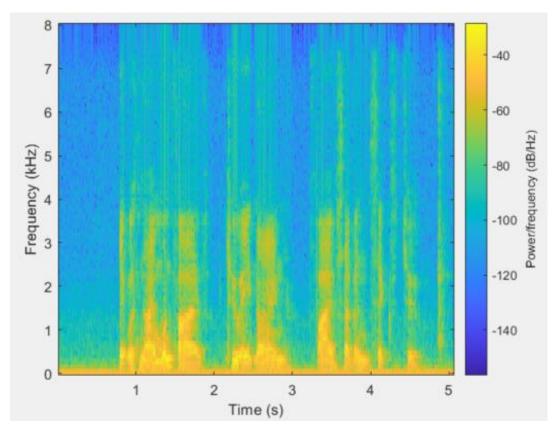
### Problem 2

(a)

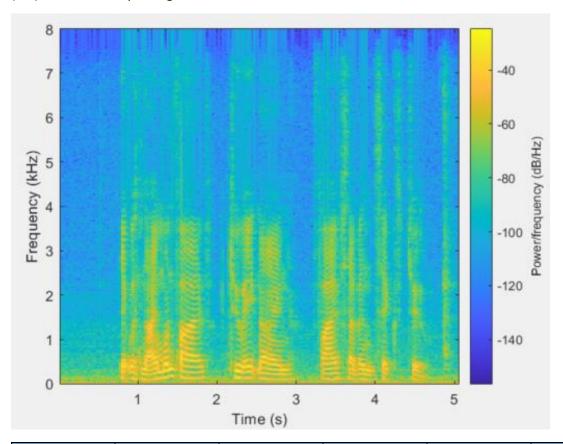
### (a-1) Wideband Spectrogram



|            | X            | Window<br>Length<br>(Hamming) | Length of<br>Overlap | f   | fs    |
|------------|--------------|-------------------------------|----------------------|-----|-------|
| Chosen     | Provided     | 200                           | 100(i.e. 50%)        | 200 | 16000 |
| parameters | audio signal |                               |                      |     |       |

It has a good temporal resolution but poor frequency resolution.

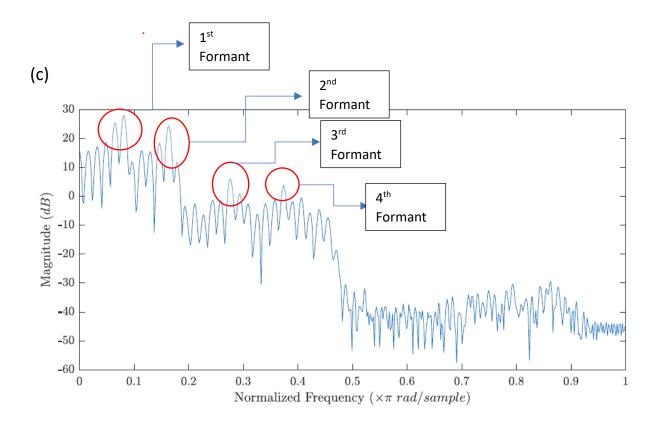
### (a-2) Narrowband Spectrogram

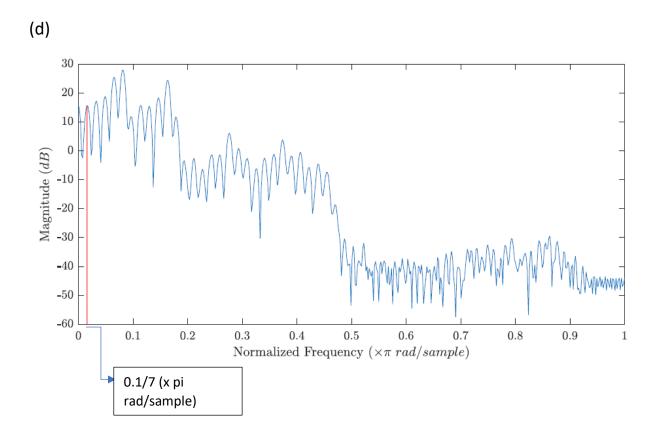


|            | X            | Window    | Length of     | f   | fs    |
|------------|--------------|-----------|---------------|-----|-------|
|            |              | Length    | Overlap       |     |       |
|            |              | (Hamming) |               |     |       |
| Chosen     | Provided     | 800       | 400(i.e. 50%) | 800 | 16000 |
| parameters | audio signal |           |               |     |       |

It has a good frequency resolution but poor temporal resolution.

(b) I think it is a part of a narrow band because it is showing a lot of dynamics in terms of frequency (i.e., good frequency resolution).

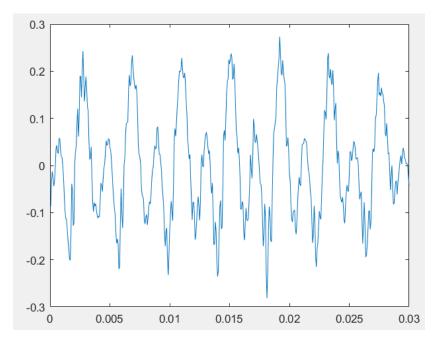




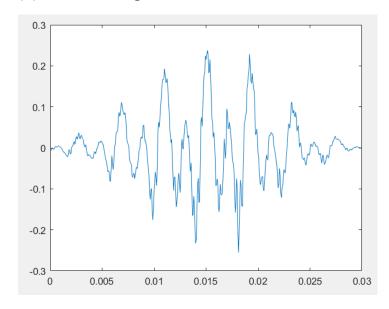
=>0.1\*pi/7\*16000/(2\*pi) = 114.2857 Hz = fundamental frequency

## Problem 4.

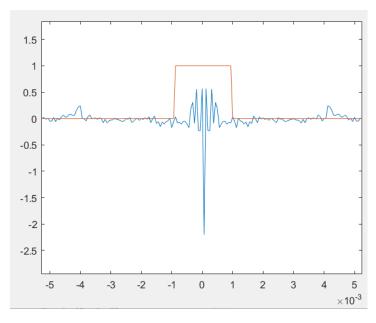
## (i)Non-windowed signal s[n].



# (ii)windowed signal x[n]



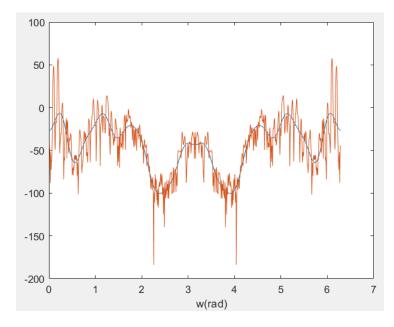
(iii)cepstrum c[n] with the cepstrum window  $w_c$ 



N' = 15

Blue: c[n], Orange: window  $w_c$ 

(iv)Spectrum of y[n] and spectrum of x[n] in dB



Blue: spectrum of y[n] in dB, Orange: spectrum of x[n] in dB

$$N' = 15$$

As N' gets bigger but still less than L, envelope patterns become sharpener. Otherwise, envelope shapes become smoother.

In (i), we can find a fundamental period by picking 2 nearest peaks, subtract their index location and convert the result to proper time.

In (iii), we can pick location of the very first envelope and convert it to proper scale.

### Index

### Problem2

```
fileName = 'hw3 SpectralAnalysis.wav';
[audioSignal,Fs ]= audioread(fileName);
audioSignal = audioSignal' ; % make it 1xlength form
lengthOfHamming4Narrowband = 800;
lengthOfHamming4Wideband = 200;
%50 percent overlap
lengthOfOverlap4Narrowband = 400;
lengthOfOverlap4Wideband = 100;
%Wideband spectrogram
figure(1)
spectrogram (audioSignal, lengthOfHamming4Wideband, lengthOfOv
erlap4Wideband, lengthOfHamming4Wideband, Fs, 'yaxis')
%Narrowband spectrogram
figure(2)
spectrogram (audioSignal, lengthOfHamming4Narrowband,
lengthOfOverlap4Narrowband,
lengthOfHamming4Narrowband,Fs,'yaxis')
```

#### Problem 4

```
fileName = 'hw2_TIMIT_LDC93S1.wav';
[audioSignal,Fs ]= audioread(fileName);
audioSignal = audioSignal'; % make it 1xlength form
%Find abs maximum in signal and normalize
absMaxOfSignal = max(abs(audioSignal));
normalizedAudioSignal = audioSignal./absMaxOfSignal;
%Pick voiced sound segment based on results from HW2
lengthOfSegment = 0.03*Fs;
```

```
normalizedAudioSignalSegment =
normalizedAudioSignal(5200:5200+lengthOfSegment-1);
%Create continuous time for display purpose
Ts = 1/Fs;
continuousTimeArray = [1:lengthOfSegment].*Ts;
%Windowing signal segment
%Generate Hamming window
hammingWindow = hamming(lengthOfSegment);
hammingWindow = hammingWindow'; % transpose
%Window s[n]
windowed normalizedAudioSignalSegment =
normalizedAudioSignalSegment .* hammingWindow;
%% First section of Homomorphic signal analysis for voiced
speech in Figure 2
numberOfDFT = 1024;
numberOfIDFT = 1024;
%Find DFT
dft windowed normalizedAudioSignalSegment =
fft(windowed normalizedAudioSignalSegment, numberOfDFT);
%Calculate natural logarithm
LogSpectrum absOfX =
log(abs(dft windowed normalizedAudioSignalSegment));
%Take inverse DFT to find cepstrum c[n]
c n = ifft(LogSpectrum absOfX, numberOfIDFT);
%Shift c n properly then c n can have negative time range.
shifted c n = ifftshift(c n);
%Generate continuous time array for c n
amountOfShift = 512;
continuousTimeArray cepstrum = Ts.*[1:numberOfIDFT] -
(Ts*amountOfShift);
%% Second section of Homomorphic signal analysis for voiced
speech in Figure 2
```

```
lengthOfLifter = 30; %any number less than L = 66 in this
case.
halfOfLengthOfLifter = lengthOfLifter/2;
%initialize
cepstrumLifter = zeros(1, numberOfDFT);
cepstrumLifter(amountOfShift-
halfOfLengthOfLifter+1:amountOfShift+halfOfLengthOfLifter)
= rectwin(lengthOfLifter);
lifted c n = cepstrumLifter .* shifted c n; %
%Calculate dft of windowed c[n]
dft lifted c n =
fft(fftshift(lifted c n), numberOfDFT); %need to be shifted
because lifted c n was shifted before.
%Convert back from log spectrum by taking exponential
originalSpectrum lifted x n = exp(dft lifted c n);
%Inverse DFT
y n =
ifft(originalSpectrum lifted x n, numberOfIDFT); %lifted x n
%Calculate dft of y n
dft y n = fft(y n, numberOfDFT);
%frequency array for plotting
frequencyArray = [1:numberOfDFT] .*(2*pi/numberOfDFT);
%% plotting
figure(1)
plot(continuousTimeArray, normalizedAudioSignalSegment)
figure (2)
plot(continuousTimeArray, windowed normalizedAudioSignalSegm
ent)
figure (3)
plot(continuousTimeArray cepstrum, shifted c n)
hold on
plot(continuousTimeArray cepstrum, cepstrumLifter)
```

```
hold off
figure(4)
plot(frequencyArray,20*log(abs(dft_y_n)))
xlabel('w(rad)')
hold on
plot(frequencyArray,20*log(abs(dft_windowed_normalizedAudio
SignalSegment)))
hold off
```

EE519 Home work 3.

| 19         | EB                      | 619 Flome Work 5.  |  |
|------------|-------------------------|--|--|
| 9 1        | Problem 1.              | = depth - mail   | $= \sum_{\infty} \left( \sum_{\infty} X[w] \omega[v-w] X[w+k] \omega[v-k-w] \right)$   |
| -          | (4) (6)                 | AND THE REPORT OF THE PARTY OF   | k- al man - jak  |
| d          | p[-k]=                  | X[m]W[n-m]x[m+]  | La - L EMMS  |
| 5          | VL 11                   | man, w[n+k-m]  | Switch of der the sol of the following   |
| 9          | Let                     | -M+K=-M'   | = 2 x[m] w[n-m]. \( \frac{1}{2} \times \frac{1}{2}  |
| 4          | - 00                    | x[m+k]w[n-m-k]x[m]w[n-m]   |  |
| H          | = 5                     |  | Let Mtkel (a)  |
| <b>(a)</b> | Let                     |  | then, k=l-m, -m-k=-l-11111   |
| <b>(a)</b> | ٥٥                      | x [m+x] w[n-m-k]x[m] w[n-m]  |  |
| -          | = <u>T</u>              | Vintelland   | > \( \times \) \(  |
|            | The second second       | A STATE OF THE STA |  |
|            | = R1                    | K T  | = 2 x[m]w[n-m]. eswm!  |
| 20         | ' k                     | [k] is an even function ofk  | Med  |
| 00         | - H-F                   | Q, E, D  | $m=-\infty$ $\sum_{n=-\infty}^{\infty} \chi[n] w[n-1] \cdot \partial_{n} v \cdot \dots \circ u(x)$   |
| <b>3</b> 1 | ( )                     |  | £-00   |
| ~          | (1) (1)                 | 10-1 10-1- 10-1- 10-1- 10-1- 10-1- 10-1- 10-1- 10-1- 10-1- 10-1- 10-1- 10-1- 10-1- 10-1- 10-1- 10-1- 10-1-   | Change in I  |
| -          | (b) sol)                | - (X, (e30)) X, (e30)  | => e4(1) = e4(1)   |
| -O         | 5n (e30)                | INVE ILIVA   | 10 X   |
| <b>3</b>   | = / \( \sum_{\infty} \) | w[n-m]-x[m].e Jum )*   | · 3 (ejw) = FT [R[x]]  |
| -          | = ( \( \sum_{m} \)      | The property of the second of  | Q, E.D.  |
| 2          | - ( 2                   | wently sell e job  |  |
|            | ( =                     | 10   | (C) 50l)   |
|            | 1 00                    | +jwM   | STIME WE proved R[K] IS AN EVEN.   |
| -          | = 5 W                   | [n-m] x[m] e tjwm  | function ofk   |
| 544        |                         | o[n-1] x[1] e ol) " e o(1)   | > R[K]= R[-K] = 1 K K K K K K K K K K K K K K K K K K  |
| ***        | ( ] U                   | OLD-XI XLX I C J C C C C C C C C C C C C C C C C C   | = 2 x [m] w[n-m] x [m-k] w[n+km]   |
| 119        | (III) Take              | I all the table too  | - May - Call In Tall   |
| 49         | (\$ y 7 - 1)            | ( , ~ L J X V L J  | = Z X[m] X[m-k] W[nm]w[m-m+x]  |
| 79         | Autos                   | the hard The fall of the fall of the   | Mark The Control of t |
| 49         | ON THE D                | the hard, to ROKI P-jwk  | This is hk[n-m] where  |
| 79         |                         | T ROEJ - F RACK E-JOK  | This is AREN'S WORKER  |
| -          | 3                       | J-A 74   | WE [N] = WEN WENTER  |
| -          | Y                       | The second secon | (4)  |
| 70         |                         |  | (1)  |

|                 |   |  | 可        |
|-----------------|---|--|----------|
|                 | E Vien Line To The Total                |  |          |
|                 | 357                                     | E Home work 3  | 0        |
| thoughout P     | mi Vija Megirija (2) (5)                | For k≥0  | PPPPPP   |
| n c. 7 - 8      | X[m]X[m-k]hk[n-m]                       | K" [K] = \ X[m] \ X[m-K] \ K[n-m]  | 6        |
| KUTK7 - T       | VILLY TILE                              | NA CITY OF THE PARTY OF THE PAR |          |
| [4] .cf         | [n]=w[n]w[n++]                          | = 25, [m] h, [n-m]<br>N=-00  | 6        |
| WIEIG 177       | PART TO BUILD BY A                      | where SECM = XEM ] XEM-K]  | 6        |
| 1 X Y Y Y       | 1 00¢ 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | = 5K[M@ h[m]   | 65       |
| (d) SO()        | -9 of Final 1941                        | 1. S. A. J. G. M. L. B. G. M.  | E        |
| w[n]=.          | 1 an 114 n20-1-11 (15)                  | > 2T [Rn[k]] = Sk(2) H(2)  | 6        |
|                 | 0 14 11 < 0                             | [wa]w[a]r[d-a-n]w[m]r = 3  | 6        |
| Printer of the  | WILLS CLENIOLEUX &                      | @ ZT[Rn-1[+]] = Sk(2)Hk(2)2-1  | 6        |
| W[ntk]:         | Jank, TA MTRZO                          | ZT [RN-2[H]] = Sk(2) H(2) 2-2  | 0        |
|                 | (10 ) 14 N+K<0                          |  | 6        |
|                 | A DESCRIPTION OF THE RESERVE AS         | > ZT[R[K]]= (ZT[KM-CK]))   | 6        |
| > hx[n]=        | 5 a. anth 3 17 1 1 1 1 20               | (2T[RN-2[F]])  | 6        |
|                 | 0 > 1 1 Nx < 0                          |  | 8        |
|                 | 0 ) 11                                  | > let 15-50 5477/21  | 6        |
|                 | for k20 11 11 2 - 11 / p = =            | $\Rightarrow let$ $\therefore R_n[k] = zT^{-1} \left( \frac{zT[R_{n-1}[k]]^2}{zT[R_{n-2}[k]]} \right)$   | - G      |
| or              |   | ZT[R-2[K]]   | 0        |
| = ]             | 10 . a , 7 + M2 EK                      |  | - 45000  |
|                 | 0 374 N < -K                            | where ak   | 8        |
|                 | 0 ) 1                                   | H,(2) = 1- 2221  | <b>8</b> |
|                 | or k<0. 00 15                           |  | 9        |
| L -Hour Val     | Eliter III Envaria Delle guiss          | (4) mas provide the state of th | 8        |
| (e) sol)        | or k50 Milly Marking to                 | WINJ= SNAT , IT NZO  | 8 8 8    |
| Hk(2) =         | 800-1                                   | 1 (a) a g ( D ) / 17 h < D   | 8        |
| and the first   | OF MARININE TO                          | M[N+K] = S(N+K) AN+K, if N+K 20  |          |
|                 | N=0 K [W] 5                             | 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1  | 6        |
| 174-29, 1201-70 |   |  | 6        |
| >               | Z 0 · 0 · 2 - 1                         | => hx[N]= 5 N(N+K) QN+K , TA NZO   | 8 8 8    |
| 1               | N-0                                     | TA ACO   | 63       |
| -/-             | F a ( a = 1)                            |  | 0        |
| 12              | 1- 22-1 (1)                             | For K20  | 0        |
|                 | 1 - A =                                 | 2)   | 0        |

EE 519 HW3.

|       |  | 51°( // V ).   |  |
|-------|--|--|--|
| 3     |  | De dank fallawak   | STREE A [N] is min phase, in a   |
| 9     |  | proof 15 dosely followed   | previous summation its valid for   |
| •     | ક્રા)  | from week 6 Lecture note.  | N-K-20 & K-20  |
|       | 501)   | 1 4 4 x x x 2 3 4 4 7 1 - 17 54 2  |  |
| 3     | ĥ [n]  | - ZT-1 [log H(2)]  |  |
| •     | (#1-1-to) J.T.   | = ZT-1[10g( G )]   | $\Rightarrow \hat{\alpha}[n] = \frac{\alpha[n]}{\alpha[o]} - \frac{n-1}{n} \frac{k \cdot \alpha[n+1] \cdot \hat{\alpha}[n]}{n \cdot \alpha[o]} \frac{1}{n} \frac{1}$ |
| 9     |  | 1- ZXKZ+   | = A[N] = A[O] /  |
| 4     |  | विकास स्थापना विकास  | The state of the s   |
| •     | = 7  | [ log 6 - log (1- E Xx2+)]   | = - < n = 1 k dn-k h[+], n>D   |
| 4     |  | 1.00=1.00=1.00=1.00  |  |
| -     | let  | A(2) = 1 - Z 0/ 2-k  | since LPC filter cousal  |
| 9     |  | 7-1 [ log 4 - loy (A(2))]  | VENJ =0 ton N<9  |
| 3     | = 2  | T. [1024 1.0[1.13]   |  |
| ø     |  | og 6. S[n] - Q[n]  | Therefore  Therefore  Therefore  Therefore  Therefore  |
| ð     | =  | od A. STUT - OLUZ  | loy4 , for N=0   |
| 4     | 1  |  | 10901   CT+7   A-400   |
| 49    | let's  | take a look at a[n]  | Xn+ FT K Xn+ h[F] for N>0  |
| 4     | Al   | 2) is min phase  | 1  |
| 9     |  | 4.80 0.85 %8   |  |
| 4     | 7 A  | $ z  = \log(A(z))$   | I for the first the first the first that the   |
| -     | The same of the sa | 1-13 vatrues   | \ 100 000 000 000  |
| 9     | =) (0)   | (A(2)  |  |
| 49    | 4  | $\hat{A}(z) = \frac{1}{A(z)} \frac{dA(z)}{dz}$   | - Marchael Central Control Section 1   |
| 100   | d ź  | SELECTION OF THE PROPERTY OF T |  |
|       |  | $\frac{1}{2} dA(2), A(2) = -2 \frac{dA(2)}{d2}$  |  |
| -     | 7 -  | 42 A(Z) JZ)  | 60) 501)   |
| -     |  | The Native   | promptate to the most field for  |
| 9     | TAKE   | Z LANGE CONTRACTOR   |  |
| -0    | 7  | na[n] @ a[n]= ha[n]  | 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1  |
| 9     | S  | × a[k] a[n-k] = na[n]  | THE PROPERTY OF THE PARTY OF THE   |
| 9     | 7  | E-00   | 131 13 45 miles and a second   |
| -     | 11   | N ≠ 0  |  |
| 9     | -570-2   | M) = Z K & [K] · M[N-K]  | Type Indiana in the second sec   |
| 9 9 9 | a  | KE-00  |  |
| -9    |  |  | THE WAR SHIP GIT !   |
| -     | D D  |  | (2)  |
| -     |  | 0.44   | (3)  |

|  | EE HI HW3  |
|--|--|
| problem 1 (f) continue.  | EE HA HW3  |
| The LCD seems than it is a sile of   | The persodicion  |
| TOF KIN] = [ N(NTK) antk, if NZO-K   | Ru[k] = KN [k+rNp]   |
| D STENKINK   | Left hand side  = \( \infty \) \( \times \)  |
| The state of the s | - Z Vr. (3   |
| $\Rightarrow H_{k}(z) = \frac{1}{2} h_{k}[n] z^{-n}$   | Right hand Side  |
| THK(Z)   | Right hand Stde  = X[m] W[n-m] X [m+k+rNp]  , w[n-(k+rNp)-m]   |
| = 0 H* [N] 5- N .   Y*[N] = 0  | I WEN-(K+tNp)-m) + W[N-K-m]  |
| n=0, assess variet for n<0   | > non periodi L Q. E.D   |
| $= \frac{2}{2} n(N+K) \stackrel{?}{O} \stackrel{?}{\sim} \frac{2}{2} - \frac{1}{2}$  | TTT) To be perrodice   |
| Also On the Also Description   | 1   k +   No   = 10   k  |
| Also,  RM[K] TS the same as  | Talla to 100 Says 5125 101 10  |
| BULK From (6)  | Right hand side  ⇒ Ø[ktrNp]  |
| > Rn[k]= ZT ( [ > T [ Rn+[k]]))  | = lim Jet = x[m] x[mt k+1Np]<br>= lim Jet = x[m] x[mt k+1Np]   |
| > Rn LFJ ZT ( ZT [Rn-2[F])   | = Irm I I X [m] x [m+r]  |
|  | =   rm  2Lt   me-L $= (rm  2Lt   me-L)$ $= (rm  2Lt   me-L)$   |
| where $H_k(z) = \sum_{n=0}^{\infty} n(n+1) a^{2n+k}$   |  |
|  | => O[k+hp]= hora   |
| (g) sol)   | Q,E,D  |
| (g) Sol)  1) \$\phi[k] = \left[ \text{Im} \frac{1}{2} \text{Im} \frac{1}{M} = \frac{1}{2} \text{M} \text{M} \frac{1}{M} 1      | THIS TO SETTION IN THE   |
| D[-K] = 1 m - 2 x[m] x[m-k]  | [MON [ WIN THE STATE OF THE STA |
| Let MT OC  | O  # N   1   |
| PRM I I L-K X [m+k]  | X[M,] [3-4] V [4-12] 4 2 - (2-4)   |
| 1900 W-77  |  |
| ) \$[k - \$[-k] → even. 0's  | (A)  |