

**ADDIS ABABA UNIVERSITY  
SCHOOL OF GRADUATE STUDIES**

**FACULTY OF SCIENCE  
DEPARTMENT OF GEOLOGY AND GEOPHYSICS**

**SEISMIC WAVEFORM ANALYSIS FROM THE  
QUARRY BLAST  
RECORDS AROUND ADDIS ABABA**

**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES  
OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT FOR  
THE DEGREE OF MASTER OF SCIENCE IN APPLIED GEOPHYSICS**

**BY  
MEKONNEN HURRISA**

**ADDIS ABABA  
JUNE 2003**



Addis Ababa University  
School of Graduate Studies

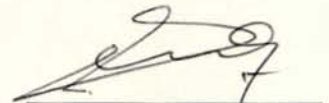
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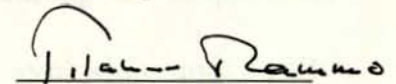
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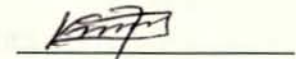
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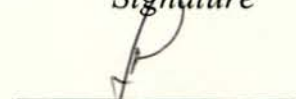
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## **Abstract**

The seismic wave generated at the quarry blasts in the area of investigation are detected and recorded by the Furi broadband seismic station. The seismic records provide the wave patterns of significant amplitudes and frequency contents that can be used for the study of different seismic and elastic parameters that characterize the types of rock formations.

This study is carried out to determine the relationships among the amplitudes, frequencies, charge size, epi-central distance, depths of explosion and finally compute the body wave velocities ( $V_p$  and  $V_s$ ), velocity ratio ( $V_p/V_s$ ) and the Poisson's ratio ( $\nu$ ) from the path  $X_a$  traversed by the seismic waves and the delay times  $\Delta t$  found from the observed arrival times and origin times.

Both the computed velocity ratio ( $V_p/V_s = 1.76$ ) and the Poisson's ratio ( $\nu = 0.26$ ) for the rock formation in the area approach the condition of Poisson's relation ( $\nu =$

0.25,  $VP/VS = 1.732$  and  $K/\mu = 1.67$ ). These results possibly describe the similarity of fractures in the whole rock formations in the area.

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I would also address my appreciation to Ato Dagnawi, Ato Abebe and Wro Amolech for their assistance in waveform display and identification of wave characteristics.

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## Chapter 1

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## **Chapter-1**

### **1. Introduction**

#### **1.1. Location of the study area**

The areas, where the study was carried out include Akaki, Kaliti (KCRBC), Bole-Bulbula (BMM), Bole-Bulbula (BCRBC) and Jimma Road (JRRCRBC). These areas are found in the southern part of Addis Ababa and they extend from  $8.851^{\circ}$  to  $8.972^{\circ}$  north and  $38.678^{\circ}$  to  $38.822^{\circ}$  east. From the above areas, the positions of quarries where the seismic waves are generated during fracturing hard rocks to produce construction materials of different sizes were identified and their positions relative to the Furi Mountain were determined. As indicated on the location map all the quarry sites lie in the east of Furi Mountain where the broadband seismic station is situated. The distances of the quarries from recording station range from 8.76km corresponding to JRRCRBC to 16.81km corresponding to akaki quarries.

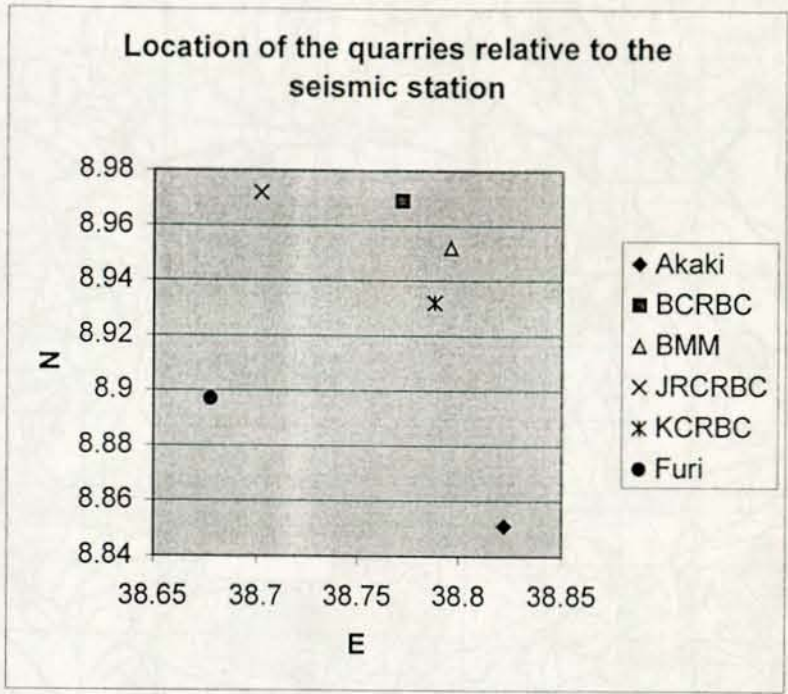


Fig.1. Locations of the Quarries Relative to Furi Seismic Station.

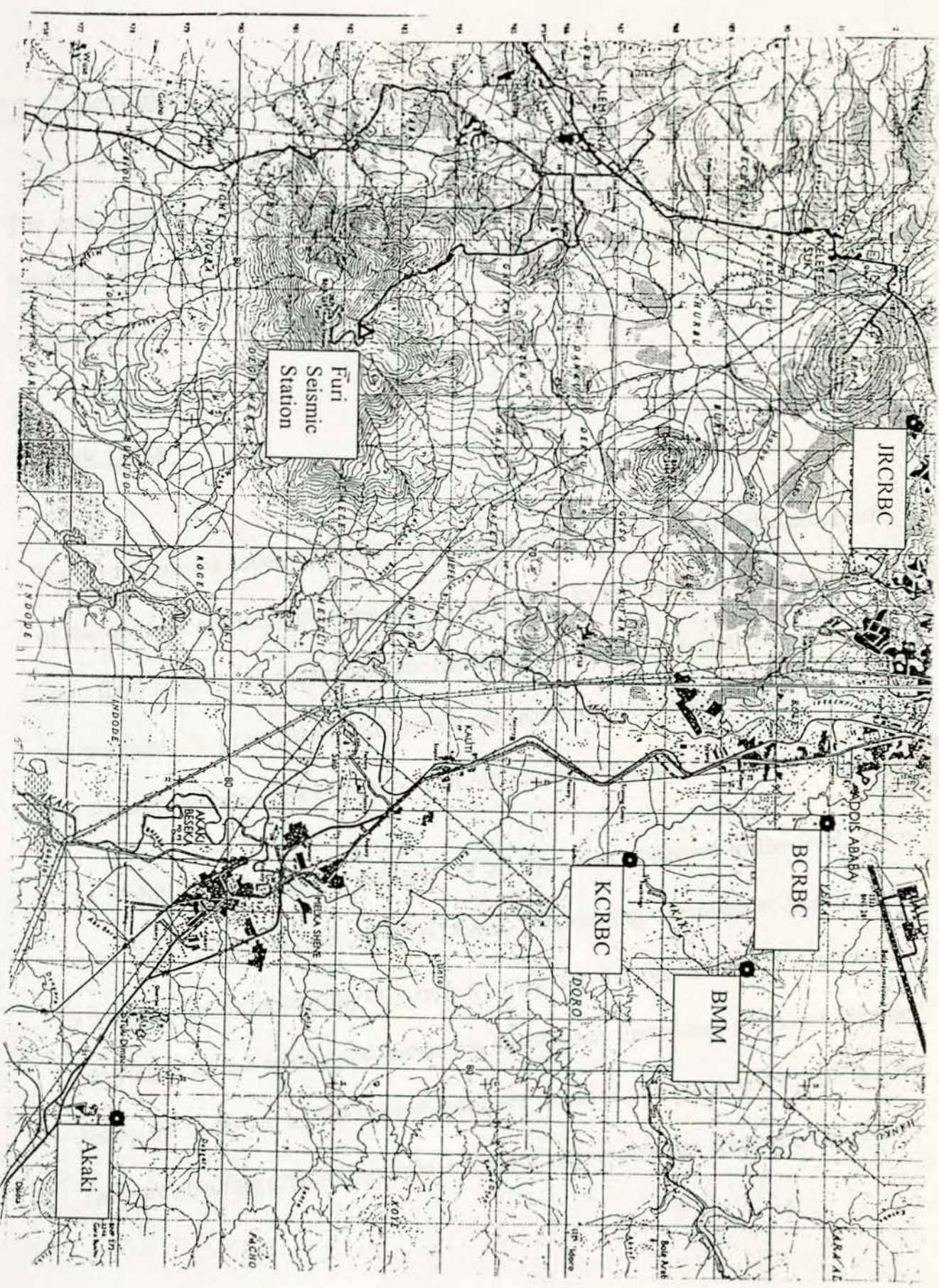


Fig.2. Modified Map of South Addis Ababa (1:50000)

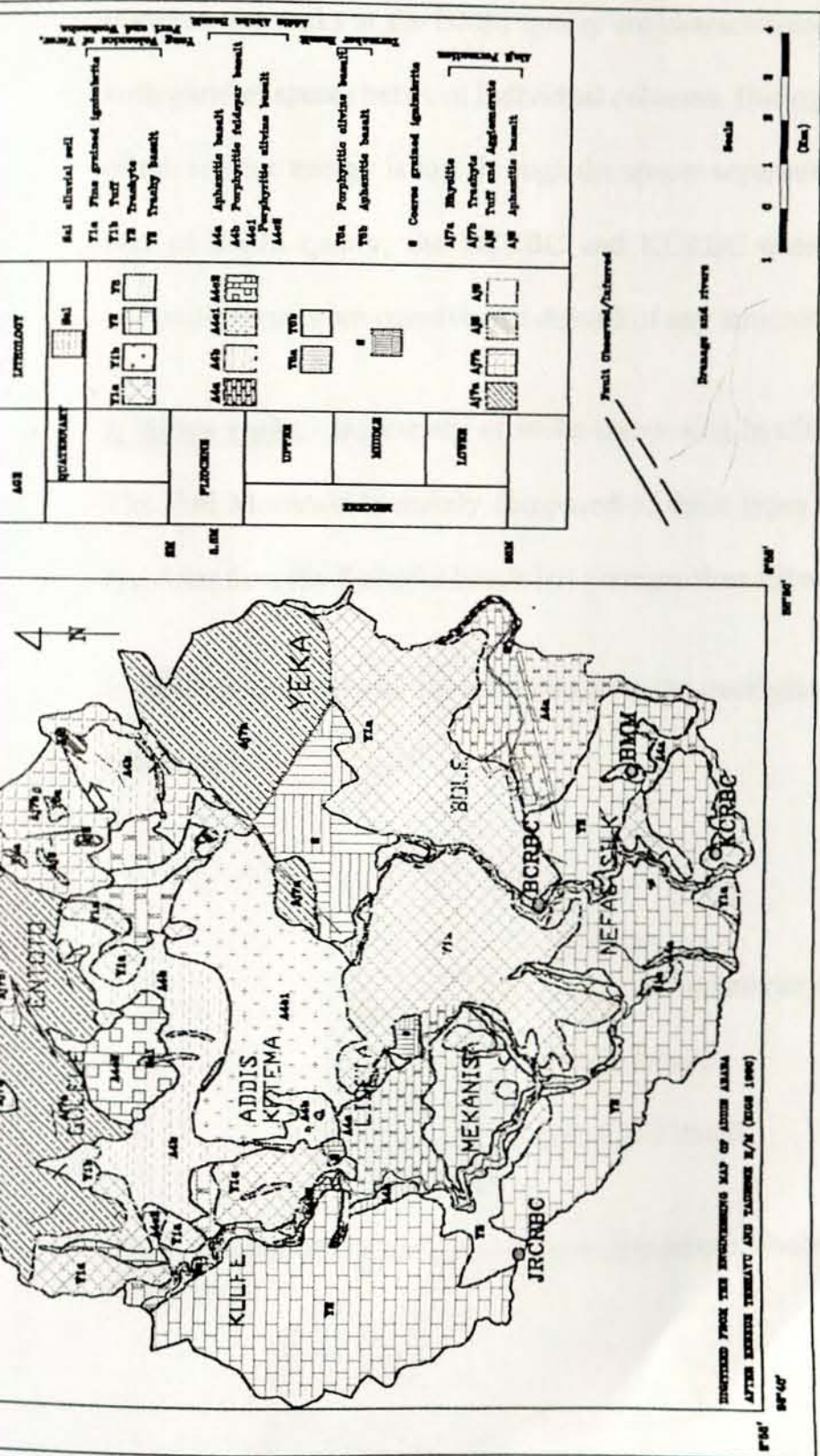
### 1.3. Geology of the Area

The area under investigation, as part of Addis Ababa region, belongs to the main Ethiopian Rift Valley and consists of different volcanic range from basic to acidic composition.

#### i. Basic rocks

These rock groups cover most of the areas in which this study was carried out. Most of the quarries are located where these types of rocks are abundant. As concluded from field observation these rocks are classified into three: Aphanatic, Bishoftu and the trachybasalt. From hand specimen the aphanatic basalts are very fine grained and the Bishoftu basalts show phenocrysts of olivine and some amphiboles.

The Bishoftu basalts are the youngest of all the rocks observed in the field. They cover most of the areas around Akaki town. The blasting operation at Akaki quarry is carried out on quarrying this type of rock for the production of construction materials. On the other hand aphanatic basalts are the oldest rocks we obtained during the field- work. The trachybasalts are found at one place at JRRCB quarry. They are also fine grained but lighter in color as compared to aphanatic basalts.



△ FURI

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FIG. 1.2 Simplified Geological Map of Addis Ababa (After Morton, WH, 1974)

The three quarries: BMM, BCRBC and KCRBC are located where aphanatic basalts are found in abundance. The structures of the rocks vary from place to place. For instance, the rocks at the BMM quarry are characterized by having columnar joints with parallel spaces between individual columns. During the blasting operation most of the seismic energy is lost through the spaces separating the parallel joints. Unlike that of BMM quarry, the BCRBC and KCRBC quarries are situated where the aphanatic basalts are massive and devoid of any structures.

**ii. Silica rocks:-** are variety of rocks composing hyalite, tracheae and welded tuff. The Furi Mountain is mainly composed of these types of rocks. The silica groups are older than the Bishoftu basalt but younger than aphanatic basalt.

In general, the rocks of the areas can form the geological succession as in the figure below.

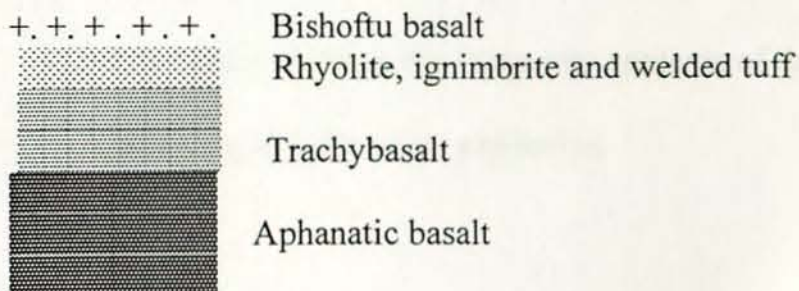


Fig.4. Simplified Successions of Rock formations observed from the rock out crops in the Area.



In addition to the rock formations characterizing the area, number of faults whose trends are sub-parallel to the Ethiopian rift fault are expected. These faults trend in the direction of NE-SW. (source: Geologic map of Addis Ababa,1972)

### 1.3. Purpose of the study

The propagation of seismic wave through the earth is affected by the elastic properties of the part of the earth through which it propagates. The study of the seismic waves means the study of the elastic properties of the medium. Therefore the seismic records are the basic sources of information about the structural signature of subsurface.

The current study is carried out for the following purposes. These are:

- (1) to investigate the relationships between the amplitudes of the waves and charge size, distance and depth of the explosion,
- (2) to observe the relationships between the frequency contents of the waves and charge size, distance and the depth of the explosion,

(3) to describe the variations of wave patterns and body wave velocities as the function of epi-central distance and delay times, and

(4) to correlate the variations of wave patterns to the causative geologic conditions.

## Theory and Principles

### 2. Theory

#### 2.1. Seismic Wave Generation

A great variety of physical phenomena occurring outside and inside of the earth involve rapid motions that excite detectable seismic waves. Quarry blast is one of the physical phenomena that occur on the earth that generate seismic waves.

Seismic waves occur whenever a transient stress imbalance is produced within or on the surface of elastic medium (the earth).

When this stress imbalance is produced the particles of the medium are displaced from their positions of equilibrium. Since the medium is continuous, the displacement of a single particle causes its neighboring particles, which again induce the same

## Chapter-2

### Theory and Principles

#### 2. Theory.

##### 2.1. Seismic Wave Generation

A great variety of physical phenomena occurring outside and inside of the earth involve rapid motions that excite detectable seismic waves. Quarry blast is one of the physical phenomena occurring within the earth that generate seismic waves.

Seismic waves/elastic waves/ are generated whenever a transient stress imbalance is produced within or on the surface of elastic medium/ the earth/.

When this stress imbalance is produced the particles of the medium are dislocated from their positions of equilibriums. Since the medium is continuous, the dislocation of a single particle disturbs its neighboring particles, which again induce the same

disturbance to the next particles in the medium in the same manner. This process continues until the disturbance decays to the level of undetectable magnitude. The disturbance produced in this manner is called wave. Since the particles in the medium recover their original equilibrium positions except in the immediate vicinity of the source the disturbance is called elastic wave/seismic wave/.

### 2.1.1. Displacement and Strain

When a particle in a medium is subjected to an external force it moves in the direction of the applied force. The change in the final position of the particle and its original position is its displacement.

When a part of a body moves /dislocates/ from its original position as it is exposed to unbalanced force one part of the medium collapses and the other bulges out. The collapse and bulging out of the medium is known as deformation.

Deformations within a medium are composed of components that involve change in size and angular distortions. Let's consider a body initially unloaded and deformed with two internal points A and B as shown in the figure below.

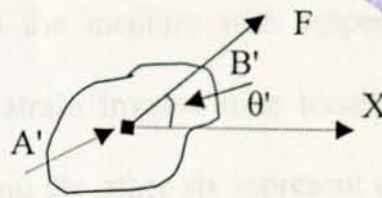
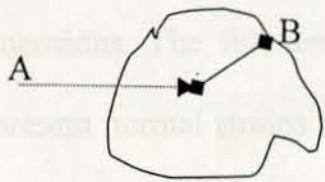


Fig.5 (a) Unloaded Body

Fig.5 (b) Loaded Body

The points A and B are connected by a straight line, AB. As the force F is applied to the body, the deformation moves the points A and B to points A' and B' respectively. These points are now connected by a straight line, A'B'. In order to describe the deformation of the medium, it is necessary to describe both the displacement A'B'-AB and any rotation of the line A'B' with respect to the surrounding material. Now it is important to define the terms strains (spatial gradient of the displacement field).

The spatial gradient of the displacement field can be described in two ways.

1. Normal strains-are the measure of elongation and defined as

$$S_n = \lim_{AB \rightarrow 0} (A'B' - AB) / AB \text{-----} 2.1$$

2. Shear strains-are the measure of internal angular distortion and are defined as;

$$S_s = 1/2 \{ \lim_{\substack{AB \rightarrow 0 \\ A'B' \rightarrow 0}} (90 - \theta) \} \text{-----} 2.2$$

where  $\theta$  is the angle between the straight lines AB and A'B'.

Since the space is three-dimensional the elongations and the angular distortions must be described at every point in the medium with respect to all three-dimensions. The full descriptions of strain involve nine terms; three of them represent normal strains  $S_{11}, S_{22}, S_{33}$  and the other six represent angular changes of each coordinate directions,  $S_{12}, S_{13}, S_{21}, S_{23}, S_{31}, S_{32}$ . These nine terms have continuous distributions throughout the medium and are functions of time.

For a General three-dimensional case, the nine elements of the strains will be

$$\begin{matrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{matrix} = S \text{-----} 2.3$$

These all are associated with the internal deformation of the material.

### 2.1.2. Stress

Stress is defined as the force per unit area. This definition is equivalent to the definition of pressure. When a force  $F$  is applied to a body the stress is the ratio of the force  $F$  to the area  $A$  on which the force is acting. If the force  $F$  varies from point to point, the stress also varies and its value at a point is found by dividing the total force  $F$  to the infinitesimally small area  $A$  on which the force acts.

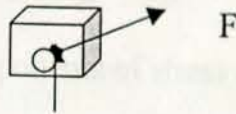


Fig.6. Force acting at a point

If the force  $F$  is normal to the area  $A$  of the body on which it is applied the stress is called normal stress or pressure. If the force  $F$  is tangential to the area  $A$  of the body upon which it is applied the stress is shearing stress. Any force, which is neither normal nor tangential to the area, can be resolved in to normal and tangential component stresses.

### 4.1.3. Strain and Stress Relations

Let a force  $F$  is applied on a body at a point  $O$  as shown in the figure below.

Since the force  $F$  is vector it can be resolved into the three components  $F_1, F_2, F_3$ . In the same manner the area  $A$  of the body upon which the force is applied can be resolved into three components  $A_1, A_2, A_3$ . Then the nine elements of stress will be;

$$T_{11} = F_1/A_1 \quad T_{12} = F_1/A_2 \quad T_{13} = F_1/A_3$$

$$T_{21} = F_2/A_1 \quad T_{22} = F_2/A_2 \quad T_{23} = F_2/A_3$$

$$T_{31} = F_3/A_1 \quad T_{32} = F_3/A_2 \quad T_{33} = F_3/A_3$$

The tensor form of the stress is then written as;

$$\begin{matrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{matrix} = T \text{ -----2.4}$$

The set of nine components of stress completely determine the stress across any small area containing the point and constitute the stress tensor. The components with identical suffixes  $T_{11}$ ,  $T_{22}$ ,  $T_{33}$  are normal components of the stress because they act along the normal of the given planes. The components with different suffixes  $T_{12}$ ,  $T_{13}$ ,  $T_{21}$ ,  $T_{23}$ ,  $T_{31}$  and  $T_{32}$  are shear components of the stress because they act parallel to the given planes.

### 2.1.3. Strain and Stress Relation

Strain and stress are related since one depends on the other. The two quantities are related by Hooke's law and using elastic constants.

When a body is subjected to a stress the strain occurs in the body. The relation between the components of stress and the components of the strain at a point at one instant of time depends on the material constitution of the body and equations relating stress and strain is called constitutive equation. The most general form of a constitutive law for linear elasticity is Hooke's law and is given by;

$$T_{kl} = C_{ijkl}S_{ij} \text{ -----2.5}$$

Where  $C_{ijkl}$  are proportionality constants or elastic constant in rock mechanics called the stiffness. Due to the symmetric behavior of the stress and strain tensors the following relation holds true.

$$C_{ijkl} = C_{jikl} = C_{ijlk} \text{ -----2.6}$$

According to Telford, et al, for isotropic medium the stress-strain relation can be written as

$$T_{ii} = \lambda(S_{11}+S_{22}+S_{33}) + 2\mu S_{ii} \text{ -----2.7}$$

$$T_{ij} = \mu S_{ij} \text{ -----2.8}$$

Where  $\lambda$  and  $\mu$  are Lamé's constants. From the above relations  $\mu$  is the measure of the resistance to the shearing strain and is called shear modulus or rigidity constant.

The term in the bracket in equation 2.7, is the normal strain and is denoted by a single term  $\theta$ . Therefore it can be rewritten as;

$$T_{ii} = \lambda\theta + 2\mu S_{ii} \text{ -----2.9}$$

$$T_{ii} = \lambda\theta + 2\mu S_{ii} \text{-----} 2.9$$

**Elastic Constants**

1. **Young's Modulus (E)** - is defined as the ratio of the stress to the longitudinal extension of the body. That is,

$$E = T_{11}/S_{11} \text{-----} 2.10$$

Equation 2.10 holds for one -dimensional body.

When a three-dimensional body is subjected to a normal stress, the dimension parallel to the stress increases its length while the rest two dimensions decrease their sizes.

For a single force F acting on a body, **Poisson's Ratio (ν)** is used which is defined as the ratio of a strain in one direction to the strain in the normal direction. That is,

$$\nu = -S_{22}/S_{11} = -S_{33}/S_{11} \text{-----} 2.11$$

$$ES_{22} = -\nu T_{11} + T_{22} - \nu T_{33} \text{-----} 2.13$$

$$ES_{33} = -\nu T_{11} - \nu T_{22} + T_{33} \text{-----} 2.14$$

Adding equations 2.12, 2.13 and 2.14, we have the following equation.

$$E(S_{11} + S_{22} + S_{33}) = (T_{11} + T_{22} + T_{33})(1 - 2\nu).$$

**2. Bulk Modulus (K)**- is defined as the ratio of hydrostatic pressure to the dilatation.

That is,

$$K = P/\theta, \text{ where } P = -T_{11} = -T_{22} = -T_{33}, \text{ when } T_{12} = T_{23} = T_{31} = 0.$$

$$E\theta = -3P(1 - 2\nu) \text{-----} 2.15$$

$$E\theta = 3K\theta(1 - 2\nu), \text{ where } P = K\theta \text{ and } \theta = S_{11} + S_{22} + S_{33}$$

$$K = E/3(1 - 2\nu) \text{-----} 2.16$$

**3. Rigidity/ Shear Modulus ( $\mu$ )**- is defined from the shear deformation and relates stress and strain as follows.

$$T_{12} = \mu S_{12}, T_{13} = \mu S_{13}, T_{23} = \mu S_{23}$$

By substituting the above relations in Hooke's law one can obtain the following relations.

$$E = \mu(3\lambda + 2\mu)/(\lambda + \mu) \text{-----} 2.17$$

$$\nu = \lambda/2(\lambda + \mu) \text{-----} 2.18$$

$$K = (3\lambda + 2\mu)/3 \text{-----} 2.19.$$



**2.2. Wave Equation**

When the force  $F$  applied on a deformable body is not equal to zero the particles in the body as well as the body itself will be set in motion. The motion of the particles of the body is governed by the equation called wave equation. This equation can be derived easily when the strain and stress of the body are confined to a single direction.

$$F = ma = (T_1(U+dU) - T_2(U)) / dt = (dT_{11}/dX) dX dA$$

Let a thin rod  $dX$  long with cross sectional area  $dA$ , Young's modulus  $E$  and density  $\rho$  is subjected to a stress  $T_{11}$  along a single direction. The point on the rod originally located at distance  $U$  moves to the new position  $U+dU$  as the net force  $F$  acts on the point.

*V is the volume of the rock*

But  $T_{11} = E dU/dX$ , hence on differentiating  $T_{11}$  with respect to  $X$  the following result is obtained.

$$\rho dU/dt^2 = dT_{11}/dX$$

$$\rho dU/dt^2 = \rho E d^2U/dX^2 \tag{2.20}$$

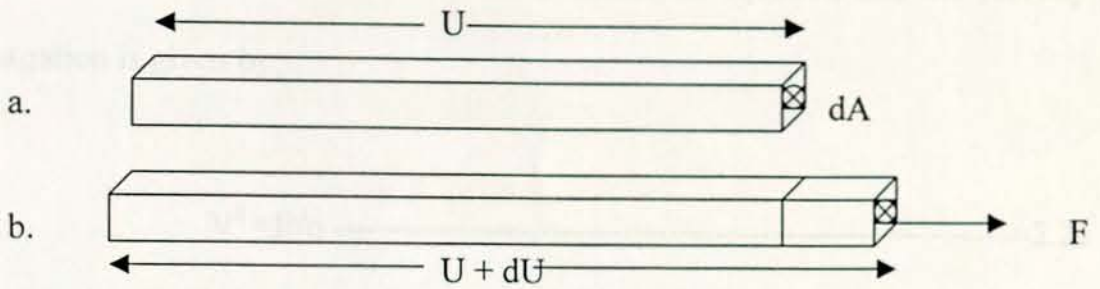


Fig.7. a. Unstretched Material b. Stretched Material

According to Newton's second law of motion, the net force  $F$  acting on the point is now given by the product of the change of stress  $T$  and the cross sectional  $dA$ .

That is,

$$F = ma = \{T_{11}(U + dU) - T_{11}U\}dA = (dT_{11}/dX)dXdA$$

$$F = \rho Va = (dT_{11}/dX)dXdA, \text{ a represents acceleration.}$$

$$F = \rho V \partial^2 U / \partial t^2 = (dT_{11}/dX)V$$

$$\rho \partial^2 U / \partial t^2 = dT_{11}/dX, \text{ where } \rho \text{ density of the medium,}$$

$V$  is the volume of the rock

But  $T_{11} = EdU/dX$ , hence on differentiating  $T_{11}$  with respect to  $X$  the following result is obtained.

$$\rho \partial^2 U / \partial t^2 = E \partial^2 U / \partial X^2$$

$$\partial^2 U / \partial X^2 = \rho/E (\partial^2 U / \partial t^2) \text{-----2.20}$$

Equation 2.20 is a form of classical one-dimensional equation and the velocity of propagation is given by;

$$V^2 = E/\rho \text{-----}2.21$$

The velocity V of the propagation is dependent of the density  $\rho$  and the elastic property E of the medium.

For three-dimensional wave motion the equivalent equation will be ;

$$\rho \partial^2 U / \partial t^2 = dT_{11}/dX + dT_{12}/dY + dT_{13}/dZ$$

$$\rho \partial^2 U / \partial t^2 = (\lambda + \mu) \partial^2 \theta / \partial X^2 + \mu \nabla^2 U \text{-----}2.22$$

$$\nabla^2 = \partial^2 / \partial X^2 + \partial^2 / \partial Y^2 + \partial^2 / \partial Z^2 \text{ and is known as Laplacian operator.}$$

In the same manner the equation along the Y- and Z- directions are given as follows.

$$\rho \partial^2 V / \partial t^2 = (\lambda + \mu) \partial^2 \theta / \partial Y^2 + \mu \nabla^2 V \text{-----}2.23$$

$$\rho \partial^2 W / \partial t^2 = (\lambda + \mu) \partial^2 \theta / \partial W^2 + \mu \nabla^2 W \text{-----}2.24$$

On adding equations 2.22, 2.23 and 2.24 one can obtain the following equation.

$$\rho \partial^2 \theta / \partial t^2 = (\lambda + 2\mu) \nabla^2 \theta \text{-----}2.25$$

$$\partial^2 \theta / \partial t^2 = \{(\lambda + 2\mu) / \rho\} \nabla^2 \theta \text{-----}2.26$$

From equation 2.26 the velocity of longitudinal wave is given by

$$V_p^2 = (\lambda + 2\mu) / \rho \text{-----}2.27$$

To find shear wave the corresponding wave equations can be written as

2.3 Basic Principles of Seismic Wave Propagation

$$\lambda\{\partial^2/\partial X^2(\partial W/\partial Y - \partial Y/\partial Z) + \partial^2/\partial Y^2(\partial U/\partial Z - \partial W/\partial X) + \partial^2/\partial Z^2(\partial U/\partial Y - \partial V/\partial X)\} = \rho \partial^2/\partial t^2 \{(\partial W/\partial Y - \partial V/\partial X) + (\partial U/\partial Z - \partial W/\partial X) + (\partial U/\partial Y - \partial V/\partial X)\} \text{-----2.28}$$

Equation 2.28 is equivalent to the following equation.

$$\mu \nabla^2(S_{12} + S_{13} + S_{23}) = \rho \partial^2/\partial t^2(S_{12} + S_{13} + S_{23}), \text{ Where } S_{12} + S_{13} + S_{23} = S_{sh}$$

$$\mu \nabla^2 S_s = \rho \partial^2 S_s / \partial t^2 \text{-----2.29}$$

From equation 2.29 the velocity of shear wave is given by

$$V_s^2 = \mu/\rho \text{-----2.30}$$

Equations 2.24 and 2.29 are known as Navier's equations and hold for infinite, homogeneous, isotropic elastic medium.

From the equations of longitudinal and shear waves one concludes that the velocity of P-wave is greater than the velocity of S-wave. In seismology these waves are called the primary and secondary waves respectively. This means the primary waves are the first arrivals to the station for a particular seismic event.

## 2.3. Basic Principles of Seismic Wave Propagation

### 2.3.1. Huygen's Principles

Once the seismic wave is produced it moves away from the source. The nature of the motion of the seismic waves is determined by the elastic behavior and the density of the medium as described in the previous sections.

The mechanics of seismic wave propagation and its geometry is governed by the following principles.

**2.3.1. Huygen's Principles**:- states that ' Every point on a wave front is a source of small secondary wavelet that travels outward in every outward direction with the velocity of the medium at that point'. From this statement one can determine:

1. the successive wave fronts relative to the source,
2. the later position of the wave front in the medium,
3. the temporal dependence of the shape of the wave front on material medium ,
4. the velocity of the wave and
5. the direction of propagating wave.

The direction of the propagation is in the direction normal to the wave front. This describes that the wave propagates in all directions from its source.

### 2.3.2. Fermat's Principle.

This principle governs the geometry of the ray path. It states that 'the wave front will move from one point to the other along the path which takes the least amount of time'.

This statement tells us that the wave travels along the path in which it travels with the highest velocity. Using these principles the fundamental of Geometrical Optics called Snell's Law can be derived.

Let's consider a medium with two layers.

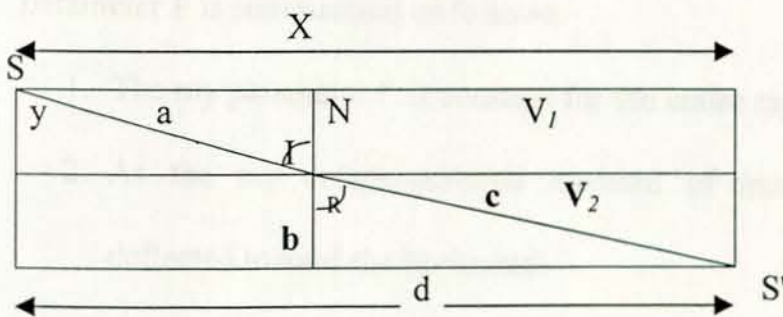


Fig.8. Two Layers Case Refractor

$I$  = angle of incidence

$R$  = angle of refraction

$N$  - normal to the refractor

S - source

S' - terminal of the wave

$V_1$  and  $V_2$  - velocities of the layers.

The travel time  $T$  on the path between  $s$  and  $s'$  is given by

$$T = a/V_1 + c/V_2 = \{(x^2 + y^2)^{1/2}\}/V_1 + \{b^2 + (d-x)^2\}^{1/2}/V_2 \text{-----}2.31$$

The minimum time path must satisfy  $dt/dx = 0$ . That is,

$$dt/dx = x/\{V_1(x^2 + y^2)^{1/2}\} - (d-x)/\{V_2(b^2+(d-x)^2)^{1/2}\} = 0 \text{-----}2.32$$

$$x/\{V_1(x^2+y^2)^{1/2}\} = (d-x)/\{V_2(b^2+(d-x)^2)^{1/2}\}$$

$$\sin I/V_1 = \sin R/V_2 \text{ or } \sin I/\sin R = V_1/V_2 \text{-----}2.33$$

Equation 2.33 is called Snell's law. The generalization of Snell's law is

$\sin I/V = P$  where  $P$  is known as the seismic parameter. The nature of seismic parameter  $P$  is summarized as follows.

1. The ray parameter  $P$  is constant for the entire ray path.
2. As the ray enters material medium of increasing velocity, the ray is deflected toward the horizontal.
3. If the ray enters material of decreasing velocity, it is deflected toward the vertical.
4. If the ray is traveling vertically, then  $P = 0$  and the ray will experience no deflection as the velocity changes.



From the above generalization one can conclude that if the velocity of the wave increases with depth, it is deflected upward and hence can be recorded by the receiver. If the velocity decreases with depth, the wave deflects toward the vertical. As a result there is no way to record the wave.

**2.3.3. Eikonal Equation and Ray Geometry**

Consider the wave traveling along X- axis with constant velocity  $c$ . If the velocity changes only in vertical direction then the following equation holds true.

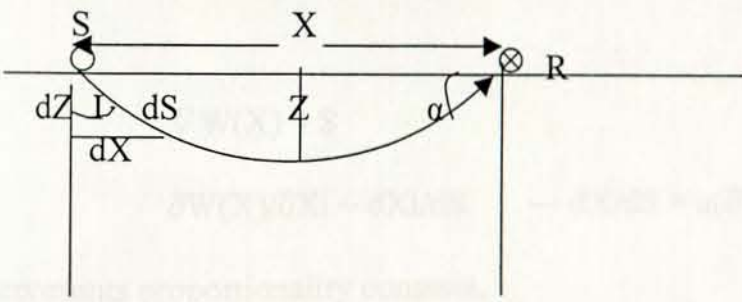


Fig.9. Geometric wave path

- S- Source
- R - Receiver
- X - Lateral distance
- $\alpha$  - Dip angle
- I - angle of incidence
- Z - Maximum Depth of Penetration

From the figure above the trigonometric ratio is given as follows.

$$\text{Sin}I = dX/dS \text{ -----}2.34$$

$$\text{Cos}I = dZ/dS \text{ -----}2.35$$

I - angle of incidence and  $\alpha$  - dip angle

For a three-dimensional body the direction cosines associated with the wave are given by  $dX/dS$ ,  $dY/dS$ ,  $dZ/dS$  and satisfy the following equation.

$$(dX/dS)^2 + (dY/dS)^2 + (dZ/dS)^2 = 1 \text{ -----}2.36$$

There is a connection between the wave front  $W(X)$  and the arc length  $S$ . This connection is described as follows.

$$\nabla W(X) \sim S$$

$$\partial W(X)/\partial X_i \sim dX_i/dS \rightarrow dX/dS = a(\partial W(X)/\partial X_i), \text{ where } a$$

represents proportionality constant.

$$(a\partial W(X)/\partial X)^2 + (a\partial W(X)/\partial Y)^2 + (a\partial W(X)/\partial Z)^2 = 1 \text{ -----}2.37$$

$$a^2 \{ \partial W(X)/\partial X)^2 + (\partial W(X)/\partial Y)^2 + (\partial W(X)/\partial Z)^2 \} = 1$$

$$(\partial W(X)/\partial X)^2 + (\partial W(X)/\partial Y)^2 + (\partial W(X)/\partial Z)^2 = (1/a^2) \text{ -----}2.38$$

Equation 2.38 is called eikonal equation.

If  $a = C(X)/C_0$  then the reciprocal of 'a' is given by  $a = C_0/C(X) = n$ , where n is the refractive index of refraction. Consequently we can have the following equations.

$$n(dX/dS) = \partial W(X)/\partial X \text{ -----2.39}$$

$$n(dY/dS) = \partial W(X)/\partial Y \text{ -----2.40}$$

$$n(dZ/dS) = \partial W(X)/\partial Z \text{ -----2.41}$$

$$d/dS(ndX/dS) = d/dS(\partial W(X)/\partial X) \text{ -----2.42}$$

This last equation can be written as follows.

$$d/dS(ndX/dS) = (\partial/\partial X)n \text{ -----2.43}$$

This equation is called the ray path equation.

The generalization of the above equation is written as follows.

$$d/dS\{(1/C(X))dX/dS\} = \nabla\{1/C(X)\} \text{ -----2.44}$$

The last equation represents the ray path. From this equation we note that the ray path is proportional to the spatial change in the velocity distribution. Two initial conditions control the behavior of this equation.

1. The direction in which the ray leaves some arbitrary reference point and
2. The position of the reference point.

If the wave through the material has a change in velocity in only one direction, say depth then  $n/X = n/Y = 0$  and,

$$n(dX/dS) = C_1 \text{ -----2.45}$$

$$n(dY/ds) = C_2 \text{ -----2.46}$$

$$d/dS \{n(dZ/dS)\} = (dn/dX) \text{ -----2.47}$$

At a given point the direction cosines of the wave are given by

$$L_1 = dX/dS = \text{Sin}I \text{ -----2.48}$$

$$L_3 = dZ/dS = \text{Cos}I \text{ -----2.49}$$

$$\text{But } n(dX/dS) = (C_0/C) \text{ Sin}I = C_0P \text{ -----2.50}$$

Writing the above equation in terms of X (horizontal distance) and Z (depth) we have the following equation.

$$\underline{X = 2 \int_0^Z [\text{Sin}I/\text{Cos}I] dZ} \text{ -----2.51}$$

In equation 2.51, **I** represents the angle at which the wave leaves the source called Angle of incidence and Z represents the maximum depth of penetration. Angle **I** is measured from the vertical.

## Chapter - 3

### Quarry Blast as the Source of Seismic Wave

#### 3.1. Purpose of Blasting Operations

Quarries are places where construction materials such as concrete, gravel and sands are produced. Here the rock formations are fractured and broken down by explosion. The fractured rocks are taken to the grinding mill (crasher) where they are further broken to the smaller and smaller sizes. The crusher sends the crashed rocks in accordance with their sizes: concrete, gravel, sands etc.

The blasting operation is equivalent to the application of transient force to certain medium in which seismic wave is produced. Here a borehole is drilled into the rock in which explosive materials are buried



Fig.10. The Quarry Site at Kaliti

On detonation these explosives undergo immediate chemical decomposition in which extreme heat and excess gases are produced. These gases need large volume to occupy which is much greater than the original volume. As the result the medium will expand to furnish this large volume for the gases. This immediate expansion in the medium results in explosion in which the particles of the medium are disturbed. The disturbances produced in this manner are called seismic waves.



Fig.11. One of the Products Observed at Akaki Quarry

When using explosives to break rock, there are number of effects: noise, total displacement in the immediate area around the explosives, plastic deformation and elastic motion. The wish of the blaster is the total displacement in the immediate area around the explosives. This is the condition in which the permanent differential deformation occurs changing the size and the shape of the rock.

When an explosive buried in the ground is detonated most of its energy is spent in shattering the rock. However some is transmitted through the earth in the form of waves or vibration. Some waves will escape in the form of noise to the air. These waves cause neither ground motion nor significant damage to any infrastructure.

The amplitude of the waves generated by explosive is affected by the following factors. These factors are: the weight of the explosives used per blast, the geologic materials through which the wave passes, the distance between the shot holes and the strength of the materials used to cover the shot-holes (stemming).

### **3.2.Types of the Explosives Used at the Quarries**

Almost at all quarries selected for this particular study, the explosives used are high commercial explosive dynamites and blasting agents. However the quantities and the blasting agents vary from one quarry to the other. The following table presents the types of explosives used at each quarry site.

<b><u>Quarry Site</u></b>	<b><u>Types of Explosive Used</u></b>
1.Akaki	Ammonium Nitrate, Jelatine, Detonating cord
2. BMM	Ammonium Nitrate, Jelatine, Detonating cord
3. BCRBC	Rock Ammonite and Blasting Caps

4. JRCRBC            Rock Ammonite and Blasting Caps

5. KCRBC            Rock Ammonite and Blasting Caps

### 3.3. Drilling Shot-holes

At all selected quarry sites the shot holes are drilled by a drilling machine. The shot holes are drilled in rows. The minimum and maximum space between successive shot holes are 2m and 3m respectively. The next row will be drilled in such away that the holes will be spaced equally in all directions. The distance between the boreholes in both the boreholes in the same row as well as the adjacent rows are always equal.

The reason is that when the explosion takes place the energy will be distributed in all directions with the same magnitude and no space is left without being affected by the blast. As the result the rock found between the holes will be crushed equally.

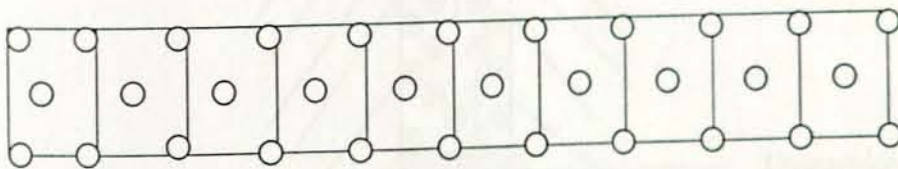


Fig.12. The arrangement of the shot - holes equally spaced in three rows

### 3.4. Burying of the Explosives

After the shot holes are drilled to the required depth by the drilling machine, the explosive materials: Jelatine dynamite, Ammonium nitrate and the detonating cord (electric blasting caps) are collected around the shot holes.

Then the blaster adds some amount of Jelatine dynamite (which form the explosive component and an inert material which binds the mixture together) with a detonating cord embedded in it. This detonating cord is connected to the caps in the other shot holes in series. The rest part of the hole is filled with ammonium nitrate below the depth of 1.5m. Then the top portion of the shot hole is filled with inert material (usually concrete or wet soil) called stemming. This is to increase the pressure so that the explosive would not extrude to the atmosphere easily.

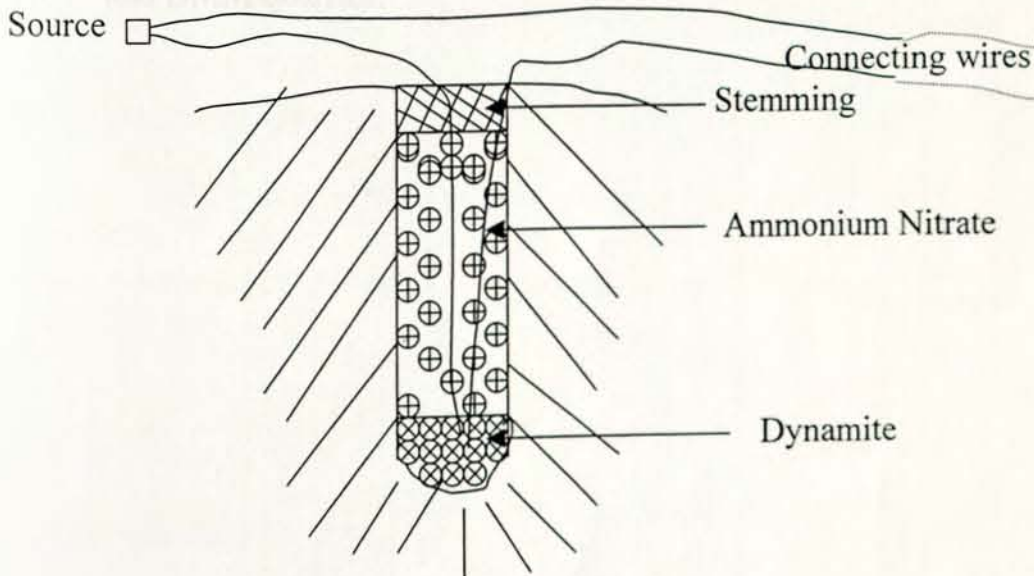


Fig.13. Loaded Single shot hole

### 3.5. Detonation

Detonation is the operation performed after the circuit connections are completed and checked for short circuits and any wrong electric system. In this operation two types of detonators are used.

1. Blasting caps- are small cylindrical tubes that detonate the cap-sensitive explosive (dynamite or rock ammonite). They are generally made up of copper or aluminium. They are connected by lead wire to form an electric blasting circuit.
2. Detonating cord- is a plastic cord with a core of high velocity explosive powder used to detonate explosive charges. They are especially used at Akaki and BMM quarries.



Fig.14. Installation of Blasting Circuit with Detonating Cord

Finally the detonators in the shot holes are connected in series and high current is made to pass through them. When the highly resistive wire in the caps become hot and ignites the explosion is initiated. The detonators are designed to create 25-milliseconds delay periods between Individual holes. The advantages of the milliseconds delay period are the following.

1. It reduces ground motion.
2. It improves fragmentation.
3. It produces less fly rock.

4. It reduces costs
5. It reduces over break.

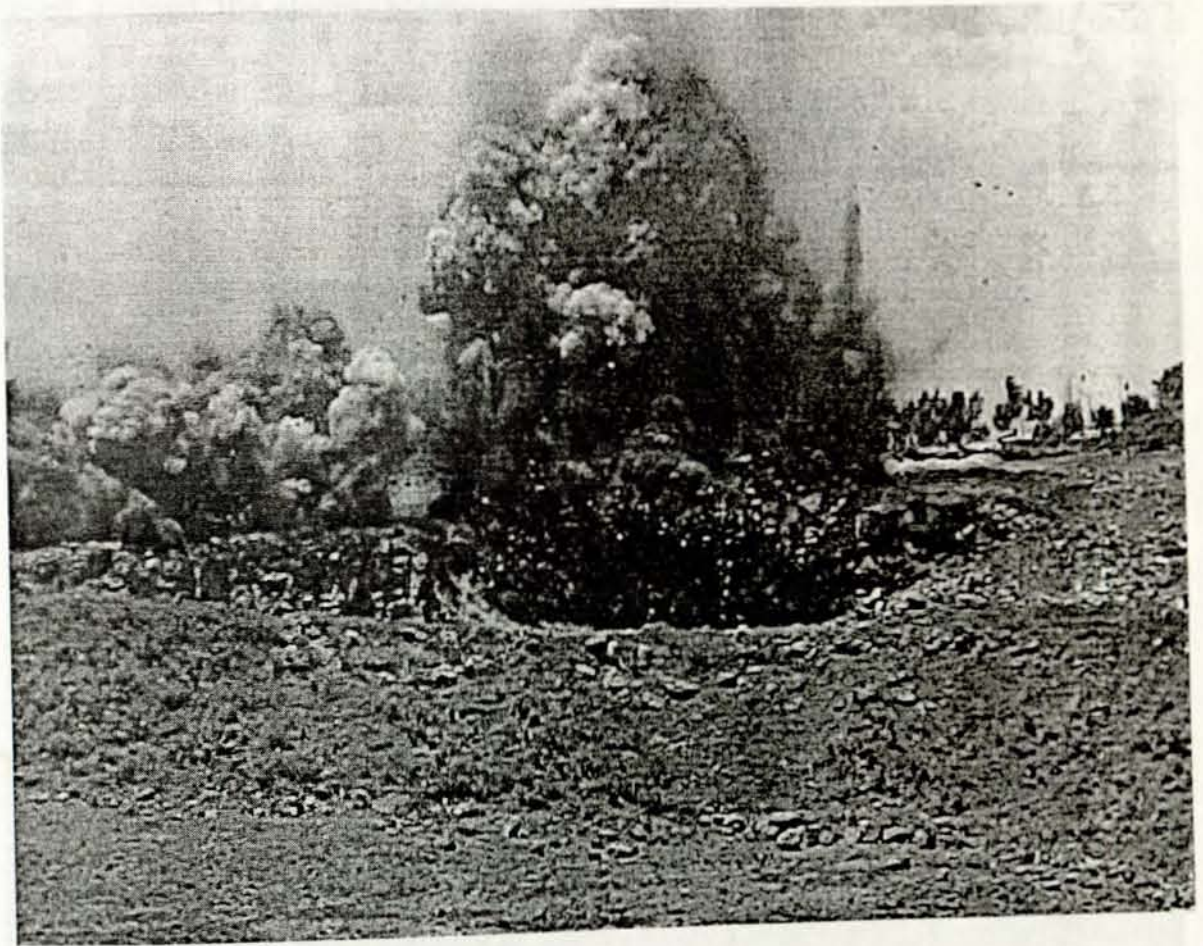


Fig.15. An explosion at Akaki Quarry (Blue Nile Construction enterprise )

When the explosion is about to start, the guard orders the nearby people to run away from the site. He also checks for the presence of animals grazing in the surrounding. Finally the red flags are posted about 300m away from the shot holes. The red flag is the sign of danger and hence it tells that no one ought to move toward the blasting site.

At the other quarries, like JRCBRC, BCRBC and KCRBC, the detonating cord is not used. Instead, the electric blasting caps are utilized. The explosive materials used at these quarry sites are rock-ammonites (an explosive powder equivalent to the combination of dynamite and ammonium nitrate).



Fig.16. The Fractured Rocks observed After Explosion (at Akaki Quarry)

## **Chapter-4**

### **Data Acquisition and Processing**

#### **4.1. Data Acquisition**

One of the ultimate goals of this study is to identify the seismic signals recorded at the Furi seismic station from any other event records. To perform this the time of explosion, the distance and the azimuth of the quarry must be recorded.

In this chapter the method of data collection from the quarry sites and identification of the corresponding seismic records at the station will be discussed. In addition, the methods and procedures followed to interpret the seismograms are explained.

##### **4.1.1. Data Collection from the Quarry Sites**

There are number of quarries around Addis Ababa. At many quarries the blasting operation is mainly done manually. However at some quarries where the study is carried out, most works are performed by machine. At quarries where the work is performed manually, small amount of explosives are used. As the result the

amplitudes of the recorded signal at the seismic station are too small to deal with them.

On the other hand at the quarries where the shot holes are drilled by drilling machine the amount of charge consumed per shot is very large. Consequently, the seismic signals with significant amplitudes are recorded at the seismic station.

For this particular study the quarries located at Akaki, Kaliti-CRBC, Bole- CRBC, Bole-Bulbula (BMM), Jimma Road (JRRCRBC) and Kaliti- Berta were selected for their relatively high amount of explosive consumption per shot. Among these six quarries Kaliti-Berta is omitted since no corresponding wave signal was obtained from the station. For the other five quarries enough signal records were found from the seismic station.

The data obtained from each selected quarry site are summarized in the table below.

Site	Lat.	Lon.	Explosion Date	Depth of Explosion	No of Holes	Time of Explosive	Charge Size
Akaki	8.85 <sup>0</sup>	38.82 <sup>0</sup>	01/06/02	7.5m	15	11:39GMT	1115kg
			13/07/02	5m	18	10:30GMT	1080kg
			26/07/02	7.5m	24	09:20GMT	1135kg
			13/08/02	8m	32	11:35GMT	1645kg
BCRBC	8.97 <sup>0</sup>	38.77 <sup>0</sup>	12/12/02	6m	21	09:15GMT	720kg
			13/12/02	6m	21	08:59GMT	750kg
			18/12/02	3m	30	08:12GMT	480kg
			23/01/03	3m	29	08:50GMT	480kg
			26/02/03	3m	27	08:35GMT	480kg
			27/02/03	3m	25	08:57GMT	450kg
			03/03/03	3m	18	08:47GMT	324kg
			24/03/03	6m	41	09:25GMT	693kg
			26/03/03	6m	37	09:38GMT	660kg
BMM	8.95 <sup>0</sup>	38.80 <sup>0</sup>	02/01/02	24m	11	0:31GMT	2192kg
			27/03/02	10m	60	08:26GMT	437kg
			26/04/02	25m	5	06:07GMT	1008kg
			17/06/02	25m	7	09:23GMT	1579kg
			02/08/02	25m	12	09:21GMT	2162kg
			24/03/03	17m	20	09:54GMT	1148kg
JRCRBC	8.97 <sup>0</sup>	38.70 <sup>0</sup>	21/01/03	3m	52	08:32GMT	303kg
			05/03/03	6m	35	09:35GMT	660kg
			07/03/03	6m	35	08:56GMT	630kg
			10/03/03	6m	43	09:43GMT	780kg
			11/03/03	6m	44	09:51GMT	780kg
			12/03/03	6m	44	09:06GMT	780kg
			14/03/03	6m	42	08:59GMT	750kg
KCRBC	8.93 <sup>0</sup>	38.79 <sup>0</sup>	22/01/03	6m	9	07:59GMT	660kg
			20/03/03	6m	43	08:43GMT	621kg

Table 1. Data from Quarry Blast

The usual detonation time of blasting operation is from 07:30GMT--

12:30GMT as listed in the table.

The data collections are carried out at the quarry sites in the following order.

1. The geological settings of the sites were visited.
2. The programs (time tables) of the explosion were arranged with heads of the quarry sites.
3. The technical procedures of blasting were discussed with the blaster orally.
4. The depth, the number of shot holes, the size of the charge used per shot hole and the total charge consumed per shot are recorded some from the files and some from the observation.
5. Being near the quarry the picture of the explosions were taken and the exact times of the events were also recorded.

The locations of the quarry sites (latitudes, longitudes and elevations) were read from GPS (Global Positioning System).

#### **4.1.2. Data Collection from the Recording Station.**

The Furi seismic station is a broad - band system that records all detectable seismic events. In addition, the three components (vertical, N-S and E-W) seismometers are working simultaneously. The advantage of this combination is to record different phases on different components since each component is sensitive to particular phases. For instance vertical seismometer is more sensitive

to longitudinal waves where as the horizontal component seismometer is sensitive to shear waves.

A broadband system uses broadband seismometers, which can be utilized for registering a wide range of signals. The dynamic range (the range between the strongest and the weakest signals that can be recorded without distortion by a given instrument) extends from a ground noise (very low frequency) to the strong acceleration (high frequency) that would result from an earthquake of large magnitude.

A broadband seismometer converts the seismic signal into a time record of seismic event (seismogram). The seismograms obtained from the Furi seismic station represent a velocity record as a function of time. On filtering these records the displacement record as a function of time is found.

Quarry events are characterized by short period (usually less than 10 seconds) of vibrations. Identification of the signals of quarry event is possible if the explosion time, the distance and the azimuth of the source are known. The detonation times taken from the quarry sites were used to compare the event times and that of the record times. In general the procedures followed to obtain the waveforms corresponding to the quarry events are as follows.

1. The dates of the explosions at the quarry sites were identified and all the files containing the events on the same date were copied from the computer at Geophysical observatory.
2. All the Seed files copied from the computer were converted into Sac files and WGSNPLOT format.
3. The times of the event in the WGSNPLOT format and the times of the explosions at the quarry sites were compared and the signals whose times correspond to that of the explosion times were selected.
4. The events of the quarry blast were identified from the local micro seismic signals by (a) the time history of the source and (b) durations of the events.
5. The signals corresponding to the same quarry sites are collected in the same files and their relations and differences were studied in relation to charge size, depth of shot holes and number of shot holes.
6. The signals from different quarry sites were compared; the similarities and differences were studied in relation to epi-central distances, and charge sizes.

Every seismic record obtained from the seismic station represents the three components seismic data. These three components are vertical (Z), horizontal (N) and (E) and are written as BHZ, BHN and BHE respectively. BH (Broadband High Gain) indicates that the signal is recorded by broadband seismometer.

## 4.2. Data Analysis

Following the conversion of SEED data into WGSNLOT format the corresponding wave forms are obtained. These waveforms are characterized by a complex structure of wave patterns that are formed by the interference of various types of phases. The major phases are (1) the P-waves (first arrivals), (2) S-waves (waves arriving later than P-waves) and (3) surface waves (waves arriving later than S-waves).

Surface waves are distinguished from P- and S- waves by their largest amplitude and low frequency content. This is one of the properties that distinguish quarry events from that of earthquakes.

The effect of P-wave is stronger on the vertical seismometer and hence its sharp arrival is usually observed on BHZ component. On the other hand the S-waves are usually observed on the horizontal components because the horizontal seismometers respond the effects more. Unlike P- and S-waves surface waves are observed on the three component records. The amplitudes of surface waves may vary from one component to the other due to the fixed azimuth of the source.

#### 4.2.1. Evaluation of Wave Patterns

The wave signals recorded by the seismograph are the finger - print of the source of seismic waves and the medium through which the waves have traversed. The shapes (waveforms) of the seismic signals contain important information about the focal mechanisms, depth and source time function. By observing different waveforms one can identify and group them according to their shapes. Some of the criteria used to group the waveforms are the velocity and displacement amplitudes, duration of the vibrations and shapes of the vibrations. Based on these criteria I tried to describe the wave patterns of the quarries as follows.

#### The Waveforms of Akaki Quarry

Akaki quarry is about 16.81km away in the southeast direction from Furi seismic station. The azimuth of the source is about  $107^{\circ}$  from north as computed from GPS readings. Akaki quarry is the farthest site among the selected quarries.

The waveforms of the seismic signals from this site have large first P-phases, which gradually decay as the S-phase overtakes. The amplitudes of P-phases are larger than that of S-phases. The maximum amplitudes of surface waves occur on the horizontal component records. The velocity and displacement amplitudes are in the order of  $10^{-6}$  m/s and  $10^{-7}$  m respectively. The intervals between P- and S-wave arrivals are larger compared to that of waveforms from the other quarries.

### **The Waveforms from BMM Quarry**

BMM (Bole-Bulbula Quarry which belongs to Ministry of Mines) is about 14.62km away from the Furi seismic station and its azimuth is about  $65.01^{\circ}$  from north as computed from GPS readings. The waveforms of the seismic signals from BMM quarry site have small amplitude P-waves that gradually increases toward the S-wave arrivals.

The maximum amplitudes of surface waves occur on the BHZ components. The velocity and displacement amplitudes are recorded in the order of  $10^{-6}$  m/s and  $10^{-6}$  m respectively. The amplitudes of S-waves are larger than that of the corresponding P-waves. The peak amplitudes recorded for BMM quarry are greater than that of any other quarry.

## Waveform of BCRBC Quarry

### Waveforms of BCRBC Quarry

BCRBC (Construction of Ring Road and Bridge Company of the Jirga Road)

BCRBC (Bole Construction of Ring Road and Bridge Company) is 13.17km away from the Furi seismic station in the northeast direction. Its azimuth is about  $52.55^{\circ}$  from north.

The waveforms corresponding to the seismic signals from this quarry site are characterized by the gradual increase of amplitudes toward the arrivals of surface waves. The determination of the positions of P- and S-phase arrivals is a little bit difficult.

The amplitudes of displacements and velocity are in the order of  $10^{-6}$  m and  $10^{-7}$  m/s.

The maximum amplitude of the surface waves occurs on the vertical component as that of BMM. The duration of the vibrations is longer compared to the duration of the vibrations of other quarry events. Like that of Akaki quarry, the maximum velocity and displacement amplitudes are in the order of  $10^{-6}$  m/s and  $10^{-7}$  m.

## Waveform of JRRCBC Quarry

JRRCBC (Construction of Ring Road and Bridge Company at the Jimma Road) quarry site is 8.76km away from the Furi seismic station. Its azimuth is about  $17.71^{\circ}$  from north.

The major properties of the waveforms of JRRCBC quarry events are the following.

1. The positions of the P-and S- phases are easily identifiable.
2. The maximum amplitudes occur on the vertical components.
3. The amplitudes of displacement and velocity are in the order of  $10^{-5}$ m/s and  $10^{-6}$ m respectively.
4. The duration of surface waves is very short and there is single prominent peak amplitude on the vertical component.

## Waveforms from KCRBC Quarry

KCRBC (Construction of Ring Road and Bridge Company at Kaliti) quarry is 11.99km away from the Furi seismic station. Its azimuth is about  $72.35^{\circ}$  from north.

The shapes of the waveforms are similar to that of JRCRBC waveforms. The corresponding velocity and displacement amplitudes are in the order of  $10^{-5}$  m/s and  $10^{-6}$  m as that of JRCRBC quarries. The frequency content of the wave pattern is very low indicating the high attenuation of the wave.

### 4.2.2 Data Processing

In the previous sections the waveforms were identified visual evaluation of the shapes and the sizes of the seismograms. In important parameters such as P- and S- arrival times, original times, peak amplitudes and local magnitudes of the waves are obtained. In addition, the azimuths of the seismic events and the corresponding dip angles are estimated. From the observed data, the azimuths of the quarry sites were computed from the GPS (Ground Positioning System) readings registered at the



quarries and the geographical coordinates of Furi seismic station. The corresponding azimuths were calculated and presented as follows.

<u>Quarry Site</u>	<u>Corresponding Azimuth</u>
Akaki	107.72 <sup>0</sup>
BMM	65.01 <sup>0</sup>
BCRBC	52.55 <sup>0</sup>
JRCRBC	17.75 <sup>0</sup>
KCRBC	72.35 <sup>0</sup>

Table 2. Azimuths of the Quarries

The computed azimuths were used to compare with the estimated azimuths while estimating the dip angles ( $\alpha$ ).

To pick the P- and S- arrival times the waveforms in the WGSNPLOT format should be retrieved. The waveforms from each quarry site in the three component BH (Broad band High gain) records are analyzed. The P- arrivals are easily identified from the BHZ (vertical component) while the S- arrivals are found from the horizontal components. The horizontal components of the waveforms are sometimes rotated to obtain the transverse records so that the S- arrivals are identified easily.

**Body Wave Arrivals**

The times corresponding to the P- and S- arrivals are known as phase arrivals. P- arrivals can easily be marked when the waves are not contaminated by interference

of any other wave. If there is no interference the identification of P-arrivals is an easy task due to the following facts.

1. P-waves are the fastest waves and hence they are the first to arrive on the seismogram.
2. S-waves are the second phases to arrive on the seismogram. They usually have stronger amplitudes than P-waves and are followed with larger-amplitude disturbances associated with surface waves.
3. P-waves are more clearly visible on the vertical component seismogram where as S-waves are more clearly seen on the horizontal component seismogram.

Using the above properties of seismic wave the arrival times of P- and S-waves can be marked on the seismogram.

## Origin Times

The times at which the seismic event occurred at its source ( $t_0$ ) can be determined using Wadati graphical method, which uses the difference of S- and P-arrival times ( $t_s - t_p$ ) and the times of corresponding P-arrival times ( $t_p$ ), and the fact that the ratio of apparent velocities ( $V_p/V_s$ ) is observed to be constant over small distance ranges.

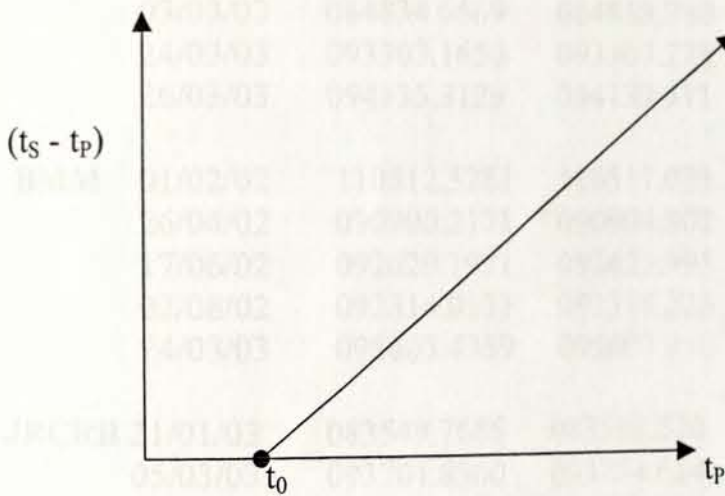


Fig. 17. Wadati Graphical Method

Site	Date	Ori.Time	P-Arrival	S-Arrival	$t_p - t_0$	$t_s - t_0$
Akaki	01/06/02	114228.003	114232.292	114234.497	4.2890	7.5490
	13/07/02	103419.379	103423.973	103426.403	4.5940	5.5870
	26/07/02	092410.686	092415.297	092417.318	4.6110	8.1149
	13/08/02	122001.731	122006.732	122009.061	5.0010	8.8011
BCRBC	13/12/02	090047.4731	090051.599	090053.883	4.1259	7.2614
	18/12/02	081530.5780	081534.778	081537.075	4.2000	7.3724
	23/01/03	085120.6291	085124.548	085126.530	3.9189	6.8971
	26/02/03	083647.3119	083651.539	083653.932	4.2271	7.4440
	27/02/03	085939.9109	085944.001	085946.059	4.0901	7.1986
	03/03/03	084834.6669	084838.780	084840.776	4.1131	7.2391
	24/03/03	093303.1650	093307.279	093309.794	4.1140	7.2410
	26/03/03	094135.3129	094139.311	094141.233	3.9981	7.0360
BMM	01/02/02	110512.5281	110517.033	110519.665	4.5049	7.9289
	26/04/02	090900.2171	090904.802	090908.173	4.5849	8.0689
	17/06/02	092620.1971	092623.995	092626.541	3.7979	6.6841
	02/08/02	092314.0131	092318.223	092320.551	4.2099	7.4100
	24/03/03	095603.4359	095607.890	095610.090	4.4541	7.8379
JRCRB	21/01/03	083549.7685	083552.526	083554.550	2.7575	4.8532
	05/03/03	093701.8300	093704.624	093706.685	2.7940	4.8758
	07/03/03	085736.3450	085739.030	085741.064	2.6850	4.7270
	10/03/03	094500.1770	094503.107	094505.211	2.9300	5.1570
	11/03/03	085430.0959	085432.918	085434.914	2.8221	4.9670
	14/03/03	090044.3020	090047.201	090049.243	2.8990	5.1010
KCRB	22/01/03	080125.1676	080130.004	080132.514	4.8367	8.5120
	20/03/03	084633.1390	084637.934	084640.787	4.7950	8.4391

Table 3. Arrival and Origin Times

### Amplitude variation

The peak amplitude on every seismogram (recording of ground motion as a function of time) is a function of the strength of the source and the path of the seismic wave. Therefore they provide information about seismic parameters (source mechanism, distance from the epicenter, original time of explosion and the magnitude of the seismic wave).

The peak amplitudes corresponding to the ground velocity and ground displacement on every seismogram can be determined by marking the maximum and the minimum of the signal on the seismogram. The maximum amplitude was recorded from the seismogram corresponding to BMM quarry and the least from the seismogram corresponding to the BCRBC quarry.

Site	Date of Explosion	Max.Amp.	Charge Size	Charge per Shot-hole	
Akaki	01/06/02	4.85768E-006m/s	1115kg	74.33kg	
		4.23868e-007m			
	13/07/02	2.06312E-006m/s	1080kg	60.00kg	
		2.20236e-007m			
	26/07/02	3.87431E-006m/s	1135kg	47.29kg	
		3.41977E-007m			
	13/08/02	6.2219E-006m/s	1645kg	51.4kg	
		5.09479E-007m			
	BCRBC	09/12/02	7.07417E-006m/s	90kg	
			2.75506e-007m		
13/12/02		6.10373e-006m/s	750kg	35.7kg	
		5.06264e-007m			
18/12/02		5.95524e-006m/s	480kg	16.0kg	
		4.07686e-007m			
23/01/03		3.52764e-006m/s	480kg	16.6kg	
		3.03703e-007m			
26/02/03		5.34926e-006m/s	480kg	17.8kg	
		5.10755e-007m			
27/02/03		1.75127e-006m/s	450kg	18.0kg	
		1.63651e-007m			
03/03/03		5.57879e-006m/s	324kg	18.0kg	
		4.22866e-007m			
24/03/03		5.39004e-006m/s	693kg	16.9kg	
		3.398653e-007m			
26/03/03		5.74150e--006m/s	660kg	17.8kg	
		3.58035e-007m			
			Continues-----		

BMM	02/01/02	7.22620e-005m/s	2192kg	199.3kg
		6.5547e-006m		
	27/03/02	5.72258e-006m/s	437kg	7.3kg
		4.65689e-007m		
	26/04/02	1.78668e-005m/s	1008kg	201.6kg
		1.37857e-006m		
	17/06/02	2.58658e-005m/s	1579kg	225.6kg
		2.57480e-006m		
	02/08/02	3.60206e-005m/s	2162kg	180.2kg
		3.36069e-006m		
24/03/03	4.92053e-006m/s	1148kg	57.4kg	
	4.54630e-007m			
JRCRBC	21/01/03	1.39904e-005m/s	303kg	5.8kg
		1.28089e-006m		
	05/03/03	1.99858e-005m/s	660kg	18.9kg
		2.08688e-006m		
	07/03/03	1.87023e-005m/s	730kg	18.0kg
		1.72523e-006m		
	10/03/03	3.48230e-005m/s	780kg	18.2kg
		3.25381e-006m		
	11/03/03	3.32333ep-005m/s	780kg	17.7kg
		3.20716e-006m		
14/03/03	3.07079e-005m/s	750kg	17.9kg	
	2.92710e-006m			
KCRBC	22/01/03	1.78809e-005m/s	660kg	73.3kg
		1.26363e-006m		
	20/03/03	9.33180e-006m/s	621kg	14.4kg
		8.584351e-007m		

Table 4. Peak Amplitudes and Charge Sizes

from the table above one can see the dependence of amplitude on total charge and charge per shot hole.



Using the quantitative values of amplitudes in the table the variations will be interpreted as a function of epi-central distance, depth of explosion and the charge size of the explosion.

### Local Magnitude Variation

As introduced by C.Richter (1935) local magnitude  $M_L$  is one of the seismic parameters and is the most popular measure of seismic strength for small seismic events. It is measured from maximum trace amplitude  $A$  on Wood\_Anderson type of seismometer.  $M_L$  is computed from the the equation,

$$M_L = \log(A/T) + 2.56 \cdot \log(S) - 0.67.$$

In this equation  $A$  – is the maximum amplitude of measured signal in meters,  $S$ - represents the distance from the station to the source in kilometers and  $T$ - is the period of measured signal in seconds.

Local magnitude  $M_L$  is an important scale due to the following reasons.

1. All other magnitude scales are tied to local magnitude scale  $M_L$ .
2. It is used for engineering work because many structures have natural periods close to that of the Wood-Anderson instrument.
3. The extent of the earthquake damage is closely related to the local magnitude scale  $M_L$ .

The local magnitude of each waveform was determined and tabulated. The largest value of  $M_L$  was determined to be 2.8 and the least was found to be 1.1. The variations of local magnitudes give information about seismic parameters. The largest measured local magnitude is directly proportional to the explosive and the depth of the explosive. It is also directly proportional to the amplitude of the seismic signal.

From  $M_L$  equation the local magnitude is inversely proportional to the period  $T$ .  
 (Dimas Software, 1997).

Site	Date of Explosion	Amplitude	Local Mag.
Akaki	01/06/02	4.85768-006m/s	1.6
		4.23868e-007m	
	13/07/02	2.063112e-006m/s	1.4
		2.096117e-007m	
	26/07/02	3.87431e-006m/s	1.6
		3.41977E-007m	
	13/08/02	6.2219e-006m/s	1.8
		5.1005E-007m	
BCRBC		7.07417E-006m/s	
		2.75506e-007m	
	13/12/02	6.10373e-006m/s	1.6
		4.98992e-007m	
	18/12/02	5.95524e-006m/s	1.5
		3.81481e-007m	
	23/01/03	3.52764e-006m/s	1.4
		2.68172e-007m	
	26/02/03	5.34926e-006m/s	1.6
		4.07380e-007m	
	27/02/03	1.75127e-006m/s	1.1
		1.23337e-007m	
	03/02/03	5.57879e-006m/s	1.4
		4.22866e-007m	
	24/03/03	5.39004e-006m/s	1.5
		3.41018e-007m	
	26/03/03	5.74150e-006m/s	1.4
		3.45900e-007m	
B.M.M	01/02/02	3.03629e-005m/s	2.2
		2.81840e-006m	
	01/02/02	7.22620e-005m/s	2.8
		6.5547e-006m	

		-----Continued	
	27/03/02	5.72258e-006m/s	1.6
		4.65689e-007m	
	26/04/02	1.78668e-005m/s	2.1
		1.37857e-006m	
	17/06/02	2.58658e-005m/s	2.3
		2.57480e-006m	
	02/08/02	3.60206e-005m/s	2.6
		3.36069e-006m	
	24/03/03	4.92053e-006m/s	1.7
		4.54630e-007m	
JRCRBC	21/01/03	1.39904e-005m/s	1.5
		1.28089e-006m	
	05/03/03	1.99858e-005m/s	1.7
		2.08688e-006m	
	07/03/03	1.87023e-005m/s	1.7
		1.72523e-006m	
	10/03/03	3.48230e-005m/s	1.9
		3.25381e-006m	
	11/03/03	3.32333ep-005m/s	1.9
		3.20716e-006m	
	14/03/03	3.07079e-005m/s	1.9
		2.92710e-006m	
KCRBC	22/01/03	1.78809e-005m/s	1.9
		1.26363e-006m	
	20/03/03	9.33180e-006m/s	1.6
		8.58451e-007m	

Table 5. Amplitudes and Magnitudes



### Azimuths and Dip Angles

Azimuth  $\Phi$  angle is the angle between north and the source. This angle was computed for every quarry site from the GPS reading and the coordinates of Furi seismic station. The azimuth  $\Phi$  is computed by the following relation.

$$\tan\Phi = \Delta E/\Delta N \text{-----} 4.1 .$$

E and N represent the values of longitude and latitude respectively.

Using Dimas program the azimuth of each quarry was also estimated.

Site	Computed azimuth	Estimated azimuth	Difference	
Akaki	107.5 <sup>0</sup>	111.11 <sup>0</sup>	4.4 <sup>0</sup>	
BMM	65.01 <sup>0</sup>	63.4 <sup>0</sup>	1.59 <sup>0</sup>	
BCRBC	52.5 <sup>0</sup>	48.1 <sup>0</sup>	4.4 <sup>0</sup>	
JRCRBC	17.75 <sup>0</sup>	19.5 <sup>0</sup>	-1.25 <sup>0</sup>	
KCRBC	72.5 <sup>0</sup>	64.8 <sup>0</sup>	7.7 <sup>0</sup>	

Table 6. Computed and Estimated Azimuths

The difference between the computed and the estimated azimuths are small. Therefore the estimated source direction approaches the actual direction of the source.

**Dip Angle ( $\alpha$ )**- is the angle between the horizontal and the direction at which the wave arrives the station. When the explosive buried in the shot hole is detonated the energy radiates in all directions. As the result the part of the waves that takes the direction along the layers of high velocity travels long distance within a short period of time (Fermat's principle) and are recorded before the other waves arrive the station.

The particle of the seismometer will first move along the direction of the pulse produced by the traveling wave. The pulse arriving the seismometer first is identified as P-wave and the direction of the particle motion relative to the horizontal is known as dip angle ( $\alpha$ ). This angle varies from  $0^{\circ}$  (horizontal direction) to  $90^{\circ}$  (vertical direction). The complimentary angle  $I$  of the dip angle is called the incidence angle or take off angle. It is the angle at which the wave leaves the source relative to the vertical.

In the figure below, (1) S- represent the seismic source (2) R- the seismic station (3) X- the distance between S and R (4)  $\alpha$ - the dip angle (5) Z- the maximum depth of penetration.

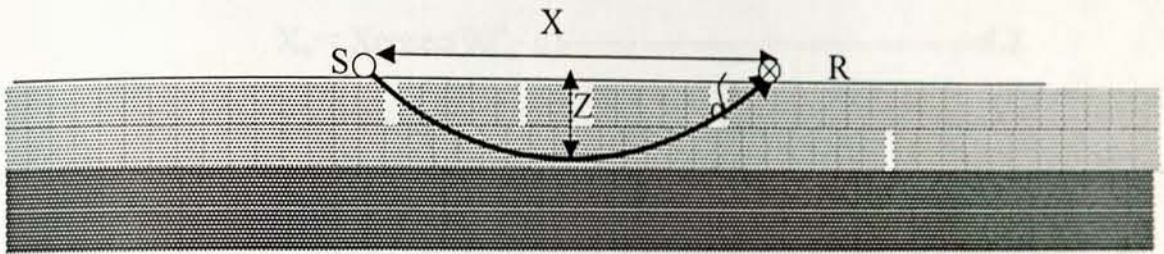


Figure 18. Simplified Path of the Wave in isotropic medium

The dip angle can be estimated when the P-arrival is clearly identified on the seismogram and the particle motion is analyzed. Obtaining the correct dip angle is very important in computing the maximum depth of penetration ( $Z$ ) and the actual path ( $X_a$ ) of the wave through the medium.

The actual path of the wave is the geometrically assumed path along which the wave would travel through before it is recorded by the seismic station. For isotropic medium the path is uniformly curved toward the horizontal since the velocity of the wave is assumed to increase as depth increases (Snell's law).

The maximum depth of penetration is the depth the recorded wave reaches in the course of down ward motion. This maximum depth ( $Z$ ) is assumed to occur below the mid-way of the source to the station. This assumption holds true when the

medium is considered to be homogeneous. The estimated dip angles ( $\alpha$ ), the take off angles (I), the actual paths ( $X_a$ ) and The maximum depth of penetration (MDP / Z) of the quarry events are related by Eikonal equation as follows.

$$X_a = X \operatorname{cosec}(90^\circ - \alpha) \text{-----} 4.2$$

$$Z = (X \tan \alpha) / 2 \text{-----} 4.3$$

The results are summarized in the table below.

Site	Dip Angle $\alpha$	$(90^\circ - \alpha) = I$	Actual path ( $X_a$ in km)	MDP (in km)
Akaki	$17^\circ$	$73^\circ$	17.58	2.58
BMM	$18.5^\circ$	$71.5^\circ$	15.42	2.46
BCRBC	$13.6^\circ$	$76.4^\circ$	13.55	1.59
JRCRBC	$9.7^\circ$	$80.3^\circ$	8.89	0.75
KCRBC	$11.4^\circ$	$78.6^\circ$	12.23	1.21

Table 7. Dip Angle, Take Off Angle, Wave path and MDP

### Travel Times

Travel time is the time required for the wave to travel the distance between the source and the recording station. In the other word it is the time interval between the recording and starting of the seismic event. The travel times of both P- and S- waves were computed using Dimas program as described in the previous sections. The travel times of P- waves can be computed from the observed P-arrival times and the



corresponding origin times. Similarly the travel times of S- waves can be calculated from the observed S- arrival times and the corresponding origin times.

The travel times were calculated for each seismic event independently and finally the average travel time of the seismic events from the same site was obtained. The reason of determining the average travel time is to decrease the variations caused by the shift of position and the variations of depth of explosions. The travel time corresponding to each seismic event were carefully picked and tabulated as follows.

Mean		4.6154	8.1251
RMSE	01/02/02	4.5149	7.9217
	17/06/02	4.2797	7.2384
	24/01/03	4.4421	7.8879
Mean		4.1259	7.5514
	23/01/03	3.9189	6.8971
	27/02/03	4.0901	7.1385
	03/03/03	4.1131	7.2391
	24/03/03	4.1140	7.2410
	26/03/03	3.9901	7.0386
Mean		4.0974	7.2383
JMCNDC	21/01/03	2.7575	4.8302
	05/03/03	2.7960	4.8758
	07/03/03	2.5850	4.7270
	10/03/03	2.9700	5.1370
	11/03/03	2.8221	4.9570
	14/03/03	2.6400	4.7010
Mean		2.8146	4.9488
KCFAC	12/01/03	4.8309	8.5170
	20/01/03	4.7690	8.4791
Mean		4.8159	8.4753

Table 6. Travel Times

The Velocity Variation

The seismic velocity of each quarry was can be determined from the relation

Site	Date	$\Delta t_p$	$\Delta t_s$
Akaki	01/06/02	4.2890	7.5490
	26/07/02	4.6110	8.1149
	13/07/02	5.0010	8.8011
<b>Mean</b>		<b>4.6154</b>	<b>8.1231</b>
BMM	01/02/02	4.5049	7.9289
	26/04/02	4.5849	8.0689
	17/06/02	3.7979	6.6841
	02/08/02	4.2099	7.4100
	24/03/03	4.4541	7.8379
<b>Mean</b>		<b>4.2903</b>	<b>7.5505</b>
BCRBC	13/12/02	4.1259	7.2614
	18/12/02	4.2000	7.3724
	23/01/03	3.9189	6.8971
	26/02/03	4.2271	7.4440
	27/02/03	4.0901	7.1986
	03/03/03	4.1131	7.2391
	24/03/03	4.1140	7.2410
	26/03/03	3.9981	7.0360
<b>Mean</b>		<b>4.0974</b>	<b>7.2085</b>
JRCRBC	21/01/03	2.7575	4.8532
	05/03/03	2.7940	4.8758
	07/03/03	2.6850	4.7270
	10/03/03	2.9300	5.1570
	11/03/03	2.8221	4.9670
	14/03/03	2.8990	5.1010
<b>Mean</b>		<b>2.8146</b>	<b>4.9468</b>
KCRBC	22/01/03	4.8367	8.5120
	20/03/03	4.7950	8.4391
<b>Mean</b>		<b>4.8158</b>	<b>8.4755</b>

Table 8. Travel Times

### The Velocity Variation

The seismic velocity of each quarry event can be determined from the relation

$$V = X_a / \Delta t \text{ ----- 4.3.}$$

Here V,  $X_a$  and  $\Delta t$  represent the velocity of the wave, the actual path traversed by the wave and the time difference between the origin time  $t_0$  and the observed time at the station respectively.

To calculate the velocity of seismic waves different phases from the above relation is very simple because all parameters required for the calculation are already obtained. Therefore the results of P- and S-wave velocities of the quarry events are summarized in the table below.

Site	P-wave velocity ( $V_p$ ) (km/s)	S-wave velocity ( $V_s$ ) (km/s)	$V_p/V_s$
Akaki	3.8090	2.1664	1.758228
BMM	3.5942	2.0423	1.759923
BCRBC	3.3070	1.8797	1.759300
JRCRBC	3.0777	1.7284	1.757532
KCRBC	2.5398	1.4430	1.760104

Table 9. Body Wave Velocities and Velocity Ratio

### P-wave velocity at maximum depth of penetration

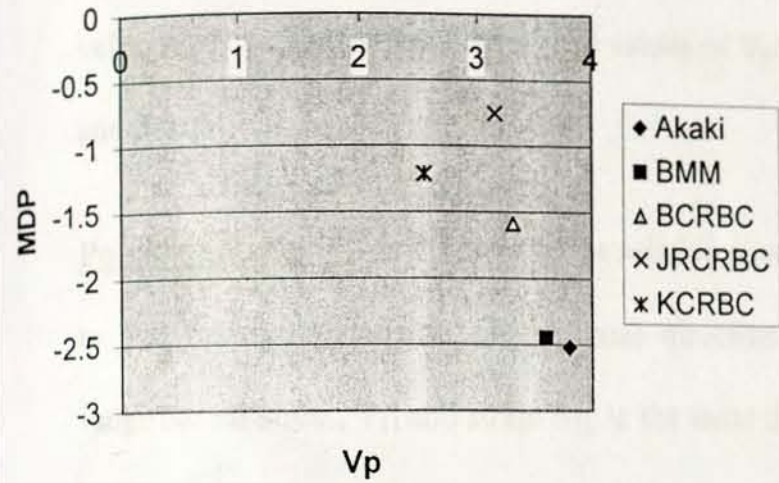


Fig.19. P-Wave Velocity at MDP

As can be seen from Fig.19 and table 9, the largest velocity was calculated for Akaki quarry event and the least velocity was calculated for the KCRBC quarry event

The velocity ratio ( $V_p/V_s$ ) is an important parameter because it measures the elastic behavior of the medium through which the wave propagates. In other words, ( $V_p/V_s$ ) can be written as the ratio of Lamé's constants as follows.

$$V_p/V_s = [(\lambda+2\mu)/\mu]^{1/2} \text{-----4.4}$$

Different rocks have different velocity ratio as indicated by (Milton B. Dobrin, 1988). Different rocks with different value of elastic constants have different

velocity ratio. The average empirical values of  $V_P/V_S$  for hard rocks lie between 1.5 and 2.0.

**Poisson's Ratio ( $\nu$ )**- is the ratio of the relative contraction in the transverse direction to the relative extension in the axial direction. In other words, it relates the longitudinal stress,  $T_{11}$  and strain  $S_{11}$ , in the same direction.

$$\nu = -S_{12}/S_{11} = \lambda/2(\lambda + \mu) \text{-----4.5}$$

From the theory of elasticity the value of  $\nu$  lies between 0.0 and 0.5. It is possible to find the relation between the Poisson's ratio and the velocities of the P - and S - waves through the equation of velocity ratio. From equation 4.5 the Lamé's constant  $\lambda$ , can be written as follows.

$$\lambda = 2\nu\mu/(1 - 2\nu) \text{-----4.6}$$

On substituting the value of  $\lambda$  from equation 4.6, into equation 4.5, one can find the following equation.

$$\nu = (V_P^2 - 2V_S^2)/2(V_P^2 - V_S^2) \text{-----4.7}$$

Poisson's ratio is one of the four elastic coefficients, namely Young's modulus  $E$  (the measure of stiffness), the shear modulus  $\mu$  (the measure of rigidity), the bulk modulus  $K$  (the measure of incompressibility) and Poisson's ratio  $\nu$  itself. It measures to what extent the rock can be compressed or expand as it is subjected to

variable stress. Poisson's ratio is approximately satisfied for most materials in the earth's interior (its value ranges 0.22 - 0.35).

If the value of  $\nu$  is less than  $1/8$ , the volume of the material changes with greater facility than it changes its form. On the other hand if the value of  $\nu$  is greater than  $1/8$  the material changes in form easily than it changes in volume.

From equation 4.7, one can calculate the values of Poisson's ratio for the seismic velocities of the quarry events. As the result the computed Poisson's ratio is presented as follows.

<u>Quarry Site</u>	<u>Poisson's ratio</u>
Akaki	0.260917
BMM	0.261584
BCRBC	0.261361
JRCRBC	0.260606
KCRBC	0.261666

Table 10. Poisson's Ratio

The Poisson's ratio value found here lies around the value of Poisson' relation ( $V_p/V_s = 1.732$ ,  $\nu = 0.25$ ,  $K/\mu = 1.67$ ). As indicated by Udias, 1999, the rock formations are characterized as the one that change their forms rather than changing their volumes.

## Chapter - 5

### Results and Interpretation

#### 5.1. Introduction

The wave patterns of the quarry blasts were identified by visual evaluation and the time history of the explosion. The records of seismic events induced by the quarry blasts vary in shape, amplitude, magnitude and duration of vibration. The variation is greater for the seismic events from different azimuths due to different factors. These variations in the seismic wave records are used to study the causes of their differences by dealing the seismic parameters of the seismic events.

In this chapter the variations of the seismic parameters (amplitudes, seismic velocities, seismic velocity ratios, maximum depths of penetration of the seismic events and the Poisson's ratio) and the causes of these variations will be discussed.

**Amplitude-** refers to the maximum trace observed on the time records of seismic signals (seismograms). The amplitude records taken for this particular study

correspond to surface wave amplitudes. The seismic record of every quarry event is unique due to the unique nature of the seismic source.

Based on the amplitudes of the seismic record the quarry events can be classified in to two: quarry events with high amplitudes and quarry events with low amplitudes.

### Quarry Events with High Amplitude

**1. BMM Quarry:-** is found in the north-east of Furi seismic station at the distance of 14.62km. The recorded ground velocity and displacement amplitudes are in the order of  $10^{-5}$ m/s and  $10^{-6}$ m respectively. The corresponding values can be found from the reference table 4.

The maximum amplitudes recorded for this quarry events are due to the maximum charge size consumed per blast as well as per shot hole. The maximum depth of explosion also affects the amplitude of the seismic event.

### JRCRBC Quarry

This quarry is found 8.76km away from the Furi seismic station in the direction of north - east at an angle of about  $17.5^{\circ}$ . This quarry is nearest to the seismic station. The ground velocity and displacement amplitudes of the corresponding seismic

records are the second maximum next to the BMM quarry event. One of The causes of this high amplitude is, the shortest distance of the quarry from the Furi seismic station. From this result, one can conclude that the distance of the source from the recording station affects the amplitude of the seismic wave.

### Quarry Events with Low Amplitudes

The quarry events from the three quarries: Akaki, BCRBC and KCRBC, posses low ground velocity and displacement amplitudes. The respective values are in the order of  $10^{-6}$  m/s and  $10^{-7}$  m. The recorded amplitudes are ten times smaller than that of the quarry events with high amplitude. This is partly due to the small charge size consumed per shot and partly due to the long distance of the quarries from the seismic station.

From the list in table 4 the size of the charge used per shot at Akaki quarry is comparable with that of BMM quarry. However, due to the longest distance of the quarry from the seismic station, the amplitudes of the quarry events are attenuated by geometrical spreading nature of the seismic waves.

On the other hand the amplitudes corresponding to the BCRBC and KCRBC quarry events are small as the one recorded for the Akaki quarry events even if they are not

as far from the seismic station as Akaki and BMM quarries. The reason for this result is the size of the charge consumed per shot.

From the above discussion one can draw the following conclusions.

1. The ground velocity and displacement amplitudes are affected by the distance of the seismic source from the seismic station due to the geometrical spreading of the seismic energy.
2. The ground velocity and displacement amplitudes are affected by the charge size consumed per shot and per shot hole.
3. The depth of the explosion also affects the amplitudes of seismic wave because the explosion at shallower depth generates high surface waves at the vicinity of the source, which dissipate in the surrounding formation.

### Local Magnitude

Local magnitude ( $M_L$ ) is the seismic parameter that measures the strength of seismic energy. It is the logarithmic function of amplitude  $A$  and is measured in Richter scale.

As listed in the table 5 the local magnitudes of the quarry events from different azimuths are different. Based on the values of the magnitudes recorded for each quarry event the events can be classified in to two: quarry events with high local magnitudes and quarry events with low local magnitudes. For my case quarry events with high local magnitudes are the seismic events whose magnitudes range 2.1 - 3.0 and the magnitudes of quarry events with low magnitudes range 1.1 - 2.0 Richter scale.

Based on this classification the BMM quarry produces a high magnitude seismic event and all the rest four quarries generate a low magnitude seismic event. The reason for magnitude distribution is again the size of the charge consumed per shot hole and the depth of the explosion. From the above discussion one can draw the following conclusions.

1. The small explosives produce the small seismic energy that result in small local magnitude.
2. The shallower the depth of explosion the lower seismic energy is produced.

As the result lower local magnitude is recorded because most of the seismic energy is lost as air concussion the surface waves that dissipate in the vicinity of the source.

### Velocity Variation

The seismic waves generated from different quarries are found to arrive the recording station after different time delay. These different delay in time results in different seismic velocities. This is due to the fact that the wave crosses different seismic layers.

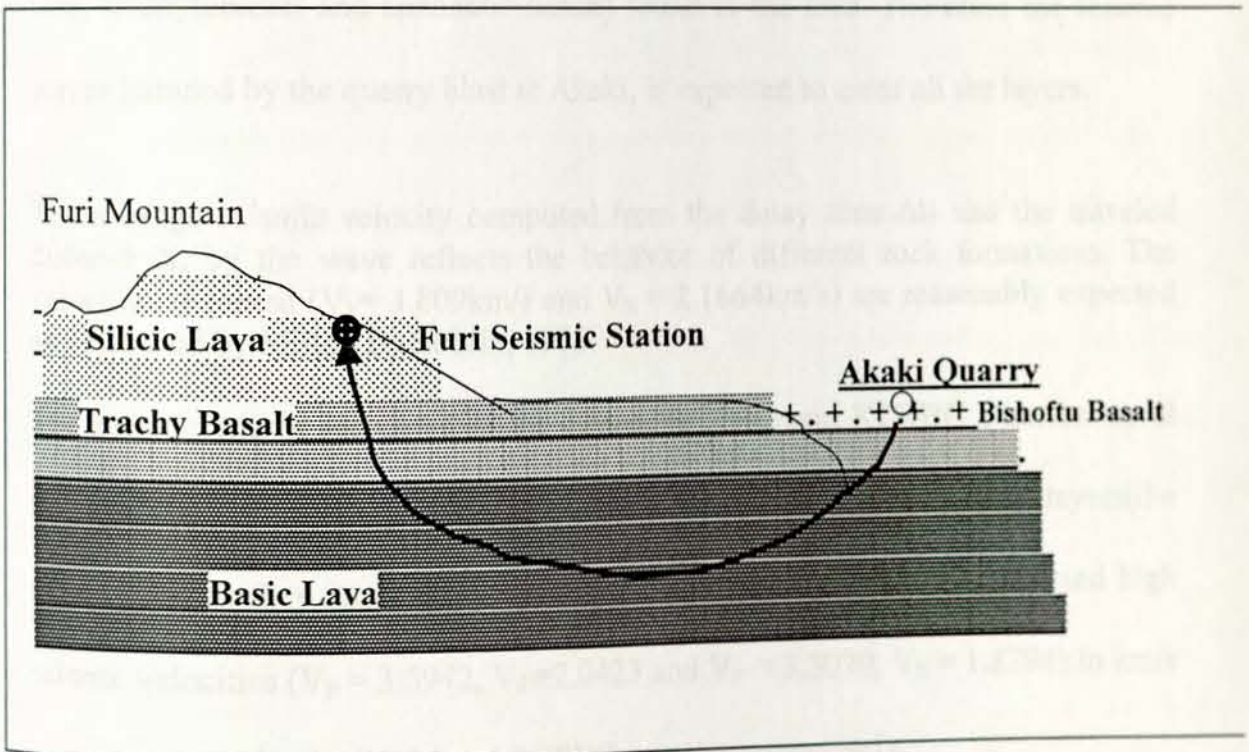


Fig.20. Simplified Diagram Showing the Path of the Seismic Wave

From the study of the rock outcrops in the area, it was concluded that the subsurface is made up of successive strata of different velocity zones. The simplified strata of these zones are sketched as follows.

The Akaki quarry is situated in the area where the youngest Bishoftu basalt is exposed at the surface. Aphanatic basalt on the other hand covers most of the areas where the BMM, BCRBC and KCRBC quarries are located.

Aphanatic rocks are the oldest of the four types of rocks (Bishoftu basalt, silicic lava, trachytebasalt and aphanatic basalt) found in the area. Therefore the seismic waves induced by the quarry blast at Akaki, is expected to cross all the layers.

The average seismic velocity computed from the delay time  $\Delta t_p$  and the traveled distance  $X_a$  by the wave reflects the behavior of different rock formations. The velocities obtained ( $V_p = 3.809\text{km/s}$  and  $V_s = 2.1664\text{km/s}$ ) are reasonably expected as illustrated by Milton B. Dobrin, 1988.

The seismic waves generated at the BMM, BCRBC and KCRBC quarries travel through the high velocity layers at the onset and in the lower velocity layers (the silicic lava) as they appear to the seismic station. As the result the expected high seismic velocities ( $V_p = 3.5942$ ,  $V_s = 2.0423$  and  $V_p = 3.3070$ ,  $V_s = 1.8794$ ) in km/s were computed for the BMM and BCRBC quarries respectively.

On the contrary the seismic waves generated from the KCRBC quarry is found to have lower ( $V_P = 2.5398\text{km/s}$  and  $V_S = 1.4430\text{km/s}$ ) than the expected seismic velocity. This lower velocity may indicate the presence of the lower velocity materials, faults and fractures or all along the way to the seismic station that hinders the propagation of the seismic wave.

The seismic wave generated at the JRCBRC quarry on the other hand is characterized by having higher velocity ( $V_P = 3.0377\text{km/s}$  and  $V_S = 1.7284\text{km/s}$ ) while the depth (0.75km) it penetrates is lower. This higher seismic velocity is not expected at this shallower depth and in the medium the wave is generated. Therefore the trachybasalt and the rhyolite through which the wave propagates must be fresh and massive with no fractures and faults.

The seismic velocity ratio ( $V_P/V_S$ ) is found to be almost the same, although the subsurface is characterized by different velocity layers, That is, the computed velocity ratio can be approximated to  $1.76 \pm 0.0022$ .

From the theory of elasticity the average  $V_P/V_S$  ratio of most consolidated rocks is between 1.5 and 2.0. Therefore the seismic waves generated by the quarry blasts must travel through the hard rocks composing the subsurface.

Another important elastic parameter found from the investigation is the Poisson's ratio ( $\nu$ ). This elastic parameter describes the elastic behavior of the rock formation.

Poisson's ratio is the part of elastic constants (elastic modulus  $E$ , shear modulus  $\mu$ , bulk modulus  $K$ , Lamé's constant  $\lambda$  and the Poisson's ratio  $\nu$ ) and its value lies between 0 and 0.5 as can be observed from the relation  $\nu = \lambda / 2(\lambda + \mu)$ .

Poisson's ratio illustrates the degree to which the material stretches or compresses under the application of force. As indicated by Hemphill, 1981, the lower the value of Poisson's ratio of the material indicates that it is prone to pre-splitting. For most crust material the value of  $\nu$  lies between 0.22 and 0.35. Therefore the computed Poisson's ratio (0.26) in the normal range and can characterize the rock formations of the subsurface around Addis Ababa.

## Chapter -6

### Conclusion and Recommendation

The patterns of seismic waves induced by the quarry blasts in the southern part of Addis Ababa could be analyzed to investigate the interrelationships between the velocity of propagating waves, epicentral distance, charge size, depth of explosion, amplitude and frequency content of the seismic waves and the geologic conditions that affect them. Based on the results obtained from the investigation and the possible geologic conditions of the area, the following conclusions can be forwarded.

1. The blasting operations at the quarries in the areas under investigation induce the seismic waves of local magnitudes of about 1.1 to 3.0 in Richter scale that can be recorded and analyzed to study the structural behavior of the rocks beneath the surface of the area.
2. The body wave velocities of the seismic events produced at the quarries vary as the functions of the distance from the quarry to the seismic station and depth of explosions.

3. Some seismic paths are characterized by high velocity layers and some other are characterized by low velocity layers. This may indicate the presence of various rock formations of the area.

4. The constant velocity ratio ( $V_p/V_s$ ) can be interpreted as that all rock formations are affected proportionally by both longitudinal and shear waves.

5. The invariance of Poisson's ratio as compared to the variations in seismic body wave velocities may indicate the equal reaction of the rock formations toward both longitudinal and shear waves.

6. The higher velocity computed for the Akaki, BMM, and BCRBC quarry events indicate a compact rock material probably of basic composition beneath the surface of the area.

7. The lower seismic velocity computed for the KCRBC quarry may be the indicator of the lower velocity materials or fractures or both along the entire path to the seismic station.

In general the variations in the velocity of seismic waves, and the invariance of velocity ratio and Poisson's ratio can provide invaluable information about the rock formations beneath the area under investigation.

Based on the results obtained from the study of the wave patterns of seismic waves induced by the quarry blasts in the area the following recommendations can be forwarded.

1. Although the purpose of blasting operations at the quarry is to break the rocks for the production of construction materials the seismic waves associated with the explosion can be used for the study of the geologic structures and the seismic layers beneath the city. The data can be accessed from the quarry blasting operations at low expense and minimum wastage of time.
2. When the explosion takes place there will be noise disturbance and the vibration damage on the nearby buildings and infrastructures. Therefore the shooters are expected to use the amplitude reduction mechanism to avoid unnecessary argument with the local people.

3. The determined values (velocity ratio and Poisson's ratio) for the rock formations in the area under investigation can be taken as reference for further study of the shallow structures of the area.

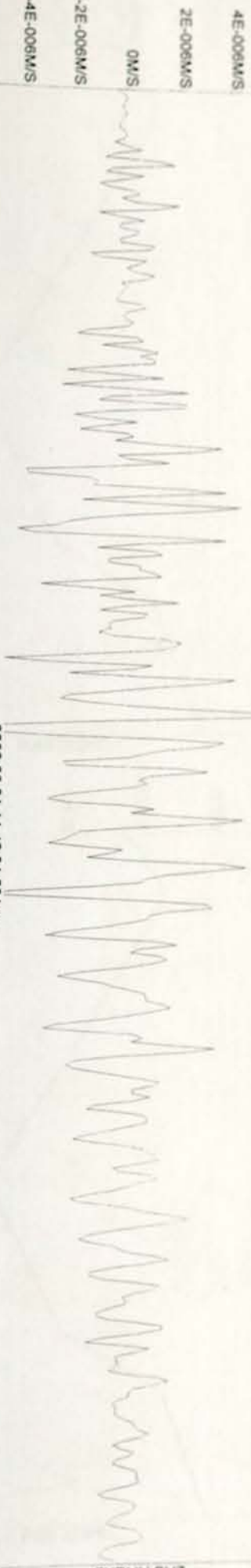
## Appendix

### Data Sources

In this section the seismograms and the corresponding wave spectra obtained from the quarry events are depicted.

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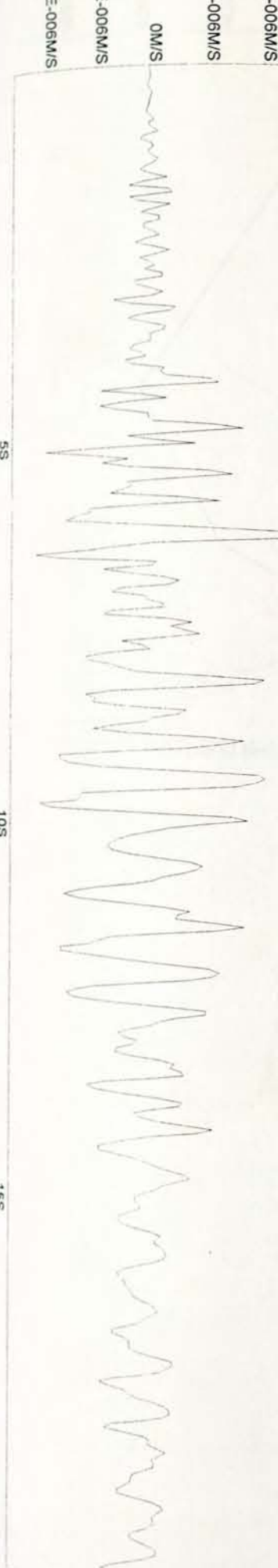
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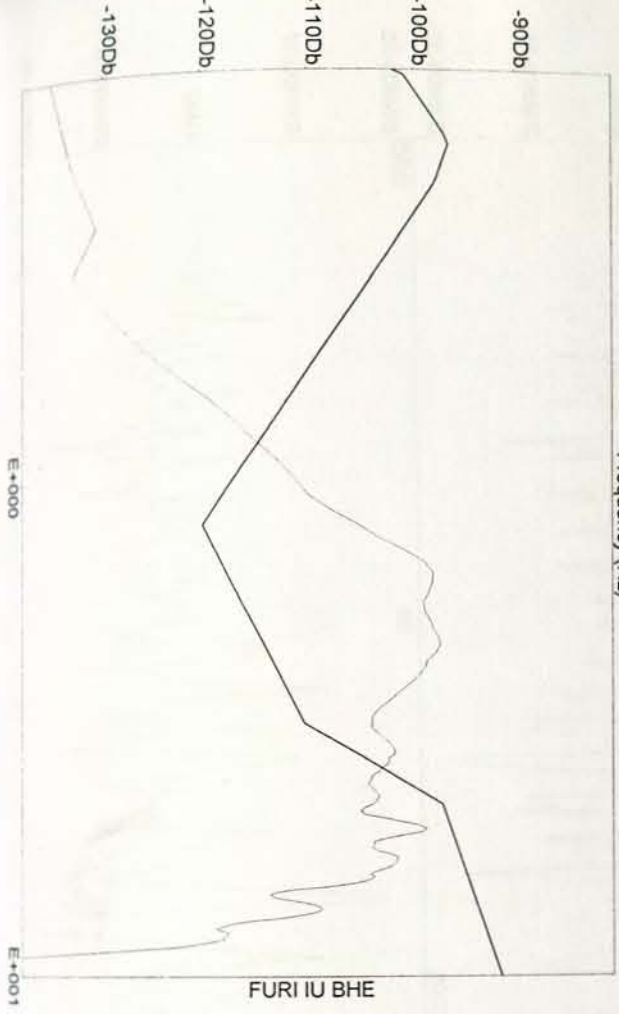
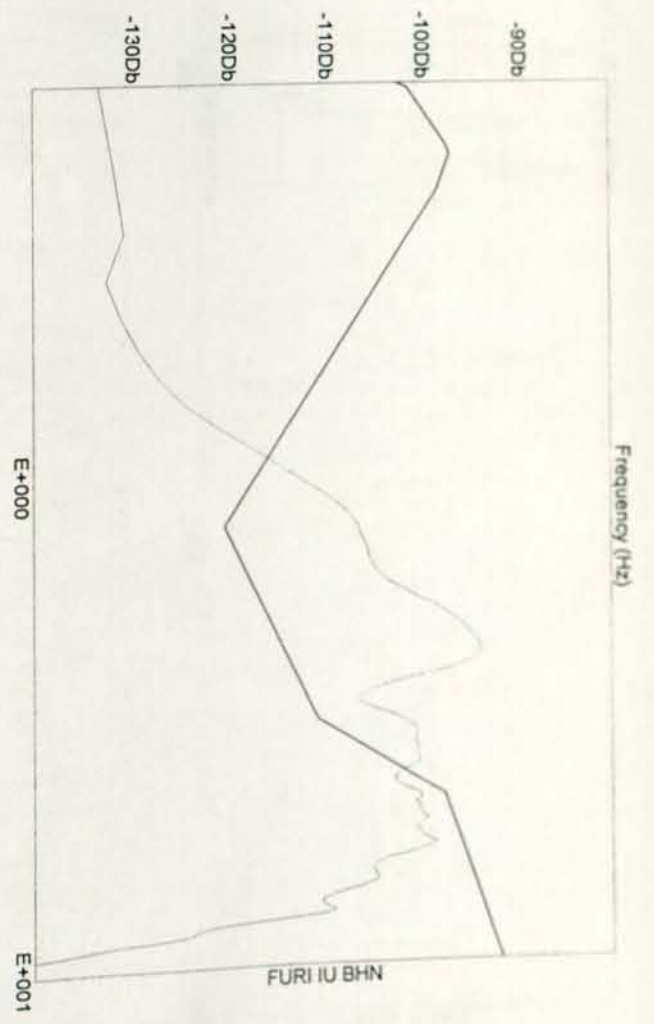
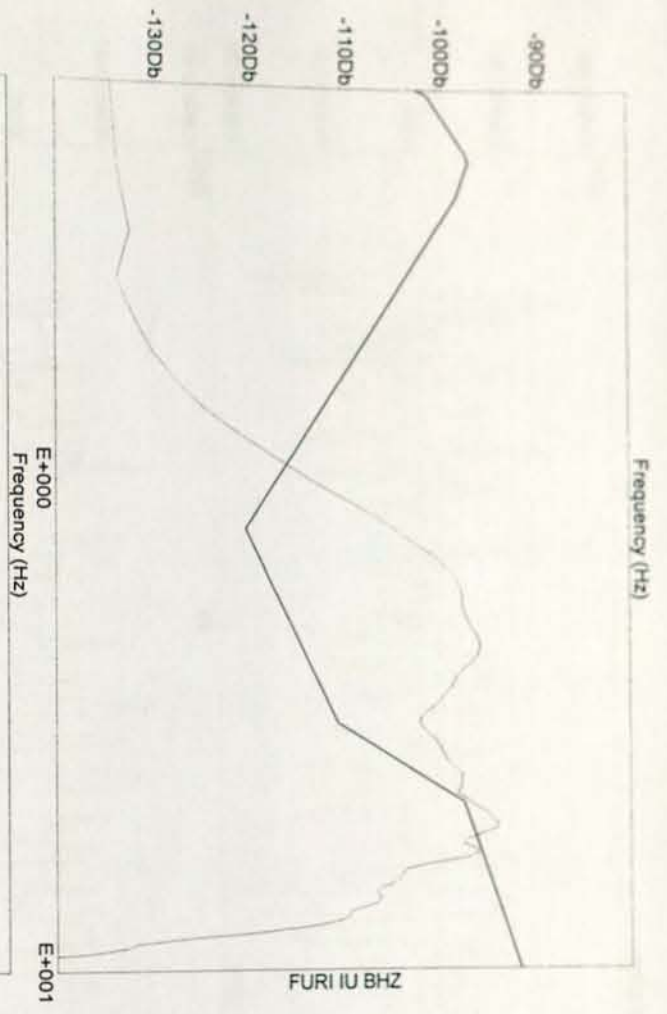
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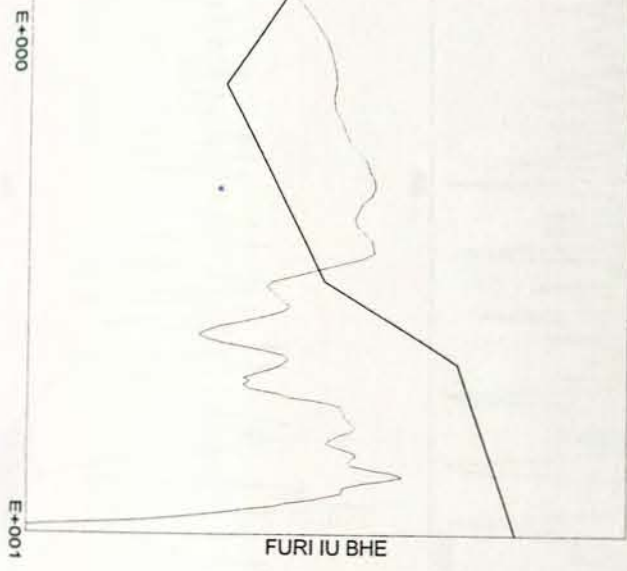
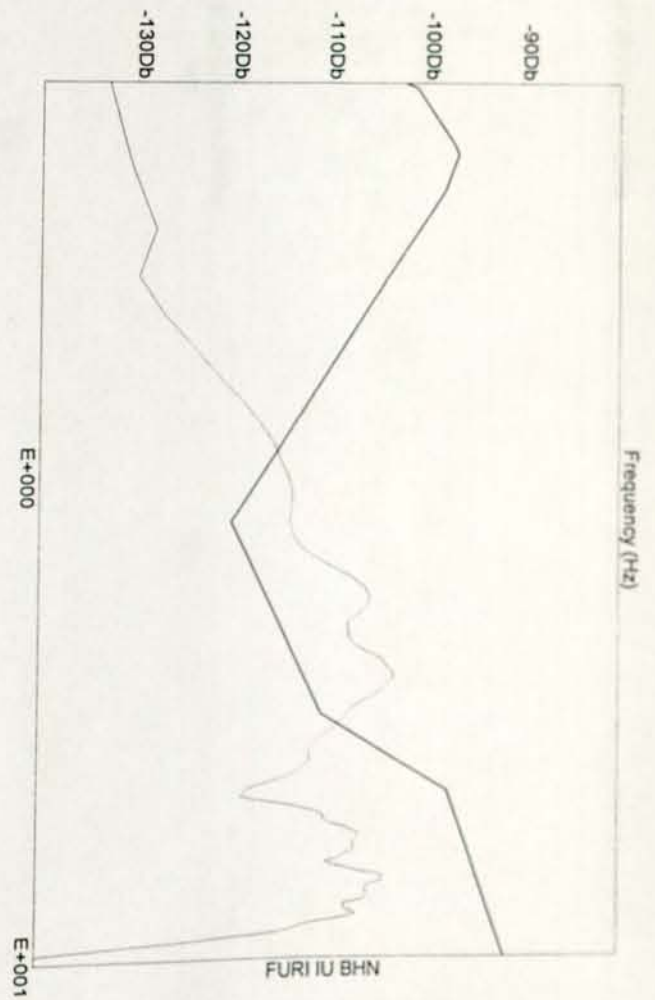
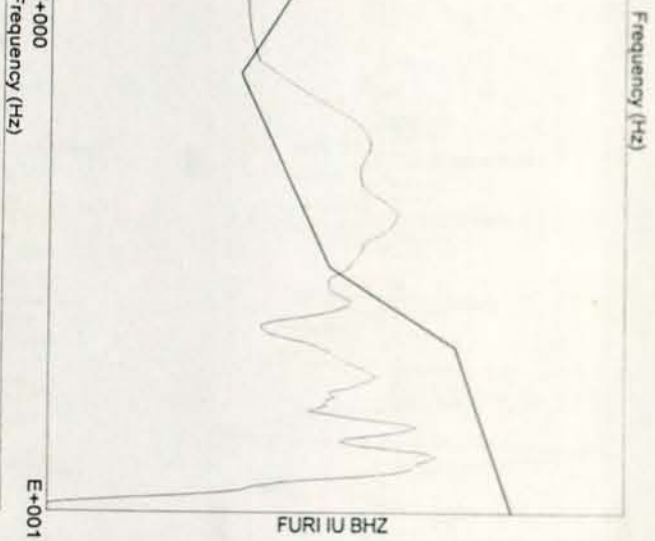
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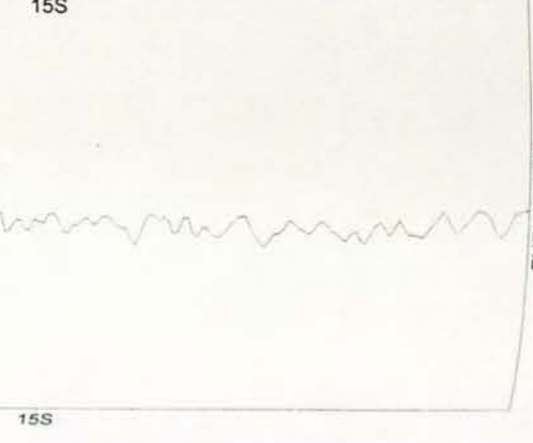
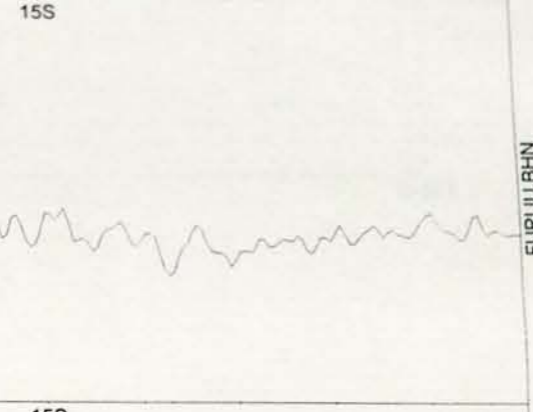
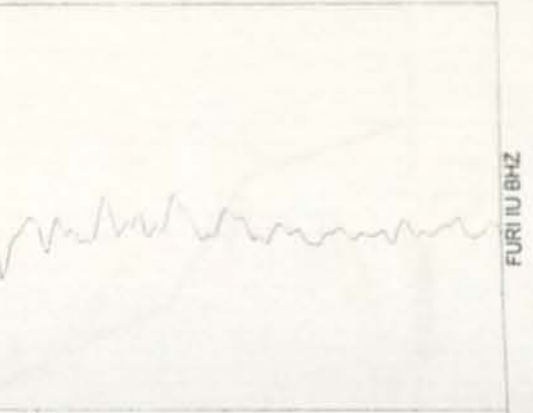
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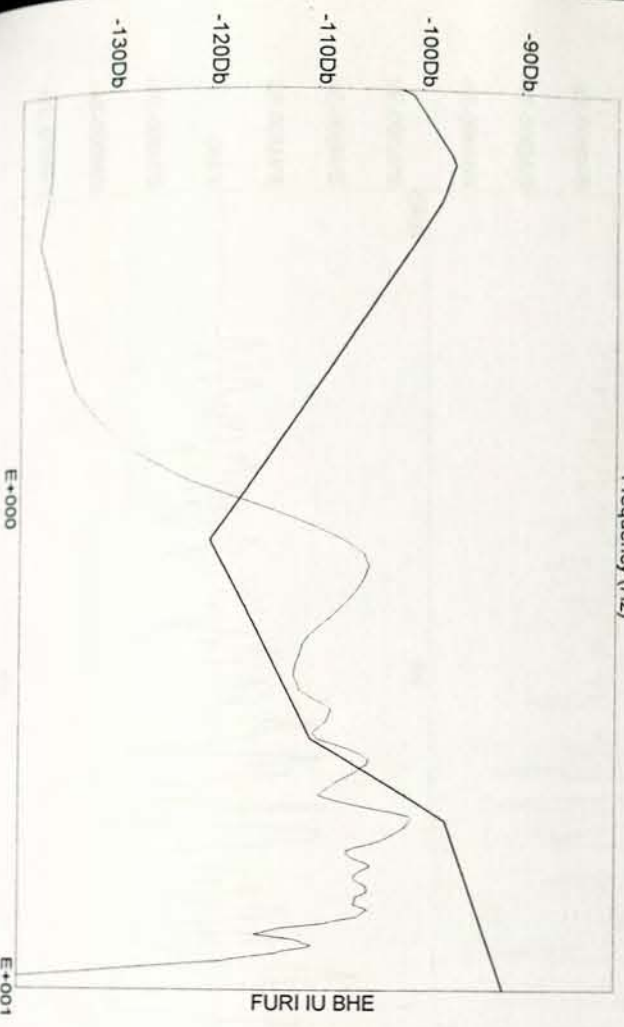
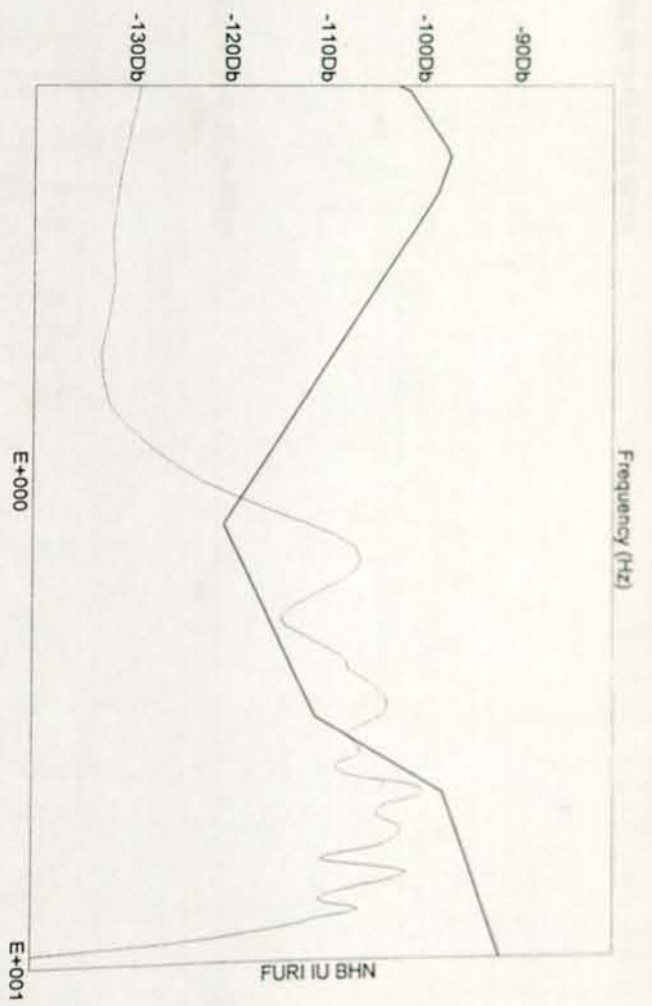
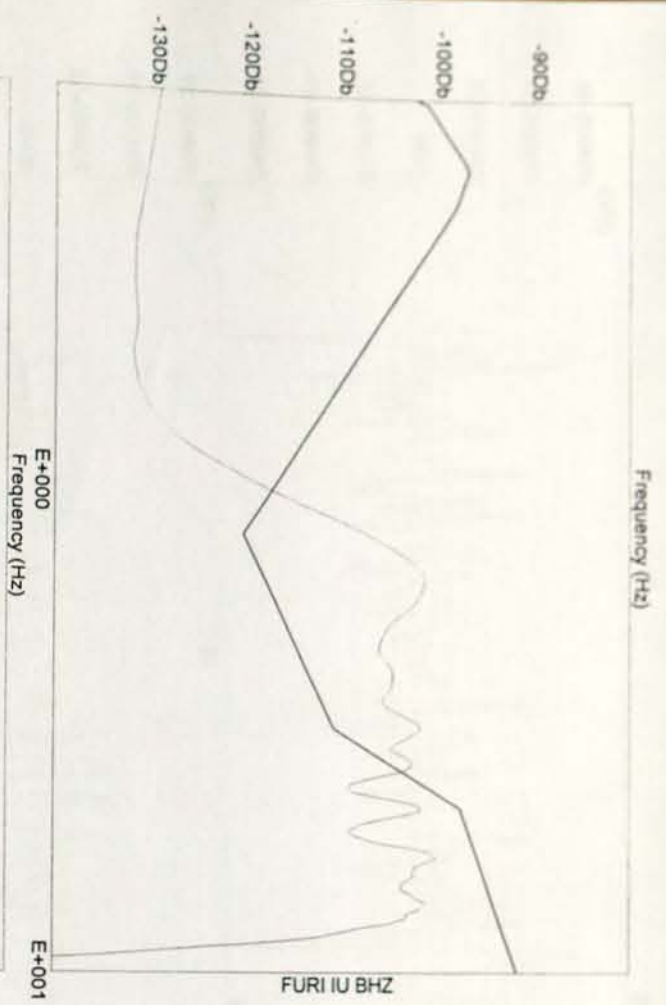
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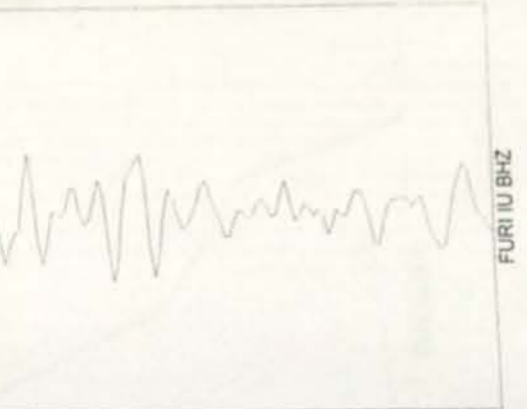
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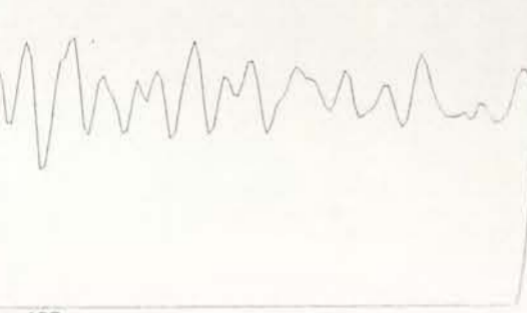




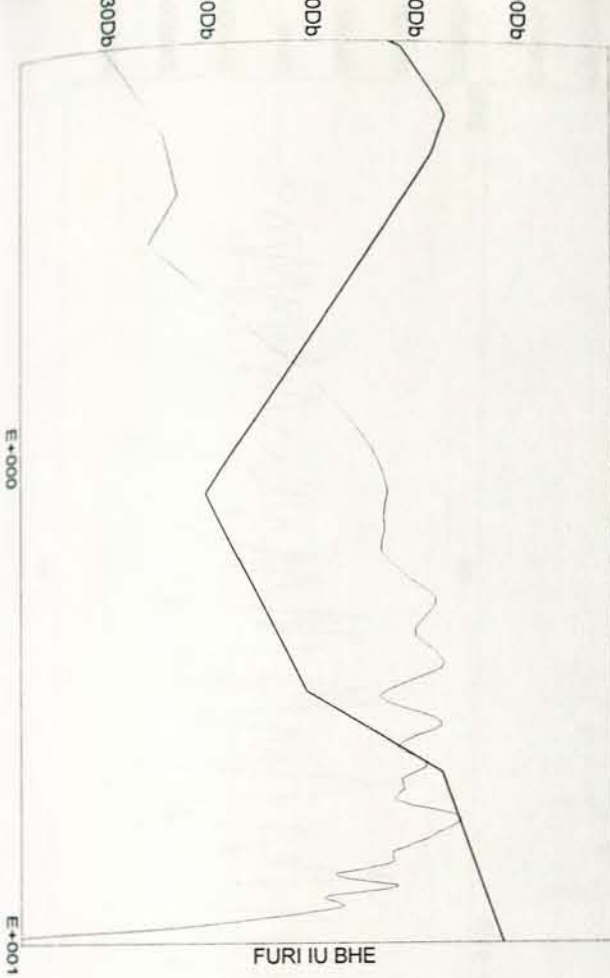
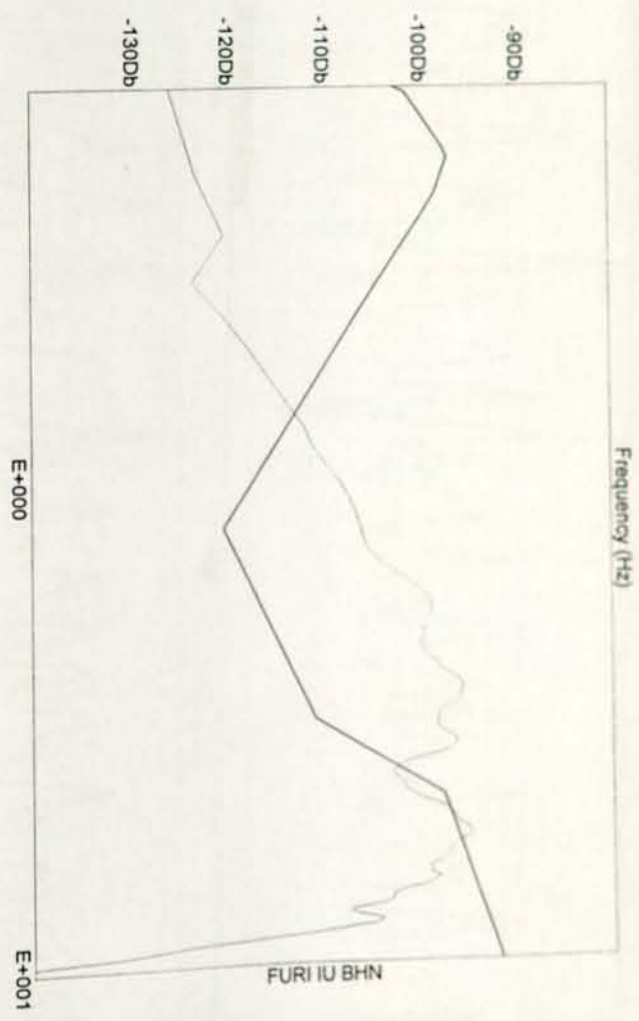
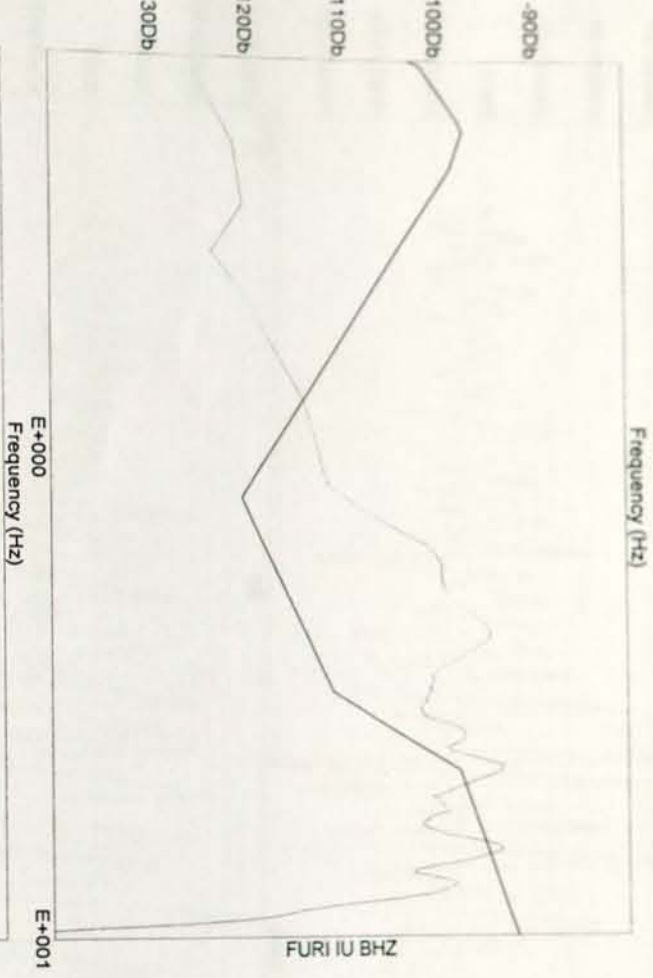
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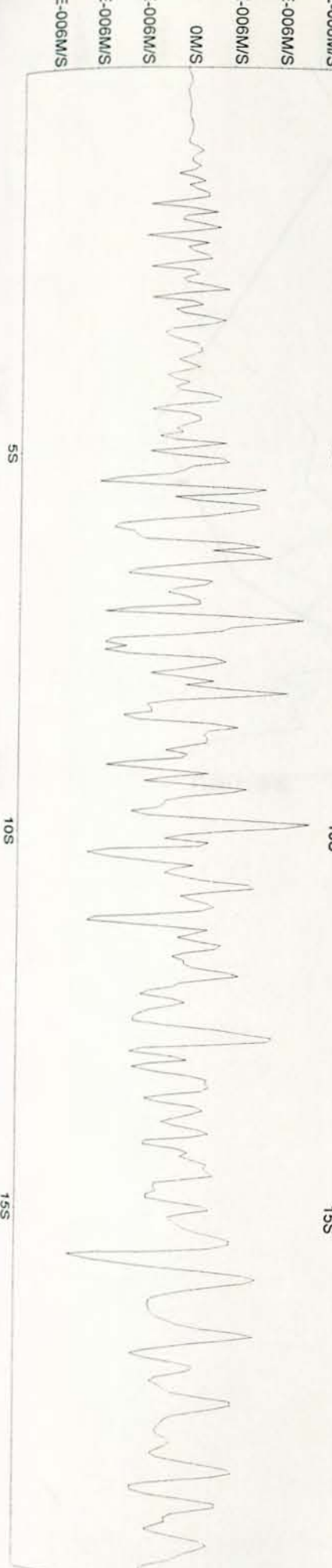
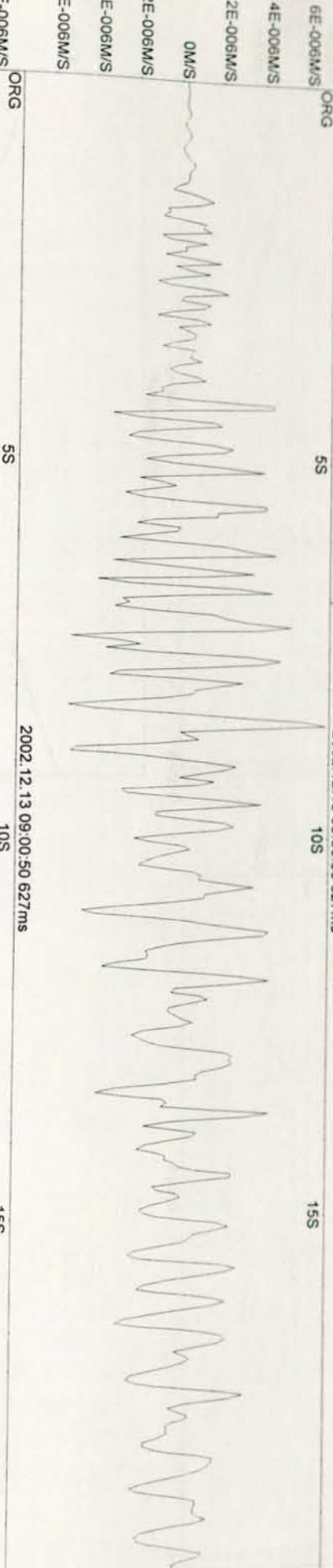
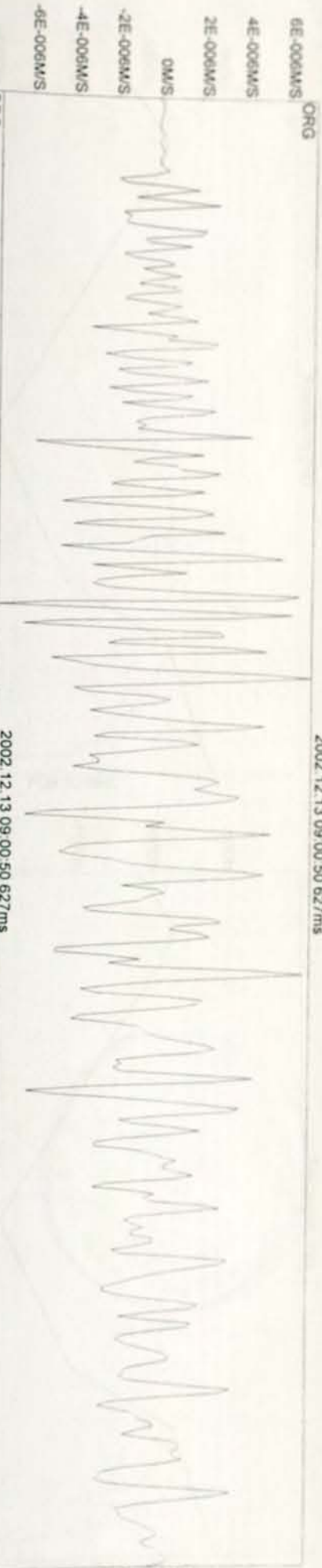


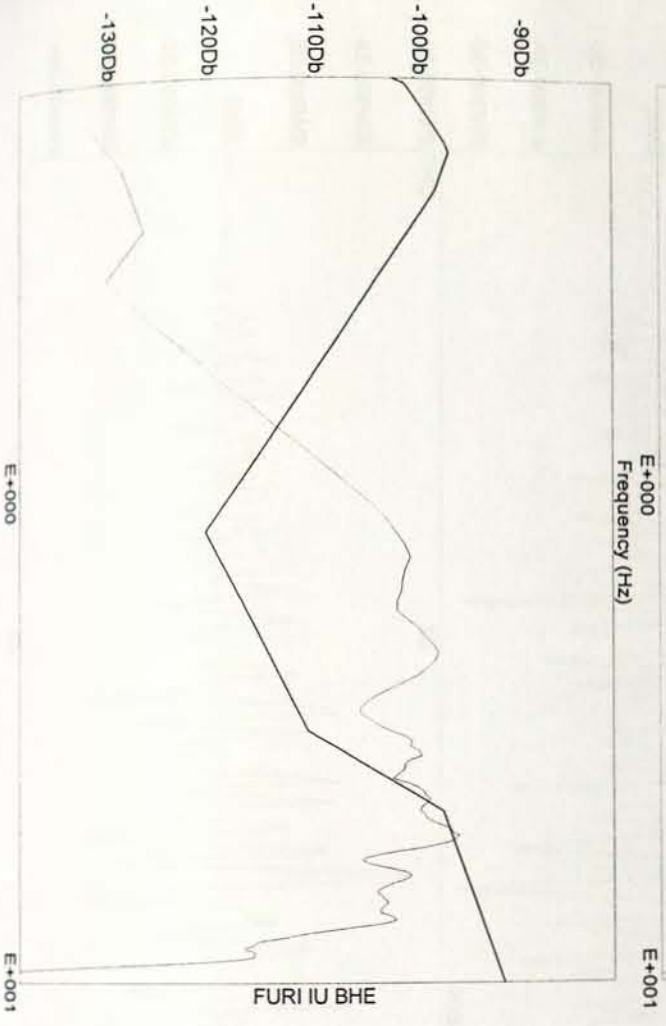
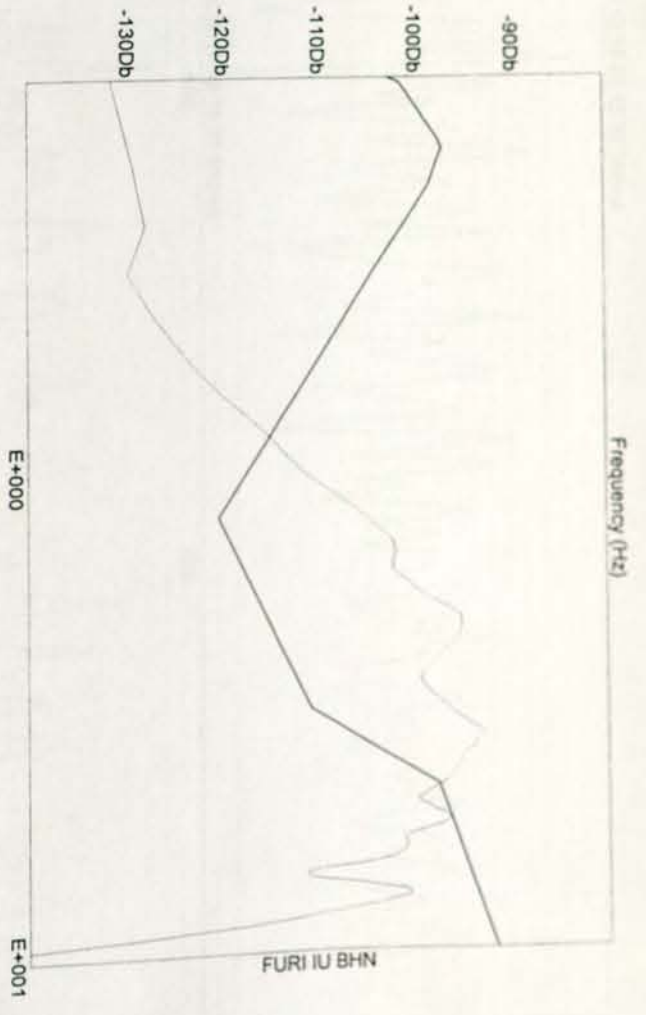
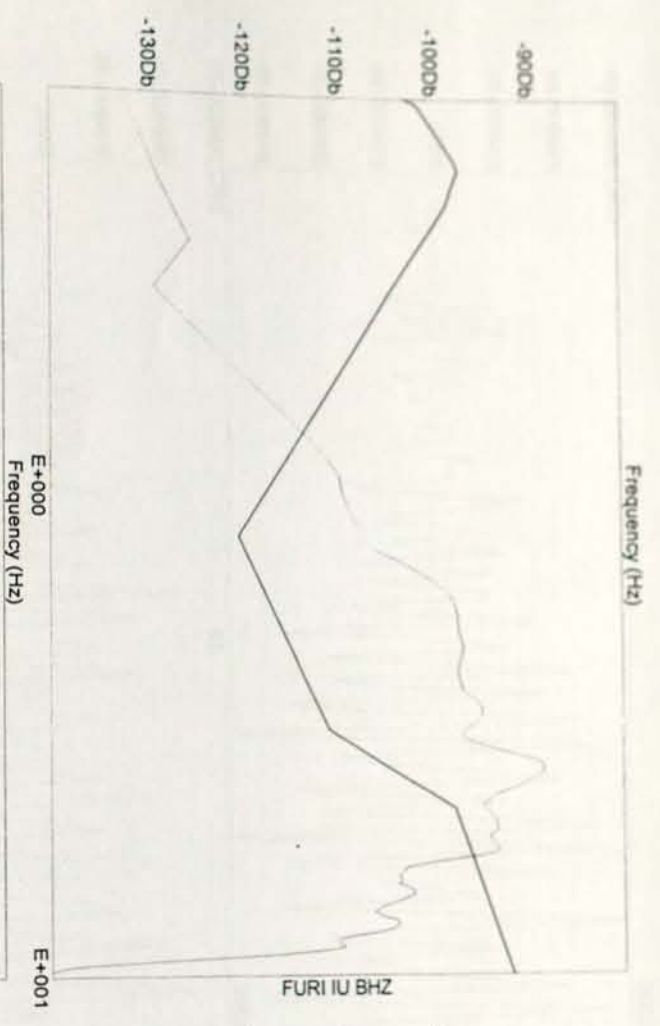
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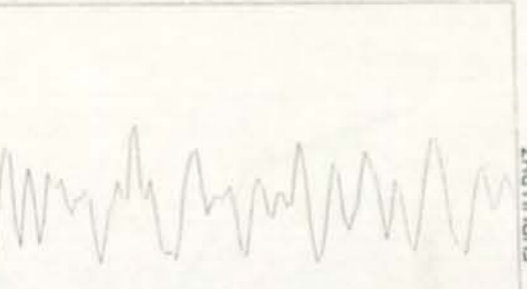


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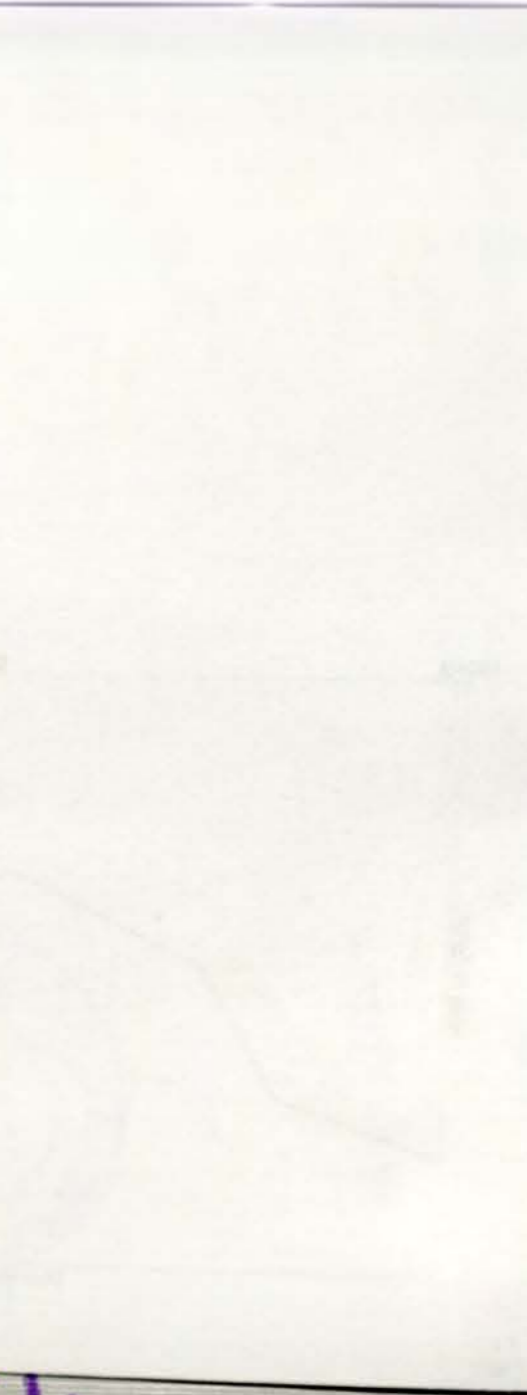
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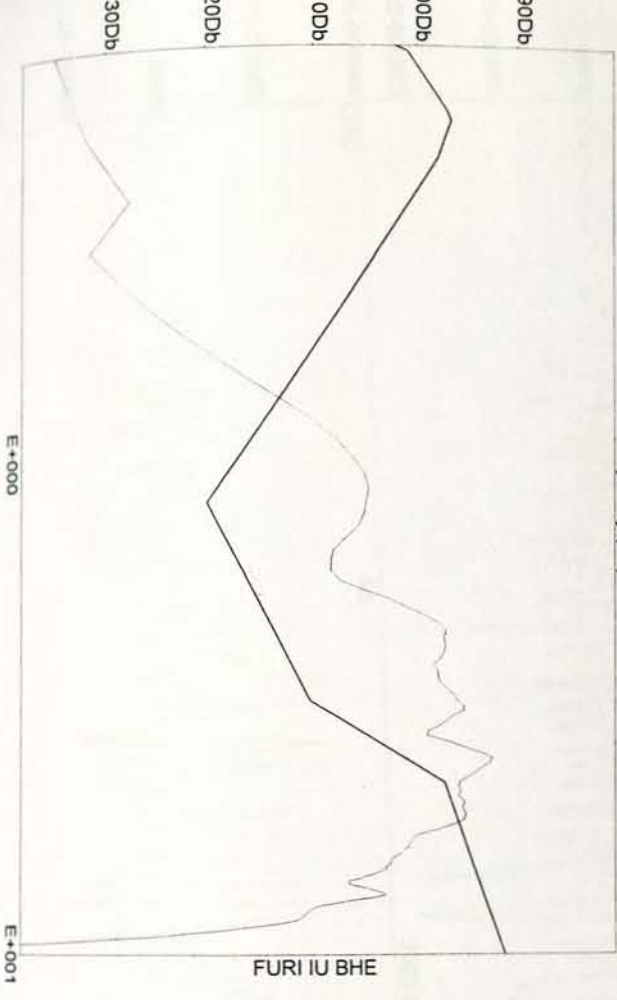
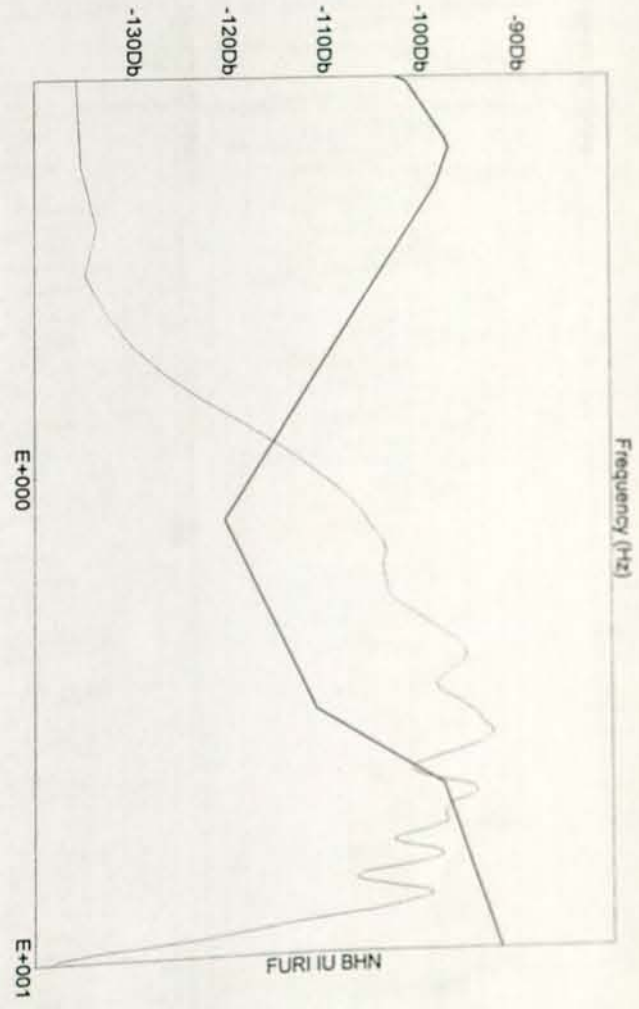
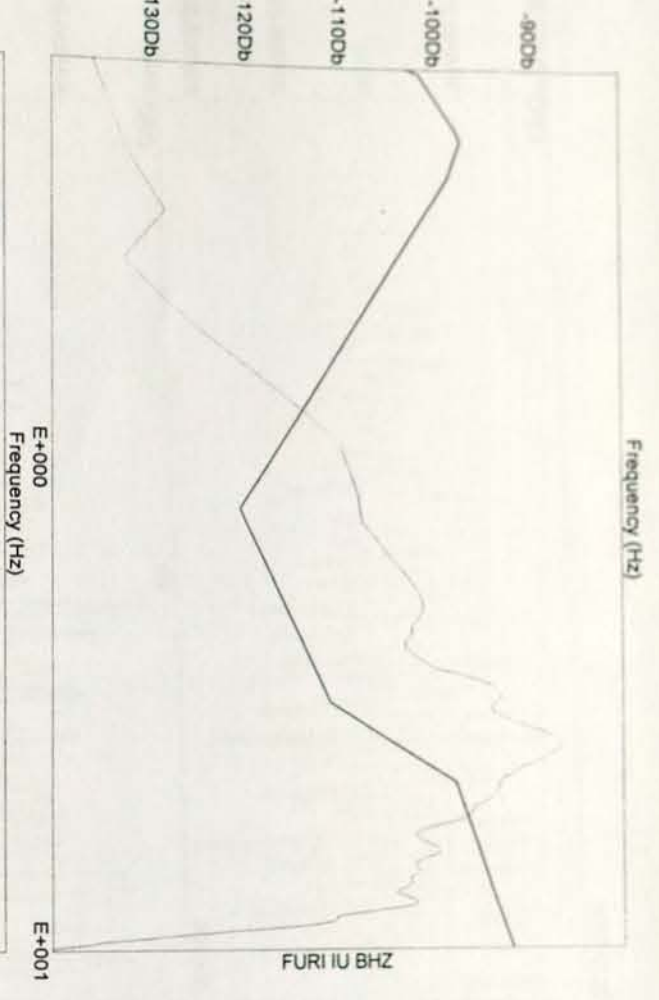


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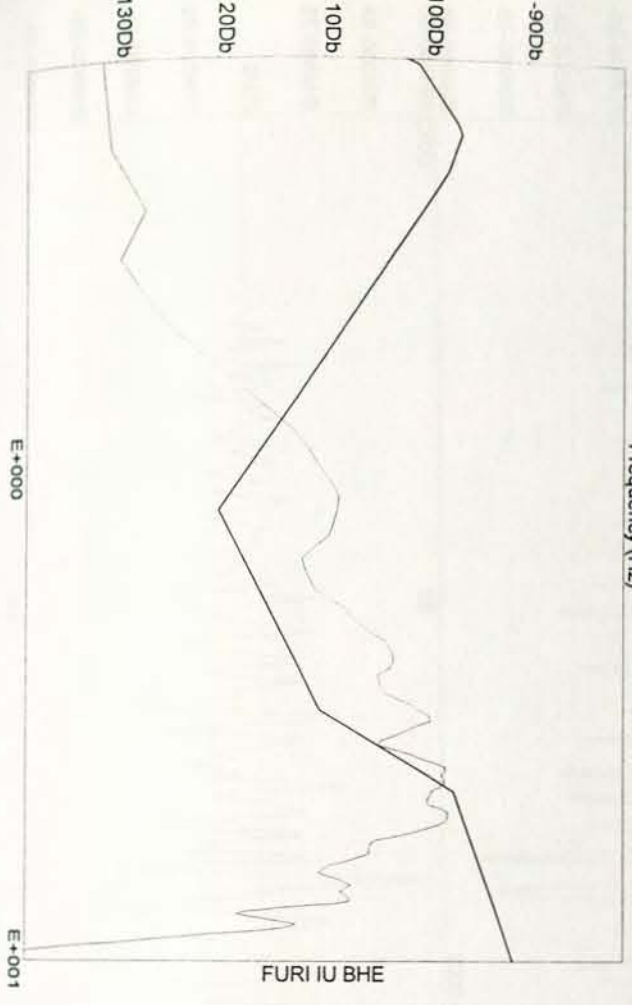
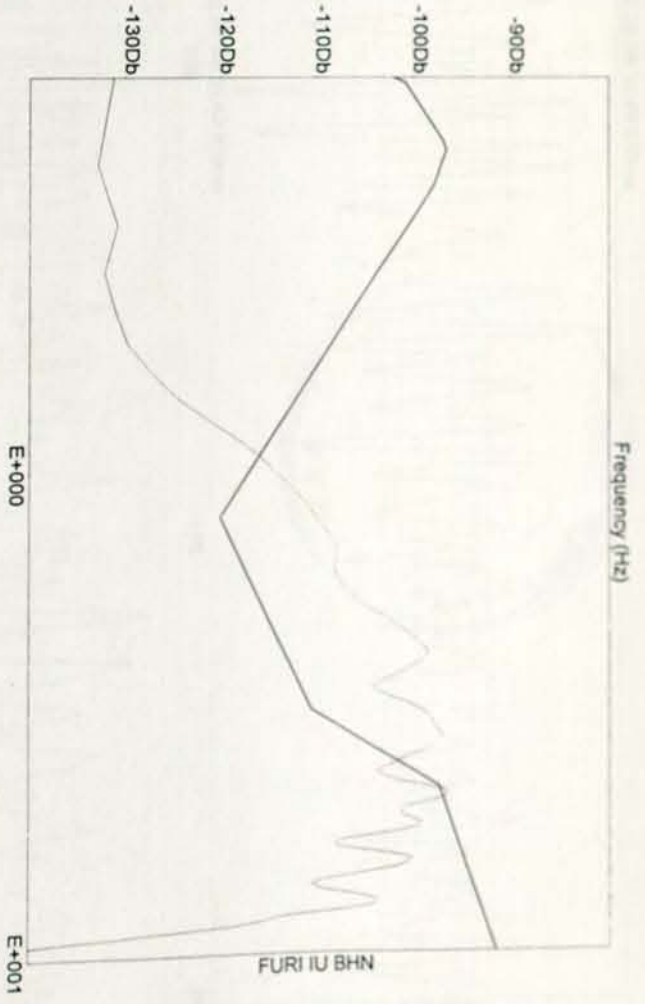
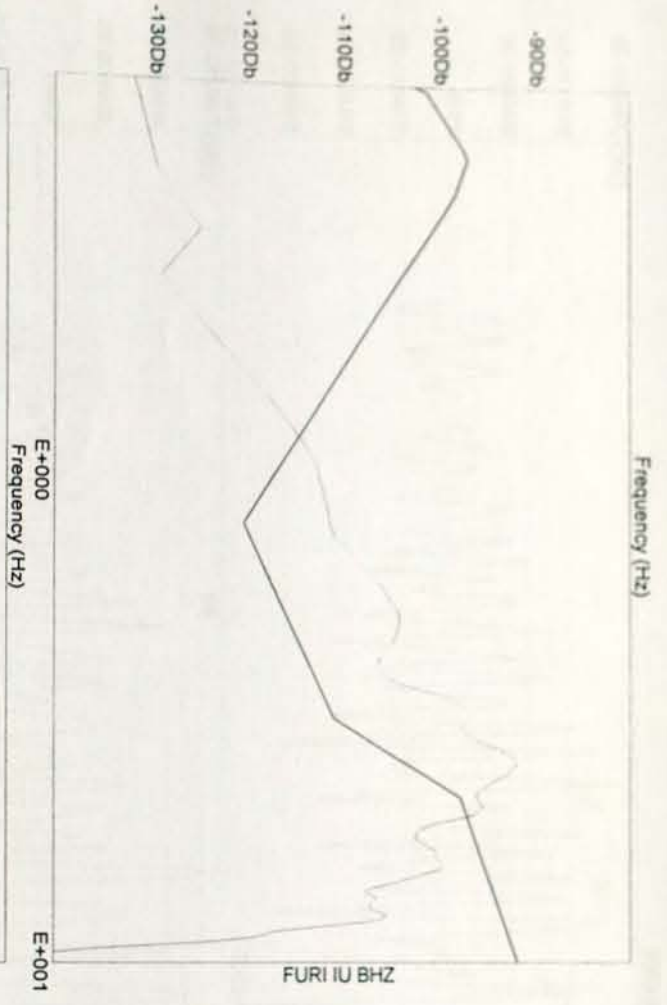
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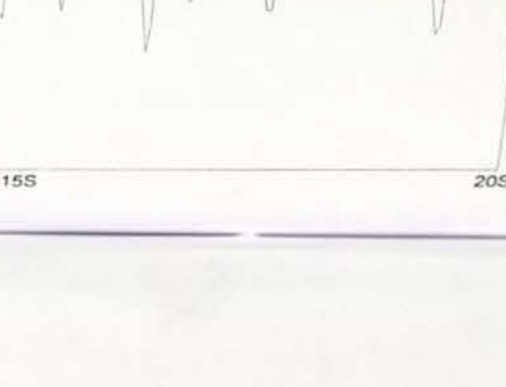
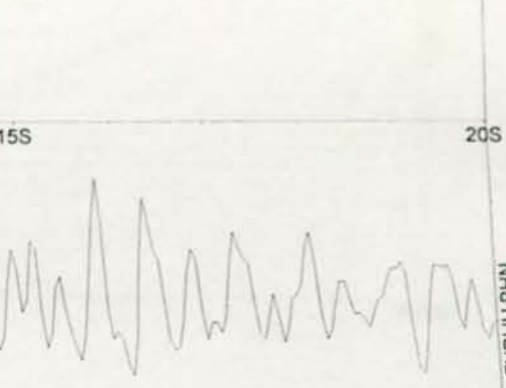
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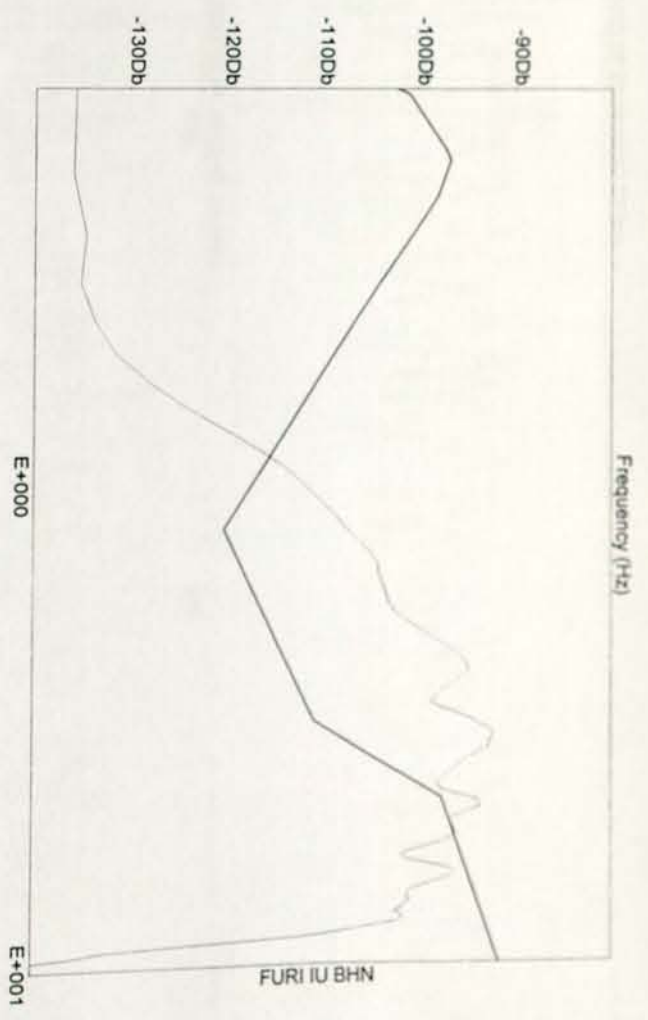
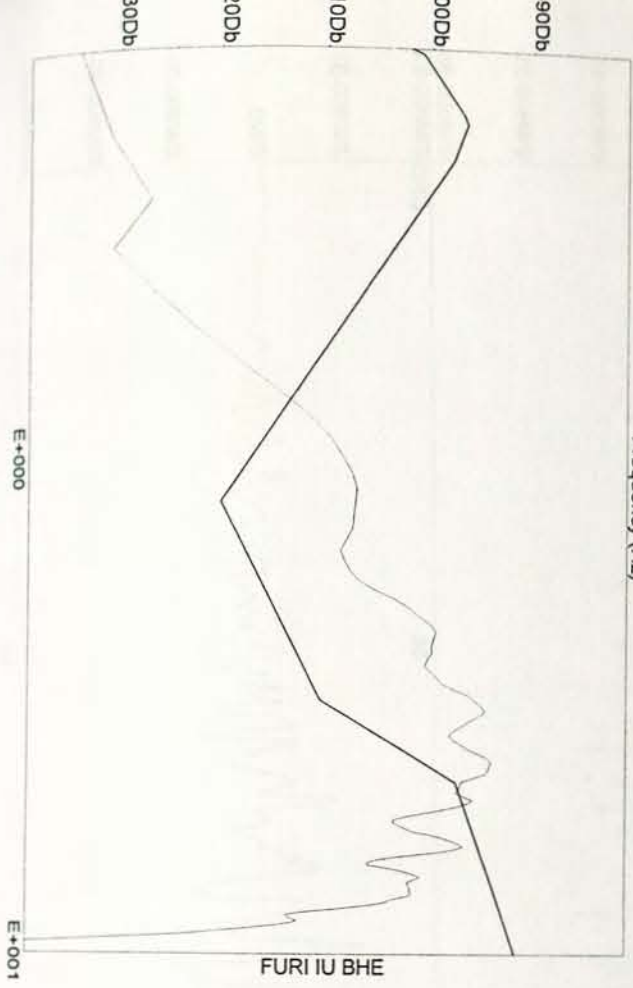
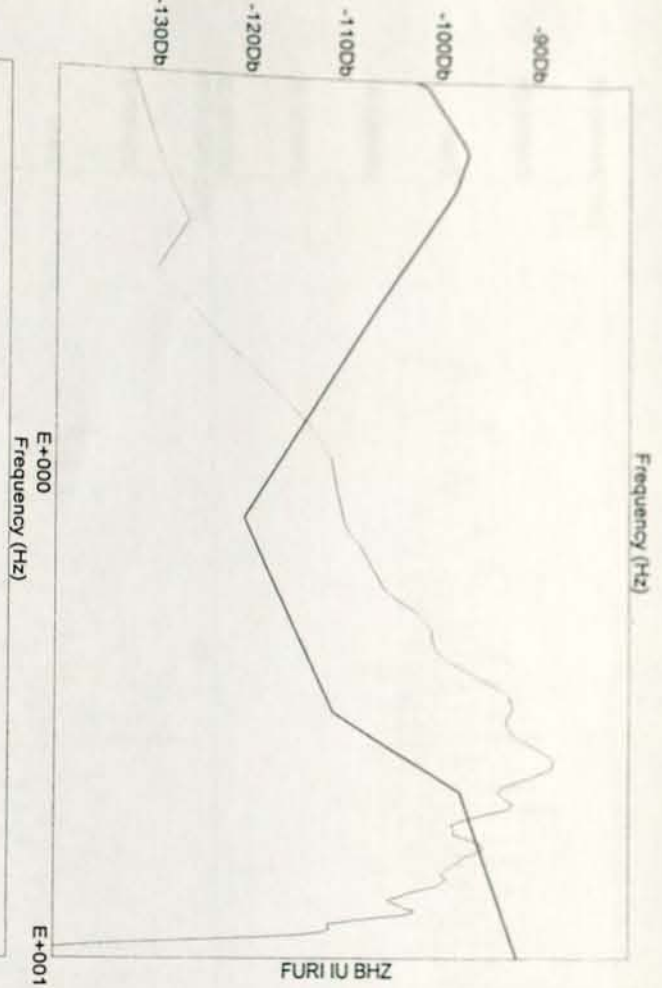
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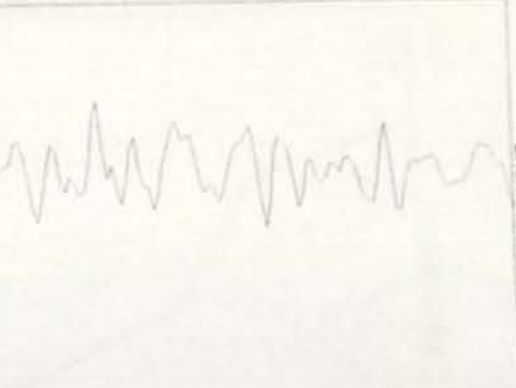
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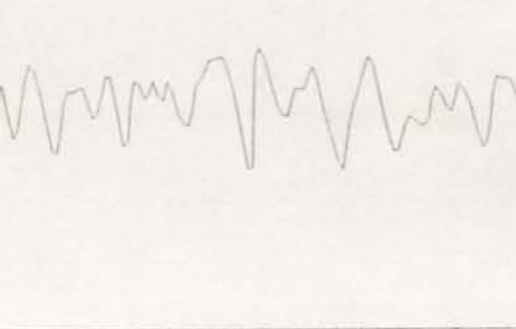




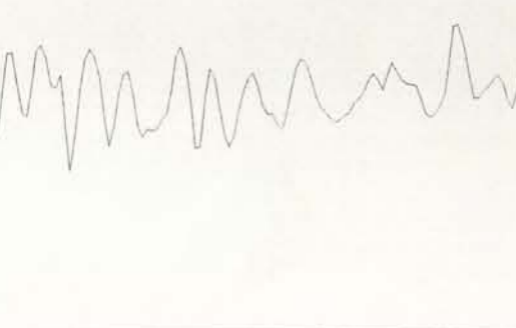


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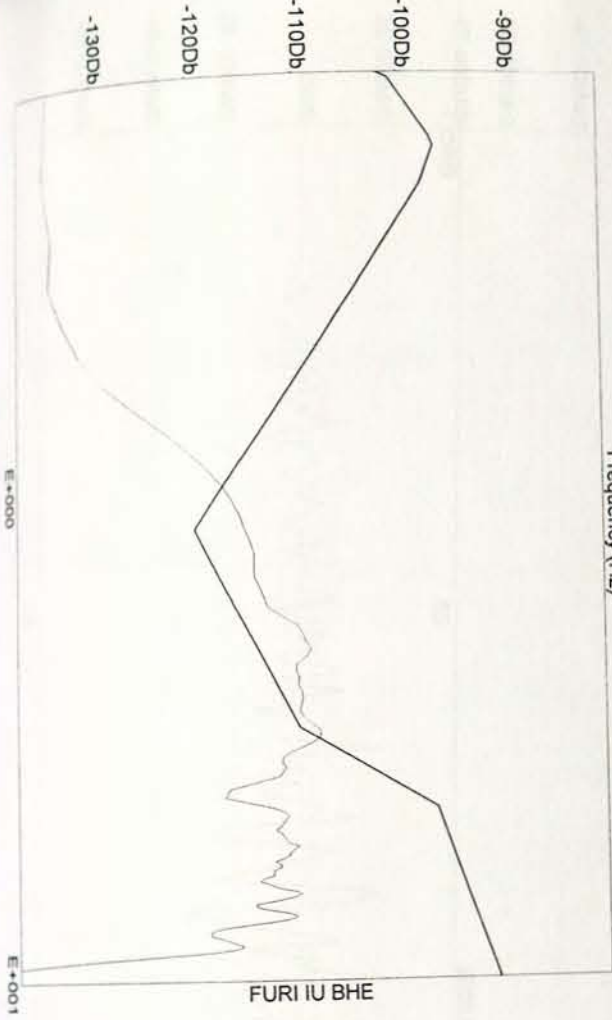
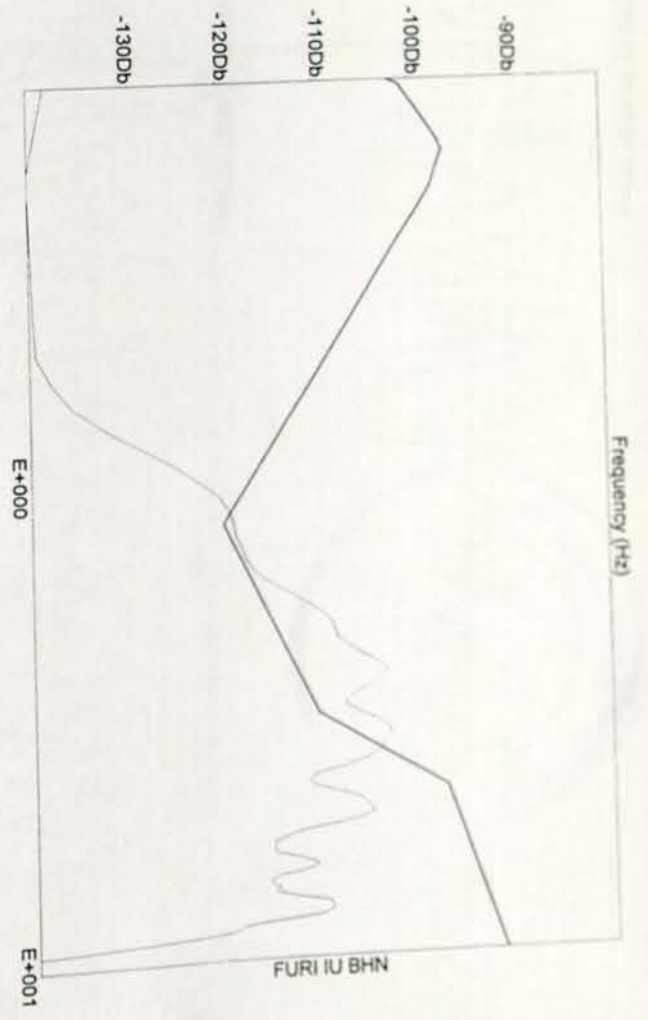
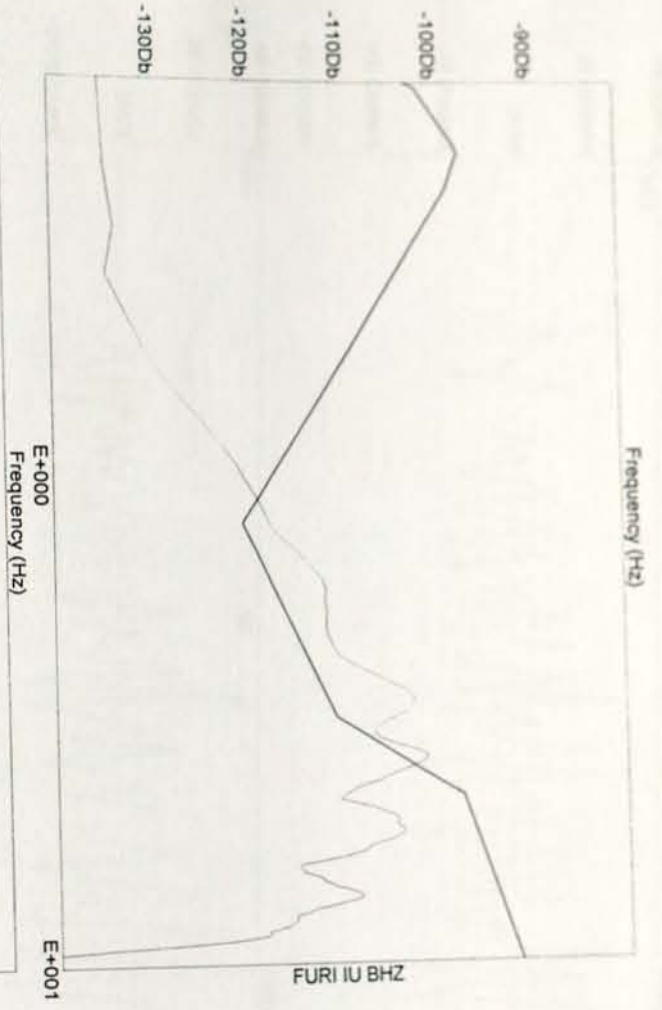
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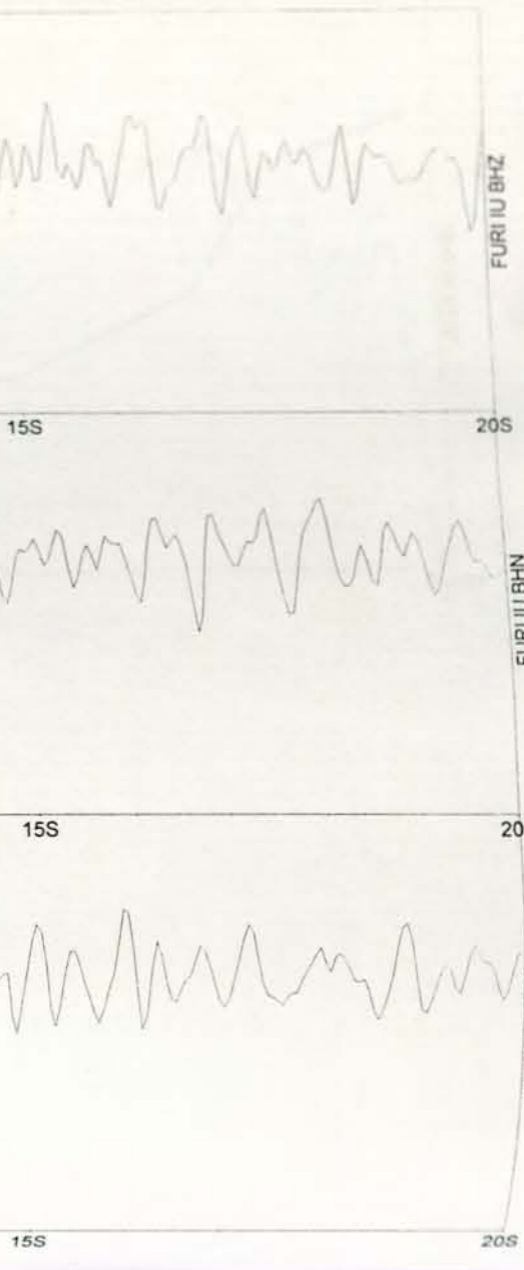


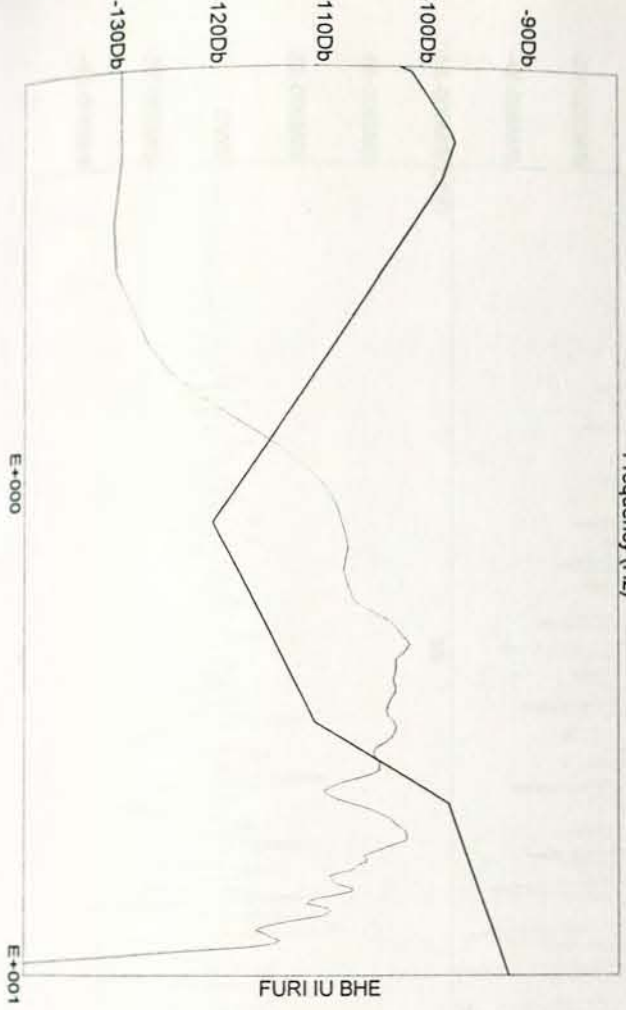
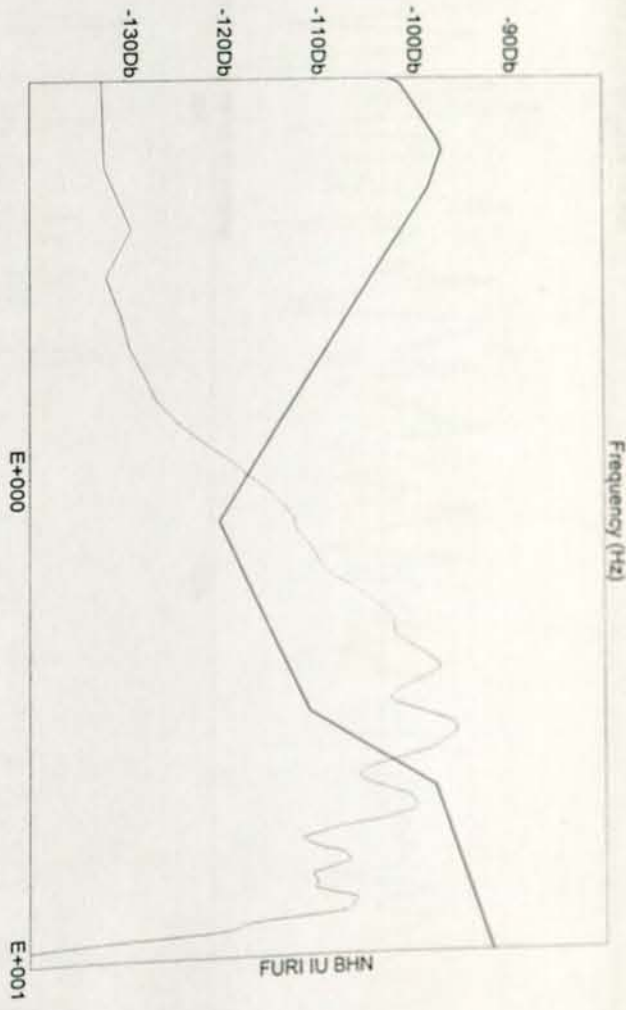
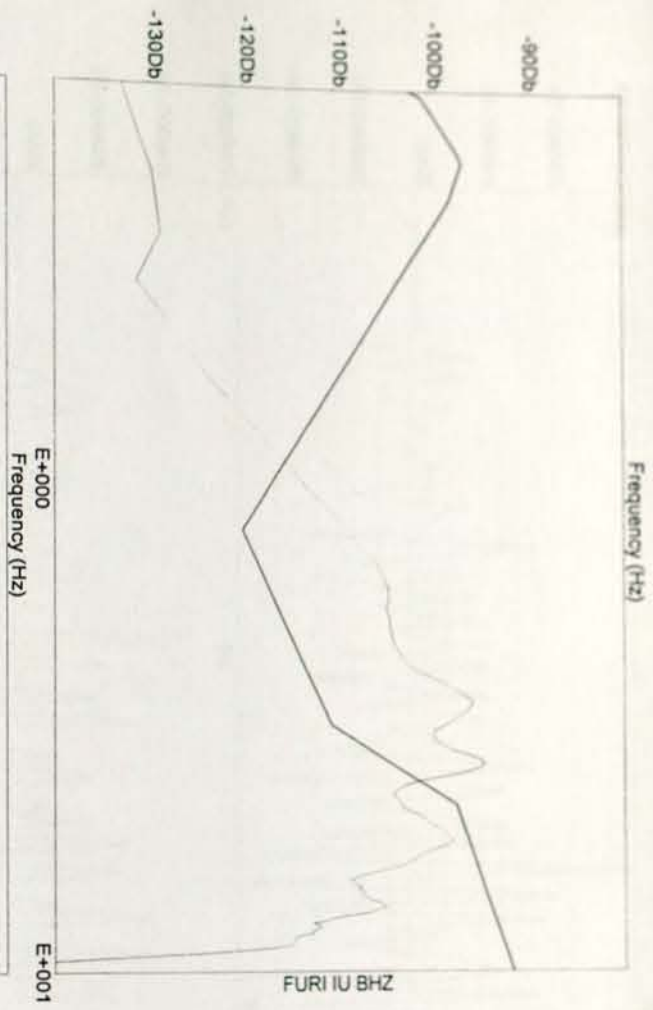
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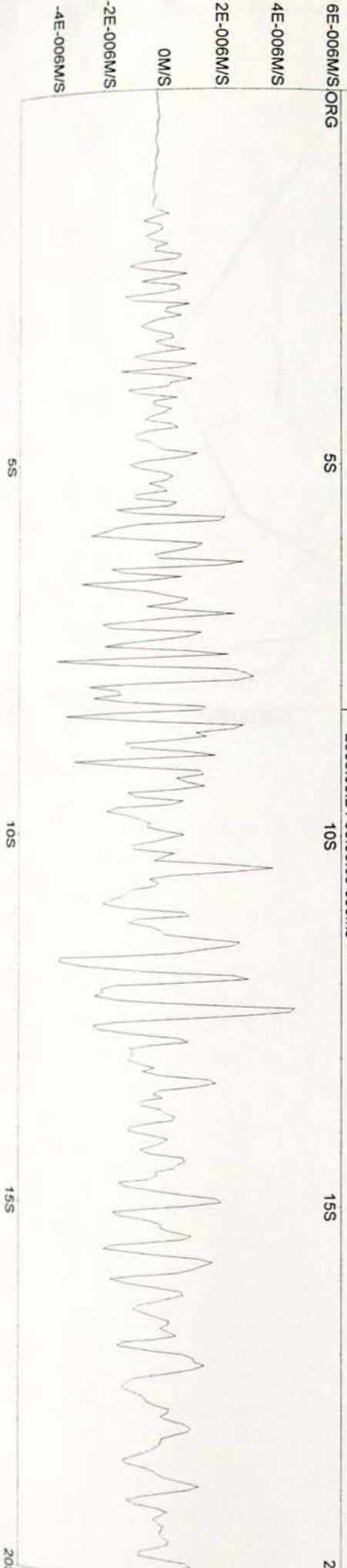
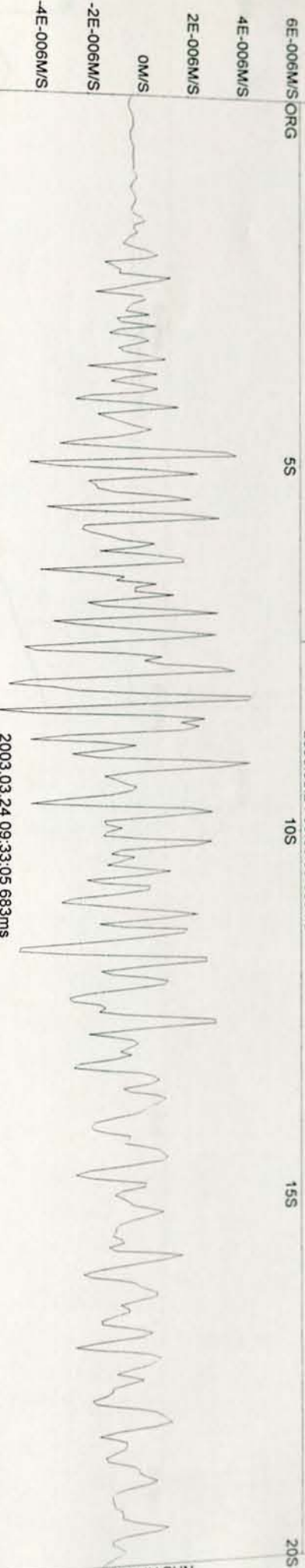
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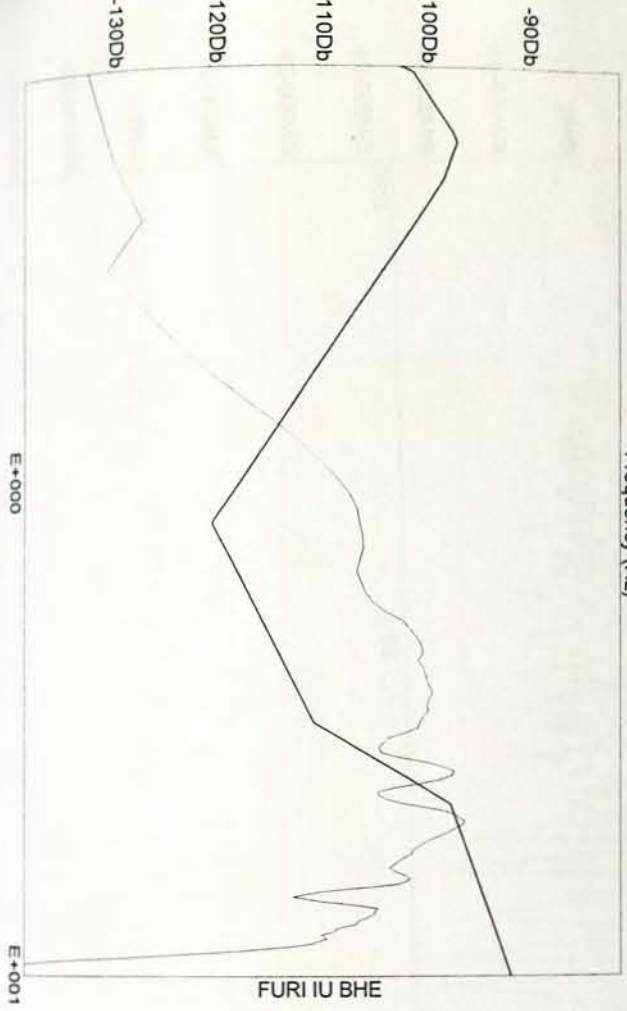
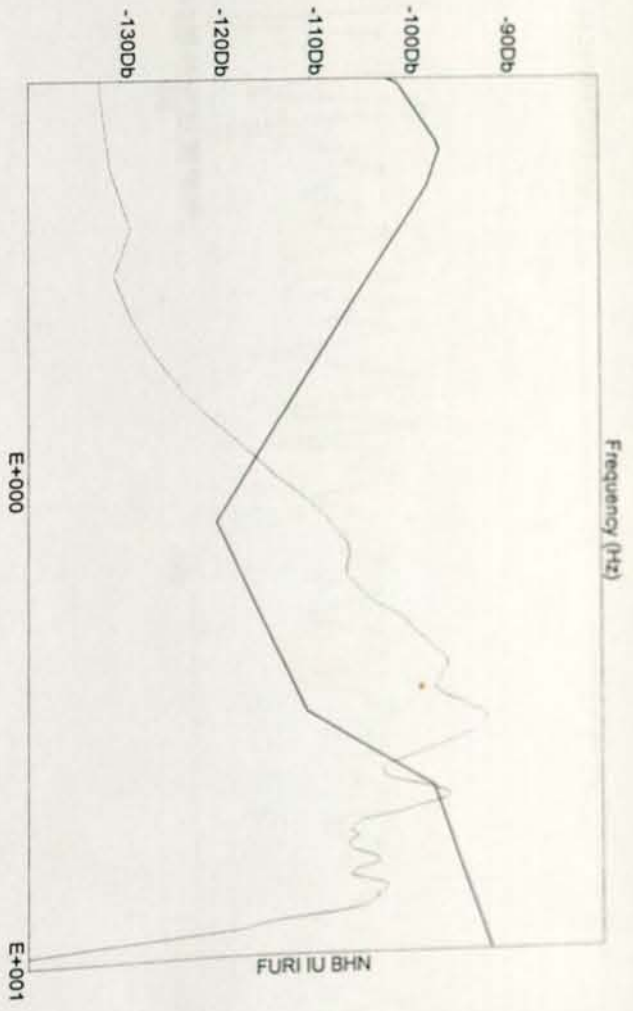
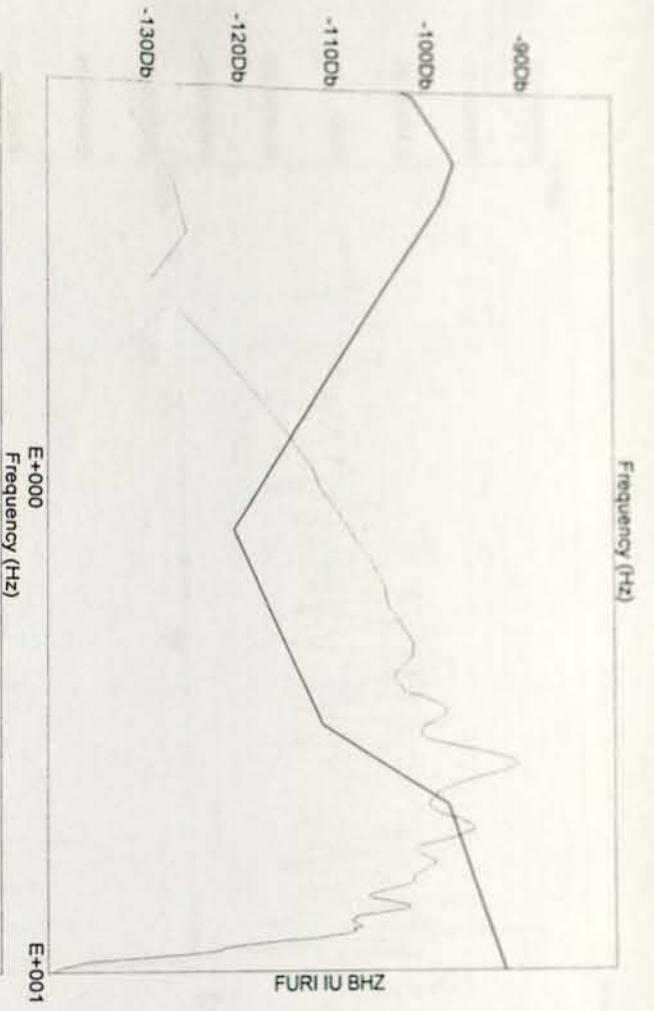






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2003.03.26 09:41:38 54ms

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-4E-006M/S

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ORG

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FURI IU BHZ

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10S

15S

20S

5S

10S

15S

20S

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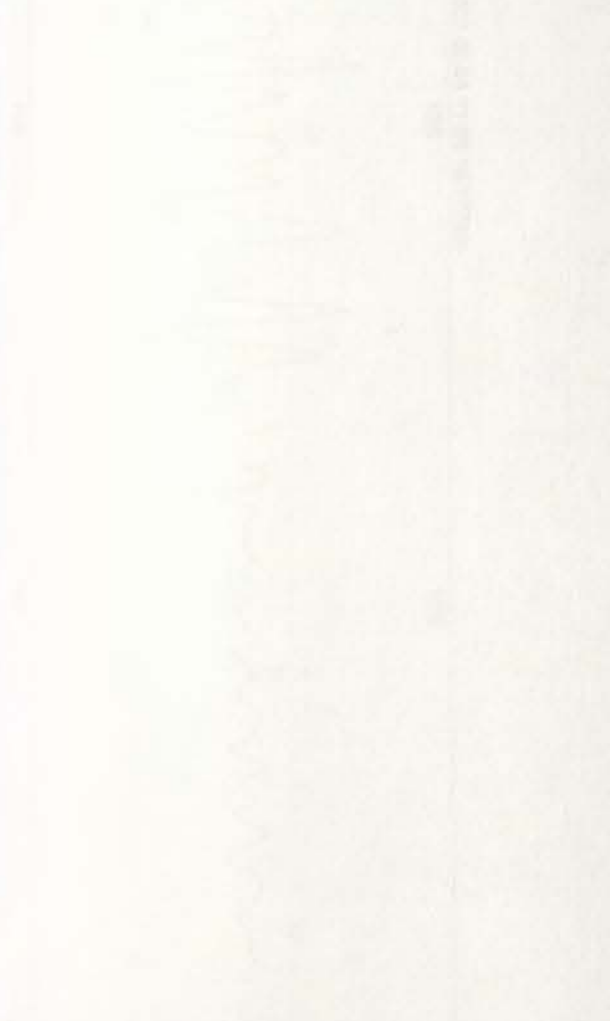
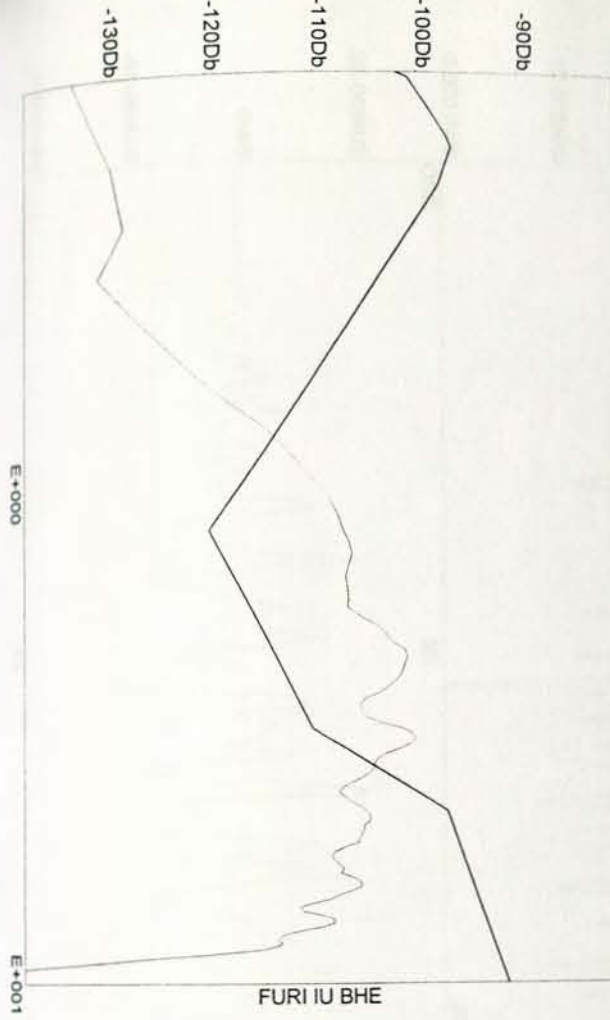
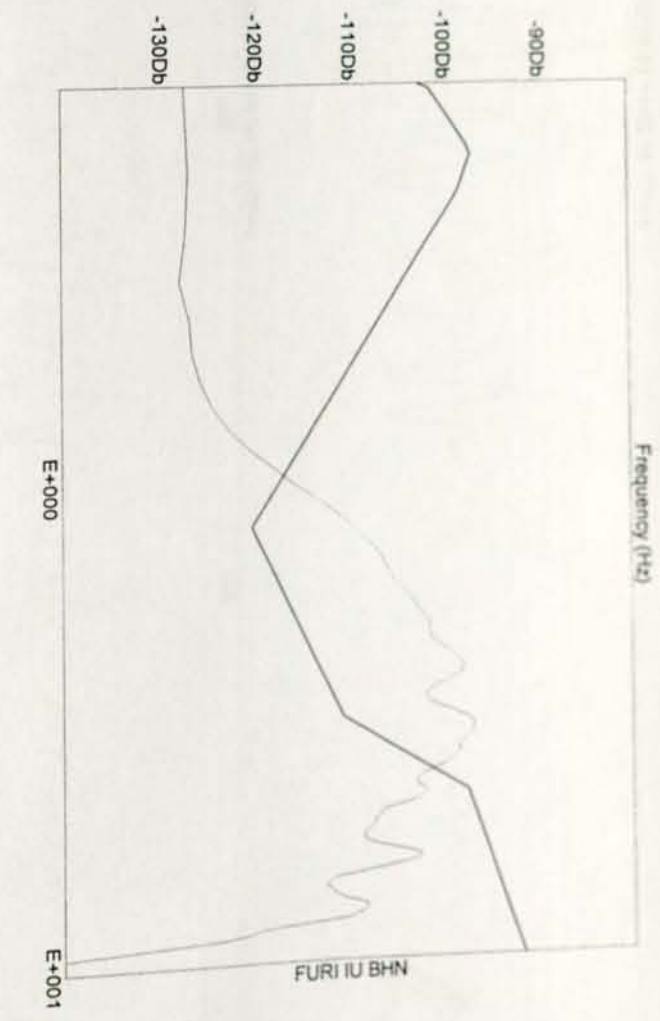
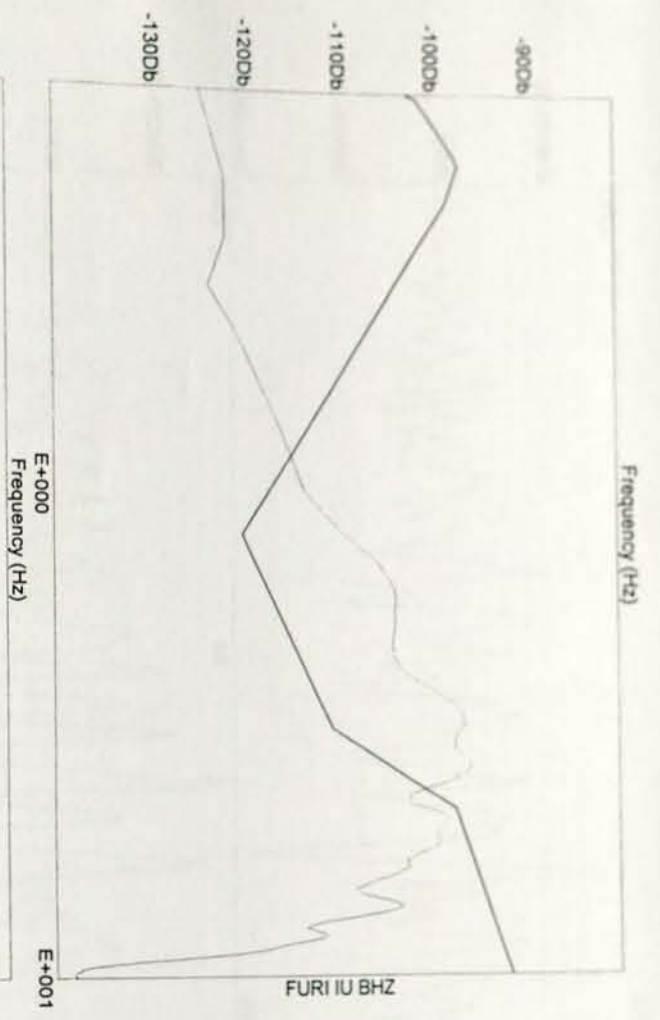
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10S

15S

20S



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ORG

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10S

15S

FURI IU BHZ

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FURI IU BHN

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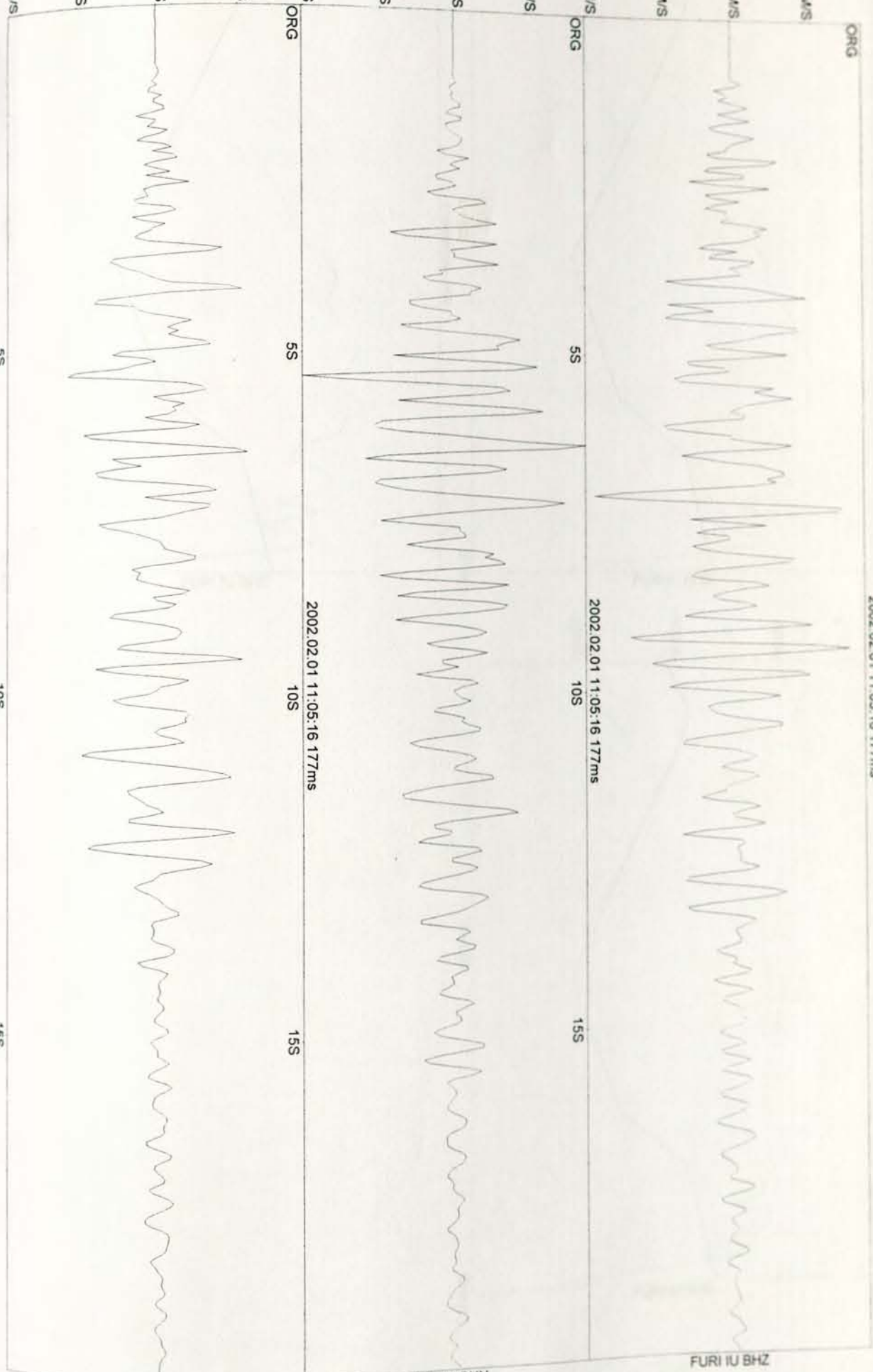
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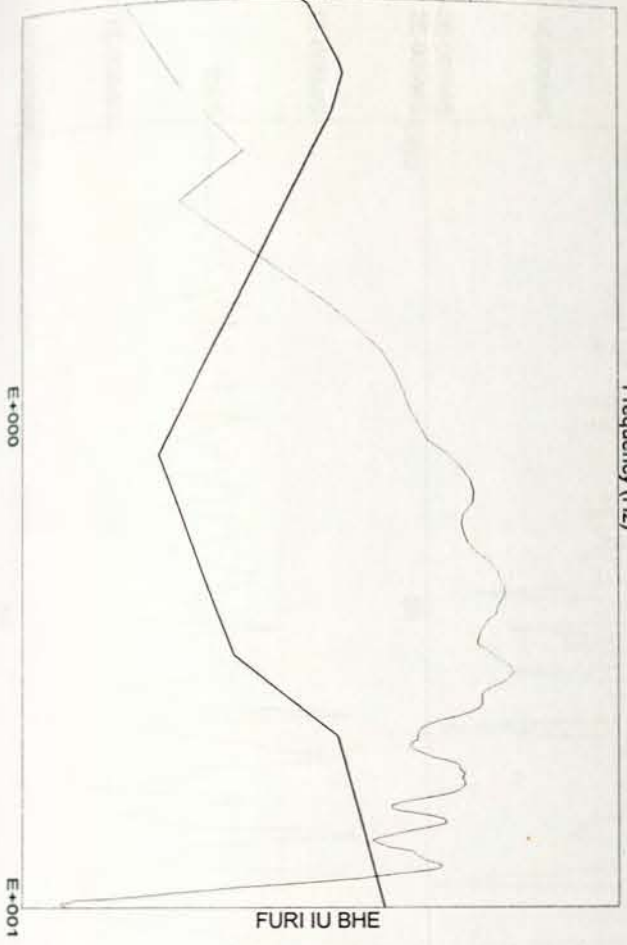
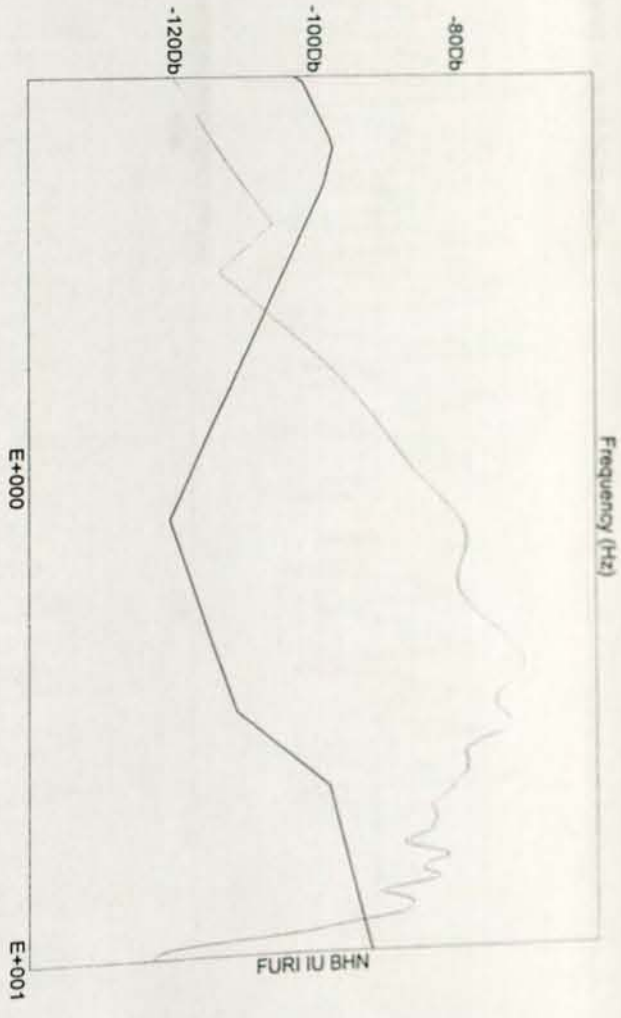
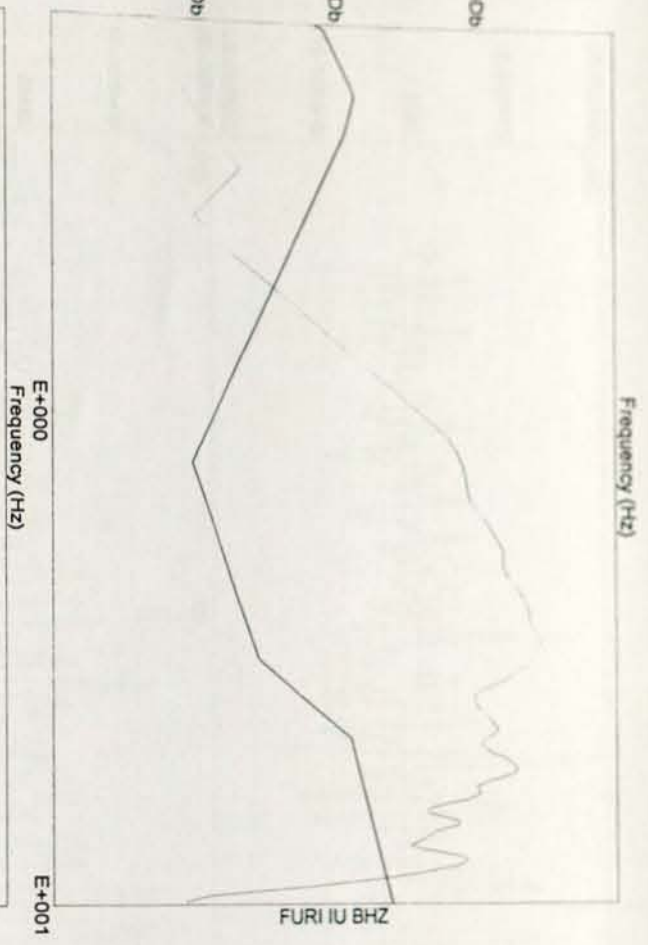
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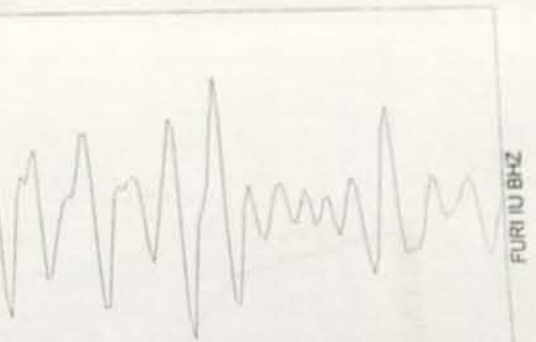
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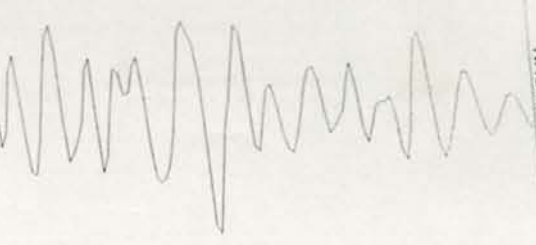






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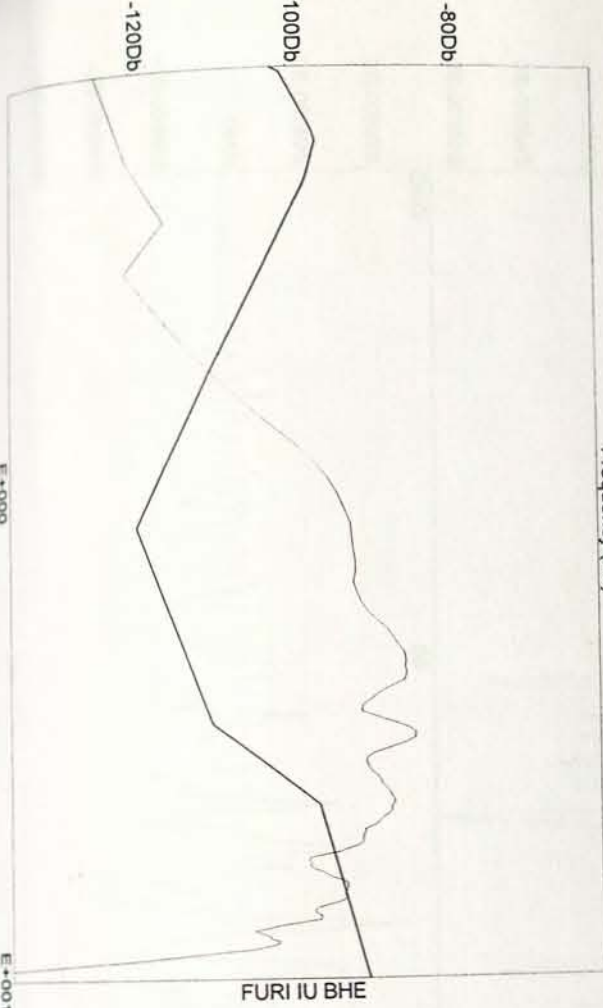
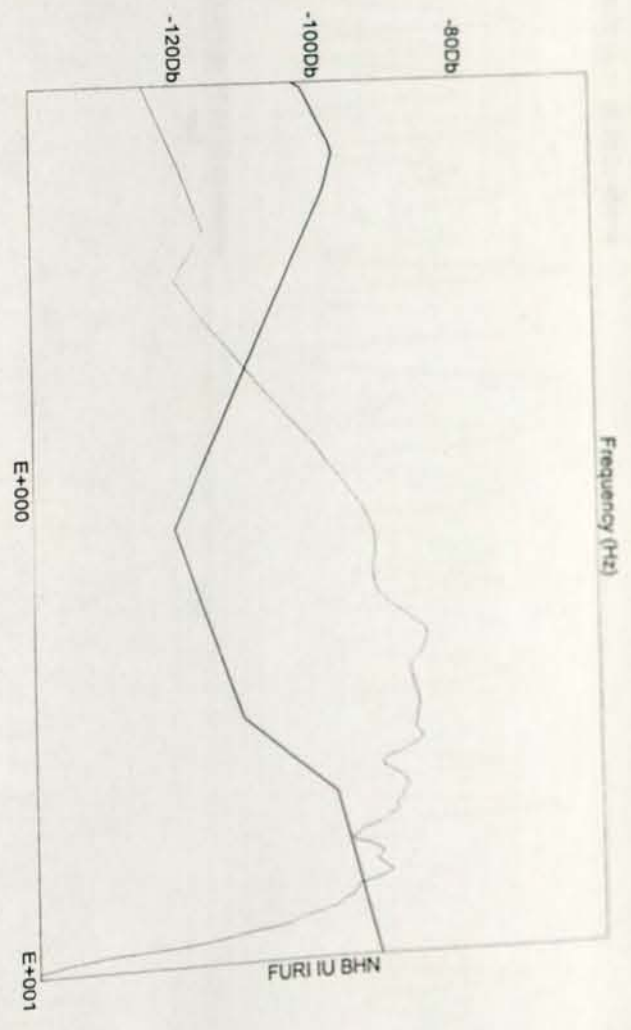
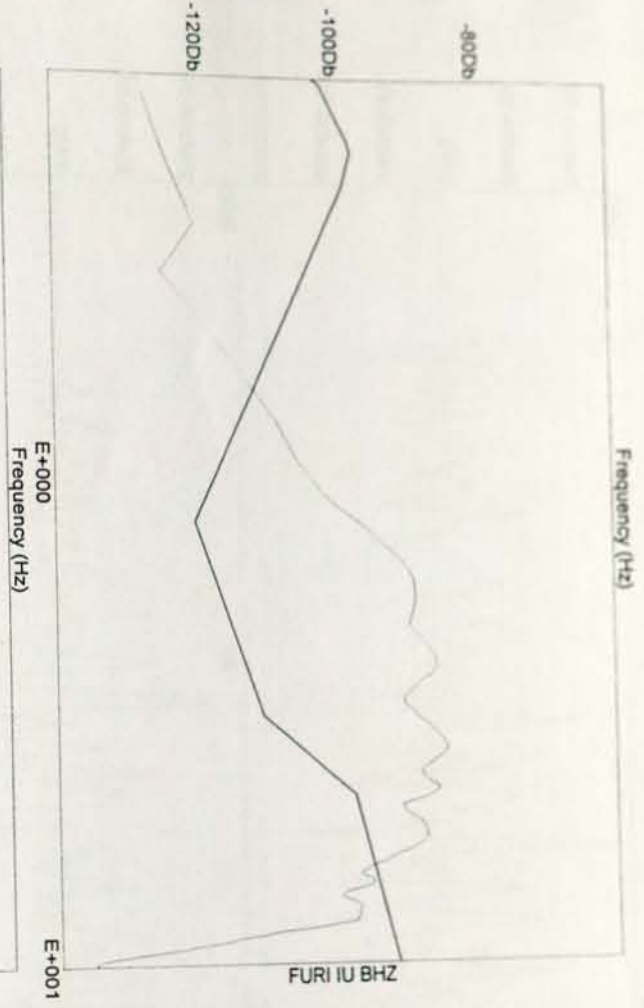
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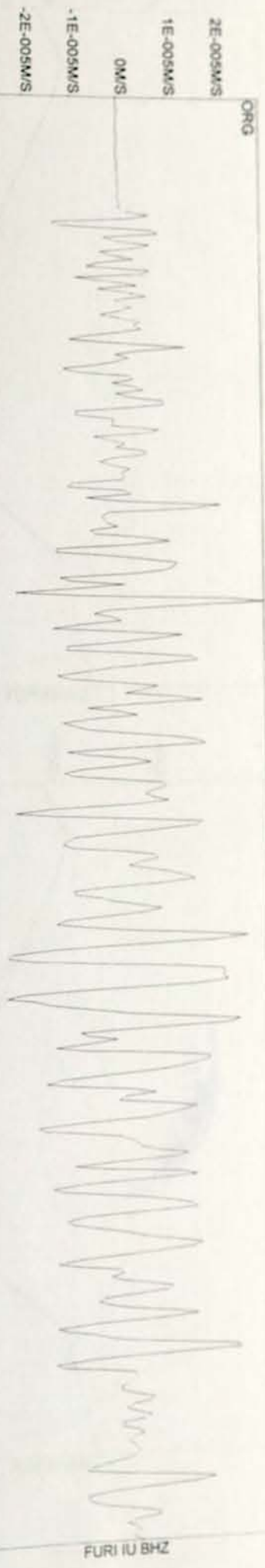
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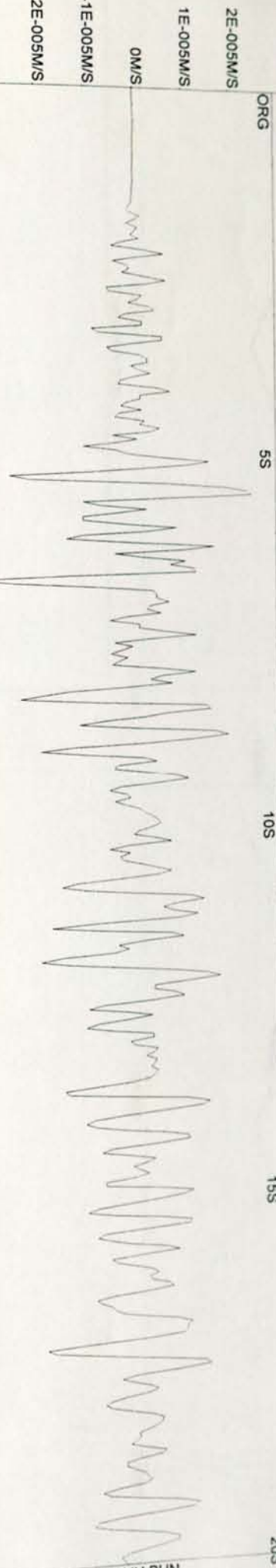




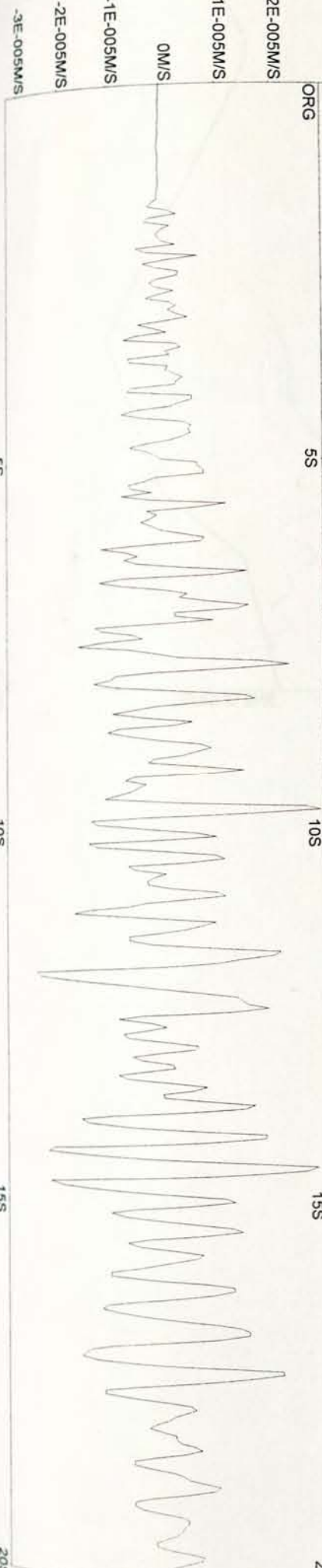
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2002.06.17 09:26:22 464ms



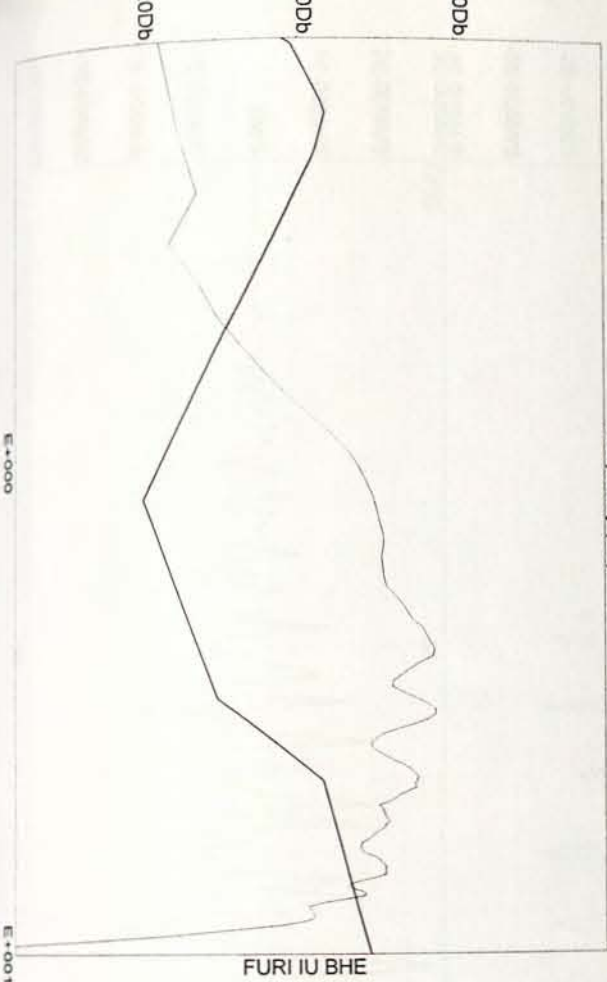
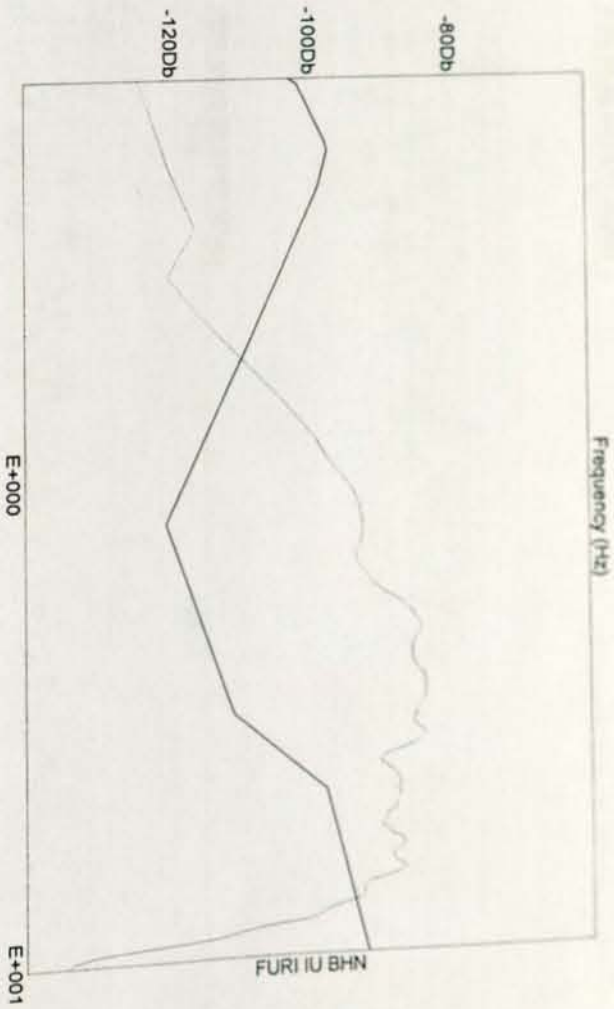
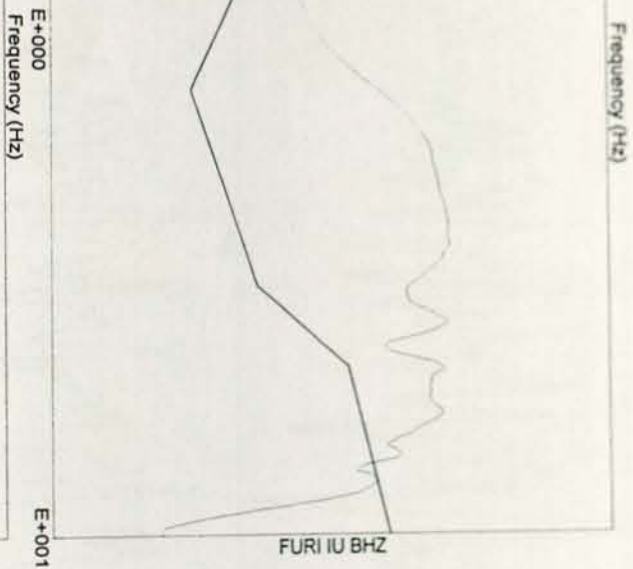
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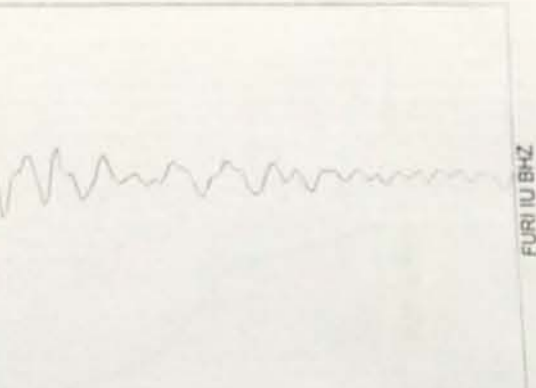


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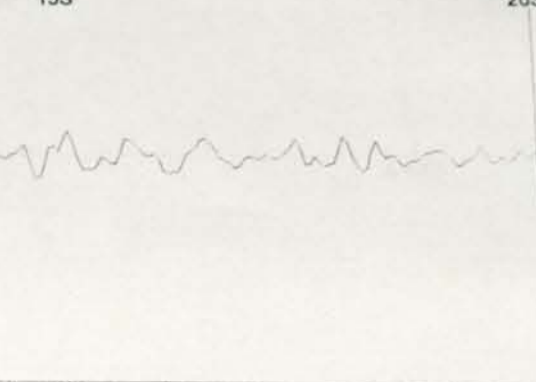
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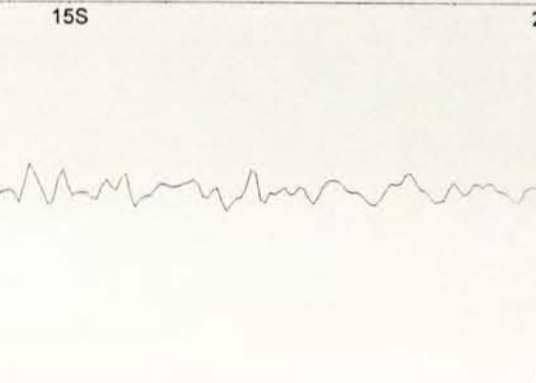
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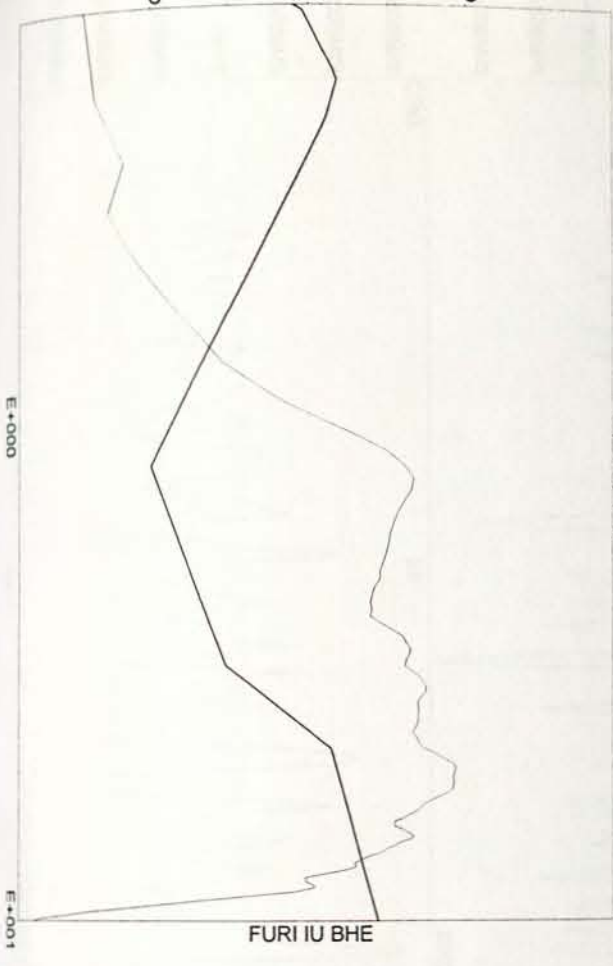
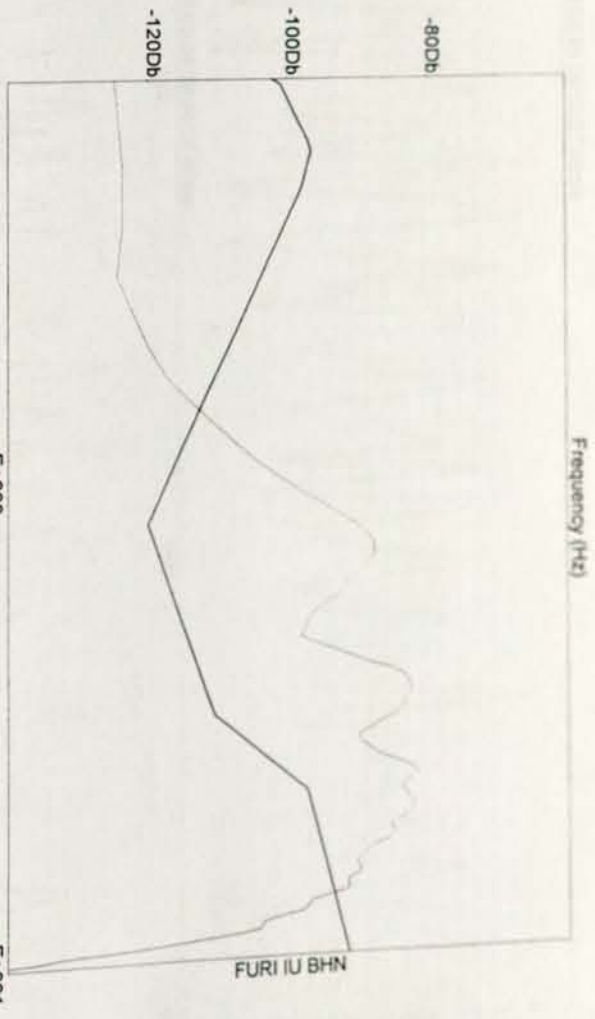
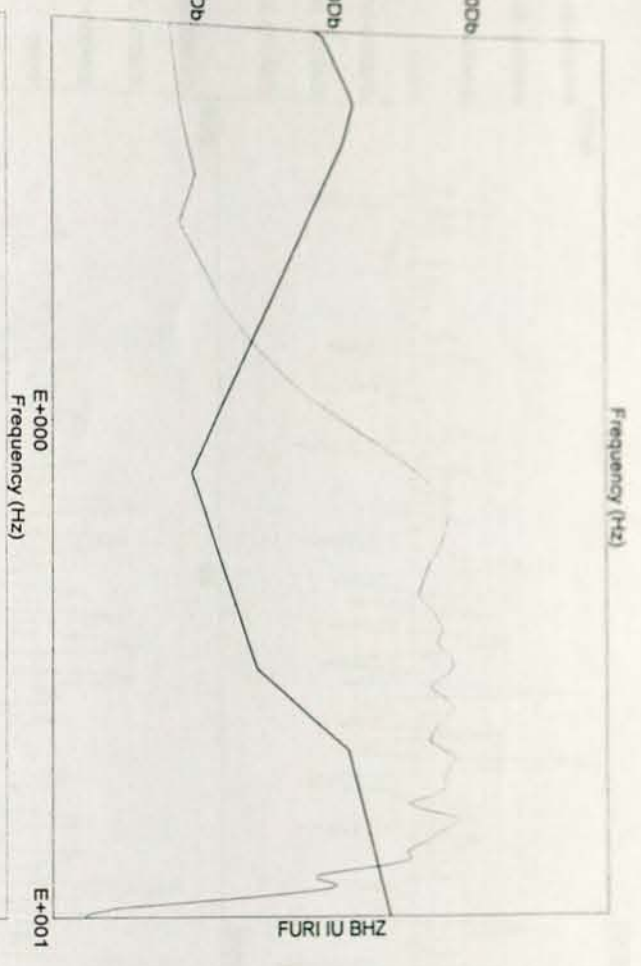
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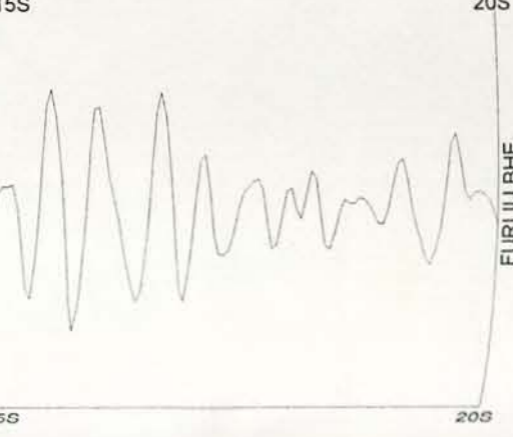
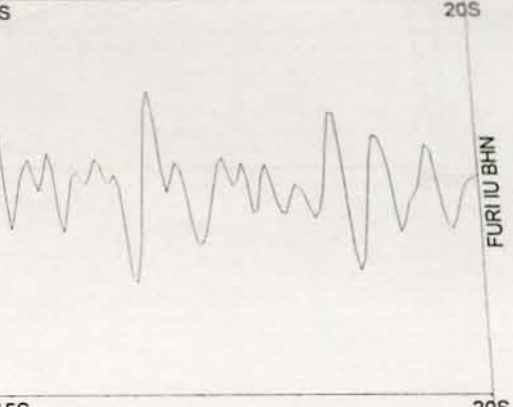
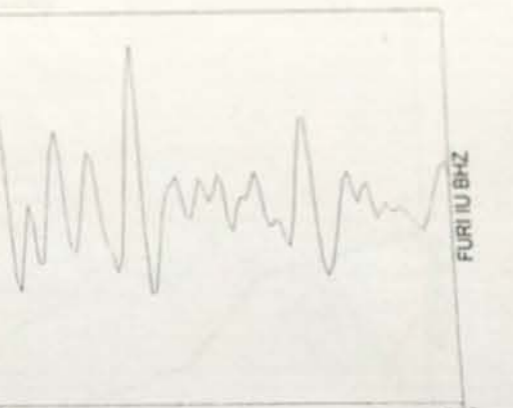


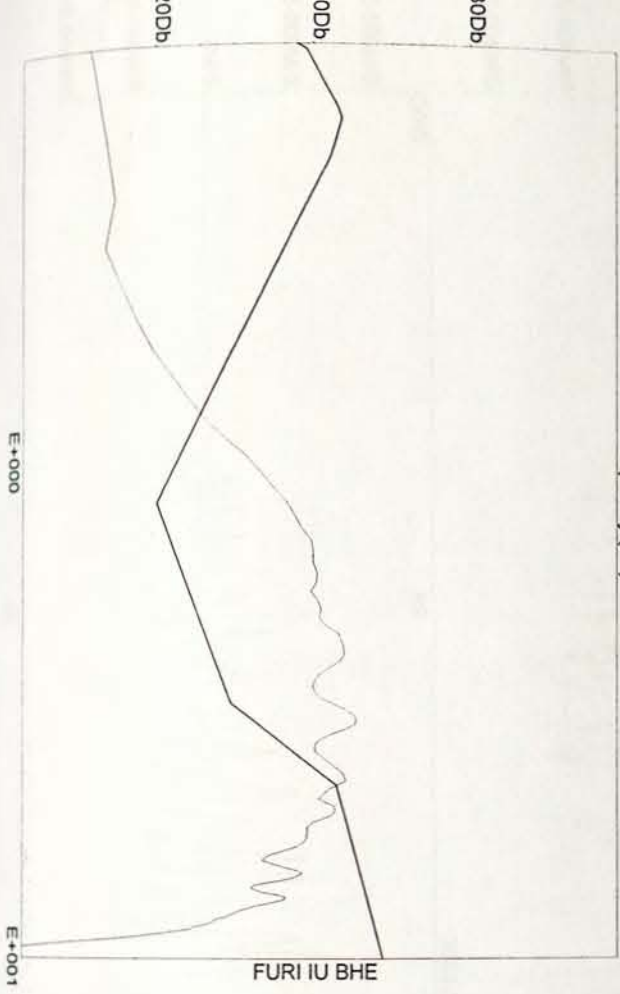
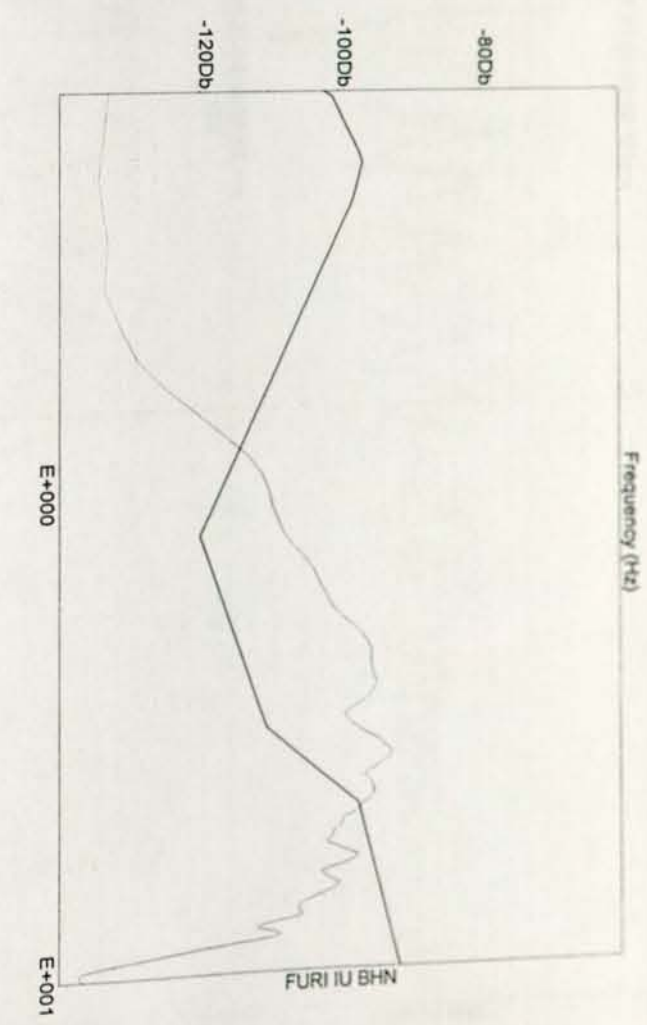
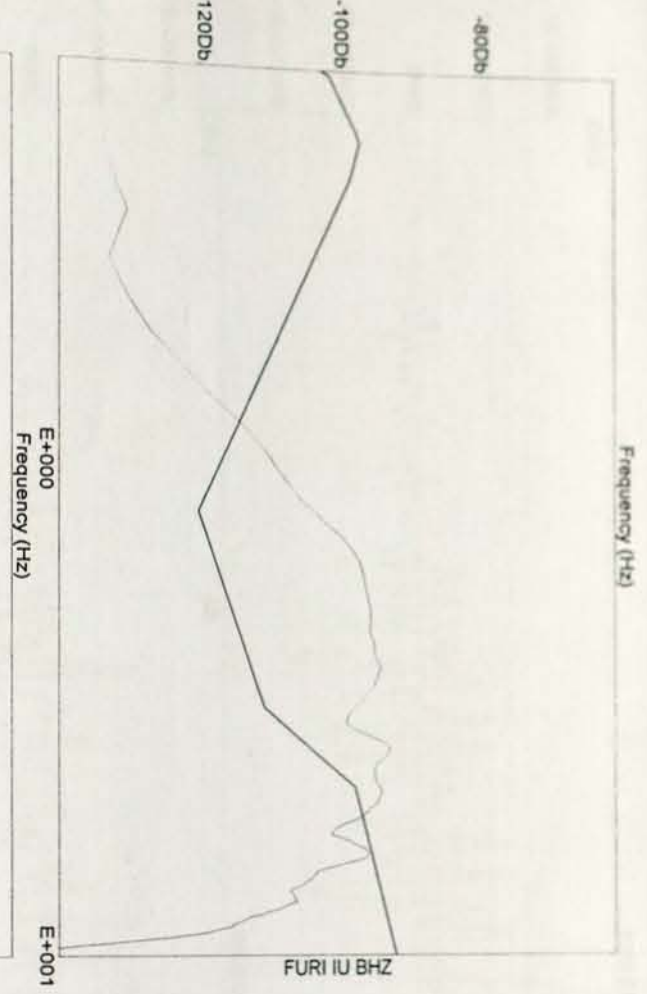
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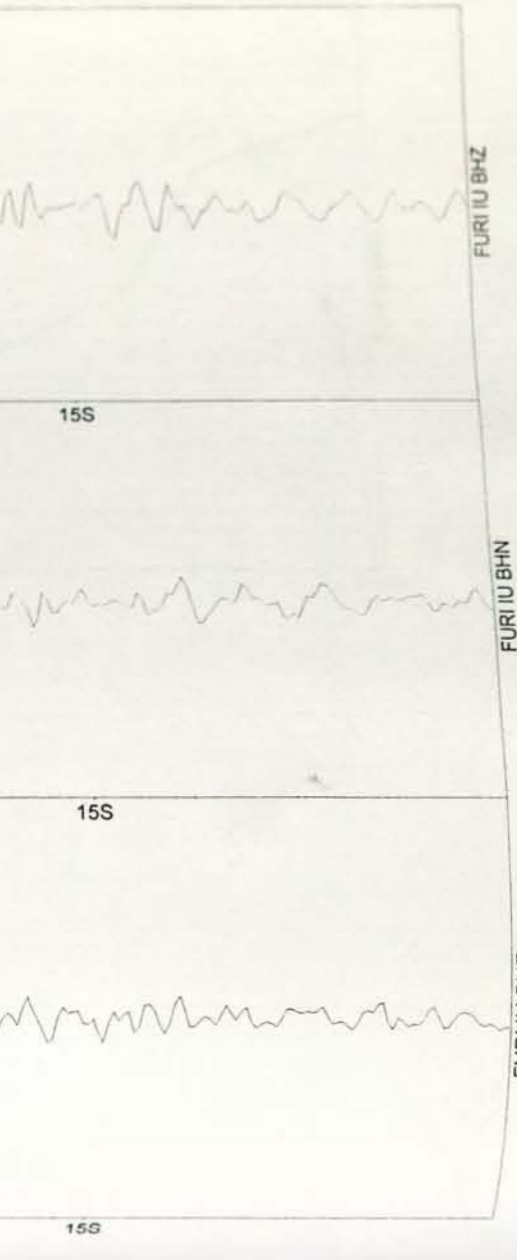
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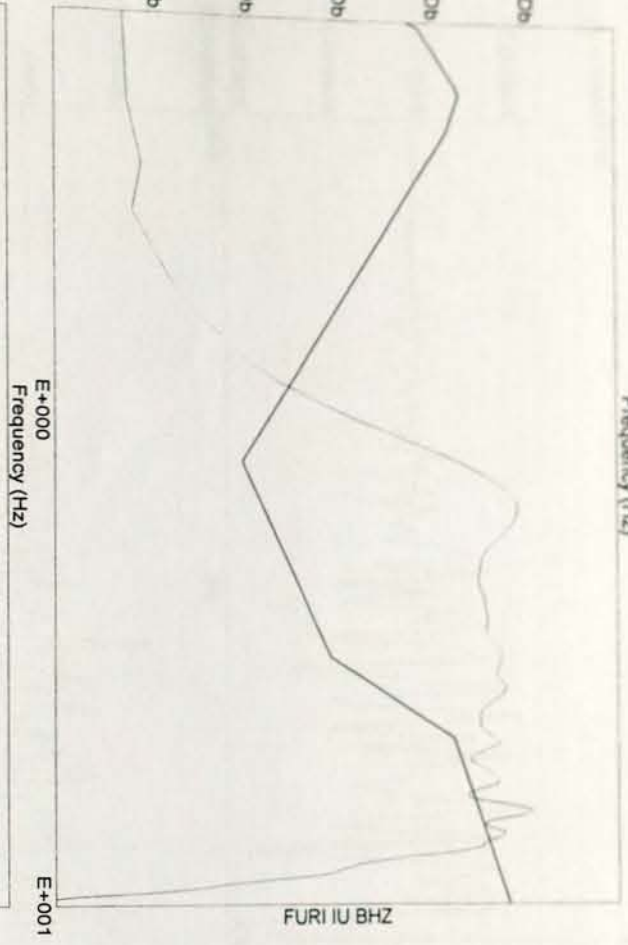




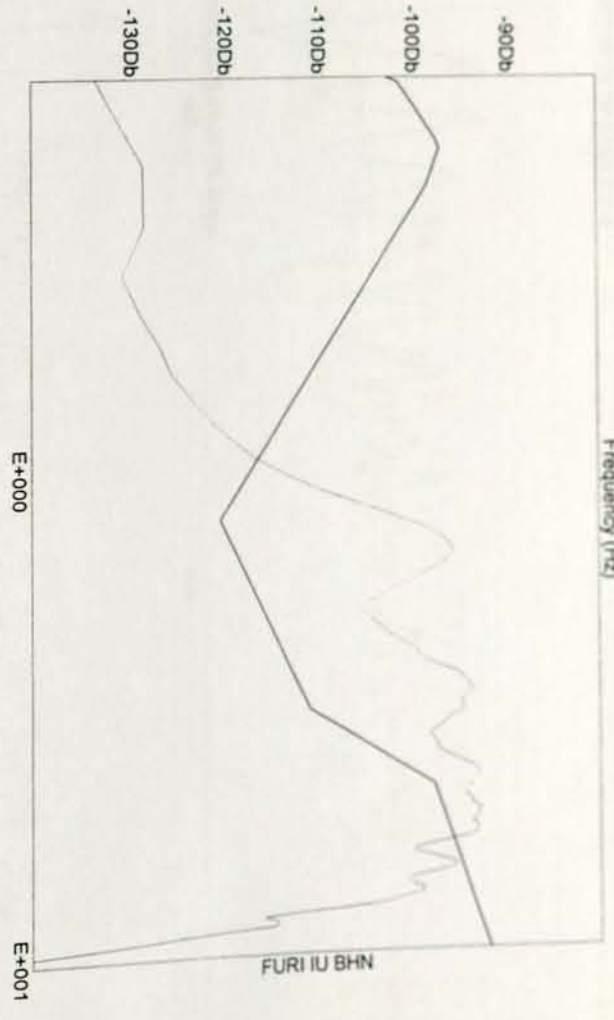




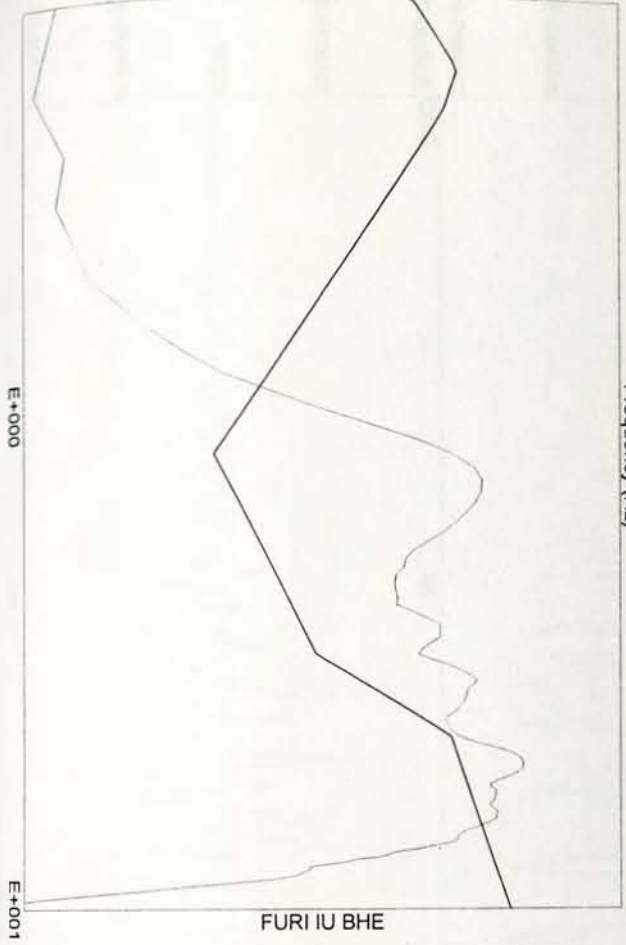
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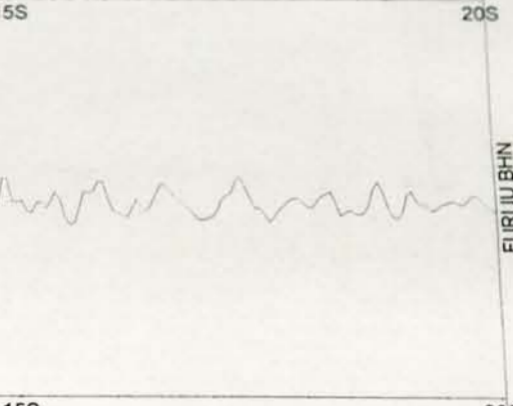
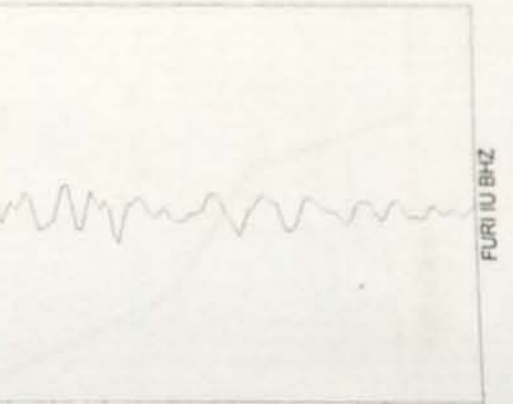


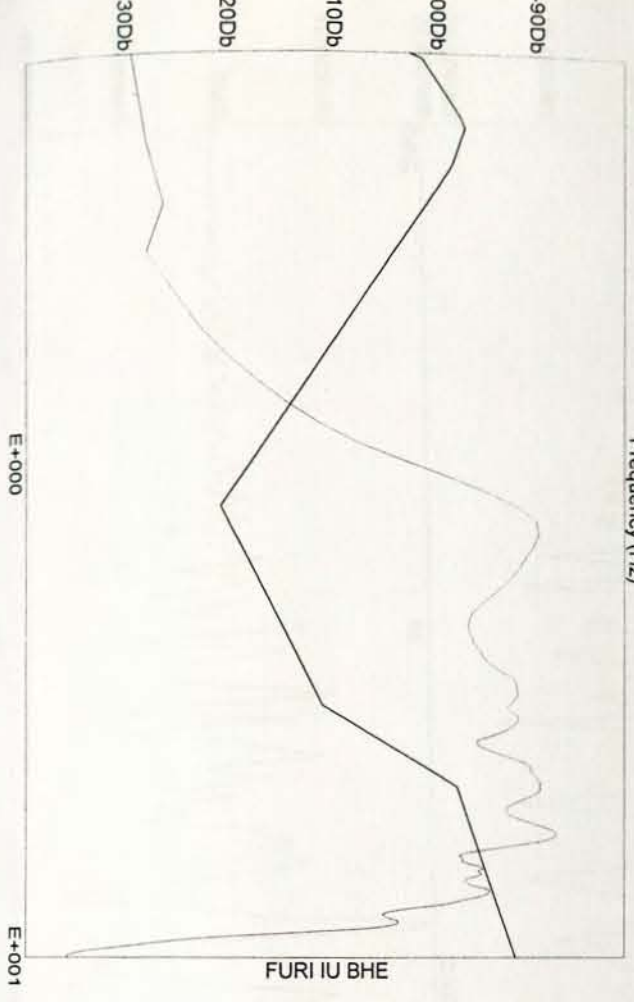
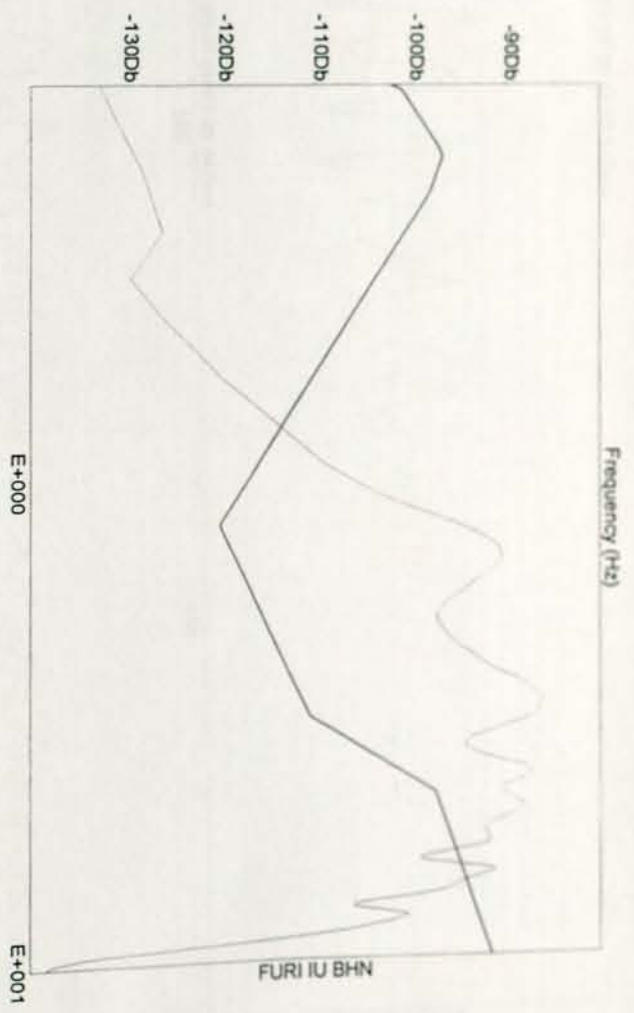
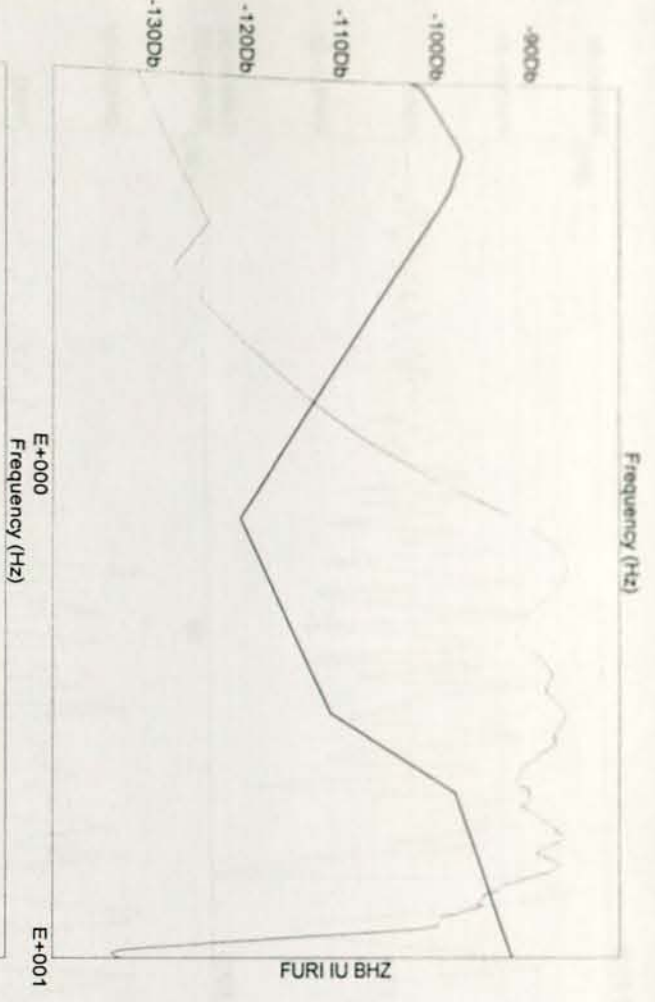
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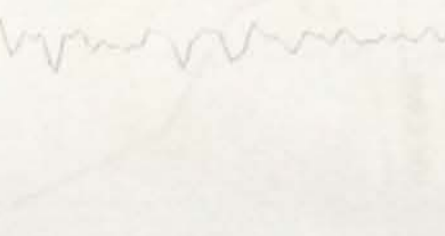
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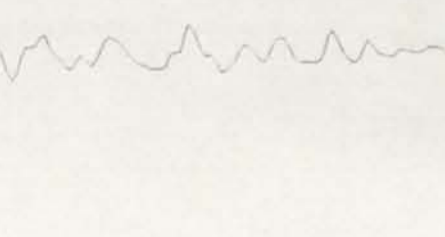




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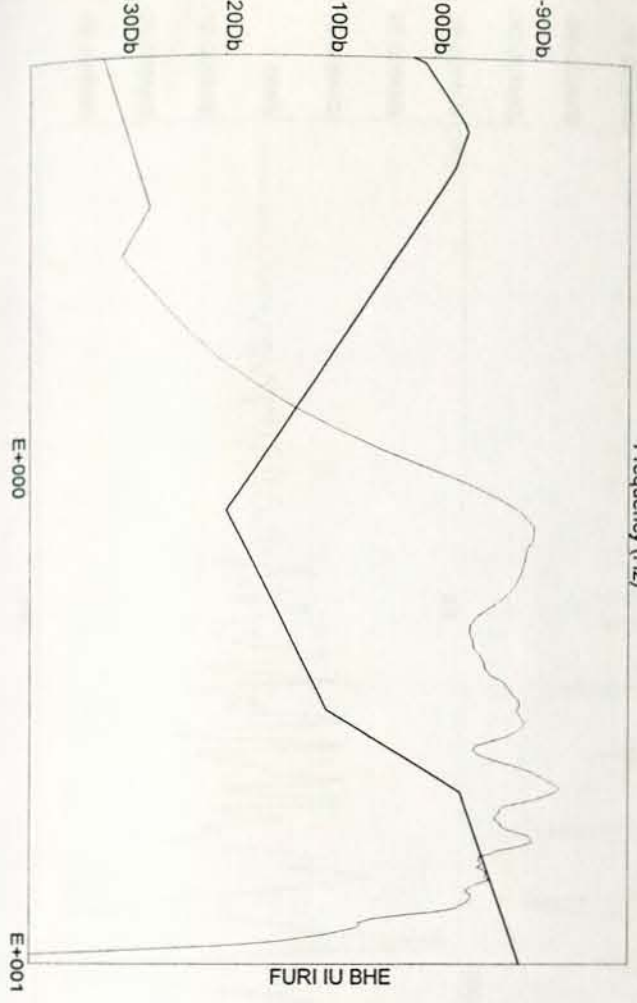
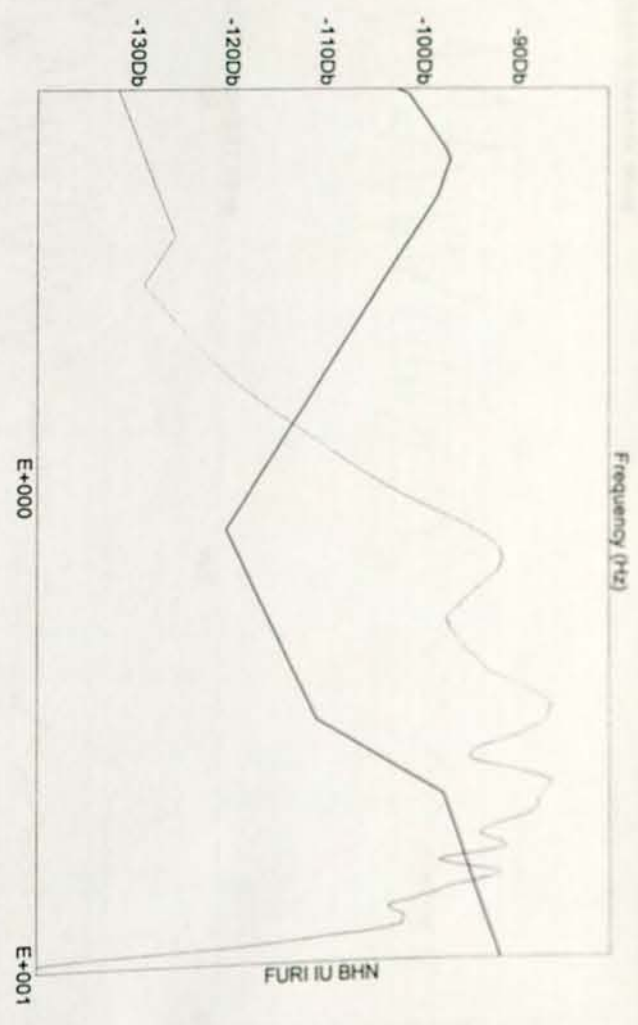
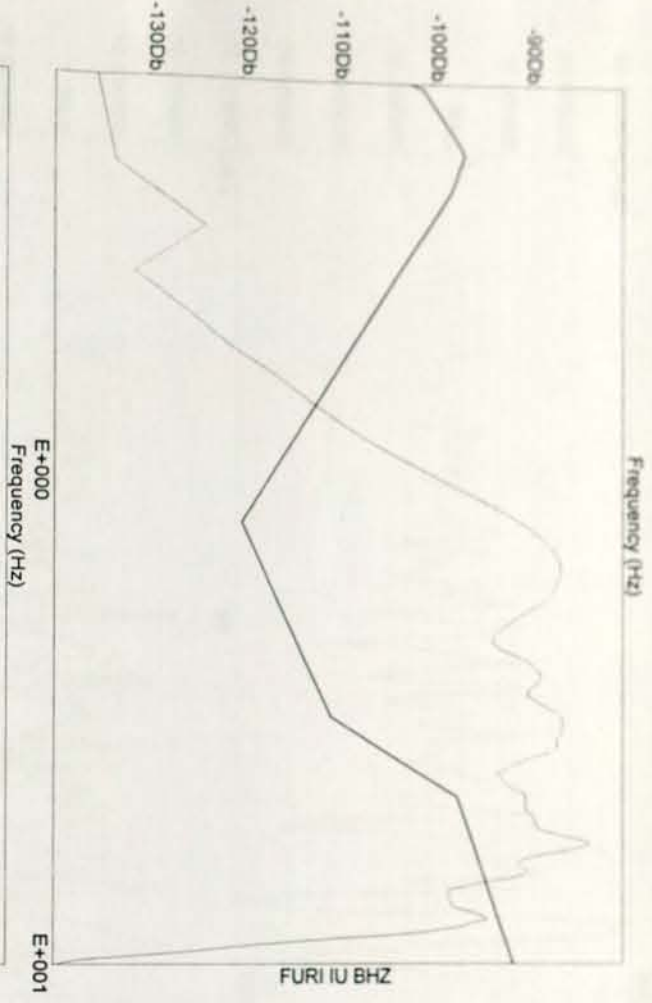
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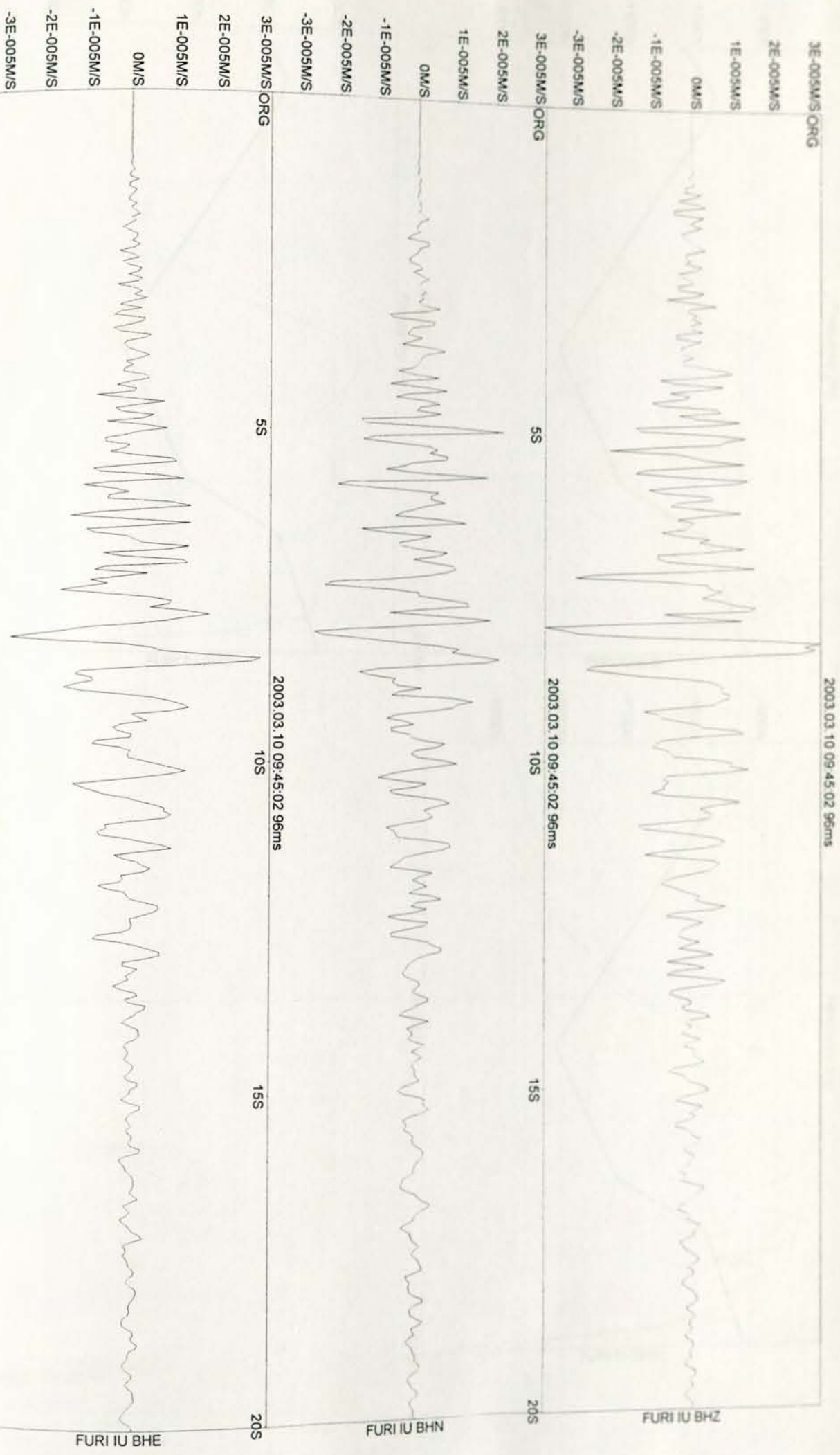
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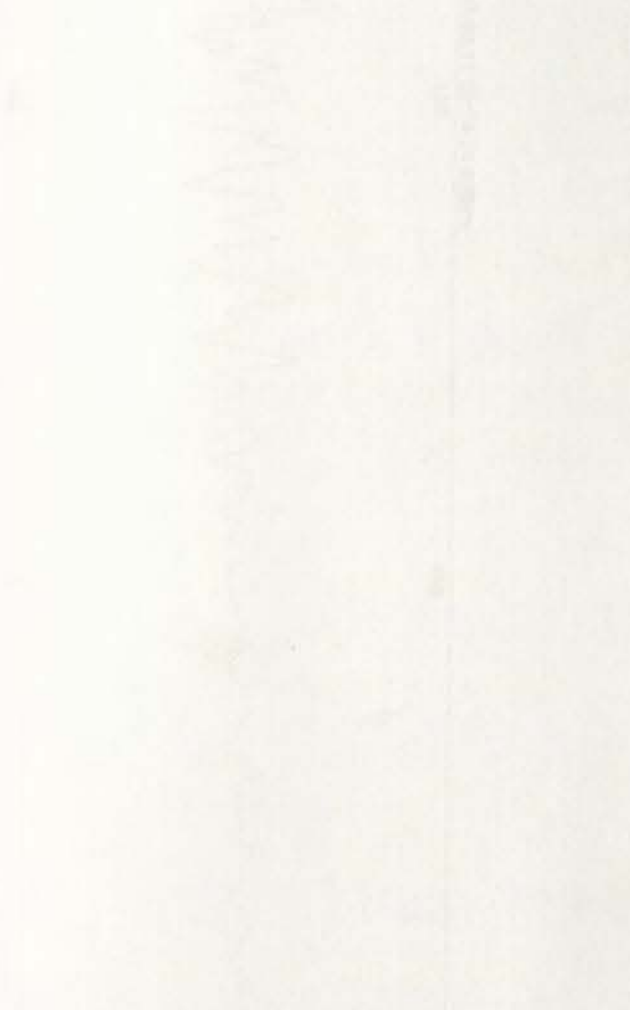
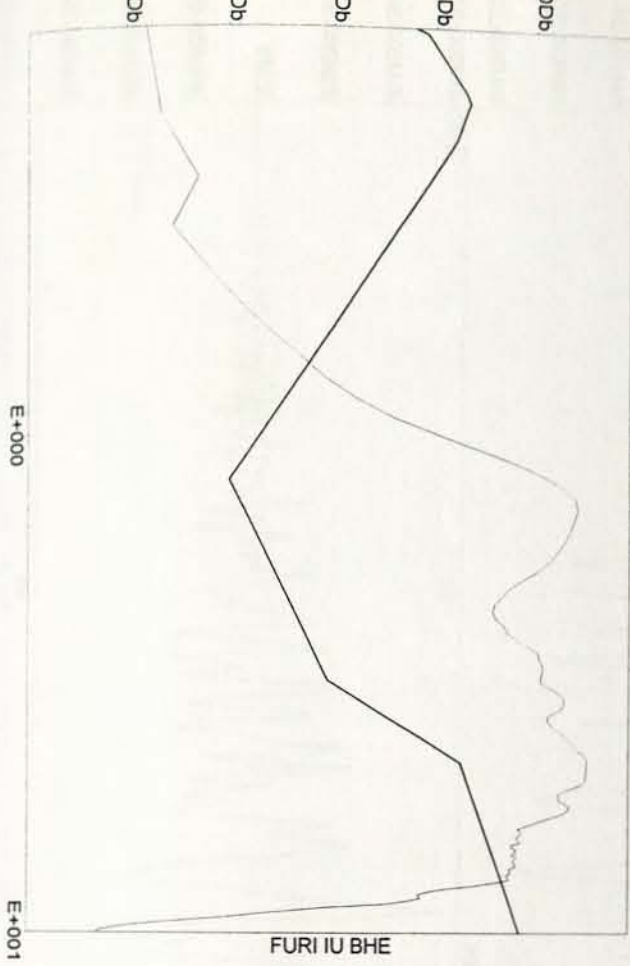
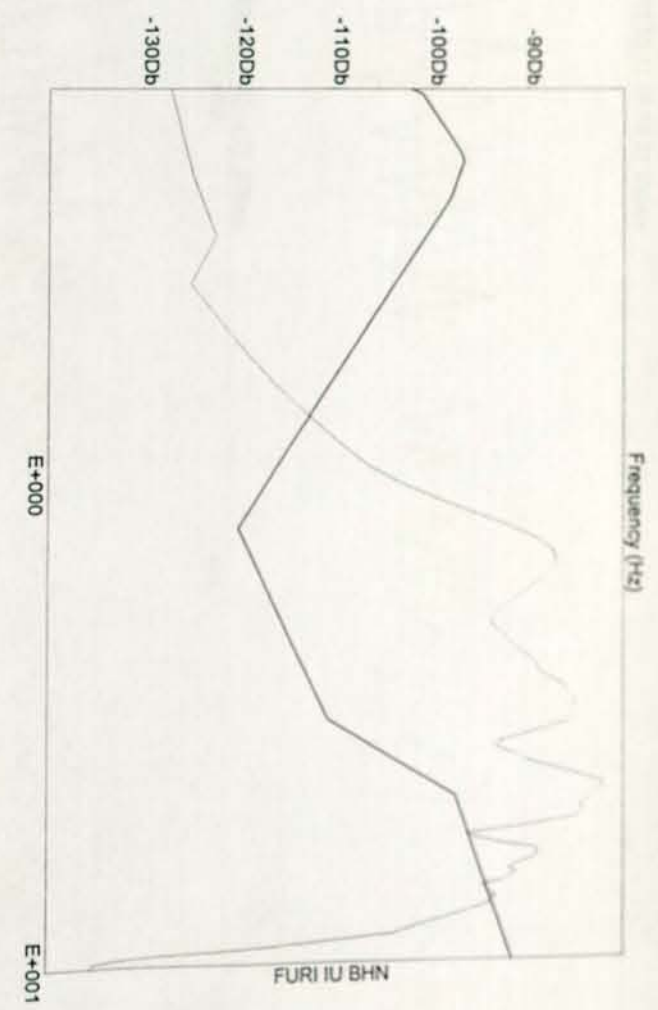
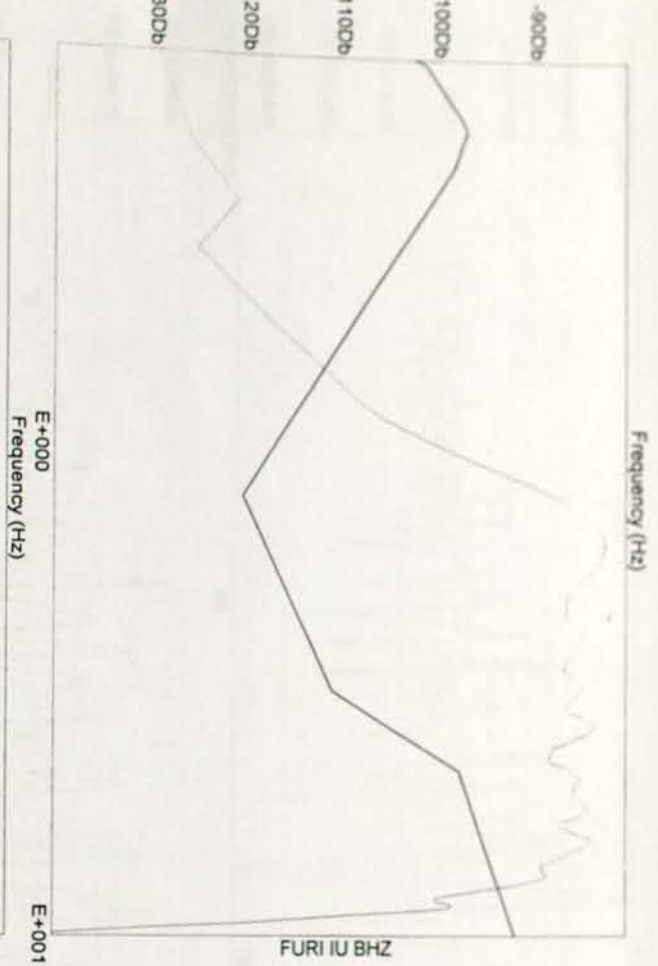


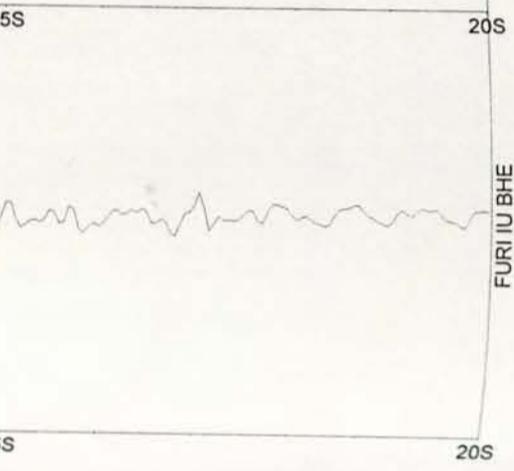
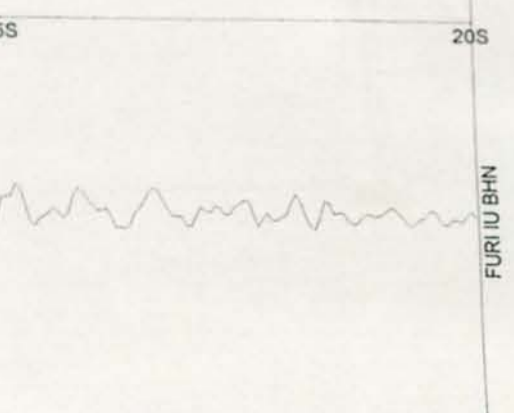
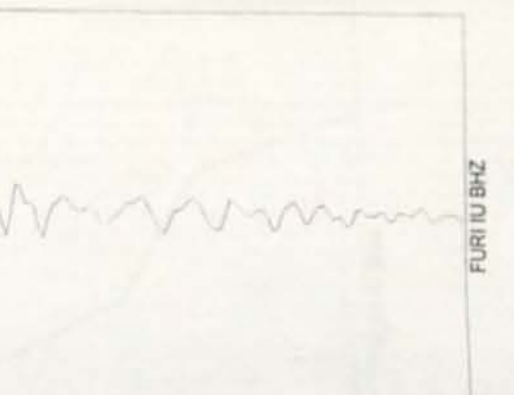
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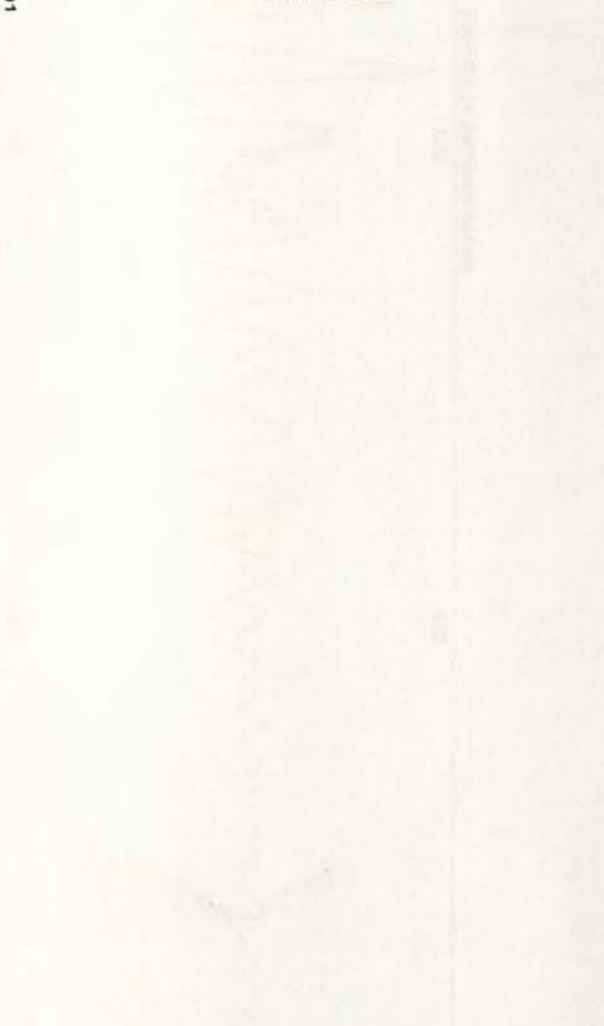
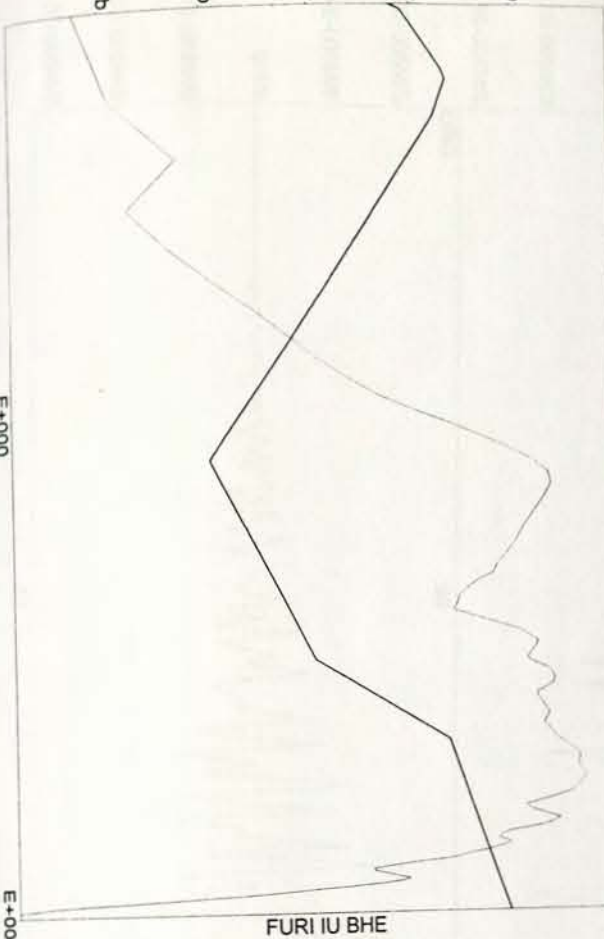
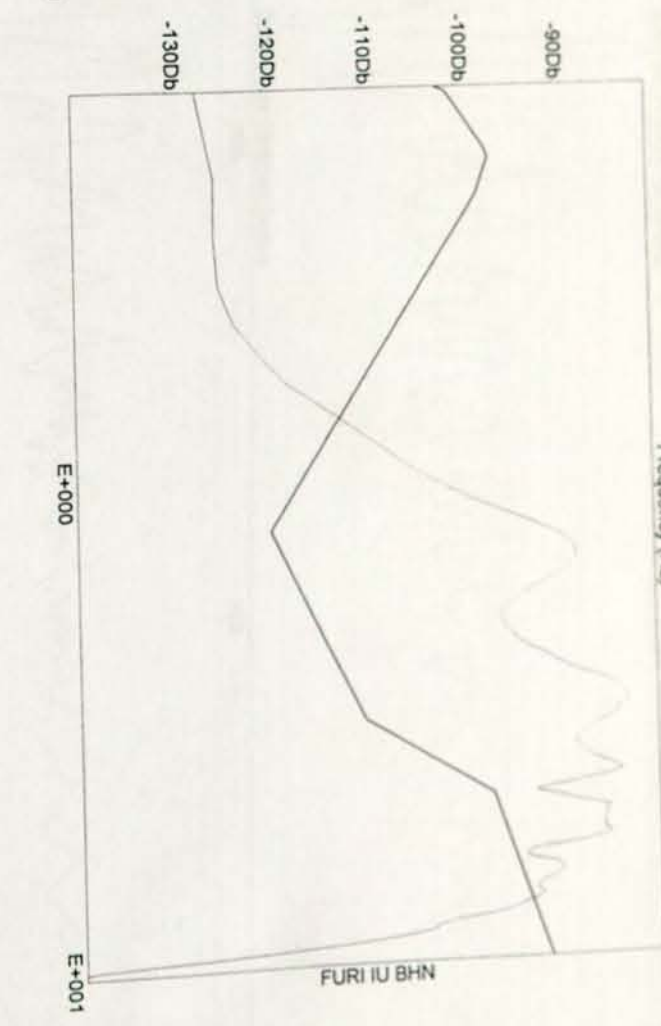
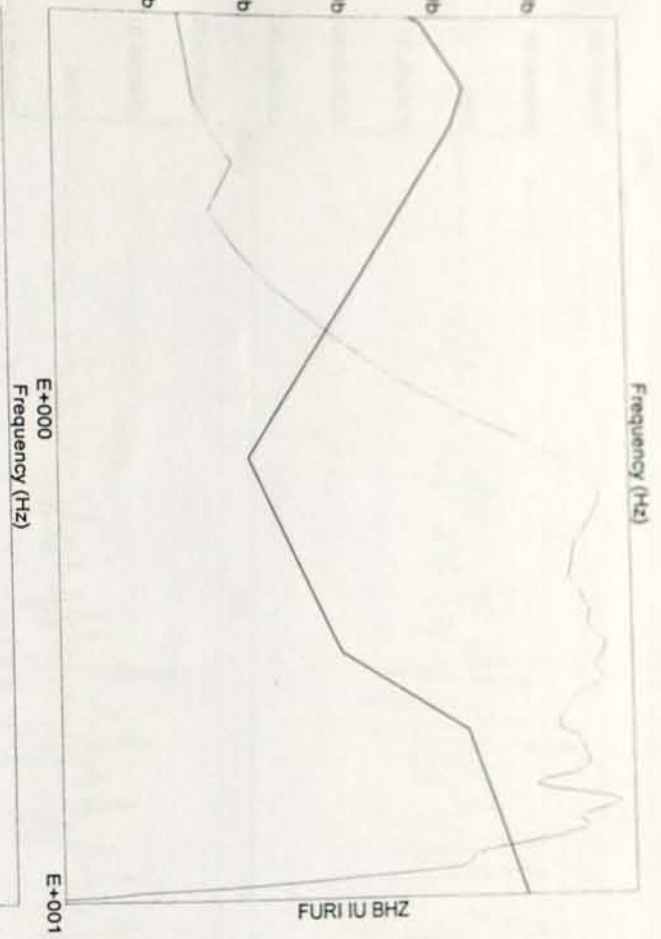


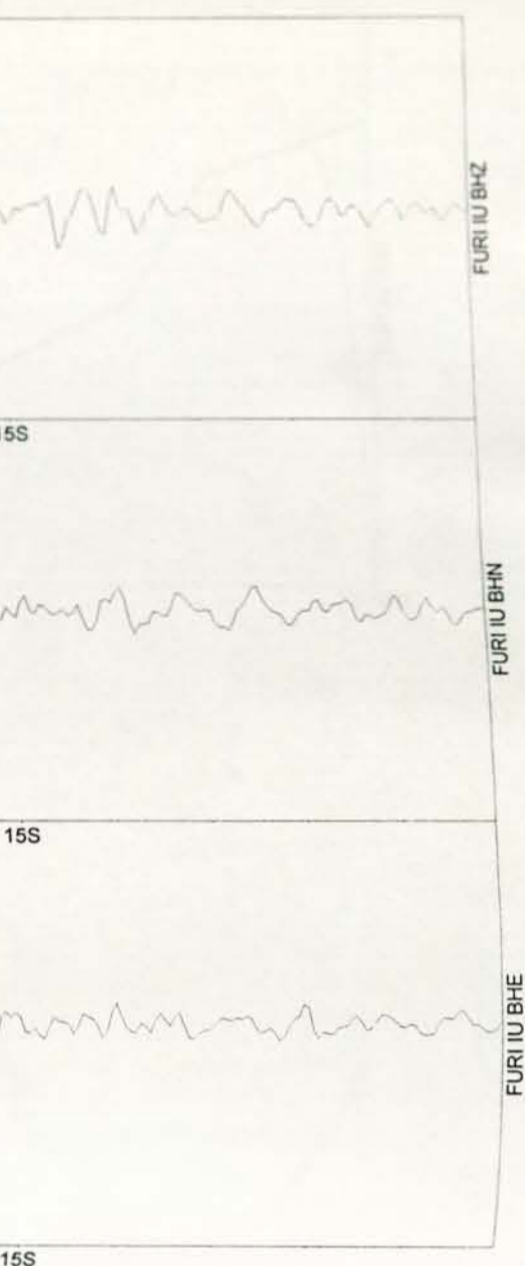


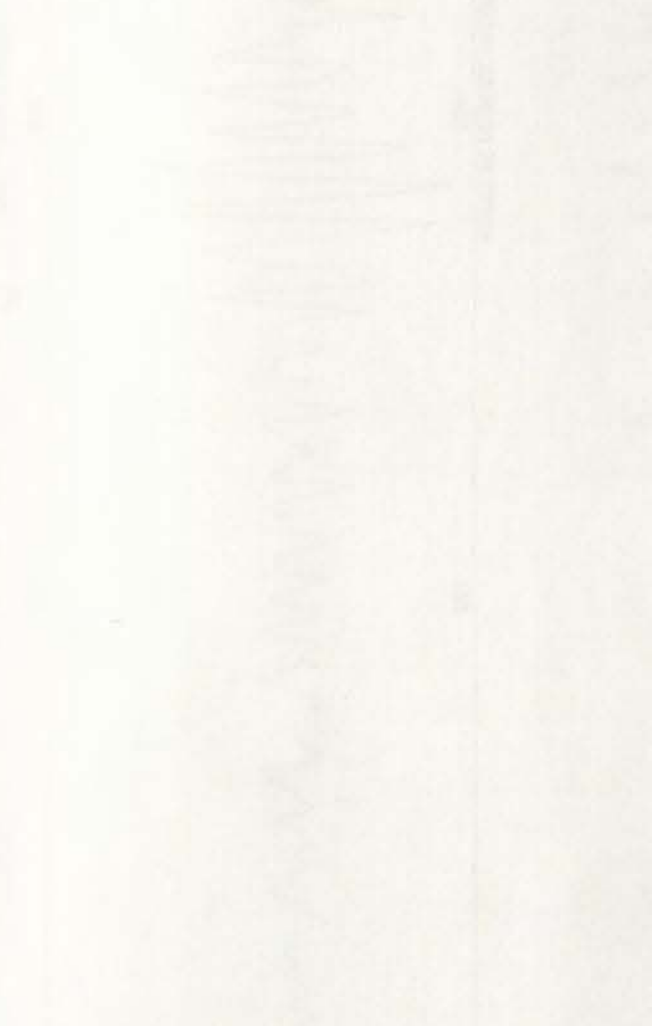
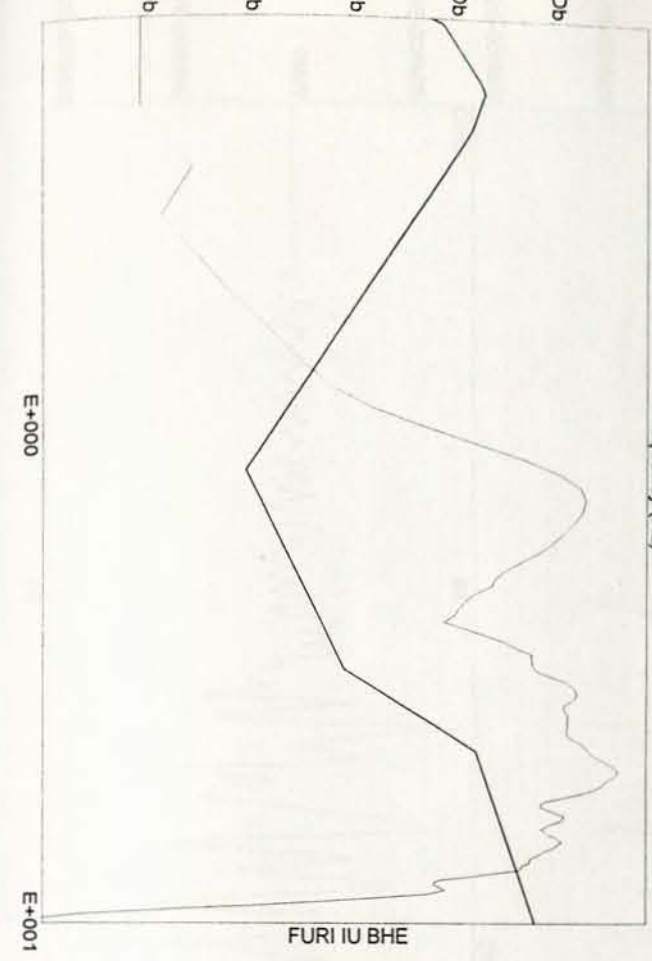
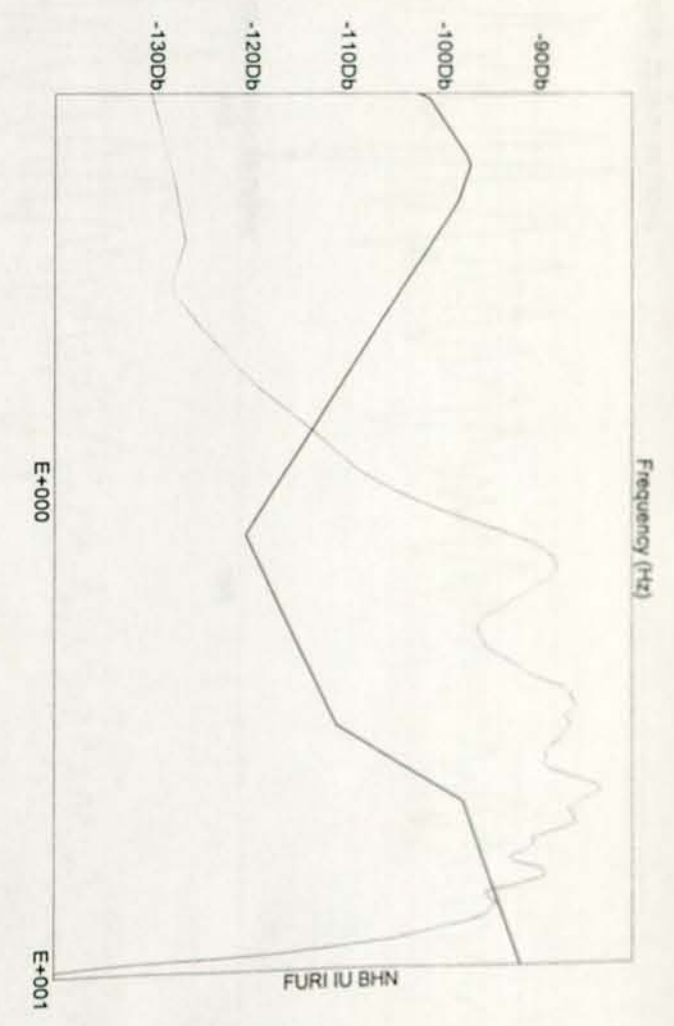
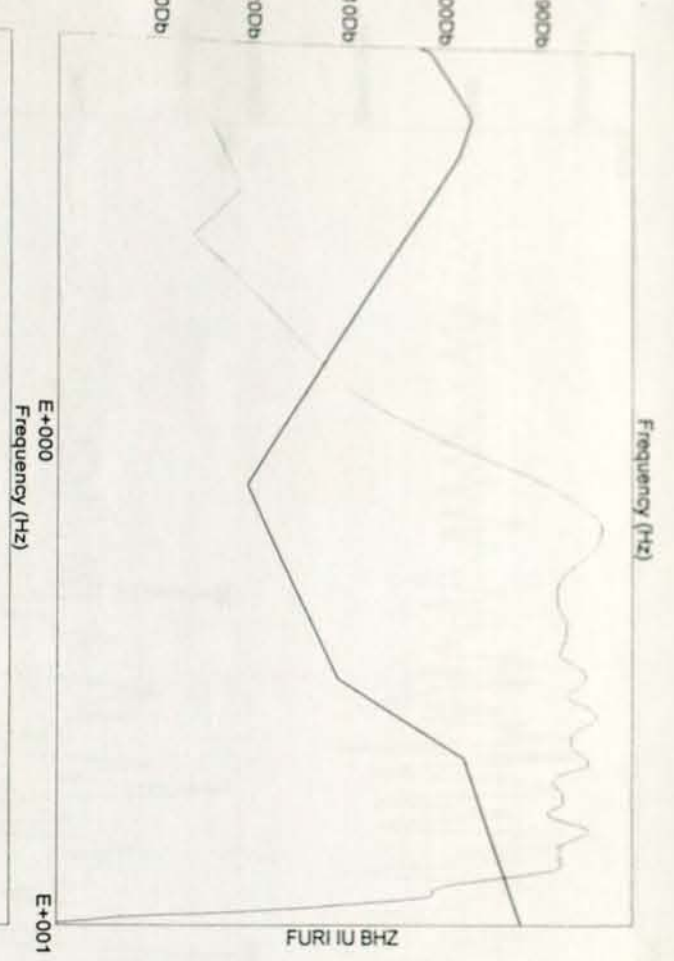












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-2E-005M/S

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-1E-005M/S

2E-005M/S

1E-005M/S

0M/S

E-005M/S

2E-005M/S

2003.01.22 08:01:28.733ms

ORG

5S

10S

15S

FURI IU BHZ

2003.01.22 08:01:28.733ms

ORG

5S

10S

15S

FURI IU BHN

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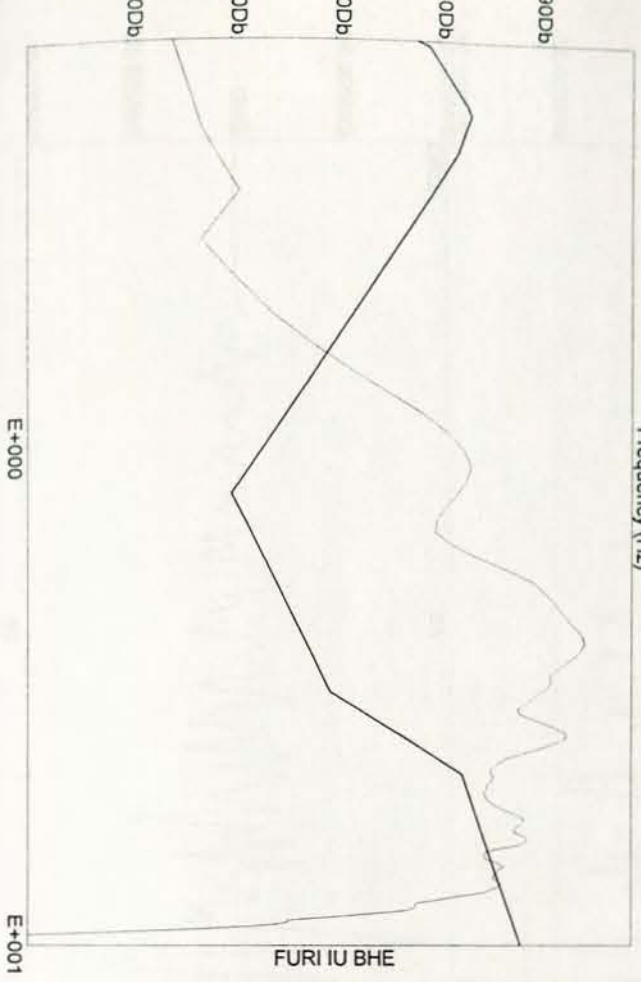
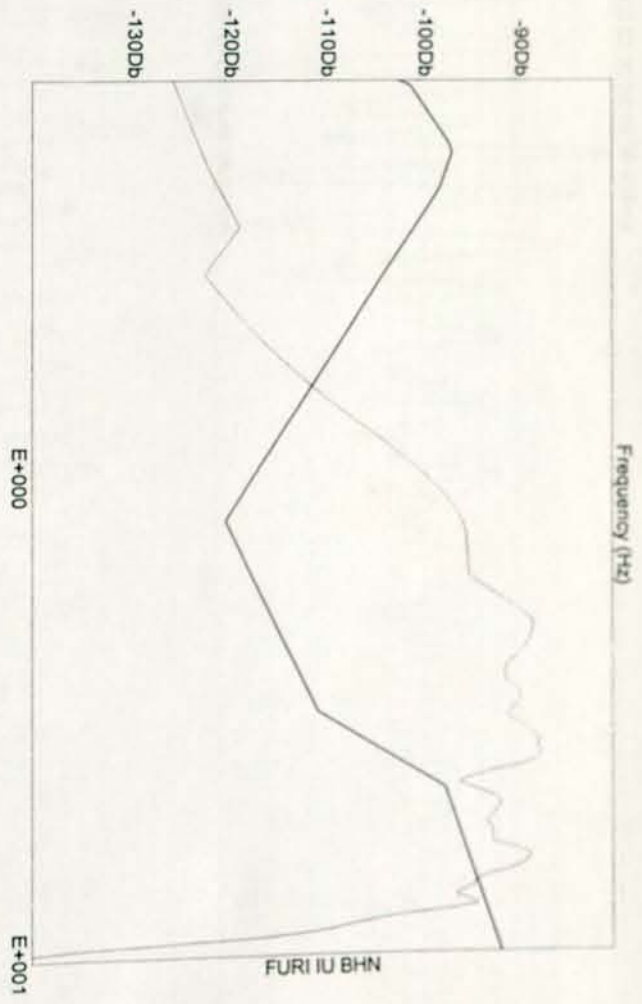
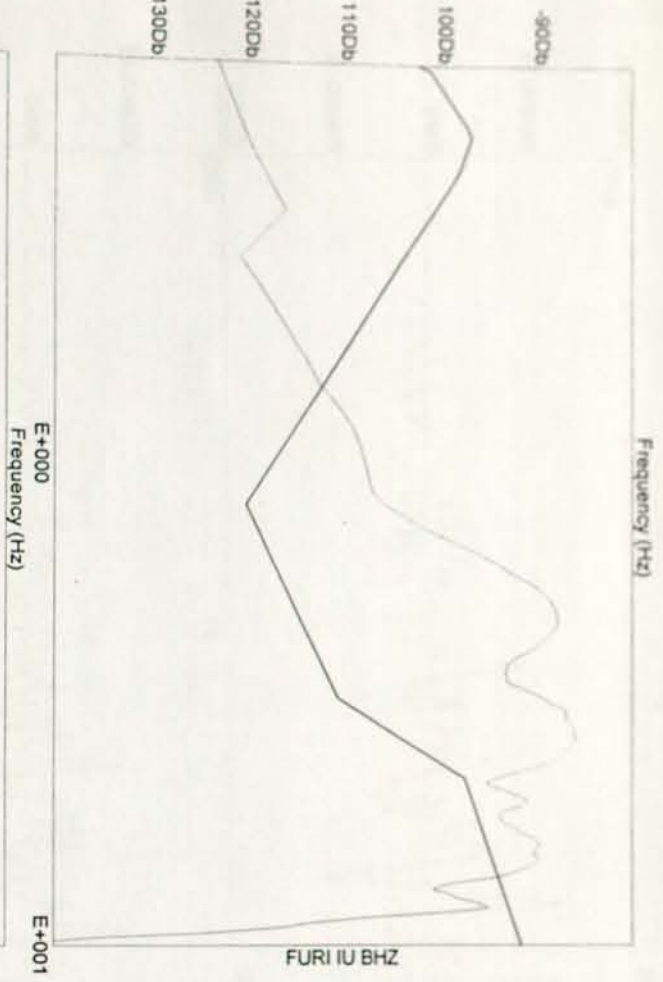
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5S

10S

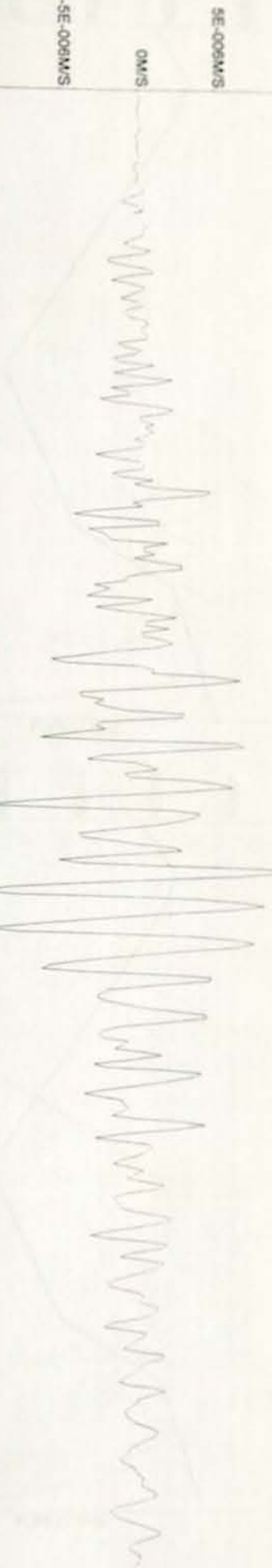
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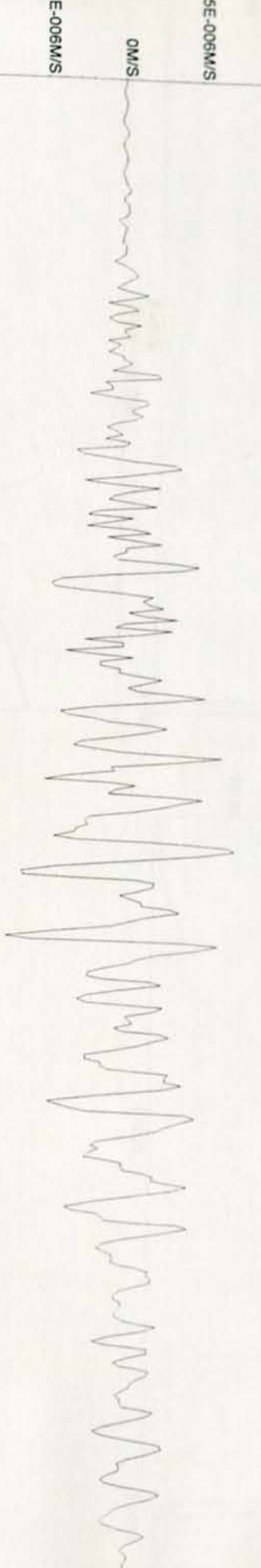
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FURI IU BHZ

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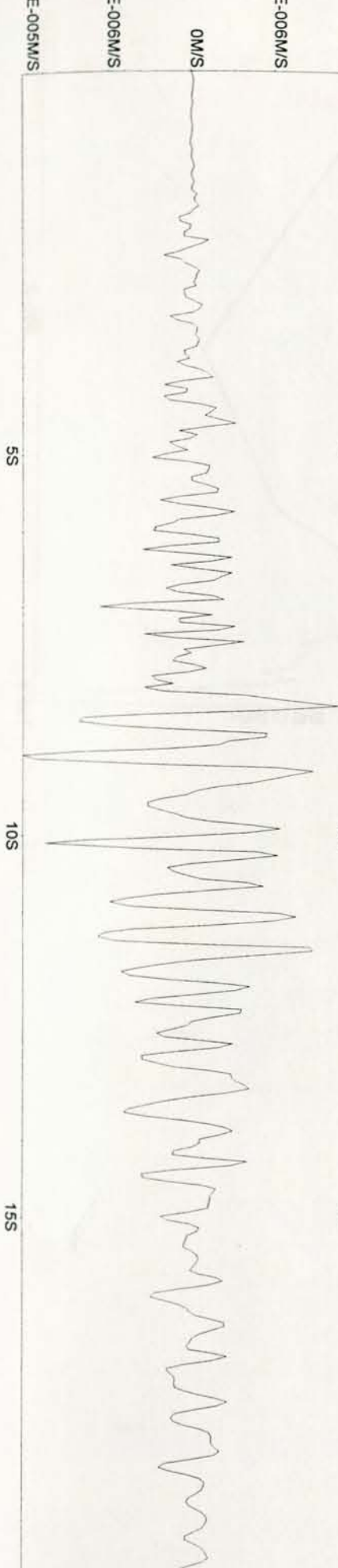
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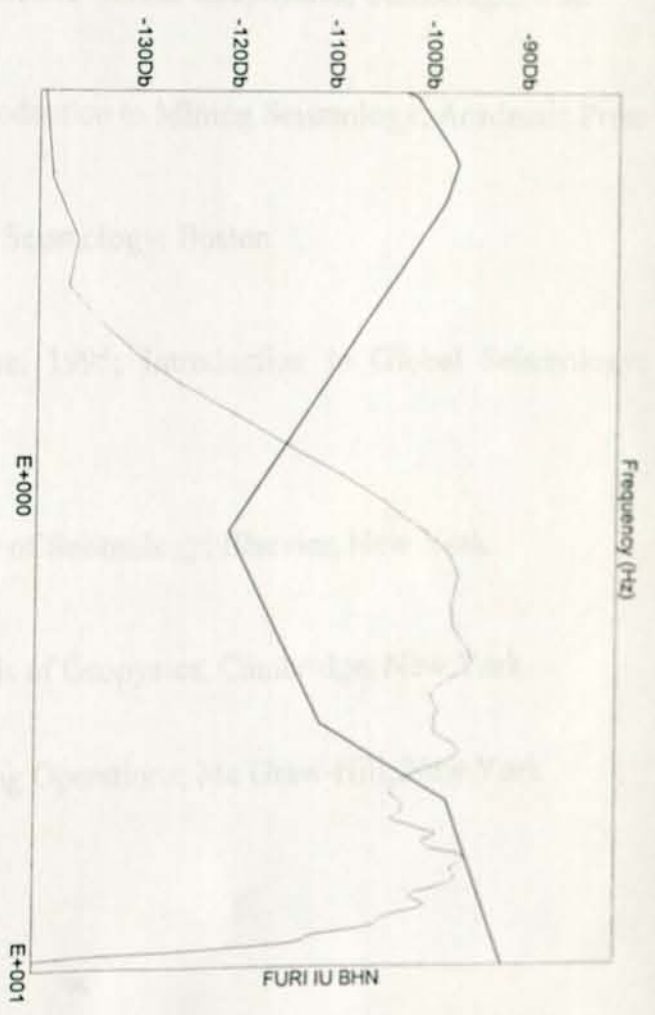
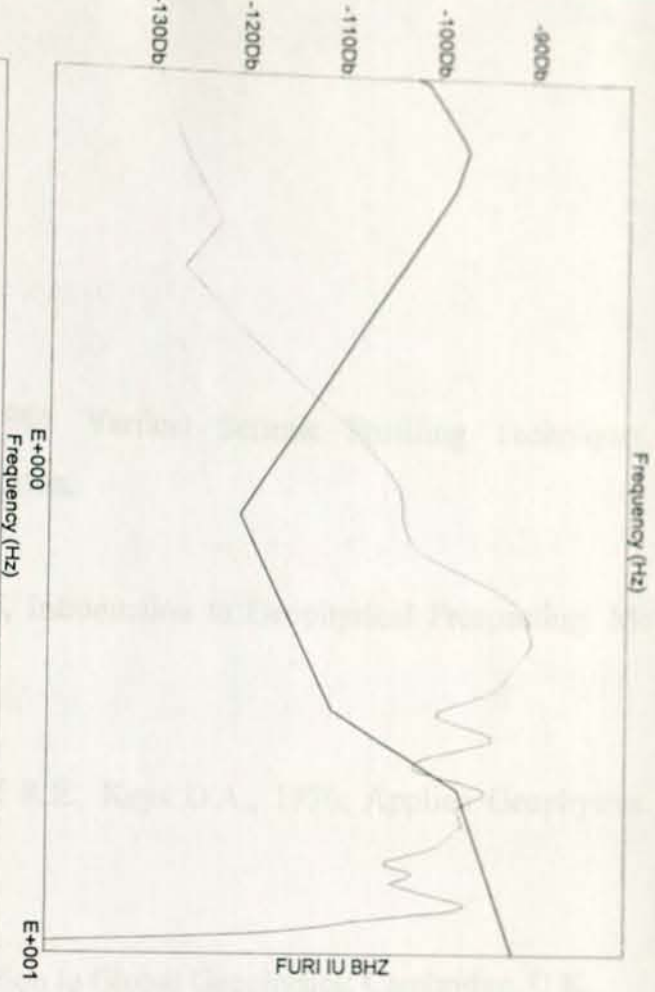
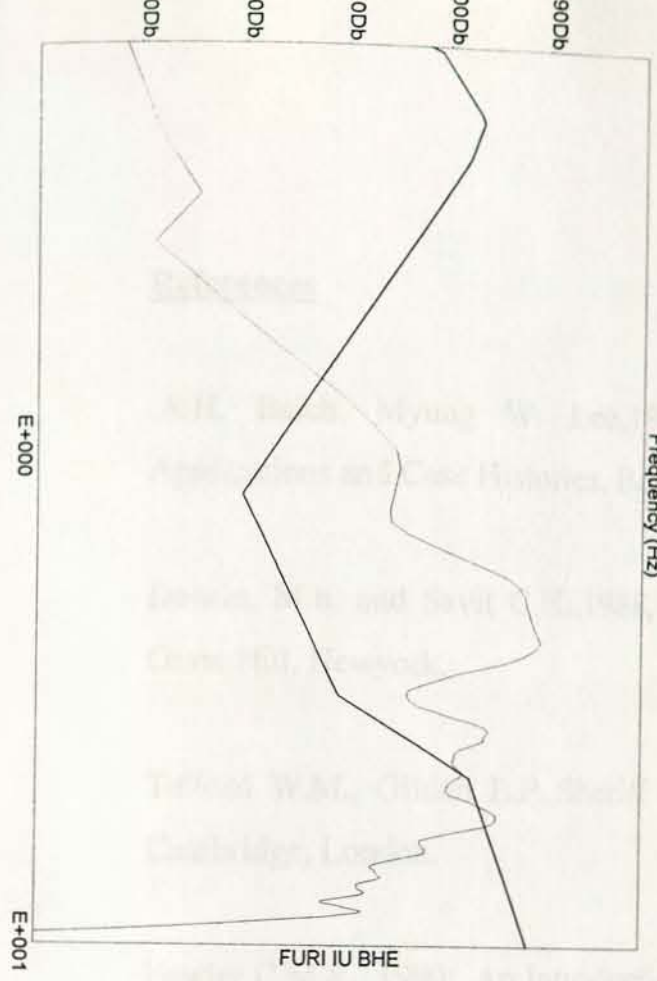
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## References

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## Declaration

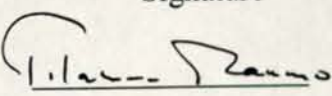

I, the designed, hereby declare that this thesis is my original work carried out under the supervision of Dr. Tilahun Mammo and Dr. Atalay Ayele, has not been presented as a thesis for a degree program in any other university and that all sources of materials used for the thesis are duly acknowledged.

Name Mekonnen Hurrisa

Signature 

Date 11-07-2003

This thesis has been submitted for examination with my approval as university advisors.

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