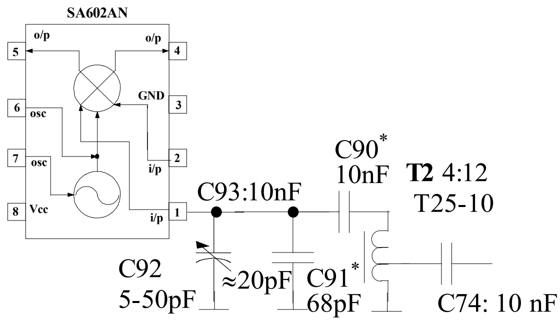


Figure 6.16 RX mixer input circuit

Mix-10 material has a relative permeability of 6. T25-10 core has an inductance constant of 1.9 nH/turns^2. With 12 turns secondary winding presents an inductance of about 300 nH. C91 and C92 tune out this inductance at 29 MHz.

SA602A has a d.c. bias at its both inputs. This bias voltage must be guarded. C90 is a d.c. blocking capacitor performing this task.

Install C90, C91 and C92, taking care to place the adjustment pin of C92 to ground side. Solder them. Check all contacts.

15. Install and solder C72. Check its connections. Solder a 51 Ω resistor and the free end of the cable from antenna jack across C79, again using ground plane construction technique. Connect a probe of a scope channel across C79 and 51 Ω resistor.

The 29 MHz section of the transmitter is complete. The circuit is given in Figure 6.17.

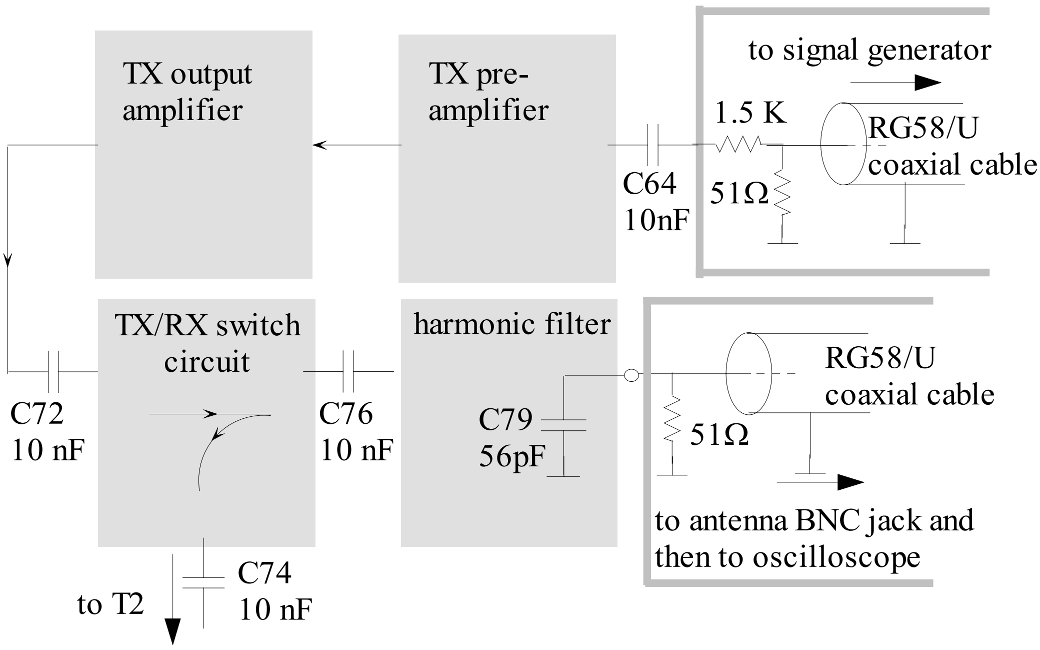


Figure 6.17 TX 29 MHz section

Solder the RG58/U cable for signal generator connection. Note that the 1.5 K and 51 Ω resistors are already on the board, left from Exercises 4.16 and 5.8.

Set the signal generator for a 29 MHz sine wave output with 50 mV p-p amplitude. Throw S2 to TX mode and watch the signal on the scope. Check that the entire 29 MHz section works. Estimate the gain of the overall section. Retune C65 and C69 if necessary.

Switch the power and the equipment off. Disconnect the oscilloscope and the signal generator. Desolder both cables, **but leave all ground plane constructed components and their connections on the board.**

6.6. Problems

1. Find the current I in the circuit of Figure 6.18(a). Also find the threshold voltage for this current. (Hint: You must refer to the data sheet of 1N4448. The solution requires iteration. Start by assuming that the threshold voltage of the diode is e.g. 0.7 V or 0 V, then calculate I. Find the threshold voltage for this value of I from data sheet and re-calculate I for new threshold voltage. Continue until convergence, i.e. the difference between two successive I values is less than e.g. 5%)

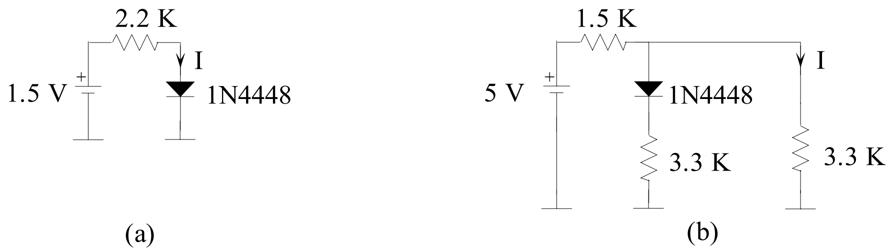


Figure 6.18. Circuit for (a) problem 1 and (b) problem 2

2. Find current I in the circuit of Figure 6.18(b). (Hint: First find the Thevenin equivalent circuit across the diode terminals and find the current through the diode as in problem 1)

3. Determine and sketch the waveform at the output for the circuits given in Figure 6.19. Assume that the diode is ideal.

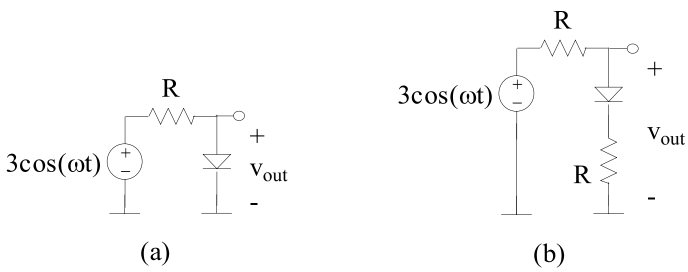


Figure 6.19 Circuits for problem 3

4. v(t) is 0.5 cos(ωt) V in Figure 6.20(a). Assume that the diode can be modeled by the piecewise linear model of Figure 2.16(a), with $V_o = 0.6$ V. What is $v_{out}(t)$ if

I = 0 A? Find the minimum value of I for which there is an undistorted replica of v(t) at the output. Find $v_{out}(t)$ for this value of I. What is the value of I such that time varying part of $v_{out}(t)$ is exactly half wave rectified (but scaled, of course) form of v(t)? (Hint: First find the Thevenin equivalent circuit, comprising both sources, across the detector circuit)

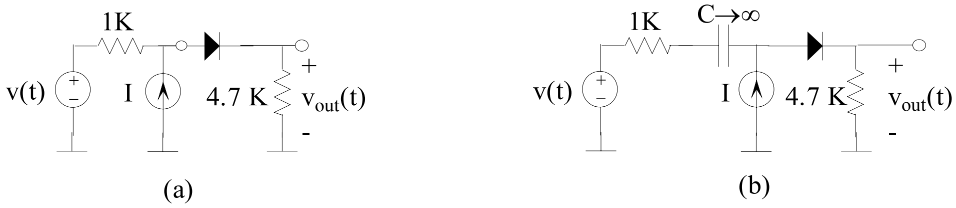


Figure 6.20 Circuit for (a) problem 4 and (b) problem 5

5. Repeat problem 4 for the circuit given in Figure 6.20(b).

6. If RC = $1/\omega_m$, in the circuit in Figure 6.3, estimate the maximum ripple on detected envelope if the modulation index is 100%? Assume $\omega_m \ll \omega_{IF}$. What is the minimum ripple? Is there any failure-to-follow distortion?

7. Calculate the attenuation with 10 mA and 14 μA bias current level in Figure 6.12, in dB. What is the *dynamic range*, i.e. the ratio between the two, of this attenuator?