Application Note

Antenna Design for MLX90130/32 13.56MHz RFID / NFC Transceivers Family

Scope

The objective of this application note is to provide guidelines to calculate the external matching network to adapt the driver's outputs of the MLX90132 NFC transceiver IC and MLX90130, RFID Transceiver IC to the inductive impedance coil used as an antenna. This to achieve best RF performances communicating with memory TAGs compliant with ISO/IEC14443, ISO/IEC15693 and ISO/IEC18092 RFID standards (MLX90132).

Applications

- ❑ RFID / NFC General Purpose

Related Melexis Products

Part No.	Temperature suffix	Package Code	Option code
MLX90130xxx	E (-40°C to 105°C)	LQ [Lead free QFN 5x5 32 leads]	--
MLX90132xxx	E (-40°C to 105°C)	LQ [Lead free QFN 5x5 32 leads]	--

Introduction

The MLX90130/32 serie is a 13.56MHz RFID / NFC transceiver ICs family. It has been designed to support communications with RF memory transponders compliant with ISO/IEC14443, ISO/IEC15693 and ISO/IEC18092 (MLX90132) RFID standards.

To allow communication with RF memory transponders the MLX90130/32 has to be connected to a suitable inductive antenna load, most of the time simply composed of a square/circle shape loop directly printed on a PCB. Three external capacitors will be used to match the dual driver architecture of the MLX90130 / MLX90132 to the inductive loop antenna and also to insure proper resonance at 13.56MHz.

The reception of transponder message is made using two external resistors connected on both RX1 and RX2 pin of the MLX90130/32. Those resistor values as well as the internal equivalent impedance of the reception chain have also to be taken into account into the calculation of the matching network.

Finally, there is also a possibility to add an EMI filter to reduce as much as possible the emissions of higher harmonics of the 13.56MHz transmitted signal. This EMI filters would not change the matching network components and would be simply composed of a LC filter directly connected at the two driver outputs.

Contents

1 Output impedance of the MLX90130 / MLX90132

The MLX90130 / MLX90132 is using a two driver topology, generating two anti-phase square signals at 13.56MHz. The equivalent impedance of each driver measured at 3V power supply VDD and VDD_TX is purely resistive and equal to 13.5Ω. The output of the MLX90130 / MLX90132 could be simplified into an equivalent circuit with only one resistance R_{OUT} equal to two times the driver's impedance output, this is illustrated into the following picture.

$$Z_{OUT} = R_{OUT} = 27\Omega$$

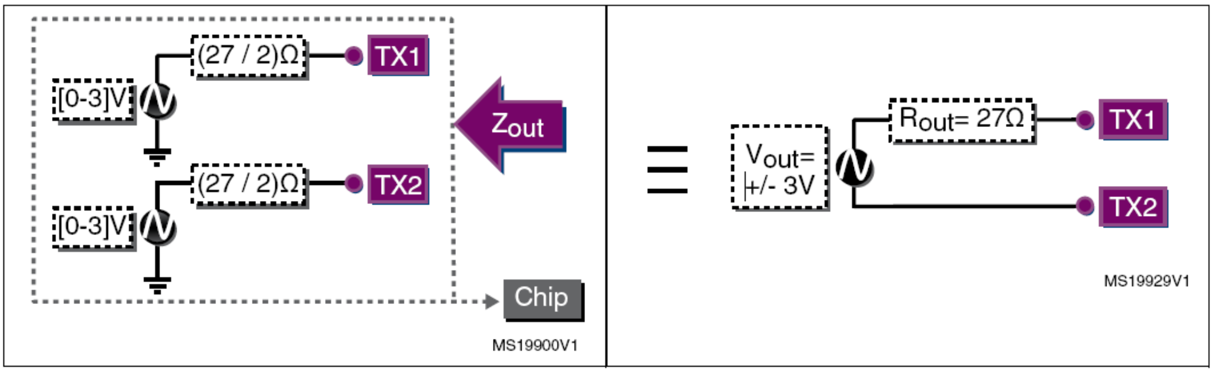

Figure 1: MLX90130 / MLX90132 equivalent output impedance

Where:

- Z_{OUT}: Matching impedance [Ω]
- R_{OUT}: Matching resistor [Ω]
- V_{OUT}: Supply voltage of the device [V]

2 Inductive antenna impedance

To communicate to RFID memory transponders, the MLX90130/32 must be connected to an external inductive antenna. In the example of the DVK90132, this antenna is simply formed by a two turn square loop directly printed on the PCB (dimension 48 mm x 34 mm).

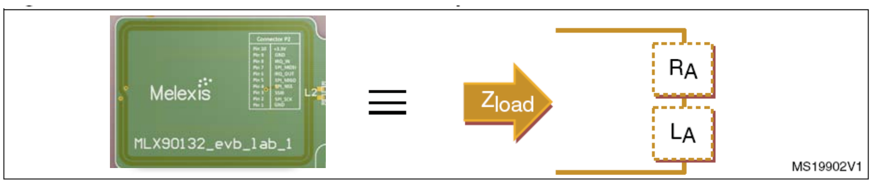

Figure 2: DVK90132 antenna board equivalent circuit

The equivalent impedance of such an antenna could be expressed as follow:

Equation 1:

$$Z_{LOAD} = R_A + j \cdot \omega \cdot L_A$$

Where:

- Z_{LOAD}: Impedance of the load [Ω]
- R_A: Antenna equivalent series resistor [Ω]
- L_A: Antenna equivalent series inductance [H]

3 Need for impedance matching

The maximum power transfer between the MLX90130/32 and the load occurs when the condition $Z_{OUT} = Z_{LOAD}^*$ is satisfied, with Z_{LOAD}^* being the complex conjugate of Z_{LOAD}.

As shown in Equation 1, the equivalent impedance of a typical inductive antenna will not match the above condition. Consequently, a matching network would be required in-between to transform this equivalent impedance to a pure resistive load of the MLX90130/32 driver outputs.

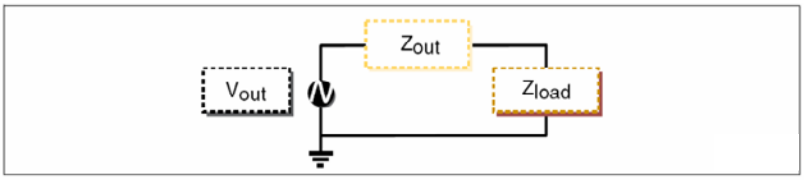

Figure 3: MLX90130/32 impedance matching

Where:

- Z_{LOAD}: Impedance of the load including the inductive antenna and the matching network [Ω]

4 Impedance matching circuit

4.1 Antenna circuit description

The impedance matching circuit is composed of a serial capacitance circuit (C_2 and C_7) and a parallel capacitance circuit (C_4 and C_5). Successive impedance transformation allows simplify the antenna equivalent circuit and calculate C_2, C_4, C_5 and C_6 capacitances easily.

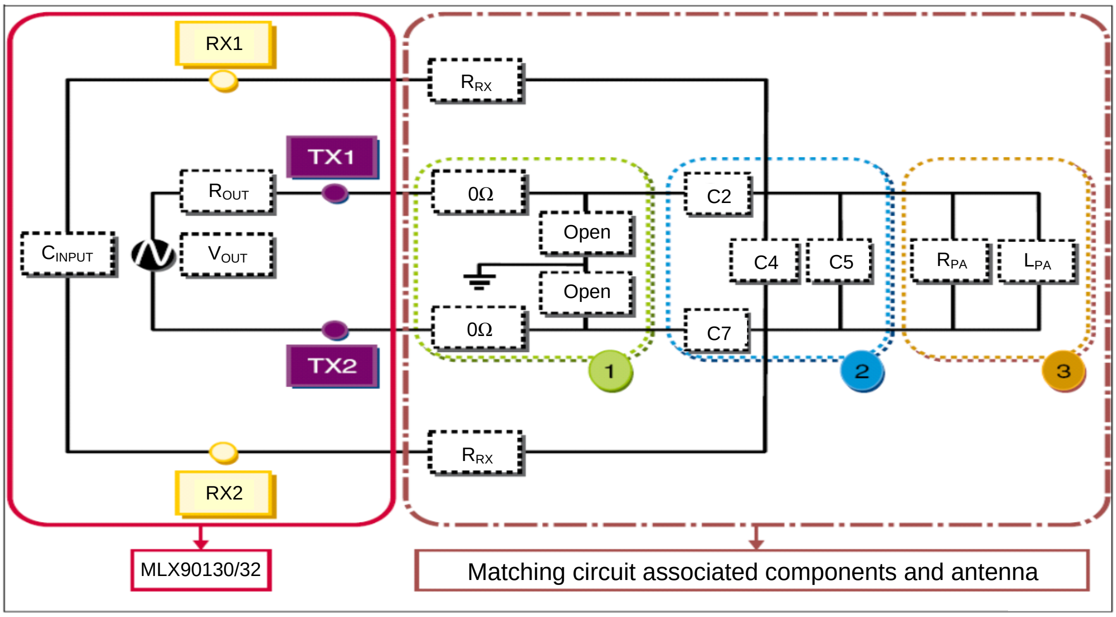

Figure 4: MLX90130/32 antenna circuit description

Where:

- RRX1/RRX2: Feedback resistors used to limit to voltage on RX1-RX2.
- R_{PA}: Antenna equivalent parallel resistor
- L_{PA}: Antenna equivalent parallel inductor
- C_{INPUT}: Integrated capacitor between RX1 and RX2 equal to 22pF.

Note: Both R_{RX} and C_{INPUT} must be considered in the calculation of the impedance matching circuit.

4.2 Antenna circuit simplifications

Their equivalent parallel values $C_{INPUT-P}$ and R_{RX-P} could be calculated as demonstrated in Demonstration of C11 and C22 calculation shown in Annex-A.

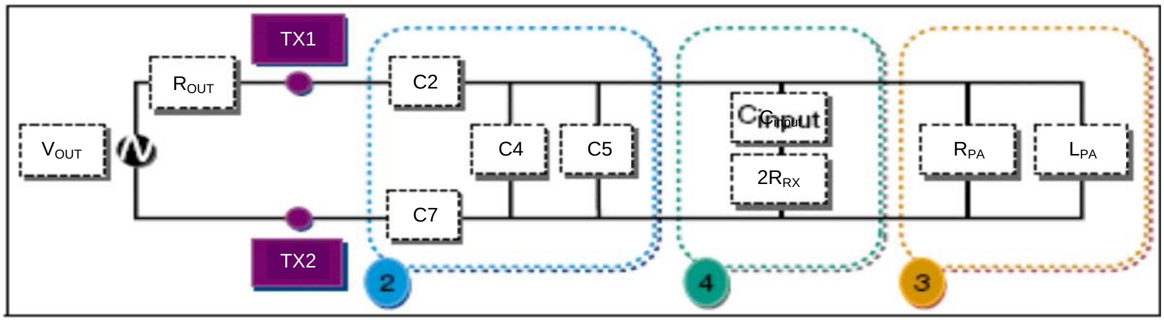

Figure 5 : MLX90130/32 antenna circuit description (parallel reception circuit)

Both serial capacitances (C_2, C_7) are equivalent to a serial capacitance $C_{11} = C_2/2 = C_7/2$. Both parallel capacitances (C_4 and C_5) are equivalent to a parallel capacitance $C_{22} = (C_4 + C_5)$. C_{INPUT} and R_{RX} can be transformed in a parallel equivalent circuit, as shown in the schematic below.

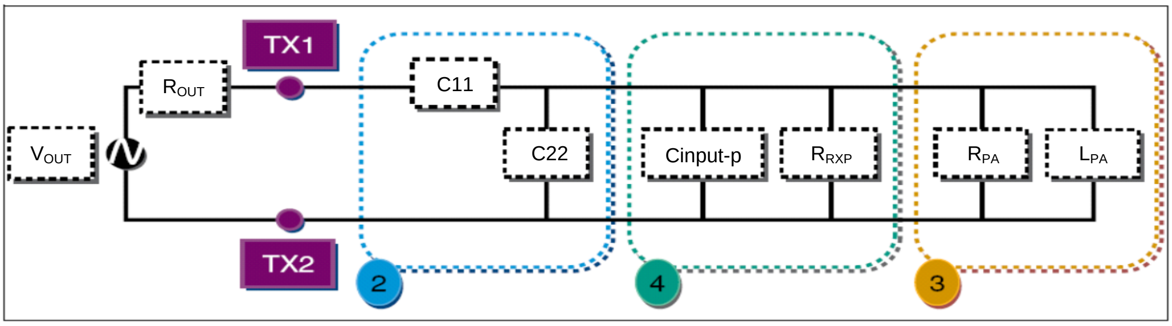

Figure 6: Antenna circuit intermediate simplification

Finally, it is possible to combine all parallel resistors and capacitors to obtain the following final equivalent circuit.

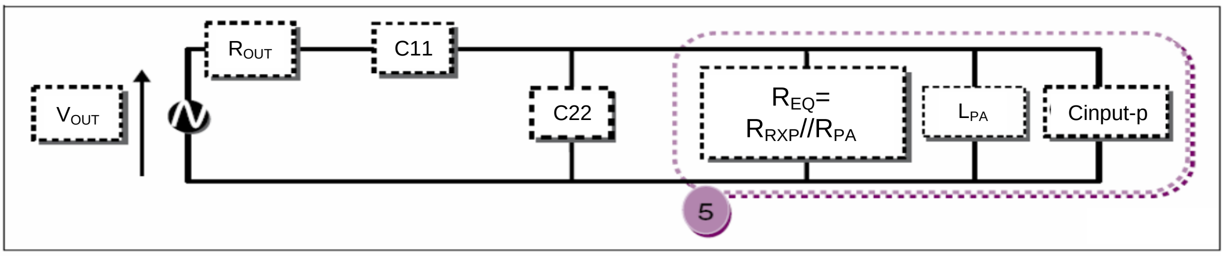

Figure 7: Antenna circuit final equivalent circuit

Where:

- R_{RX-P}: Equivalent parallel resistor of R_{RX} [Ω]
- R_{EQ}: Equivalent parallel resistor of R_{RX} and R_{PA} [Ω]
- $C_{INPUT-P}$: Equivalent parallel capacitance of C_{INPUT} [F]
- C_{11}: Equivalent serial capacitance of C_2 and C_7 [F]
- C_{22}: Equivalent serial capacitance of C_4 and C_5 [F]

The resulting equivalent circuit allows to calculate the matching circuit composed of C_{11} and C_{22} that satisfies the condition $Z_{OUT} = Z_{EQ}^*$. Where Z_{EQ}^* is the complex conjugate of Z_{EQ}. The complete calculation is demonstrated in Demonstration of C11 and C22 calculation.

Equation 2:

$$C_{11} = \frac{1}{R_{EQ} \cdot \omega} \cdot \sqrt{\frac{R_{EQ}}{R_{OUT}} - 1}$$

Equation 3:

$$C_{22} = \frac{1}{L_{PA} \cdot \omega^2} - C_{11} - C_{INPUT-P}$$

5 Numerical example (DVK90132)

The evaluation board DVK90132 is provided with a 48 mm x 34 mm square PCB loop antenna, with a value measured to:

- $R_A = 0.6[\Omega]$
- $L_A = 430[nH]$

Giving a quality factor of

Equation 4:

$$Q_A = \frac{\{IM(Z_{LOAD})\}}{\{RE(Z_{LOAD})\}} = \frac{\omega \cdot L_A}{R_A} = 61.1$$

This provides an equivalent parallel model of:

- $R_{PA} = R_A \cdot (1 + Q_A^{\ 2}) = 2238\Omega$
- $L_{PA} = L_A = 430nH$

The two feedback resistors have to be selected to limit the voltage swing at the RX1 and RX2 to less than 14Vpp (internal clamping). A good starting point is too select 150Ω, the value could be adjusted afterwards if required and the matching network components recalculated accordingly.

Based on the following known values:

Name	Value	Comment
C_{input}	22pF	Internal capacitance between R_{X1} and R_{X2}
R_{RX}	560Ω	Feedback resistor on R_{X1} and R_{X2}
L_A	430nH	Equivalent inductance of the inductive antenna of DVK90132
R_A	0.6Ω	Equivalent resistance of the inductive antenna of DVK90132
R_{ON}	9Ω	Equivalent impedance of the internal driver of MLX90132 (VDD=5V)
Rp	10kΩ	Resistor parallel to the antenna

Table 1: DVK90132 measured parameters

It is possible to calculate the different intermediate parameters as shown in the table below:

Name	Value	Comment
$C_{input-p}$	4.07pF	Equivalent parallel value of internal capacitance between R_{X1} and R_{X2}
R_{RX-P}	1374Ω	Equivalent parallel value of feedback resistor on R_{X1} and R_{X2}
L_{PA}	430nH	Equivalent parallel value of inductance of the antenna of DVK90132
R_{PA}	1828Ω	Equivalent parallel value of resistance of the antenna of DVK90132
Q_A	61	Quality factor of the antenna of DVK90132
C_{11}	98pF	Equivalent serial capacitance of the simplified matching network
C_{22}	196pF	Equivalent parallel capacitance of the simplified matching network

Table 2: DVk90132 calculated intermediary components

Finally leading to the matching network components populated on the DVK90132:

Name	Calculated value	Normalized value	Comment
L_1	-	220nH	No EMI filter
L_3	-	220nH	No EMI filter
R_2 & R_7	-	560Ω	Feedback resistor R_{Xn}
R_6	-	10kΩ	Resistor parallel to antenna
C_1 & C_6	-	270pF	No EMI filter
C_2 & C_7	196pF	150pF	Series resonance capacitance T_{Xn}
C_4	218pF	180pF	Parallel resonance capacitance
C_5		56pF	Parallel resonance capacitance

Table 3: DVK90132 matching network components

Important notes:
Antenna inductances in the range from 400nH up to 600nH are optimum values.

6 Conclusion

Thanks to its high level of integration, the MLX90130 / MLX90132 series only requires few components to match to a required inductive antenna. This application note has defines a way to easily calculate the external component of the matching network for a suitable transfer of energy to the TAG. Also the example of the DVK90132 has been discussed and full numeric calculation performed as an example.

7 Appendix A: detail of calculation

7.1 Demonstration of C11 and C22 calculation

Z_{tot} defines the input impedance of the matching circuit and the equivalent parallel antenna.

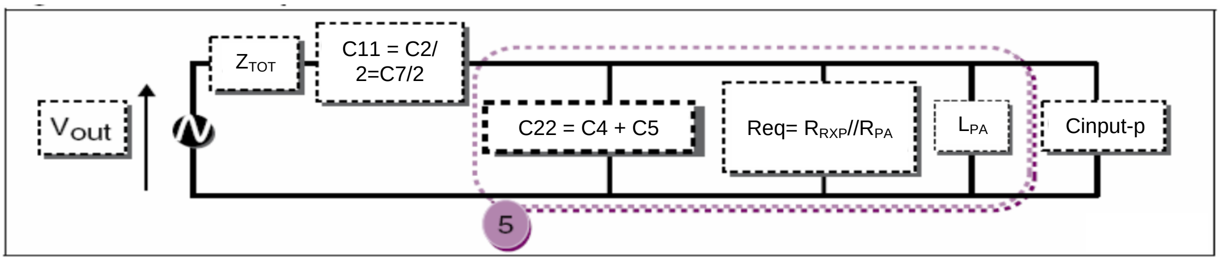

Figure 8: Final equivalent circuit

Calculation of R_{eq}:

Equation 5:
$$R_{eq} = \frac{R_{RXP} \cdot R_{PA}}{R_{RXP} + R_{PA}}$$

Calculation of Z_{tot}:

Equation 6:
$$Z_{tot} = \frac{1}{j \cdot \omega \cdot C_{11}} \cdot \frac{R_{eq} \cdot \left(1 - L_{PA} \cdot \omega^2 \cdot (C_{22} + C_{11})\right) + j \cdot \omega \cdot L_{PA}}{R_{eq} \cdot \left(1 - L_{PA} \cdot C_{22} \cdot \omega^2\right) + j \cdot \omega \cdot L_{PA}}$$

Resonance pulsation:

$$Z_{tot} = R_{tot} + j \cdot X_{tot}$$

To determine the resonance pulsation, the imaginary part of Ztot must be cancelled. The conditions are:

$$R_{tot} = R_{out} \qquad \text{and} \qquad X_{tot} = 0$$

Equation 7:
$$R_{tot} = \frac{-R_{EQ} \cdot L_{PA} \cdot C_{11} \cdot \omega^2 \cdot \left(1 - L_{PA} \cdot \omega^2 \cdot (C_{22} + C_{11}) + \omega^2 \cdot L_{PA} \cdot R_{EQ} \cdot C_{11} \cdot \left(1 - L_{PA} \cdot \omega^2 \cdot C_{22}\right)\right)}{(R_{EQ} \cdot C_{11} \cdot \omega)^2 \cdot \left(1 - L_{PA} \cdot C_{22} \cdot \omega^2\right)^2 + \left(\omega^2 \cdot L_{PA} \cdot C_{11}\right)^2}$$

Equation 8:
$$X_{tot} = -\omega \cdot C_{11} \cdot \frac{R_{EQ}{}^2 \cdot \left(1 - L_{PA} \cdot \omega^2 \cdot C_{22}\right) \cdot \left(1 - L_{PA} \cdot \omega^2 \cdot (C_{22} + C_{11})\right) + \omega^2 L_{PA}}{(R_{EQ} \cdot C_{11} \cdot \omega)^2 \cdot \left(1 - L_{PA} \cdot C_{22} \cdot \omega^2\right)^2 + \left(\omega^2 \cdot L_{PA} \cdot C_{11}\right)^2}$$

Neglecting $\omega^2 x L_{PA}$, then resolving the numerator leads to two different resonance pulsation ω_0 and ω_1:

Equation 9:
$$\omega_0 = \sqrt{\frac{1}{L_{PA} \cdot (C_{22} + C_{11})}}$$

Equation 10: $$\omega_1 = \sqrt{\frac{1}{L_{PA} \cdot C_{22}}}$$

Finally inserting Equation 9 in Equation 8 leads to:

Equation 11: $$C_{11} = \frac{1}{R_{EQ} \cdot \omega} \cdot \sqrt{\left(\frac{R_{EQ}}{R_{OUT}} - 1\right)}$$

Equation 12: $$C_{22} = \frac{1}{L_{PA} \cdot \omega^2} - C_{11} - C_{INPUT-P}$$

Note: $C_{input\text{-}p}$ is in parallel with C_{22} and has to be subtracted to C_{22}.

7.2 Antenna parallel equivalent model

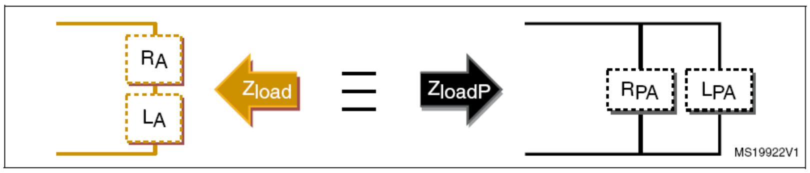

Figure 9: Antenna serial-to-parallel RL equivalent circuit

$$Z_{LOAD} = Z_{LOADP}$$

$$R_A + j \cdot \omega \cdot L_A = \frac{R_{PA} \cdot j \cdot \omega \cdot L_{PA}}{R_{PA} + j \cdot \omega \cdot L_{PA}}$$

Equation 13: $$R_A + j \cdot \omega \cdot L_A = \frac{R_{PA} \cdot L_{PA}^2 \cdot \omega^2}{R_{PA}^2 + (\omega \cdot L_{PA})^2} + j \cdot \frac{R_{PA}^2 \cdot L_{PA} \cdot \omega}{R_{PA}^2 + (\omega \cdot L_{PA})^2}$$

Considering that:

Equation 14: $$Q_A = \frac{|\Im(Z_{load})|}{\Re(Z_{load})} = \frac{\omega \cdot L_A}{R_A} = \frac{\Re(Z_{load\,P})}{|\Im(Z_{load\,P})|} = \frac{R_{PA}}{L_{PA} \cdot \omega}$$

Equation 13 and Equation 14 above lead to:

$$R_A + j \cdot \omega \cdot L_A = \frac{R_{PA}}{1 + Q_A^2} + j \cdot \frac{Q_A \cdot R_{PA}}{1 + Q_A^2}$$

Identify the real and imaginary parts:

Equation 15: $$R_A = \frac{R_{PA}}{1 + Q_A^2}$$

Equation 16: $$\omega \cdot L_A = \frac{Q_A \cdot R_{PA}}{1 + Q_A^2}$$

From Equation 15 and Equation 16 above:

Equation 17: $$R_{PA} = R_A \cdot (1 + Q_A^2)$$

Equation 18: $$L_{PA} = L_A \cdot \frac{(1 + Q_A^2)}{Q_A^2}$$

7.3 MLX90130 / MLX90132 receiving circuit parallel equivalent model

This section describes the receiving part of the MLX90130/32 and its equivalent parallel model, as shown in the following picture.

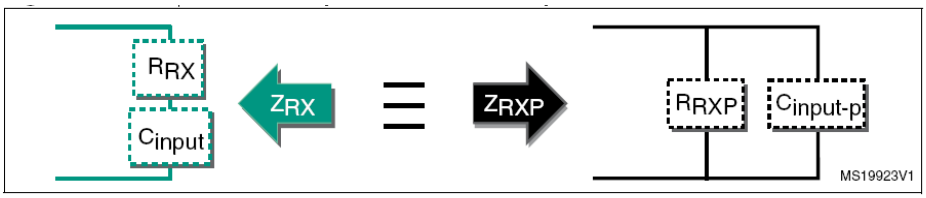

Figure 10: MLX90130/32 receiving circuit parallel equivalent model

$$Z_{RX} = Z_{RXP}$$

$$2 \cdot R_{RX} + \frac{1}{j \cdot \omega \cdot C_{input}} = \frac{R_{RXP}}{1 + j \cdot \omega \cdot R_{RXP} \cdot C_{input-p}}$$

So:

Equation 19: $$2 \cdot R_{RX} + j \cdot \frac{1}{\omega \cdot C_{input}} = \frac{R_{RXP}}{1 + (R_{RXP} \cdot C_{input-p} \cdot \omega)^2} - j \cdot \frac{R_{RXP}^{\ 2} \cdot C_{input-p} \cdot \omega}{1 + (R_{RXP} \cdot C_{input-p} \cdot \omega)^2}$$

Considering that:

Equation 20: $$Q_{RX} = \frac{|\Im(Z_{RX})|}{\Re(Z_{RX})} = \frac{1}{2 \cdot \omega \cdot C_{input} \cdot R_{RX}} = \omega \cdot C_{input-p} \cdot R_{RXP}$$

Equation 19 and Equation 20 leads to:

Equation 21: $$2 \cdot R_{RX} - j \cdot \frac{1}{\omega \cdot C_{input}} = \frac{R_{RXP}}{1 + Q_{RX}^{\ 2}} - j \cdot \frac{Q_{RX}^{\ 2}}{1 + Q_{RX}^{\ 2}} \cdot \frac{1}{C_{input-p} \cdot \omega}$$

Identifying the real and imaginary parts:

Equation 22: $$2 \cdot R_{RX} = \frac{R_{RXP}}{1 + Q_{RX}^{\ 2}}$$

Equation 23: $$\frac{1}{\omega \cdot C_{input}} = \frac{Q_{RX}^{\ 2}}{1 + Q_{RX}^{\ 2}} \cdot \frac{1}{C_{input-p} \cdot \omega}$$

By Equation 22 above:

Equation 24: $$R_{RXP} = 2 \cdot R_{RX} \cdot (1 + Q_{RX}^{\ 2})$$

Equation 25: $$C_{input-p} = C_{input} \cdot \frac{Q_{RX}^{\ 2}}{1 + Q_{RX}^{\ 2}}$$