Worcester Polytechnic Institute
Department of Electrical and Computer Engineering
ECE3311 Principles of Communication Systems B05
Exercise#5

Envelope detector with non-zero bias current

Contents

I. Input impedance of the biased diode (HSMS-285x [1])

Fig 1 shows the equivalent circuit for the Agilent HSMS-285x zero bias Schottky diode [1]:

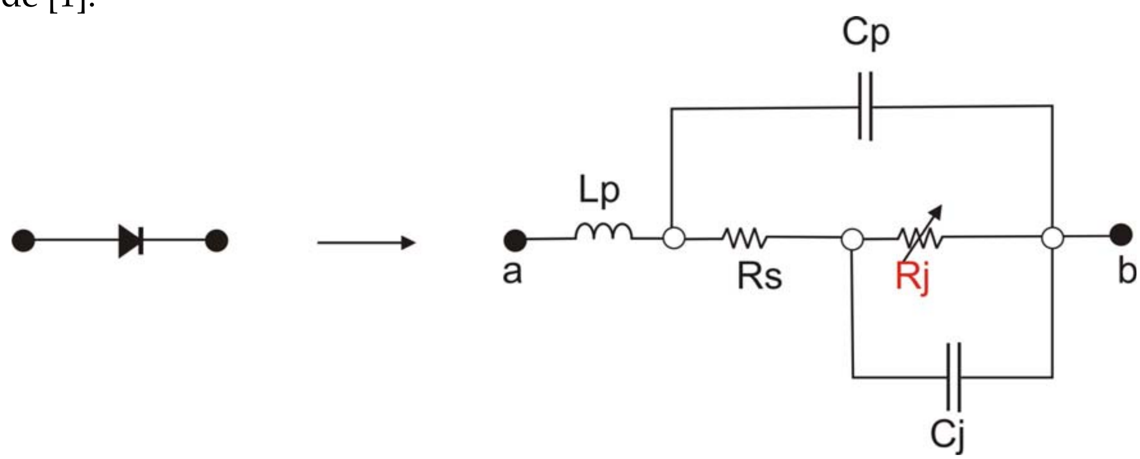

Fig. 1. Equivalent small-signal model of the diode including package parasitics.

Here (see the HSMS-285x family data sheet [1]):

1. Lp – parasitic (package) inductance; Lp=2.0 nH
2. Cp – parasitic (package) capacitance; Cp = 0.08 pF
3. Rs – series parasitic resistance representing losses in the bondwire, etc., Rs=25Ω
4. Cj – junction capacitance, Cj = 0.18 pF
5. Rj – the most important diode parameter – junction resistance. The junction resistance is a function of the applied bias current – see below.

It looks like that all this data is related to the center frequency of 915 MHz [1].
Rj (given in Ohms) depends on the applied bias current and given by (see Refs. [1, 2])

$$R_j = \frac{0.026}{I_T}, \quad I_T = \quad I_S + I_B \tag{1}$$

where (all currents are in amperes):

I_T – the total diode current;
I_S – diode saturation (zero bias) current; $I_S = 3$ μA at 25 C.
I_B – diode bias current (an external DC current applied to the diode). From Eq.(1) one can see that the diode nonlinearity is just characterized by the junction resistance Rj, more specifically – by its dependence on the applied current.

Task 1:

a. Determine and plot (MATLAB) the input impedance of the diode (input impedance between terminals *a* and *b* in Fig. 1) at 920 MHz including both resistance and reactance. The input impedance is plotted as a function of the bias current I_B in the range 0-1000 μA.
b. Determine the value of the bias current corresponding to the resonant diode at 920 MHz (reactance is zero). What is diode resistance at that point?

II. Input impedance of the biased envelope detector

With or without external DC bias, Schottky diode detector circuits can be used to create low cost RF and microwave receivers with a sensitivity from -55 dBm to -57 dBm (see [2]). These circuits can have a variety of forms but in the simplest case they are equivalent to the envelope detector circuit shown in Fig. 2.

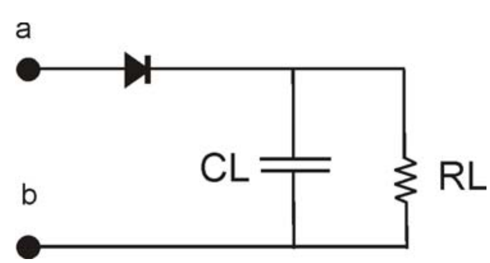

Fig. 2. Basic schematic of the envelope detector.

Here, RL is called the load resistance (or sometimes the video output resistance) and CL is called the load capacitance. The typical values used in envelope detectors are [1, 2]

RL = 100 kΩ
CL = 100 pF

Task 2:

a. Modifying the MATLAB script of task 1 determine and plot the input impedance of the entire envelope detector (input impedance between terminals *a* and *b* in Fig. 2) at 920 MHz including both resistance and reactance. The input impedance is plotted as a function of the bias current I_B in the range 0-1000 μA.
b. Determine the value of the bias current corresponding to the resonant condition at 920 MHz (the reactance of the envelope detector is zero). What is circuit resistance at that point?
c. Compare the plots of task 1 and task 2. Why are they almost identical?

III. Role of diode bias current

The exercise #3 started before Thanksgiving had a difficult task: match to 50 Ω the impedance of an *unbiased* Agilent diode (envelope detector). The figure obtained in the previous section shows us that this impedance is mostly reactive and large – a capacitance of about -j650 Ω. No wonder that exercise #3 failed[1,2].

Best and simplest matching to 50 Ω is achieved when the load impedance is predominantly real and is on the order of 25-200Ω. Now, which value of the bias current should we choose to satisfy this condition?

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[1] Ok, only the quick solution to this exercise failed but this is a good indicator of problem difficulty. Remember that the quick solution involved *fast* frequency sweep.

[2] One can match the unbiased diode impedance modifying the antenna itself. The antenna, in principle, does not have to have the impedance of 50 Ω. This (very interesting and practical) question is beyond the scope of the exercise.

The MATLAB figure obtained in the previous section should help us to answer this question. This figure indicates that any value of the bias current I_B greater than or equal to 0.3 mA is basically giving us an appropriate result. Moreover, when the bias current is approaching 1 mA the resistance becomes 51 Ω and the reactance is approaching +j8Ω.

Task 3:

a. Determine the return loss in dB when the detector circuit has the bias current of 1 mA (resistance is 51 Ω and the reactance is +j8Ω). Are you satisfied with this value?

Perhaps one would be really satisfied: the return loss goes below -20 dB. What does it mean for us? Just that we do not need any impedance matching circuit at 1 mA bias current!!

However, one important task at the receiver may be to minimize power consumption. In view of this the lowest possible diode bias current is desired, which is about 0.30-0.35 mA in our case. This gives the detector impedance on the order of

$$100\Omega + j0\Omega \qquad (2)$$

at 920 MHz. To simplify the further analysis we assume that Eq. (2) is the exact result.

IV. Matching impedance: 100 Ω to 50 Ω

Thus, we need to match antenna impedance of **50** Ω to the detector impedance of **100** Ω - see Fig. 3. This task is routinely accomplished with the so-called quarter-wavelength microstrip transformer (ECE3113, [3, 4]). This quarter-wave transformer is just a microstrip with

i. the width that gives the characteristic impedance equal to geometrical mean of two real impedances to be matched: $Z = \sqrt{50 \times 100}\ \Omega$
ii. the length equal to λ/4, where λ is the propagation wavelength along this microstrip. λ involves the effective dielectric constant and thus again involves the width of the microstrip.

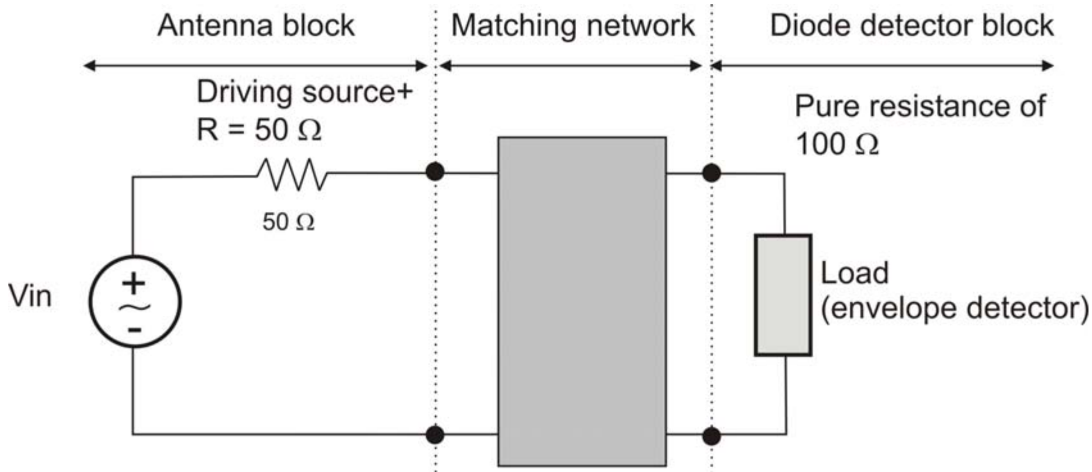

Fig. 3. The position of the matching circuit.

Task 4:

a. Using the applet at http://www.rogerscorporation.com/mwu/mwi_java/Mwij_vp.html (or another microstrip calculator of your choice) find the microstrip width W that approximately corresponds to the characteristic impedance of $Z = \sqrt{50 \times 100}\ \Omega$. The material is FR4 epoxy with the relative dielectric constant of $\varepsilon_r = 4.4$ and the loss tangent $\tan\delta = 0.02$. The FR4 thickness is 62 mil (1.58 mm). Record this value.
b. Using the same applet read the value of propagation wavelength λ and determine the necessary microstrip length L. Record this value. Watch carefully the operation frequency![3]

V. Primitive detector board

The basic circuit on FR4 with the impedance transformer is an ANSOFT project entitled Project 5. Since a preliminary exposure to ANSOFT has been already given, this project will be described in terms of functional building blocks only. Do not forget to assign the boundary type (PEC, RLC, lumped port, radiation) or the material type to each object!

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[3] Do not try to use the corresponding values from the ANSOFT circuit suggested below. They have been *rounded* toward nearest measures in inches and are slightly different!

1. **Radiation boundary.** A box with geometry parameters:

Command	CreateBox			
Coordinate System	Global			
Position	-70 ,-70 ,-30	mm	-70mm , -70mm , -30mm	
XSize	140	mm	140mm	
YSize	140	mm	140mm	
ZSize	60	mm	60mm	

2. **Dielectric substrate.** A box (3.8″x2.5″x0.062″; assigned material - FR4) with geometry parameters:

Command	CreateBox			
Coordinate System	Global			
Position	-96.52/2 ,-63.5/2 ,-0.79	mm	-48.26mm , -31.75mm , ...	
XSize	96.52	mm	96.52mm	
YSize	63.5	mm	63.5mm	
ZSize	1.58	mm	1.58mm	

3. **PEC Ground plane.** A PEC rectangle with geometry parameters:

Command	CreateRectangle			
Coordinate System	Global			
Position	-96.52/2 ,-63.5/2 ,-0.79	mm	-48.26mm , -31.75mm , ...	
Axis	Z			
XSize	96.52	mm	96.52mm	
YSize	63.5	mm	63.5mm	

4. **Opening in the ground plane.** The PEC ground plane will have a non-plated rectangle opening. This opening will be needed later on in order to connect the DC power supply for the diode bias current. Create an unassigned rectangle first:

Command	CreateRectangle			
Coordinate System	Global			
Position	20.16 ,26.67 ,-0.79	mm	20.16mm , 26.67mm , -...	
Axis	Z			
XSize	5.08	mm	5.08mm	
YSize	5.08	mm	5.08mm	

Then , select the ground plane rectangle. While holding Ctrl key simultaneously select the above rectangle. Go to 3D Modeler/Boolean/Subtract and mark “Clone tool objects before subtracting”. Perform subtraction and see the subtraction result.

5. PEC microstrip (50 Ω). A PEC rectangle with geometry parameters:

Command	CreateRectangle			
Coordinate System	Global			
Position	-96.52/2 ,-3.05/2 ,0.79	mm	-48.26mm , -1.525mm , ...	
Axis	Z			
XSize	30.32mm+e		30.32mm	
YSize	3.05	mm	3.05mm	

This rectangle has a variable length parameter – "e". The parameter will be used later on in order to fine tune the circuit. You will be asked about its value: give 0mm for now.

6. PEC quarter-wave microstrip transformer. A PEC rectangle with geometry parameters:

Command	CreateRectangle			
Coordinate System	Global			
Position	-17.94mm+e ,-0.76mm ,0.79mm		-17.94mm , -0.76mm , 0...	
Axis	Z			
XSize	45.72mm-e		45.72mm	
YSize	1.52	mm	1.52mm	

A similar dependence on the parameter "e" is present for this microstrip.

7. Lumped port (50 Ω feed to antenna). A rectangle with geometry parameters:

Command	CreateRectangle			
Coordinate System	Global			
Position	-96.52/2 ,-3.05/2 ,-0.79	mm	-48.26mm , -1.525mm , ...	
Axis	X			
YSize	3.05	mm	3.05mm	
ZSize	1.58	mm	1.58mm	

8. Primitive diode detector model (100 Ω RLC). A RLC rectangle with geometry parameters:

Command	CreateRectangle			
Coordinate System	Global			
Position	27.78 ,-0.76 ,0.79	mm	27.78mm , -0.76mm , 0....	
Axis	Z			
XSize	1.27	mm	1.27mm	
YSize	1.52	mm	1.52mm	

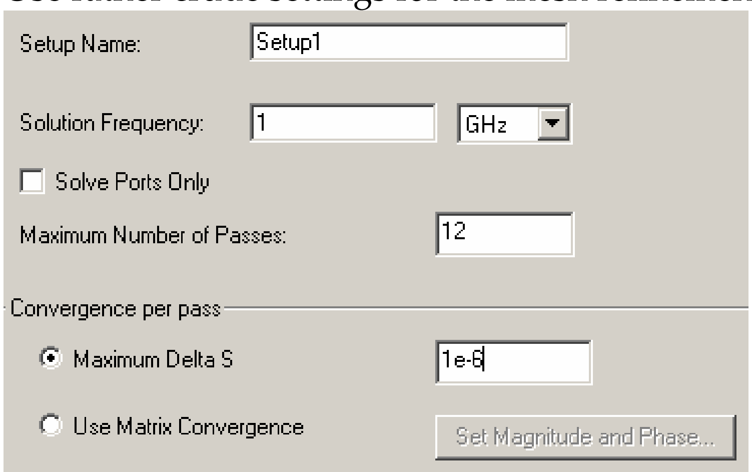
9. Ground to diode detector PEC connection. A PEC rectangle with geometry parameters:

Command	CreateRectangle			
Coordinate System	Global			
Position	29.05 ,-0.76 ,-0.79	mm	29.05mm , -0.76mm , -0...	
Axis	X			
YSize	1.52	mm	1.52mm	
ZSize	1.58	mm	1.58mm	

By the end of geometry assembly procedure, you should have four PEC boundaries, one radiation boundary, and one RLC boundary.

10. Solution settings.

Use rather crude settings for the mesh refinement:



Note that, since the convergence condition on the error between two subsequent iterations is very strong (relative error is less than 1e-6); the program therefore always runs through all 12 passes for the present geometry.

11. Sweep settings

Never, not ever use the fast frequency sweep here! Please, use the discrete (precise) frequency sweep:

Run validation check and start the project.

12. Output settings Please output the return loss to diode detector in dB.

Task 5:

a. Plot return loss to diode detector in the frequency range between 900 and 940 MHz. Mark the value at 920 MHz. Are you satisfied with the detector performance?

VI. Report

1. A report to exercise#5 should address tasks 1 to 5 listed in this handout.
2. The report is to be prepared and submitted **separately** from HW#4. Due: Friday, together with HW#4.

VII. Conclusions

Even though the final result to this exercise may look quite impressive, one should keep in mind that the real diode detector circuit has a finite size and a number of different discrete components connected by microstrips. An attempt to model the entire detector as a lumped resistor of 100 Ω may have a significant influence on the solution accuracy. Moreover, the present model also ignores the diode bias network and the associated PCB vias that may have even larger effect on the solution performance.

In upcoming exercise #6, ANSOFT Project 5 will be modified in order to create a more realistic PCB model. Therefore, do not delete the present project after it is done. To save the space, one may want to delete the results only.

References

1. *Agilent HSMS -285x Series Surface Mount Zero Bias Schottky Detector Diodes*- Data Sheet 5898-4022EN, Agilent Technologies, Inc., Sep. 2005.
2. *Designing Detectors for RF/ID tags*, Application Note #1089, Agilent Technologies, Inc., Nov. 1999.
3. R. Ludwig and P. Bretchko, *RF Circuit Design*, Prentice Hall, Upper Saddle River, NJ, 2000.
4. D. M. Pozar, *Microwave Engineering*, Wiley, New York, 2005, 3rd ed.