5.4 EMI/RFI FILTERS

In every electronic circuit and device, analog and digital, undesired noises, electromagnetic waves and radio frequencies are demonstrated. The filters that suppress all that are called EMI (Electro-Magnetic Interference) RFI (Radio-Frequency Interference).

In Fig. 5.17 you can see the four ways of broadcasting those noises: 1. though the pipe, 2. through the environment, 3.from the pipe to the environment and 4. from the environment to the pipe. In Fig. 5.18 you can see the basic EMI/RFI way of suppressing.

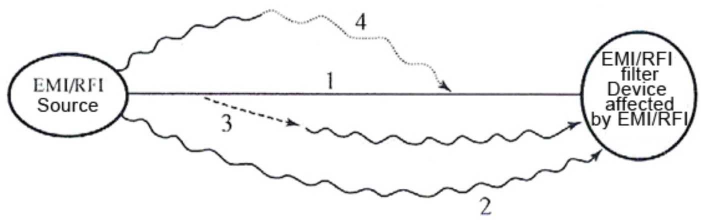


Figure 5.17

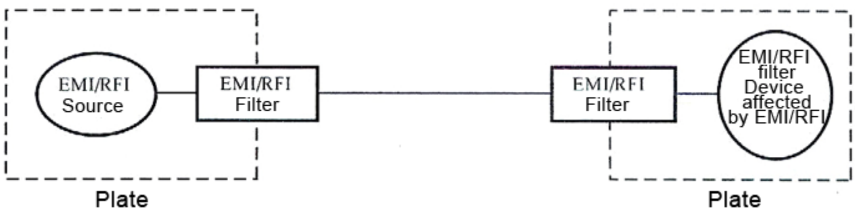


Figure 5.18

In Greece, as in the rest of the E.U., since 1/1/1997, every electric ore electronic device must have antiparasitic EMI/RFI filters (IEC 1000-4-X/95) and for their certification, they will have the symbol CE (Conformitee Europenne).

There are various regulations for the EMI/RFI suppressing requirements, as FCC, CISPR, VDE etc. In Fig. 5.19 you can see one of the most popular set of limitations, the <CISPR> set:

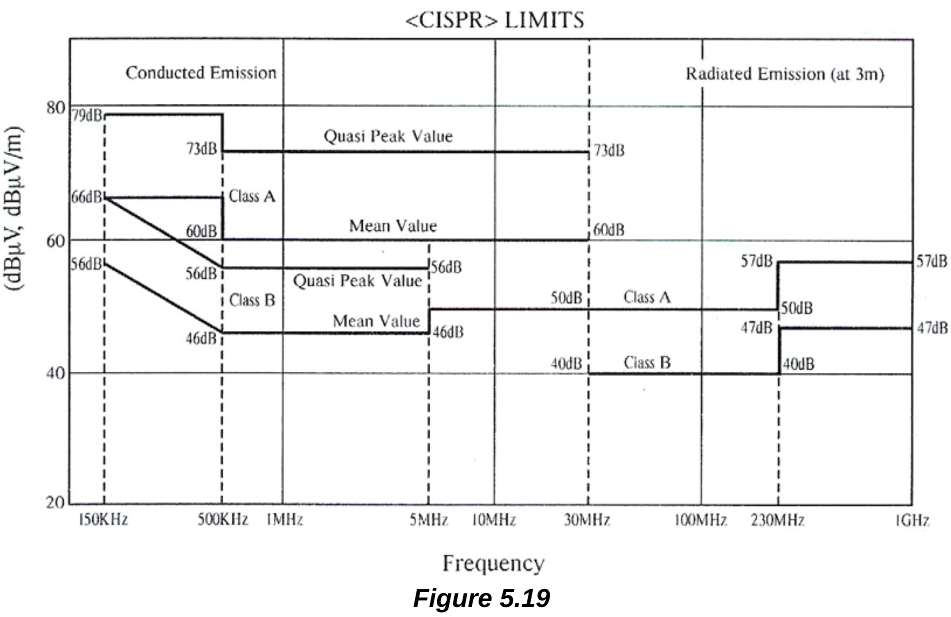


Figure 5.19

The EMI/RFI interferences in the analog circuits are coming from biomechanical parasites, atmosphere and cosmic noises, electronic elements, i.e. thermal noise, electronic circuits etc. In digital circuits we have interferences:

a. in the current line of the ICs.
b. radiation from the ICs' plate,
c. radiation from the signal line,
d. radiation from the I/O (input/output) wires, and
e. radiation from the ground.

We are going to examine further down the production of the noises we mentioned above as well as ways of suppressing them.

In Fig. 5.20, you can see the spectrum of the harmonics of an ideal square signal with d=49.5%, that is duty cycle equal to t/T. In Fig. 5.21 you can see the circuit of 75AS04 (NOT) with frequency 4MHz (a) and the spectrum produced by it numbers many thousands MHz (b).

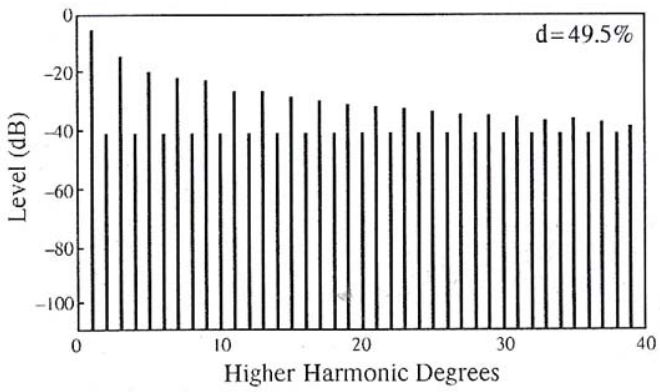


Figure 5.20

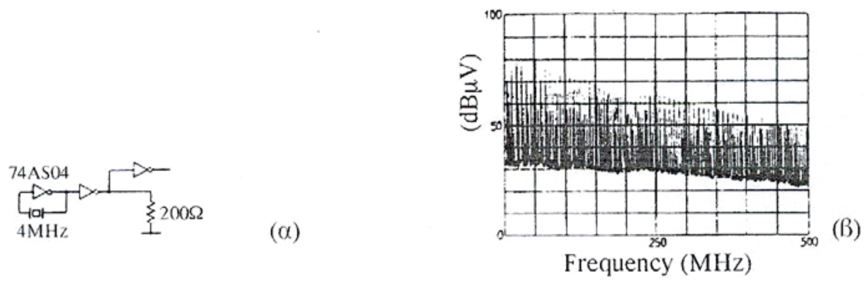


Figure 5.21

A. In Fig. 5.22, the 74AS04 in 8MHz transmits in the current line the spectrum of noise which seems to be a spectrum of many thousands MHz. In Fig. 5.23 you can see an example of those noises in a TV screen.

5.5.2.1 SAW Filters

The Surface Acoustic Wave is the wave transmitted along the surface of an elastic underlay, which has a width decreasing exponentially against the depth of the underlay. A SAW filter is the filter which is stamped by an acoustic surface wave, produced by the IDT (InterDigital Transducer) and transmitted along the surface of the underlay towards a connector IDT. The IDT is a com-shaped structure, consisting of interjectored metal electrodes which convert electric energy to acoustic energy and conversely, through the piezoelectric phenomenon. The SAW electromechanical coupling factor is:

$$K_s^2 = 2\left|\frac{\Delta U}{U}\right|$$

and expresses the ability to convert electric to acoustic energy and vice versa. The elastic silicone acts as absorber; it is the silicone which covers the side of the output of the IDTs and it is placed there to obstruct the acoustic surface wave to transmit to the output, because the construction of IDTs is symmetrical and the acoustic surface wave is transmitted to the right and left.

Undesired signals in a SAW filter:

1. Triple Transit Echo are the signals which go through the transit road three times between input and output of the IDTs.
2. Bulk Wave Signals which are caused by the stimulation of the bulk wave and are suppressed by the grounding of the bottom of the underlay.
3. Feed-through Signals are the signals which from the input of the filter appear to the output and are caused by the coupling of the leak capacities and other electromagnetic couplings.

Whatever we mentioned above is an introduction to SAW filters for their farther study. They were introduced in 1976 and have similar attributes with the LC filters and also, they don't need adjustment, they require less work, improve the picture on TVs, have small temperature coefficient, are manufactured in integrated form with other circuits and they also cost less.

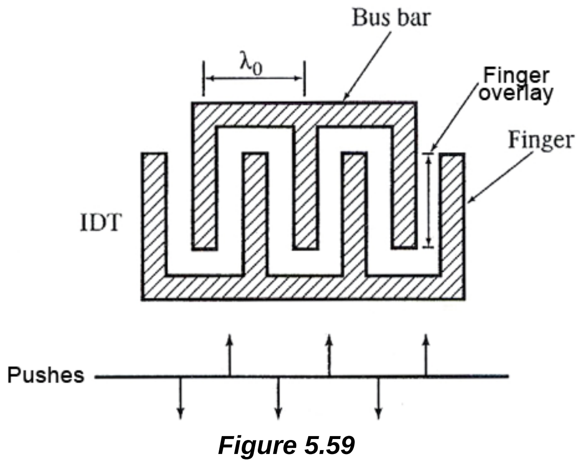


Figure 5.59

In Fig. 5.59 you can see the interior structure of a SAW filter with normal IDT, that is fixed finger overlay and fixed distance λ_0. The first IDT which is connected to the input, produces an acoustic surface wave, while the second IDT is connected to the output and converts the SAW energy to electric voltage. The SAW energy is transferred from one IDT to the other, with thickenings and rarefactions on the overlay, through the piezoelectric phenomenon. Thus, a couple of adjacent pushes of contrary polarity corresponds to a couple of electrodes (fingers). When the length wave of the acoustic surface wave equals λ_0, we get the maximum SAW energy. The attenuation in a SAW filter with normal IDT is given by the equation:

$$A_f = \frac{\sin N \pi X}{N \pi X} \quad \text{(dB)}$$

where

$$X = \frac{f - f_0}{f_0} \quad \text{and} \quad f_0 = \frac{V}{\lambda_0} ,$$

N is the number of the couples of electrodes,
V is the speed of the wave, and
λ_0 is the distance between the electrodes.

In Fig. 5.60, the eigenfunctions of frequency are applied to SAW filters with normal IDT. These eigenfunctions can be changed in two different ways: a. by changing the overly of the electrodes, that is the size of the pushes which is called apodize, and b. by changing the distance of the electrodes (pitch), that is the position of the pushes which is called variable pitch. These two ways are mentioned as balancing method. In Fig. 5.61 you can see the balancing pushes.

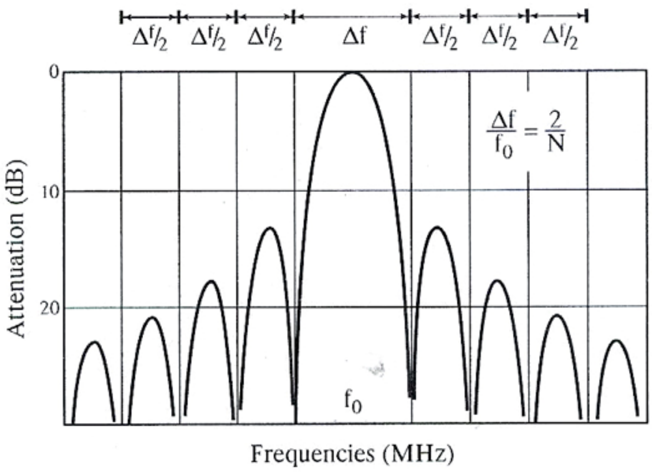


Figure 5.60

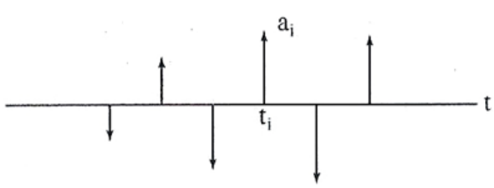
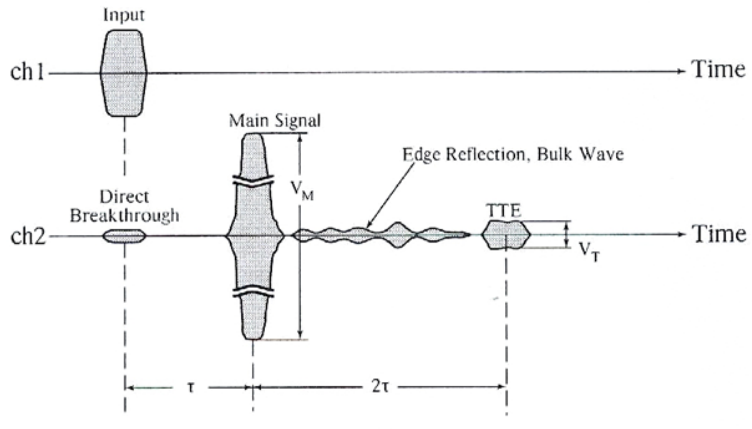


Figure 5.61

In Fig. 5.62, the main signal in the output is shown with hysterisis (τ) and corresponds to the input signal, while the undesired signals TTE, the edge reflection, bulk wave signals and the feed-through (Direct Breakthrough) signals are shown too.



$$TTE = 20\log \frac{V_T}{V_M}$$

Figure 5.62

In Fig. 5.63 you can see the structure of a SAW filter with an absorber only in the output.

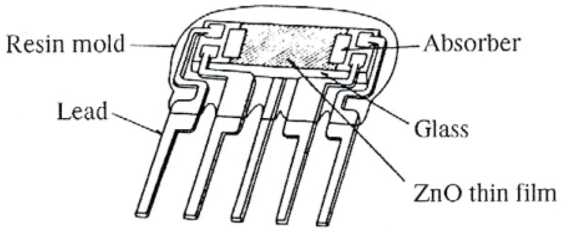


Figure 5.63

In Fig 5.64, you can see the response of frequency of a SAW filter and the total hysterisis between input and output. The difference with the LC filters is obvious; there are ripples outside the transit band, which are mostly owed to the TTE and the Direct Breakthrough signals.

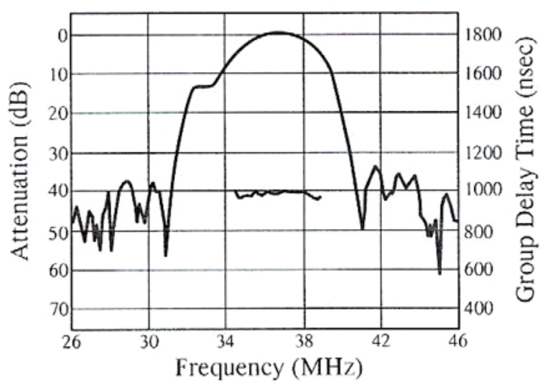


Figure 5.64

From Fig. 5.65a, the losses in voltage are defined by the equation $20\log U_S/U_L$ with a SAW filter.

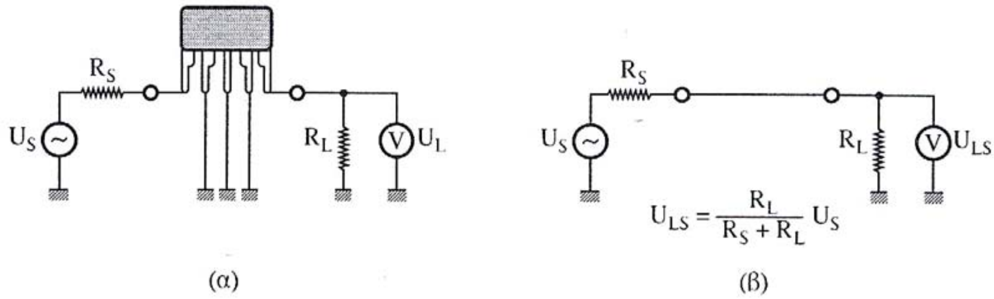


Figure 5.65

From Fig. 5.65b, we have without filter respectively:

$$20 \log \frac{U_S}{U_{LS}} = 20 \log \frac{R_S + R_L}{R_L}$$

The insertion losses are defined by the equation:

$$I.L = 20 \log \frac{U_S}{U_L} - 20 \log \frac{R_S + R_L}{R_L} \qquad (dB)$$

and the power losses are defined by the equation :

$$P.L = I.L + 10 \log \frac{(R_S + R_L)^2}{4 R_S \cdot R_L} \qquad (dB)$$

It is clear that if R_S=R_L, then P.L=I.L, that is the power losses are equal to the insertion losses. The power losses of a SAW filter are defined by the complex resistors of its input and output. Close to the central frequency of the filter, the complex resistors of its input and output equals to a coil and a resistor in a parallel way. This resistor is called radiation resistance and the power is consumed by that resistor and converts to energy of a surface wave. If for the SAW filter we have R_S=$|Z_{in}|$ and R_L=$|Z_{out}|$, then the power losses are minimized.
The Z_{in} and Z_{out} include also capacitive elements, which can be cancelled through a self-inductance and so the remained ohmic elements would be adjusted with R_S and R_L.

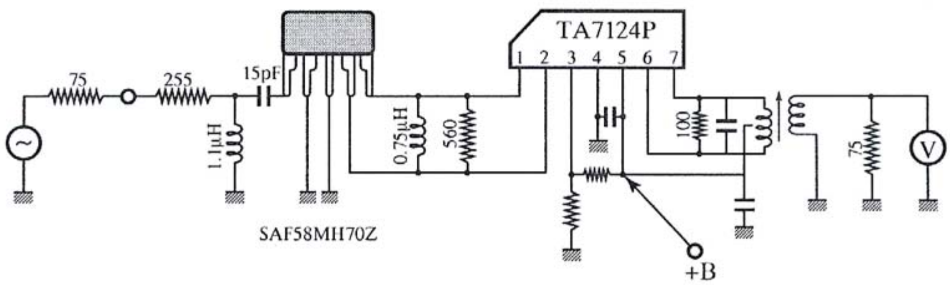


Figure 5.66

This figure shows the adjustment of resistors through the self-inductances 1.1μH and 0.75μH. Last, the required suppression of the TTE must be –40dB, that's why the power losses, even without suppression, must be bigger than 18dB.

The complex input-output resistors of a SAW filter are determined mostly by the material of the piezoelectric underlay. Thus, for high complex resistors we use thin film Zn0 with small dielectric constant (8.5), while for low complex resistors we use piezoelectric ceramic PZT [$Pb(Sn1/2Sb1/2)0_3$-$PbTi0_3$-$PbZr0_3$] with relatively big dielectric constant (400). Also, the method we use (resonant or not) determines the complex resistors of a SAW filter.
In Fig. 5.67a, you see the equivalent circuit of an unresonant SAW filter, whose capacities are neutralized with coils of parallel resonance and the complex resistors close to the resonance are getting equal to R_p.

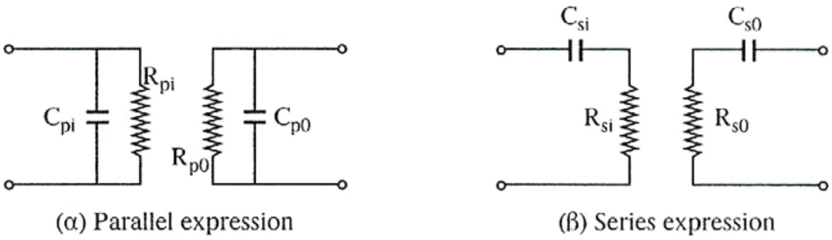


Figure 5.67

In fig. 5.67b, we have a circuit of series resonance and the complex resistors (including the self-inductances) are getting equal to R_S. From the Table 5.9, if we compare SAF58MH70Z with SAF58MSA70P, we can see the explicitly smaller values of R_p and R_S in the second type, which are caused by the material of the underlay. Also, the difference of the values in the first type (and in others as well) between R_{pi}, R_{si} and R_{p0}, R_{s0}, which are owed to the resonance, is obvious.