Benha University
Faculty of Engineering- Shoubra
Electrical Engineering Department
Msc (Electronics) CME607

2nd semester Final Exam
Date: 28/05/ 2019
Sonic and ultrasonic
Duration : 3 hours

- The exam contains compulsory quesions
- Illustrate your answers with sketches when necessary.
- The exam. Consists of One page
- No. of questions: **3**
- Total Mark: **60** Marks
- Examiner: Dr. Moataz Elsherbini

Answer all the following Questions

(Q1) (a) Give a brief account on :

- **Acoustic wave**
- **plane wave**
- ***velocity of acoustic waves in solids.***
- ***Interdigital transducers (IDTs)***
- ***Famous types of Piezoeletric material used for SAW devices***

(b) Write the propagation equation for plane wave (piezo electric equation), describe each parameter.

(c) What are the main uses of SAW devices.

(d) List the advantages of using SAW devices.

30 marks

Q(2) Write a simplified report on:

(a) ultrasonic Transducers

(b) piezoelectric Transducers

15 marks

Q(3) Design A SAW delayline using the mason equivalent model circuit, show how to calculate the insertion loss and frequency response of the overall system. Use the following parameters:

- **ST-cut Quartz piezoelectric material (Cs=0.503385 pf/cm) (v=3158 m/s) (K=0.04)**
- **The synchronous frequency is 70 MHz**
- **Null bandwidth of 1.5MHz.**
- **The delay length between two IDTs is 5 wavelengths**
- **Both input and output resistance are assumed to be 50Ω**

Draw All Expected Graphs

15 marks

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(Q1) (a) Give a brief account on :

- **Acoustic wave *(3marks)***

The acoustic wave is a physical phenomena which transsimet the power from one point to another through a medium and have a speed frequency and wave length, the most known wave is electromagnetic wave and mechanical wave.

- **plane wave*(3marks)***

The deformation is harmonic in space and time, the all atoms on a particular plane normal to the propagation direction, the plane waves divided into two types :

1. Longitudinal waves :

   In which the atoms vibrate in the propagation direction.

2. Shear waves :

   In which the atome vibrate in the plane normal to the propagation direction.

- ***velocity of acoustic waves in solids. (3marks)***

Acoustic waves in solids propagate at a velocity some five orders of magnitude less than electromagnetic waves.

These properties have been exploited in a number of bulk waves devices for electronic systems where the term Bulk waves :

- Is often used to describe waves which are not bound to surface.

On other hand, a medium with dimensions much larger than the wavelength can support waves with characteristics similar to those of waves in an infinite medium.

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- ***nterdigital transducers (IDTs) (3marks)***

In another application of piezoelectricity, a set of metal strips in the path of a surface wave can be used to generate a secondary surface wave, which may be displaced laterally w.r.t. the input wave. This principle is used in the multip-strip coupler.

Another application of piezoelectricity is that a metal strip on the surface may be used as a waveguide for surface waves, enabling a narrow beam to propagate long distances without diffraction spreading.

- ***Famous types of Piezoeletric material used for SAW devices(3marks)***

All surface - wave devices use piezoelectric materials. Crystalline materials are usually chosen in order to obtain low attenuation of the waves (Quartz and lithium niobate).

(e) Write the propagation equation for plane wave (piezo electric equation), describe each parameter. (5marks)

Propagation Equation :

When working with plane waves the most convenient way to write the piezoelectric equation of state is :

$$T = cS - eE ,$$

$$D = eS + \varepsilon E$$

Where

c is the elastic constant at constant electric field

ε permittivity at constant strain,

E The electric field,

T The stress,

e The piezoelectric constant, and

D The electric displacement.

(b) What are the main uses of SAW devices. (5marks)

There are many industrial uses of acoustic waves :-

1. In particular non distructive Testing.
2. In which invisible defects such as cracks are detected without damping the material.

(c) List the advantages of using SAW devices. (5marks)

a. Good dynamic range (80 dB) and temperature stability.

b. Center frequency 5 MHZ - 1 GHZ, bandwidth 0.2 - 300 MHZ, time bandwidth products up to at least 1000.

c. Passive (except for programmable filters).

d. Straight forward fabrication using a technique similar to semi-conductor fabrication.

e. Versatile response function obtained with little or no trimming necessary, Design is relatively straight forward. (steps like IC fabricat

f. Good repeatability and small size weight and radiation resistance.

g. Small faults generally cause small changes in performance.

h. The sophistication is built into the mask used in delineating the Transducer structure.

i. Show velocity of the acoustic wave relative to that of electro-magnetic waves leads to a spatial compression of a signal by about 10^5 along the propagation path.

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Q(2) Write a simplified report on:

(c) ultrasonic Transducers (8 marks)

The name transducer is given to devices which convert energy from one form to another; and to convert acoustical signals into electrical signals. Some transducers performs the tasks of both transmission and reception, it must possess the characteristics of linearity and reversibility. A transducer is linear if it produces an exact equivalent in electrical terms of the incident acoustic waveform, and it is reversible if it has the ability to convert energy between the electrical and acoustical forms in either direction. The term reversible is frequently used, however, in a more specialized form, which denotes that energy is converted with equal efficiency in either direction.

The majority of transducers fall into two categories, those which employ electric fields in their transduction process and those which employ magnetic fields. Some are inherently linear whilst others have to be polarized to produce linear action. This arises from the fact that the force producing acceleration of the active mass of the transducer, which in turn causes acoustic radiation, can be directly proportional to or proportional to the square of the applied electric signal, depending upon the physical mechanism employed for transduction.

If the electrical signal is sinusoidal of the form

$$E(t) = E_e Sin(\omega t)$$

A square-law transducer produces a force proportional to

$$(E_e Sin(\omega t))^2 = \frac{1}{2} E_e^2 (1 - Cos(2\omega t))$$

i.e a steady component plus a sinusoidal component varying at twice the applied frequency. If now a steady polarizing quantity E_o together with the sinusoidal signal the force produced is modified, becoming proportional to

$$(E_o + E_e Sin(\omega t))^2 = E_o^2 + 2E_o E_e Sin(\omega t) + E_e^2 Sin^2(\omega t)$$

And if E_o is made much greater than E_e the final term of this expression can be ignored and an alternating force is produced which is a linear function of the applied sinusoid.

(d) piezoelectric Transducers (7marks)

Consider first the direct piezoelectric effect. The surface charge induced on a slice of piezoelectric material is called the polarization charge p and is measured in coulombs/m^2. It is related to an applied stress *T*, measured in *newtons* /m^2 by

$$p = Td \qquad (1)$$

Where d is the piezoelectric strain coefficient, defined as the charge density per unit applied stress, measured in coulombs/newton, when no external electric field is applied to the slice, i.e. under short-circuit conditions.

If now an electric field *E* measured in *V/m*, is applied to the slice, the electric flux density *D*, in *coulombs/*m^2, within it becomes

$$D = E\varepsilon + Td \qquad (2)$$

Where ε is its permittivity, measured in *farads/m*.

Now consider the converse effect. If an unstressed slice is subjected to an electric field it undergoes a mechanical strain *S* which is related to the electric field intensity by

$$S = Ed' \qquad (3)$$

Consideration of the princciple of the conservation of energy shows that $d = d'$ and yields an alternative definition for *d*, i.e. the mechanical strain produced per unit applied field, measured in *m/V* under condition of no load.

Applying a tensile stress *T* to the slice which possesses an elastic constant *s*, measured in *m/newton*, results in a total strain

$$S = Ts + Ed \qquad (4)$$

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In a non-piezoelectric material eqns. (2) and (4) reduced to the well known relations.

$$D = E\varepsilon \qquad (5)$$

$$S = Ts \qquad (6)$$

When a compressive stress *(-T)* is applied, eqn. (4) becomes

$$S = -Ts + Ed \qquad (4\text{-a})$$

and the slice can be effectively clamped if S is made zero by balancing the strain produced by the electric field by the compressive strain. Under these conditions eqn. (4-a) gives

$$T = eE \qquad (7)$$

Where $e = \frac{d}{s}$ is the piezoelectric stress coefficient defined as the stress produced per unit applied field measured in *newtons/Vm*.

Equations (1) and (6) give

$$P = eS \qquad (8)$$

And an alternative definition for e, i.e. the charge density obtained per unit strain, expressed in *coulombs/m*^{2}.

Q(3) Design A SAW delayline using the mason equivalent model circuit, show how to calculate the insertion loss and frequency response of the overall system. Use the following parameters:

- **ST-cut Quartz piezoelectric material (Cs=0.503385 pf/cm) (v=3158 m/s) (K=0.04)**
- **The synchronous frequency is 52.633 MHz**
- **Null bandwidth of 1.5MHz.**
- **The delay length between two IDTs is 5 wavelengths**
- **Both input and output resistance are assumed to be 50Ω (15 marks)**

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2. *Number of fingers* =

$$N_P = round\left(\frac{2f_o}{NBW}\right)$$

Where NBW is null bandwidth

3. *The time response* h(t) of SAW IDT is given by

$$h(t)\alpha 4\sqrt{K^2C_s}f_o^{3/2}(t)sin(2\pi f_o t)$$

4. *The frequency response* obtained by taking fast Fourier transform of time response

$$H(f) = 20log\left|\left\{4K^2C_sW_af_oN_p^2\left(\frac{\sin X}{X}\right)^2 e^{-i\left(\frac{N+D}{f_o}\right)}\right\}\right|$$

Where D is the delay length in wavelength between the IDTs, Wa is the Aperture height (finger overlap).

5. The Variable

$$X = N_p\pi\left[\left(\frac{f-f_o}{f_o}\right)\right]$$

6. *The aperture* (finger overlap) is dedicated from

$$W_{a=}\frac{1}{R_{in}}\left(\frac{1}{2f_oC_sN_p}\right)\left\{\frac{4K^2N_p}{\left(4K^2N_p\right)^2+\pi^2}\right\}$$

Where, R_{in} is source resistance.

7. *The radiation conductance* derived from

$$G_a(f) = 8K^2C_sW_af_oN_p^2\left(\frac{\sin X}{X}\right)^2$$

8. The acoustic susceptance derived from taking the Hibert transform of the radiation conductance.

$$B_a(f) = \frac{G_a(f_o)\sin(2X)-2X}{2X^2}$$

9. The total static capacitance

$$C_T = C_sW_aN_p$$

10. The total admittance is

$$Y(f) = G_a(f) + j(2\pi C_{T+}B_a(f))$$

11. The system impedance is

$$Z(f) = \frac{1}{Y(f)}$$

12. The insertion loss is

$$IL(f) = -10log\left\{\frac{2G_a(f)R_{in}}{(1+G_a(f)R_{in})^2+\left(R_{in}(2\pi fC_T+B_a(f))\right)^2}\right\}$$

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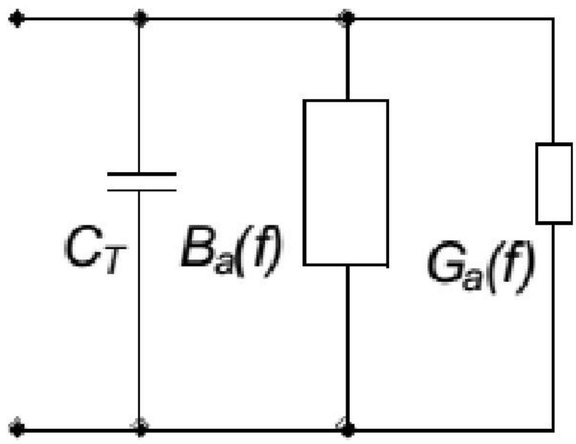

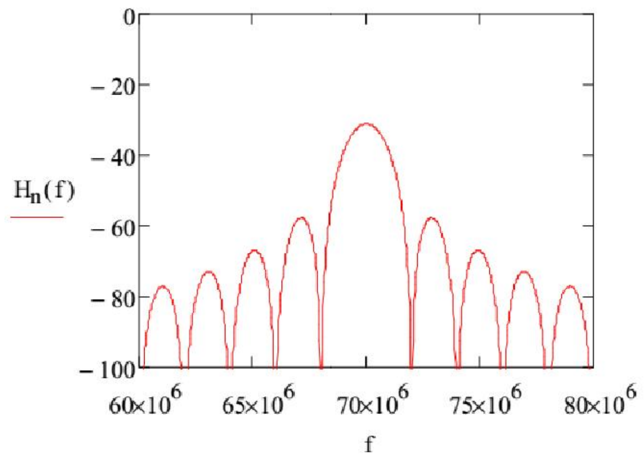

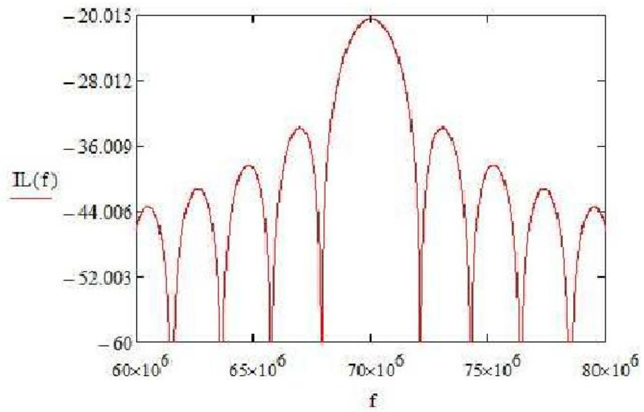

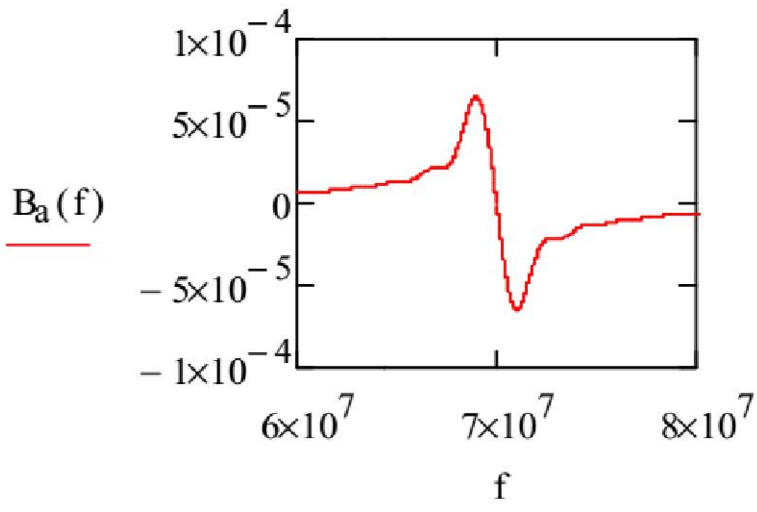

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