LABORATORY REPORT - CHAPTER 7

v7.5

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Total Grade	/100

Remarks: Record all your measurements and write all your answers in the boxes provided.

Preliminary Work

1. Envelope detector

1. The envelope detector circuit of TRC-11 is given in Fig. 1. It serves to recover the AM modulation signal present on the RF signal. It does so by rectifying the positive side of the AM modulated signal. A low-pass circuit composed of C65 and R65 gets rid of the RF signal frequency.

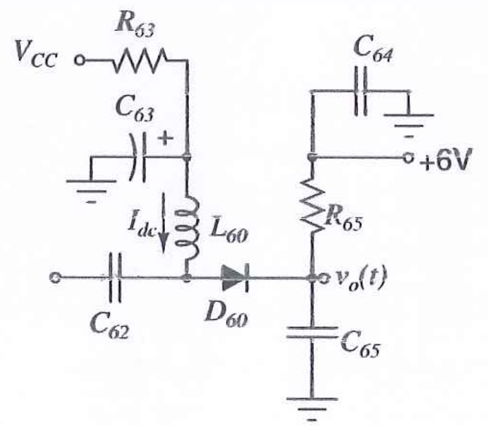


Figure 1: TRC-11 envelope detector circuit.

Calculate the dc bias current, I_{dc}, through R63, the detector diode 1N4148, and R65, from V_{CC}=12 V to +6 V, assuming C62, C63, C64, C65 are open-circuit and L60 is short-circuit. For this calculation, first assume that V_o of the diode is approximately 0.7 V. Then, find the actual voltage V_o of 1N4148 for this bias current. You can do this by examining the datasheet of 1N4148 on page 370. The graph "V_F -Forward Voltage" versus "I_F -Forward Current" reveals this information. Record this voltage.

Designator	Comment	Description
C63	100 μF	Electrolytic capacitor, polarized 16V
C64	100 nF	Capacitor, ceramic disc, 50V
C65	1 nF	Capacitor, ceramic disc, 50V
D60	1N4148	Silicon signal diode
L60	6.8 μH	Inductor, axial leaded
R63	56 K	Resistor, carbon film, axial leaded, 1/4W
R65	10 K	Resistor, carbon film, axial leaded, 1/4W

Figure 2: Bill of materials for the envelope detector circuit

2. Calculate the DC voltage at the cathode of the diode (V_{ed}, envelope detector output voltage):

$$V_{ed} = 6 + I_{dc}R_{65}$$

3. From the same datasheet, find the capacitance, C_D, of 1N4148 when it is zero-biased.

4. L60 is a 6.8 μH fixed inductor with a color code just like resistors, and the value is specified in μH. It resonates at 15 MHz with the parallel combination of C62 and capacitance, C_D, of the 1N4148 diode. The signal magnitude increases by the quality factor of the resonator. Find the value of C62 and pick the closest standard value.

5. The cutoff frequency of the low-pass network formed by C65 and R65 is set sufficiently high so that the envelope detector output can follow the variation at the high-frequency end of the modulation frequency. Find the corner frequency, f_c,

I_{dc}= 80.3 μA V_{dc}= 475-500 mV V_{ed}= 6.803 V   (See Appendix 1 for calculations)

C_D= 4.0 pF C_{62}= 12.56 pF (12 pF std. value) f_c= 15.915 kHz

1.5. GRADE:

2. Automatic gain control (AGC)

1. A PIN diode acts like an RF resistance whose value is determined by the DC current flowing through it. It is inserted between the first and second IF amplifiers when the jumper JP70 is shorted. If the DC current through it increases, its resistance reduces and hence attenuates the signal going to the second IF amplifier as shown in Fig. 1. Refer to the datasheet of the PIN diode on page 375. Find the reverse breakdown voltage, V_R, and the series RF resistance, R_S, and the forward voltage, V_F of the PIN diode when 1 mA DC flows through it.

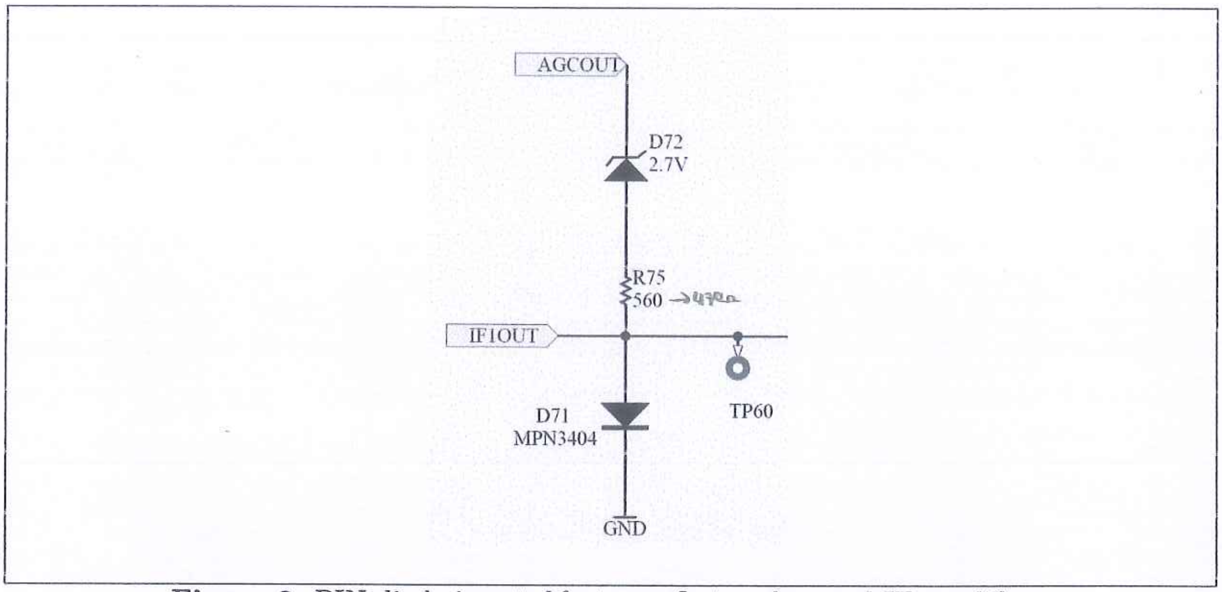


Figure 3: PIN diode inserted between first and second IF amplifiers.

V_R= 20V R_S=1.5-1.6Ω V_F= 0.6-0.7V

2.1. GRADE:

2. The automatic gain control (AGC) circuit of TRC-11 is given in Fig. 4.

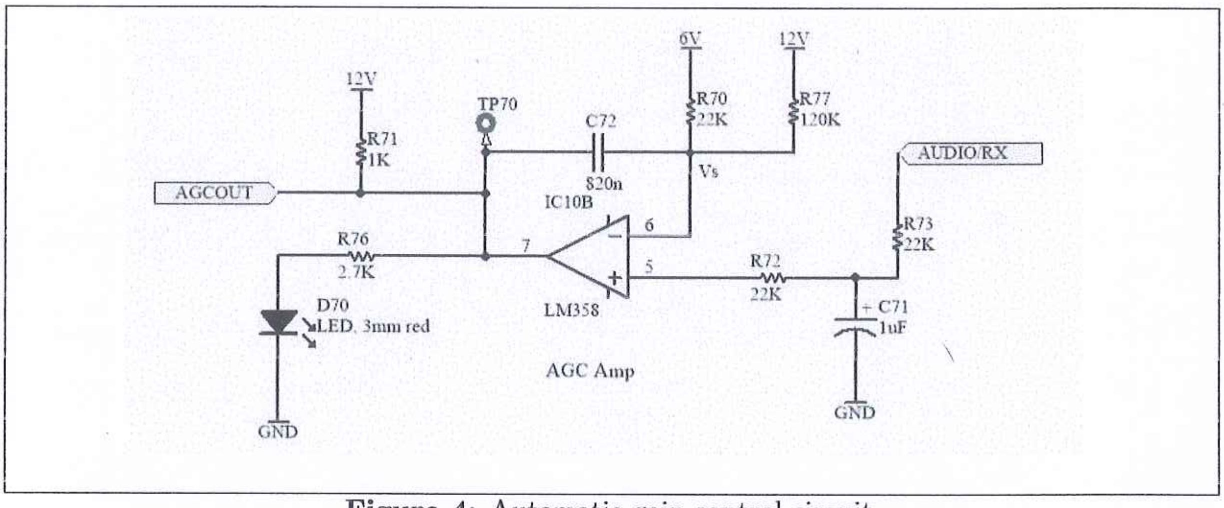


Figure 4: Automatic gain control circuit.

AGC circuit uses the OPAMP configured as an integrator in the feedback path. Integration gain is determined by C72 (820 nF) capacitor and the parallel combination of R70 and R77. A resistor (R71) to 12V is connected to the output of OPAMP to increase its maximum output voltage.

3. The set point, V_S, at the negative input of OPAMP is determined by R70, R77, and by the voltages they are connected to. Using nodal analysis or superposition theorem, find V_S.

Designator	Comment	Description
C71	1 μF	Electrolytic capacitor, polarized 16V
C72	820 nF	Capacitor, ceramic disc, 50V
D70	LED, 3mm red	Light-Emitting-Diode
D71	MPN3404	PIN diode
D72	BZX55C2V7	Zener diode, 2.7 V
R70,R72,R73	22 K	Resistor, carbon film, axial leaded, 1/4W
R71	1.8 K	Resistor, carbon film, axial leaded, 1/4W
R75	470	Resistor, carbon film, axial leaded, 1/4W
R76	2.7 K	Resistor, carbon film, axial leaded, 1/4W
R77	120 K	Resistor, carbon film, axial leaded, 1/4W

Figure 5: Bill of Materials of the automatic gain control circuit.

V_S= 6.930V (see Appendix 2 for calculations)

2.3. GRADE:

The AGC circuit is intended to reduce the gain of the IF amplifier to prevent the saturation of the second stage. The AGC circuit observes the average value (by the integration operation) of the detector output and adjusts the IF gain by using a PIN diode placed in shunt in between the first and second IF stages. The average value of the detector output at the positive input of the OPAMP is compared with the set point, V_S, at the negative input of the OPAMP.

When there is no 15 MHz signal, the average envelope detector output voltage is V_{ed} found above. This value is compared with V_S. We should make sure that V_{ed} is less than V_S, not to reduce the gain of the IF amplifier in the absence of 15 MHz signal.

When the 15 MHz signal is present, the average value of envelope detector may become higher than the set point. In that case, the output of the OPAMP increases to a higher voltage. That increases the DC current through the PIN diode, reducing the RF resistance of the PIN diode and hence reducing the IF gain.

On the other hand, if the average detector output is less than the set point, the OPAMP output voltage decreases, decreasing the DC current through the PIN diode. This, in turn, increases the RF resistance of the PIN diode, causing an increase in the IF gain. Overall, the AGC circuit keeps the detector output at the same average level once the signal is sufficiently high. If the input signal is below the threshold, the OPAMP output is set to zero, making the DC current through the PIN diode also zero. Under that condition, the PIN diode is open-circuit for RF signals, maximizing the IF gain.

→ D70 is a red LED.

4. We have a visual indication of the AGC feedback circuit using a green LED, D70. It is connected to the OPAMP output through a resistor, R76. We would like the LED to turn on as soon as the AGC circuit begins to work. Find the current, I_{LED}, flowing in the green LED when the AGC circuit works and OPAMP output reaches its maximum value of 10 V. For this purpose, you may assume an LED forward voltage drop of 2 V. Refer to the LED datasheet on page 378 to find the maximum allowable LED current, I_F.

I_{LED}= $\frac{(10-2)V}{2.7k\Omega} \approx 2.96mA$ I_F= 25 mA

2.4. GRADE:

5. The OPAMP output that generates the DC current for the PIN diode can become as high as 10 V. Find the maximum DC current, I_{FMax}, through D72, R75, and D71 assuming the forward voltage drop of the PIN diode is 0.7 V. Find the RF resistance, R_{SMin}, of the PIN diode when this current is flowing through it using its datasheet.

I_{FMax}= $\frac{(10-2.7-0.7)}{470} \approx 14 mA$ R_{SMin}= 0.6-0.7 Ω

2.5. GRADE:

Experimental Work

1. Envelope Detector

1. Install the components L60, R63, R65, D60, C63, C64, C65 (watch the polarity of C63) and solder them. For C62, use the value of the capacitor you calculated in the Preliminary Work.
2. Solder a loop of wire to TP62.
3. Apply the power. Using your multimeter, measure the voltage V_F, across the D60 diode. Does it agree with V_F that you have found from the datasheet of 1N4148?

Measured V_F= 0.485V, It is in the 475-500 mV band as per datasheet.

1.3. GRADE:

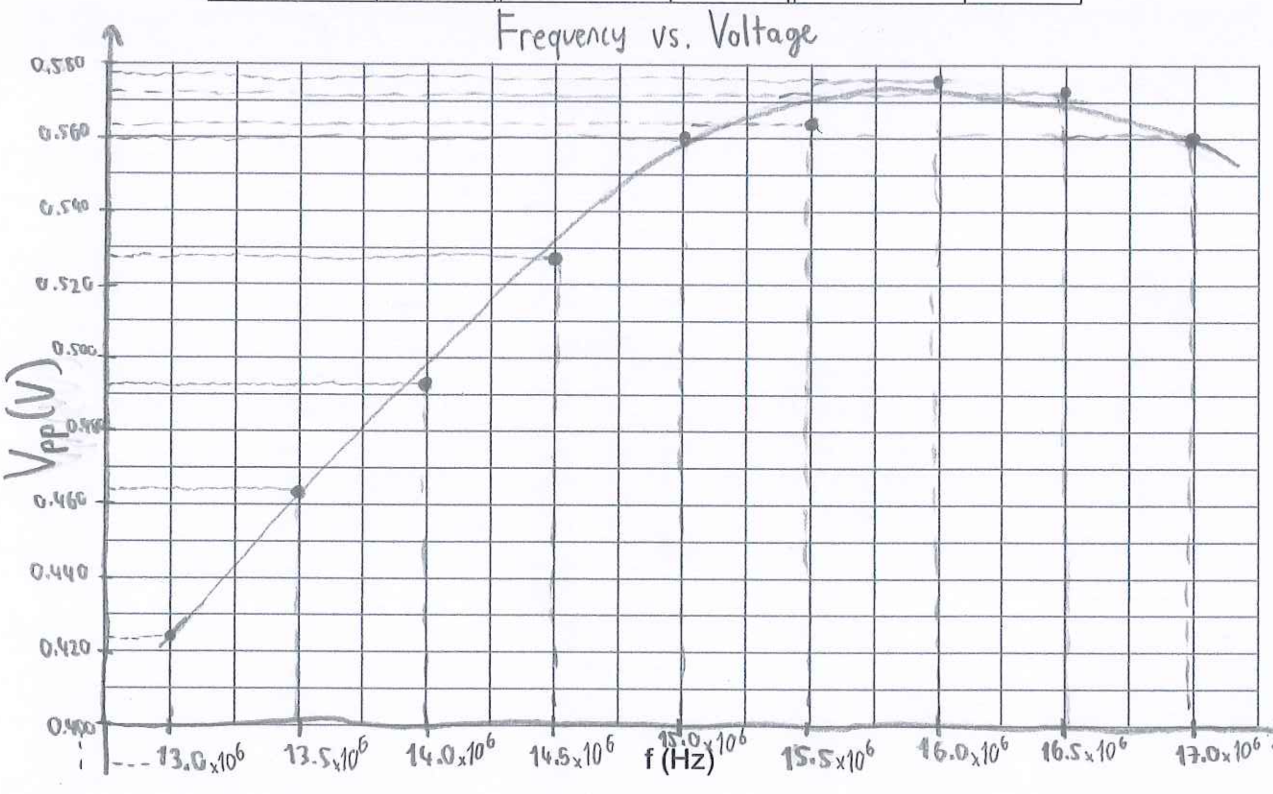
4. Set to signal generator to AM signal with 5 V_{pp} amplitude and 50% modulation to obtain

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

where f_m is 1 KHz, and f_{IF} is 15 MHz. Press [RATE] to adjust the modulation frequency, f_m, to 1 KHz. Press [DEPTH] to adjust the modulation index to 50%. Connect the oscilloscope probe to the output of the generator. On the oscilloscope, set ACQUIRE to PEAK DETECT. Set the time setting to 5 ms/div. Connect the "Modulation" output of the signal generator (on the back of the signal generator) to EXT trigger input of the oscilloscope using a coaxial BNC cable. Set the Trigger source of the oscilloscope to Ext, coupling AC. Make sure that the oscilloscope is triggered. Observe the AM waveform.

5. Set the signal generator output voltage to 20 mV peak-to-peak. Connect the signal generator between TP60 and the ground. Connect the Ch 1 probe to the envelope detector output, TP62. Apply the power to TRC-11. Record the peak-to-peak voltage, V_{pp}, as f_{IF} is varied between 13 to 17 MHz in 0.5 MHz steps. Since C62 value is adjusted to resonate with L60, you should see the maximum variation at 15 MHz. If the resonance occurs at frequencies greater than 17 MHz or lower than 13 MHz, you may change the value of C62 to the next higher or the next lower standard value.

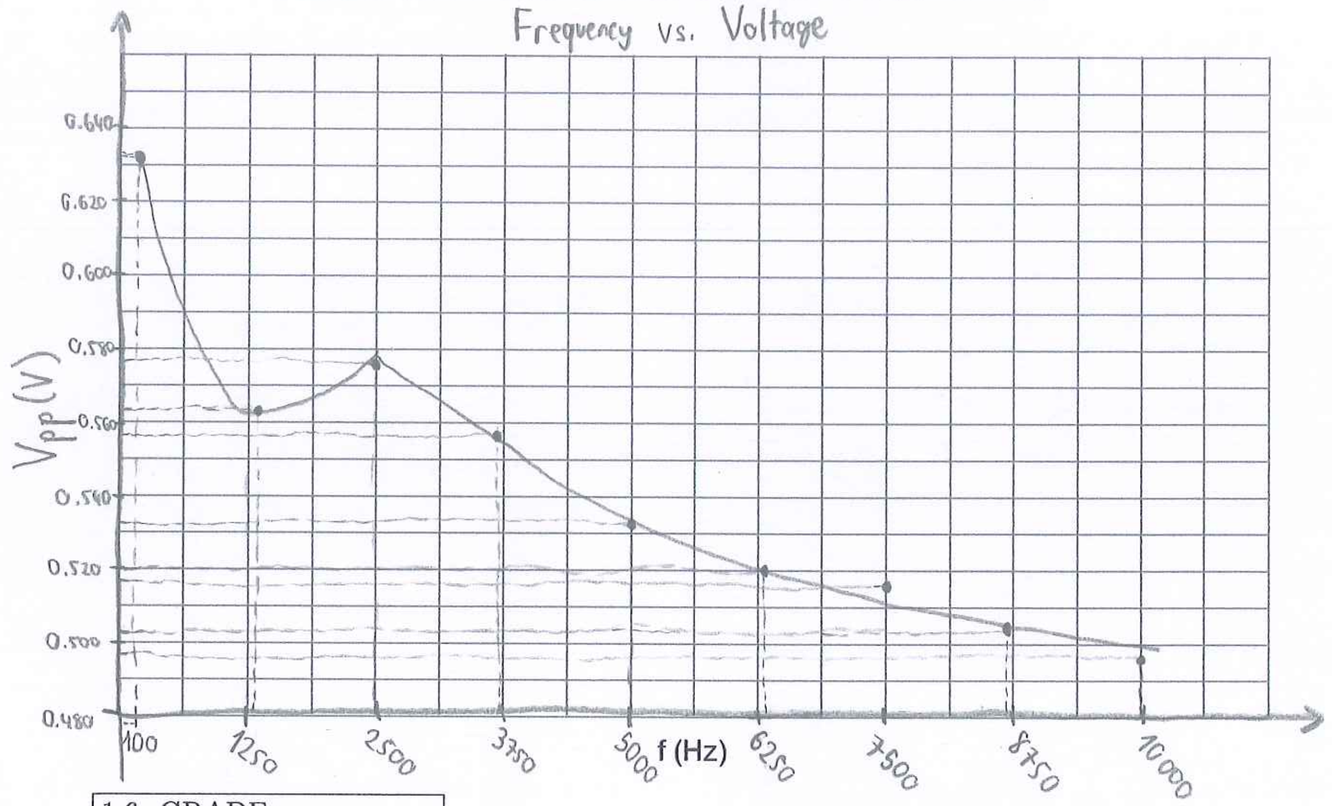
f_{IF} (MHz)	V_{pp}(V)	f_{IF} (MHz)	V_{pp}(V)	f_{IF} (MHz)	V_{pp}(V)
13.0	0.424	14.5	0.528	16.0	0.576
13.5	0.464	15.0	0.560	16.5	0.572
14.0	0.492	15.5	0.564	17.0	0.560



1.5. GRADE:

6. Set f_{IF} to 15 MHz and vary the modulation frequency f_m between 100Hz and 10 kHz after pressing [RATE]. Modulation [DEPT] should be at 50%. Measure the envelope detector output at TP62. Choose the number of measurements and measurement frequencies adequately. Plot the peak-to-peak output voltage as a function of f_m.

f_m (Hz)	V_{pp}(V)	f_m (Hz)	V_{pp}(V)	f_m (Hz)	V_{pp}(V)
100	0.632	3700	0.556	7500	0.516
1300	0.564	5000	0.532	8700	0.504
2500	0.576	6300	0.520	10 000	0.496



1.6. GRADE:

7. Adjust the volume pot all the way counter-clockwise to reduce the volume. Plug in the earphones. Increase the volume until you hear a sound. This sound is the detected modulation signal.

8. Connect the signal generator between TP40 and GND. Set the amplitude of the signal generator to the smallest amplitude (10mV). Set the frequency to the center frequency of your IF filter. This should be very close to 15.00 MHz. Set the AM modulation frequency f_m to 1 kHz. Set the modulation index to 50%. Apply the power. Now, you should hear the demodulated 1 kHz signal from the earphones. Observe 1 kHz signal at TP62 using the scope. Change the frequency of the carrier, f_{IF}, around 15 MHz in 1 KHz steps to find the maximum signal position.

9. Increase the input signal amplitude. At some point, IF amplifiers saturate. The demodulated signal gets distorted. As the input amplitude increases further, the demodulated signal gets smaller. Record the input peak-to-peak signal level where the saturation begins and the signal observed on the scope begins to distort.

Input signal level for saturation= 12 mV

1.9. GRADE:

2. Automatic gain control (AGC) circuit

1. Now, we are ready to incorporate the automatic gain control (AGC) circuitry to prevent saturation of the IF amplifiers. Refer to Fig. 4. Note that the PCB annotations of C72 and R72 are inadvertently swapped. Correct PCB annotations are shown in Fig. 6.

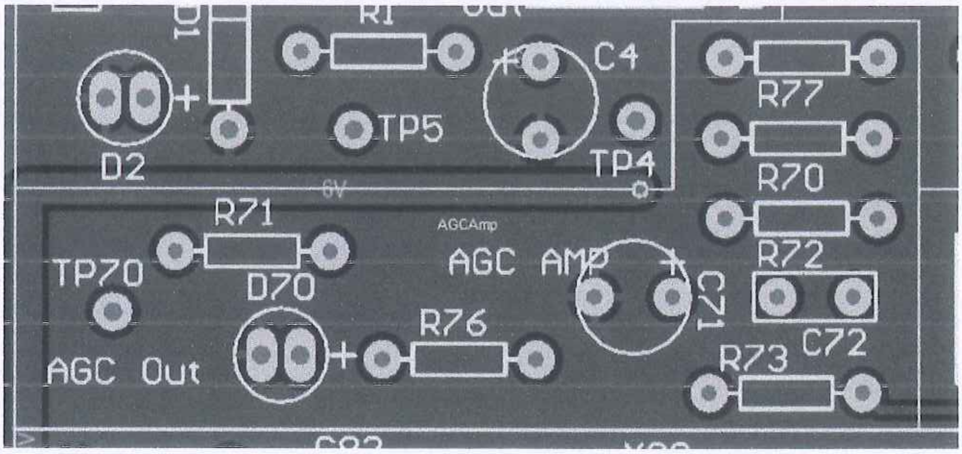


Figure 6: Correct PCB annotations for AGC circuit.

2. The automatic gain control (AGC) circuit of TRC-11 is given in Fig. 4. Place R70, R71, R72 (in its corrected place), R73, R75, R77, and D71. Watch the direction of the PIN diode. Solder them. Cut the leads on the back side.
3. Place the zener diode, D72. Watch the direction of the zener diode. Place the black striped end to the left of D72 marking on the PCB.
4. Solder C71.
5. Place and solder C72 (in its corrected place).
6. Place the red LED, D70. Note that the longer lead is the positive terminal. Solder it. Place and solder R76.
7. Solder a loop of wire to TP70 as a test point.
8. Connect the signal generator between TP40 and GND. Make sure that the test resistor R41 is still in place. Set the signal generator frequency to the center frequency of your IF filter (15 MHz). Set the amplitude to 10 mVpp. Set the AM modulation frequency to 1 kHz and modulation index to 50%. Using the oscilloscope, observe the demodulated signal at TP62. Increase the amplitude of the signal generator beyond the point where saturation took place. Observe that saturation is now avoided and a demodulation takes place without distortion at larger signal levels.
9. Observe that the LED turns on. You may need to increase the generator voltage or change the center frequency in small steps if the LED does not turn on. With a well-tuned receiver, the LED should turn on with about 10 mVpp at 15.000 MHz. Record the center frequency, f_0, and the smallest input amplitude which turns on the LED.

10. Debugging step: If the signal presence LED is always on, even without the input signal, measure the voltages at pins 5 and 6 of the IC10 using multimeter. These are + and − inputs of the OPAMP. Without the input signal, the voltage at + pin (pin 5) should be less than the voltage at − pin (pin 6). The expected values are 6.80 V at pin 5 and 6.84 V at pin 6. Because of resistance tolerances the voltages may be different than those. Change R77 to 100K (instead of 120K). In that case, the voltage at pin 6 should become higher (6.97 V) and the LED should turn off. With this change, the LED may turn on at a higher input signal level.

11. While at the smallest signal level, change the frequency in both directions with small steps to find out where the LED turns off.

f_0= 15 MHz LED turns on with V_{inpp}= 10 mV
LED turns off at f_1=14 998 700 Hz and at f_2= 15 004 300 Hz

2.11. GRADE:

12. Since the testing of IF amplifier is finished, remove the resistor R41. You may just cut its ungrounded lead.

CHECK POINT:

Appendix Sheet

Appendix 1: $I_{dc} = \frac{(12-6-0.7)V}{(56k+10k)\Omega} \approx \underline{80.3\mu A}$ $V_{ed} = 6 + I_{dc}R_{GS}V = 6V + (80.3\mu A)(10k\Omega) \approx \underline{6.803\,V}$

$$C_{G2} = \frac{1}{(2\pi f)^2 L} - C_D = \frac{1}{(30\pi 10^6)^2(6.8\mu H)} - 4pF \approx \underline{12.56pF}$$

closest std. : $\underline{12pF}$

$$f_c = \frac{1}{2\pi R_{GS} C_{GS}} = \frac{1}{2\pi(10k\Omega)(1nF)} \approx \underline{15.915\ kHz}$$

Appendix 2: From nodal analysis, $V_S = \left(\frac{12V}{120k\Omega} + \frac{6V}{22k\Omega}\right)\left(\frac{1}{120k\Omega} + \frac{1}{22k\Omega}\right)^{-1} \approx \underline{6.930V}$