$$\mathbf{h(n)} = \left[\frac{\mathbf{1}}{\mathbf{2\pi}}, \frac{\mathbf{1}}{\sqrt{\mathbf{2}}\pi}, \frac{\mathbf{1}}{\mathbf{4}}, \frac{\mathbf{1}}{\sqrt{\mathbf{2}}\pi}, \frac{\mathbf{1}}{\mathbf{2\pi}}\right]$$

The frequency response $H(\omega)$ of the digital filter is given by

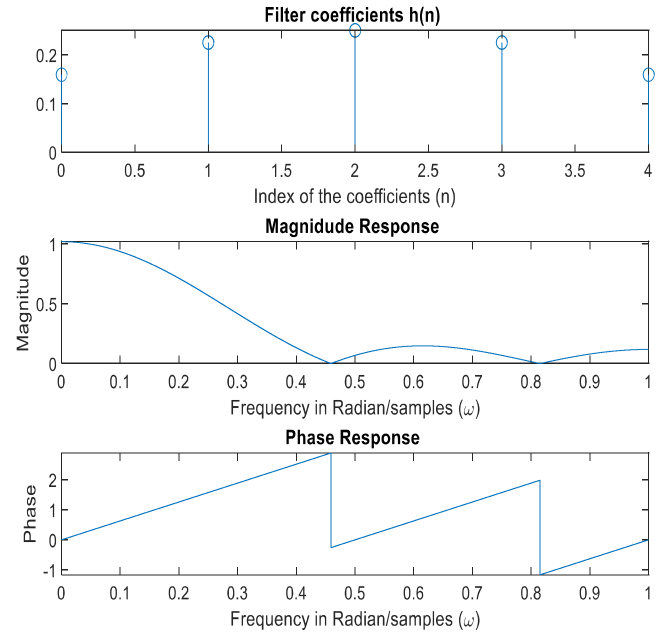
$$H(\omega) = \sum_{n=0}^{4} h(n) e^{-j\omega n}$$

$$= h(0) + h(1)\, e^{-j\omega} + h(2)\, e^{-j2\omega} + h(3)\, e^{-j3\omega} + h(4)\, e^{-j4\omega}$$

$$= e^{-j2\omega}[h(0)\, e^{j2\omega} + h(1)\, e^{j\omega} + h(2) + h(3)\, e^{-j\omega} + h(4)\, e^{-j2\omega}]$$

$$= e^{-j2\omega}[h(2) + h(1)\,(e^{j\omega} + e^{-j\omega}) + h(0)\,(e^{j2\omega} + e^{-j2\omega})]$$

$$= e^{-j2\omega}\left[\frac{1}{4} + \frac{\sqrt{2}}{\pi}\cos\omega + \frac{1}{\pi}\cos 2\omega\right]$$



$$\omega = [\mathbf{0},\ \pi/\mathbf{4},\ \pi/\mathbf{2},\ \mathbf{3}\pi/\mathbf{4},\ \pi]$$

$$\mathbf{H}(\omega) = [\mathbf{1.0185}, \mathbf{0.5683i}, \mathbf{0.0683}, \mathbf{0.0683i}, \mathbf{0.1182}]$$

$$|\mathbf{H}(\omega)| = \sqrt{\mathbf{re}(\mathbf{H}(\omega))^{\mathbf{2}} + \mathbf{im}(\mathbf{H}(\omega))^{\mathbf{2}}}$$

$$\angle\mathbf{H}(\omega) = \mathbf{tan}^{-1}\frac{\mathbf{im}(\mathbf{H}(\omega))}{\mathbf{re}(\mathbf{H}(\omega))}$$

The window design for FIR filter has certain advantages and disadvantages.

Advantages

1. The filter coefficients can be obtained with minimum computation effort.
2. The window functions are readily available in closed-form expression.
3. The ripples in both stop band and pass band are almost completely eliminated.

Disadvantages

1. It is not always possible to obtain a closed form expression for the Fourier series coefficients $h(n)$.
2. Windows provide little flexibility in design.
3. It is somewhat difficult to determine, in advance, the type of window and duration N required to meet a given prescribed frequency specification.

Frequency Sampling Method

Frequency Sampling Method

Advantage

- Unlike the window method, this technique can be used for any given magnitude response.
- This method is useful for the design of non-prototype filters where the desired magnitude response can take any irregular shape.
- Major advantage of Frequency sampling method lies in the efficient frequency sampling structure, which is obtained when most of the frequency samples are zero.

Disadvantage

One disadvantage with this method is that the frequency response obtained by interpolation is equal to the desired frequency response only at the sampled points. At the other points, there will be a finite error present.

Procedure for type-I design

1. Choose the ideal (desired) frequency response $H_d(\omega)$.
2. Sample $H_d(\omega)$ at N-points by taking $\omega = \omega_k = \dfrac{2\pi k}{N}$, where $k = 0, 1, 2, 3, \ldots, (N-1)$ to generate the sequence $\tilde{H}(k)$.

   $$\therefore \qquad \tilde{H}(k) = H_d(\omega)\,|_{\omega=(2\pi k)/N}; \quad \text{for } k = 0, 1, 2, \ldots, (N-1)$$

3. Compute the N samples of $h(n)$ using the following equations:

   $$\text{When } N \text{ is odd,} \quad h(n) = \frac{1}{N}\left[\tilde{H}(0) + 2\sum_{k=1}^{(N-1)/2} \text{Re}\left(\tilde{H}(k)\, e^{j\frac{2\pi nk}{N}}\right)\right]$$

   $$\text{When } N \text{ is even,} \quad h(n) = \frac{1}{N}\left[\tilde{H}(0) + 2\sum_{k=1}^{\left(\frac{N}{2}-1\right)} \left(\tilde{H}(k)\, e^{j\frac{2\pi nk}{N}}\right)\right]$$

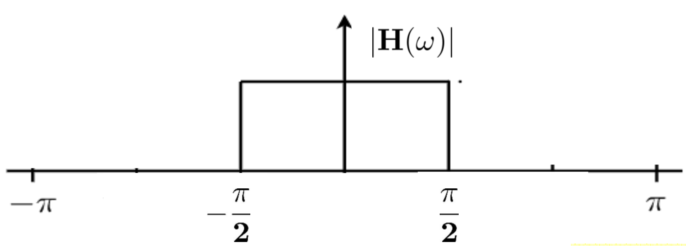
   where 'Re' stands for 'real part of'.
4. Take Z-transform of the impulse response $h(n)$ to get the transfer function $H(z)$.

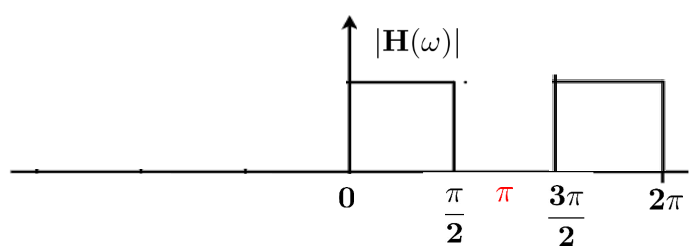
   $$\therefore \qquad H(z) = \sum_{n=0}^{N-1} h(n)\, z^{-n}$$

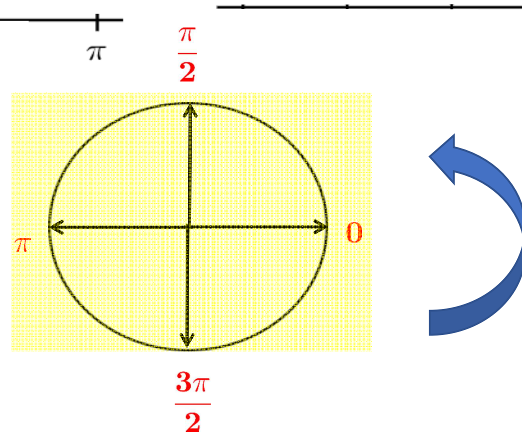
Design LPF which has the following specifications, N=7 using frequency sampling Technique.

$$H_d(e^{j\omega}) = \begin{cases} e^{-j3\omega} & , 0 \le \omega \le \dfrac{\pi}{2} \\ 0 & , \dfrac{\pi}{2} \le \omega \le \pi. \end{cases}$$

Shifting from $-\pi \to \pi$ to $0 \to 2\pi$

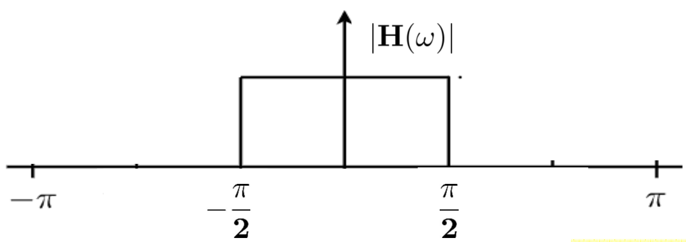




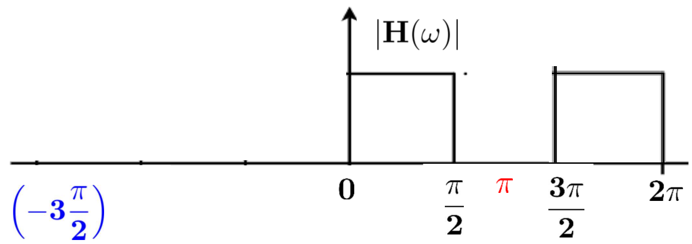


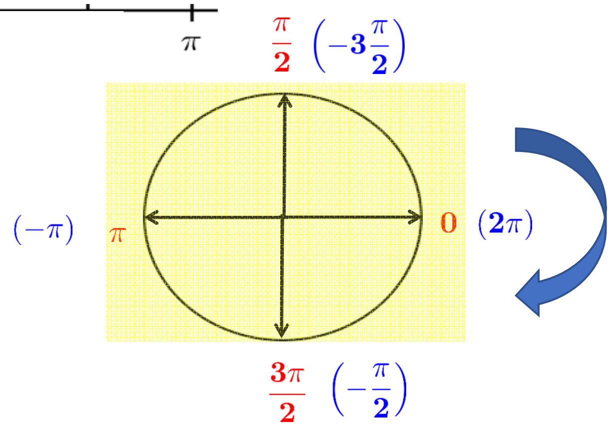
Design LPF which has the following specifications, N=7 using frequency sampling Technique.

$$H_d(e^{j\omega}) = \begin{cases} e^{-j3\omega} & , 0 \le \omega \le \dfrac{\pi}{2} \\ 0 & , \dfrac{\pi}{2} \le \omega \le \pi. \end{cases}$$



Shifting from $-\pi \to \pi$ to $0 \to 2\pi$





Procedure for type-I design

1. Choose the ideal (desired) frequency response $H_d(\omega)$.
2. Sample $H_d(\omega)$ at N-points by taking $\omega = \omega_k = \dfrac{2\pi k}{N}$, where $k = 0, 1, 2, 3, \ldots, (N-1)$ to generate the sequence $\tilde{H}(k)$.

   $\therefore \qquad \tilde{H}(k) = H_d(\omega)|_{\omega=(2\pi k)/N}; \quad \text{for } k = 0, 1, 2, \ldots, (N-1)$
3. Compute the N samples of $h(n)$ using the following equations:

   When N is odd, $$h(n) = \frac{1}{N}\left[\tilde{H}(0) + 2\sum_{k=1}^{(N-1)/2} \text{Re}\left(\tilde{H}(k)\, e^{j\frac{2\pi nk}{N}}\right)\right]$$

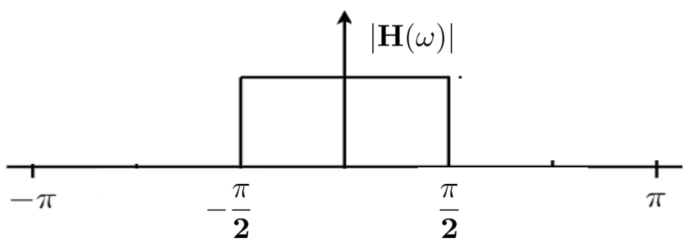
   When N is even, $$h(n) = \frac{1}{N}\left[\tilde{H}(0) + 2\sum_{k=1}^{\left(\frac{N}{2}-1\right)} \left(\tilde{H}(k)\, e^{j\frac{2\pi nk}{N}}\right)\right]$$

   where 'Re' stands for 'real part of'.
4. Take Z-transform of the impulse response $h(n)$ to get the transfer function $H(z)$.

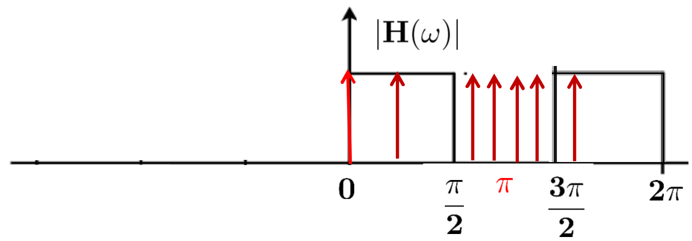
   $$\therefore \qquad H(z) = \sum_{n=0}^{N-1} h(n)\, z^{-n}$$

Design LPF which has the following specifications, N=7 using frequency sampling Technique.

$$H_d(e^{j\omega}) = \begin{cases} e^{-j3\omega} & ,0 \le \omega \le \frac{\pi}{2} \\ 0 & ,\frac{\pi}{2} \le \omega \le \pi. \end{cases}$$



Shifting from $-\pi \to \pi$ to $0 \to 2\pi$



Replace $\omega = \omega_k = \frac{2\pi k}{N} = \frac{2\pi k}{7}$ **where** $k = 0, \ldots, 6$

$$\omega_k = \left[0, \frac{2\pi}{7}, \frac{4\pi}{7}, \frac{6\pi}{7}, \frac{8\pi}{7}, \frac{10\pi}{7}, \frac{12\pi}{7}\right]$$

$$\omega_k = [0, 0.2857\pi, 0.5714\pi, 0.8571\pi, 1.1429\pi, 1.4286\pi, 1.7143\pi]$$

N=7.

$$H(k) = \begin{cases} e^{-j\frac{6\pi k}{7}} & for\ k = 0,1,6 \\ 0 & for\ k = 2,3,4,5 \end{cases}$$

Procedure for type-I design

1. Choose the ideal (desired) frequency response $H_d(\omega)$.
2. Sample $H_d(\omega)$ at N-points by taking $\omega = \omega_k = \frac{2\pi k}{N}$, where $k = 0, 1, 2, 3, \ldots, (N-1)$ to generate the sequence $\tilde{H}(k)$.

   $\therefore \quad \tilde{H}(k) = H_d(\omega)|_{\omega=(2\pi k)/N}; \quad$ for $k = 0, 1, 2, \ldots, (N-1)$
3. Compute the N samples of $h(n)$ using the following equations:

When N is odd, $$h(n) = \frac{1}{N}\left[\tilde{H}(0) + 2\sum_{k=1}^{(N-1)/2} \mathrm{Re}\left(\tilde{H}(k)\, e^{j\frac{2\pi nk}{N}}\right)\right]$$

When N is even, $$h(n) = \frac{1}{N}\left[\tilde{H}(0) + 2\sum_{k=1}^{\left(\frac{N}{2}-1\right)} \left(\tilde{H}(k)\, e^{j\frac{2\pi nk}{N}}\right)\right]$$

where 'Re' stands for 'real part of'.

4. Take Z-transform of the impulse response $h(n)$ to get the transfer function $H(z)$.

$$\therefore \quad H(z) = \sum_{n=0}^{N-1} h(n)\, z^{-n}$$

OBSERVE OPTIMIZE OUTSPREAD

$$h(n) = \frac{1}{N}\left\{H(0) + \sum_{k=1}^{\frac{N-1}{2}} 2\,\mathrm{Re}\left(H(k)e^{\frac{j2\pi kn}{N}}\right)\right\} \qquad \therefore H(0) = 1$$

$$= \frac{1}{7}\left\{1 + \sum_{k=1}^{3} 2\,\mathrm{Re}\left(e^{-j\frac{6\pi k}{7}} . e^{\frac{j2\pi kn}{7}}\right)\right\}$$

$$= \frac{1}{7}\left\{1 + 2\sum_{k=1}^{3} \mathrm{Re} \quad .e^{\frac{j\pi k(2n-6)}{7}}\right\}$$

$$h(n) = \frac{1}{7}\left\{1 + 2\sum_{k=1}^{3} \cos\left(\frac{\pi k(2n-6)}{7}\right)\right\}$$

$$h(n) = \frac{1}{7}\left\{1 + 2\left(\cos\left(\frac{\pi(2n-6)}{7}\right)\right)\right\} \quad for\ k = 1.$$

$$h(0) = -0.114; h(1) = 0.079; h(2) = 0.321; h(3) = 0.4286; h(4) = h(2); h(5) = h(1); h(6) = h(0)$$

EXAMPLE 9.19 Design a linear phase FIR filter of length $N = 11$ which has a symmetric unit sample response and a frequency response that satisfies the conditions:

$$H\left(\frac{2\pi k}{11}\right) = \begin{cases} 1 \ , & \text{for } k = 0, 1, 2 \\ 0.5 \ , & \text{for } k = 3 \\ 0 \ , & \text{for } k = 4, 5 \end{cases}$$

Solution: For linear-phase FIR filter, the phase function, $\theta(\omega) = -\alpha\omega$, where $\alpha = (N-1)/2$.

Here $N = 11$, $\quad \therefore \quad \alpha = (11 - 1)/2 = 5$.

Also, here $\omega = \omega_k = \dfrac{2\pi k}{N} = \dfrac{2\pi k}{11}$.

Hence we can go for type-I design. In this problem, the samples of the magnitude response of the ideal (desired) filter are directly given for various values of k. Therefore,

$$\tilde{H}(k) = H_d(\omega)|_{\omega=\omega_k} = \begin{cases} 1\, e^{-j\alpha\omega_k} \ , & k = 0, 1, 2 \\ 0.5\, e^{-j\alpha\omega_k} \ , & k = 3 \\ 0 \ , & k = 4, 5 \end{cases}$$

where, $\omega_k = \dfrac{2\pi k}{11}$

When $k = 0$, $\tilde{H}(0) = e^{-j\alpha\omega_0} = e^{-j5\times\left(\frac{2\pi\times 0}{11}\right)} = 1$

When $k = 1$, $\tilde{H}(1) = e^{-j\alpha\omega_1} = e^{-j5\times\left(\frac{2\pi\times 1}{11}\right)} = e^{-j\left(\frac{10\pi}{11}\right)}$

When $k = 2$, $\tilde{H}(2) = e^{-j\alpha\omega_2} = e^{-j5\times\left(\frac{2\pi\times 2}{11}\right)} = e^{-j\left(\frac{20\pi}{11}\right)}$

When $k = 3$, $\tilde{H}(3) = 0.5\, e^{-j\alpha\omega_3} = 0.5\, e^{-j5\times\left(\frac{2\pi\times 3}{11}\right)} = 0.5\; e^{-j\left(\frac{30\pi}{11}\right)}$

When $k = 4$, $\tilde{H}(4) = 0$

When $k = 5$, $\tilde{H}(5) = 0$

The samples of impulse response are given by

$$h(n) = \frac{1}{N}\left\{\tilde{H}(0) + 2\sum_{k=1}^{(N-1)/2} \mathrm{Re}\left[\tilde{H}(k)\, e^{j2\pi nk/N}\right]\right\}$$

$$= \frac{1}{11}\left\{\tilde{H}(0) + 2\sum_{k=1}^{5} \mathrm{Re}\left[\tilde{H}(k)\, e^{j2\pi nk/N}\right]\right\}$$

$$= \frac{1}{11}\left\{\tilde{H}(0) + 2\sum_{k=1}^{2} \mathrm{Re}\left[\tilde{H}(k)\, e^{j2\pi nk/11}\right] + 2\,\mathrm{Re}\left[\tilde{H}(3)\, e^{j2\pi n3/11}\right]\right\}$$

$$= \frac{1}{11}\left\{1 + 2\sum_{k=1}^{2} \mathrm{Re}\left[e^{-j5\left(\frac{2\pi k}{11}\right)} \times e^{j\left(\frac{2\pi nk}{11}\right)}\right] + 2\,\mathrm{Re}\left[0.5^{-j5\left(\frac{2\pi\times 3}{11}\right)} \times e^{j\left(\frac{2\pi n3}{11}\right)}\right]\right\}$$

$$= \frac{1}{11}\left\{1 + 2\sum_{k=1}^{2} \mathrm{Re}\left[e^{j\frac{2\pi k}{11}(n-5)}\right] + 2\,\mathrm{Re}\left[0.5\, e^{j\frac{6\pi}{11}(n-5)}\right]\right\}$$

$$= \frac{1}{11} + \frac{2}{11}\cos\frac{2\pi}{11}(n-5) + \frac{2}{11}\cos\frac{4\pi}{11}(n-5) + \cos\frac{6\pi}{11}(n-5)$$

$$h[n] = \frac{1}{11} + \frac{2}{11}\cos\frac{2\pi}{11}(n-5) + \frac{2}{11}\cos\frac{4\pi}{11}(n-5) + \cos\frac{6\pi}{11}(n-5)$$

$$n=0,\ h(0) = \frac{1}{11} + \frac{2}{11}\cos\left(\frac{-10\pi}{11}\right) + \frac{2}{11}\cos\left(\frac{-20\pi}{11}\right) + \cos\left(\frac{-30\pi}{11}\right) = -0.5854$$

$$n=1,\ h(1) = \frac{1}{11} + \frac{2}{11}\cos\left(\frac{-8\pi}{11}\right) + \frac{2}{11}\cos\left(\frac{-16\pi}{11}\right) + \cos\left(\frac{-24\pi}{11}\right) = 0.787$$

$$n=2,\ h(2) = \frac{1}{11} + \frac{2}{11}\cos\left(\frac{-6\pi}{11}\right) + \frac{2}{11}\cos\left(\frac{-12\pi}{11}\right) + \cos\left(\frac{-18\pi}{11}\right) = 0.3059$$

$$n=3,\ h(3) = \frac{1}{11} + \frac{2}{11}\cos\left(\frac{-4\pi}{11}\right) + \frac{2}{11}\cos\left(\frac{-8\pi}{11}\right) + \cos\left(\frac{-12\pi}{11}\right) = -0.9120$$

$$n=4,\ h(4) = \frac{1}{11} + \frac{2}{11}\cos\left(\frac{-2\pi}{11}\right) + \frac{2}{11}\cos\left(\frac{-4\pi}{11}\right) + \cos\left(\frac{-6\pi}{11}\right) = 0.1770$$

$$n=5,\ h(5) = \frac{1}{11} + \frac{2}{11}\cos 0 + \frac{2}{11}\cos 0 + \cos 0 = \frac{5}{11} + 1 = 1.4545$$

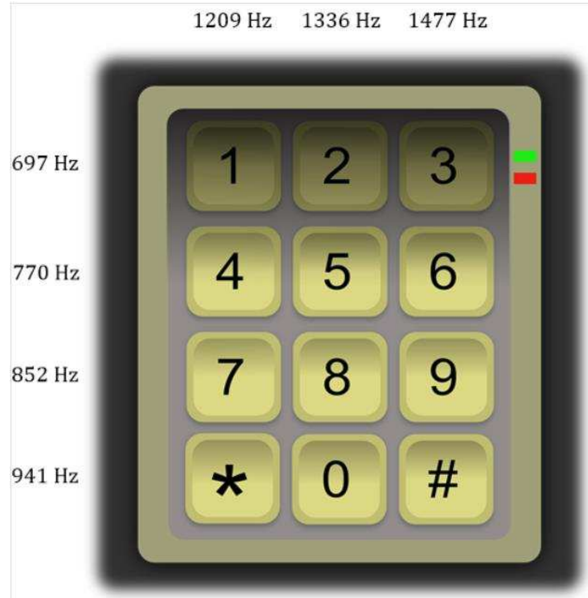
For linear-phase FIR filters, the condition $h(N-1-n) = h(n)$ will be satisfied when $\alpha = (N-1)/2$.

CO5

How to Generate and Detect Dual Tone Multi-Frequency (DTMF) Signals

- In the early days of telephone, you could not call anyone directly. Instead, a telephone operator used to sit on the other side of the line. Whenever you picked up the phone, you told the operator where to connect and they manually relayed your call on a central switchboard.

- This was not going to last. People need to connect to a lot of people beyond the capacity of this kind of system. A control signaling mechanism for automatic routing was the answer.



How to Generate and Detect Dual Tone Multi-Frequency (DTMF) Signals

In DTMF, there are 4 tones in a low group of frequencies (corresponding to each row of the keypad above).

$$697, 770, 852, 941 \quad \text{Hz}$$

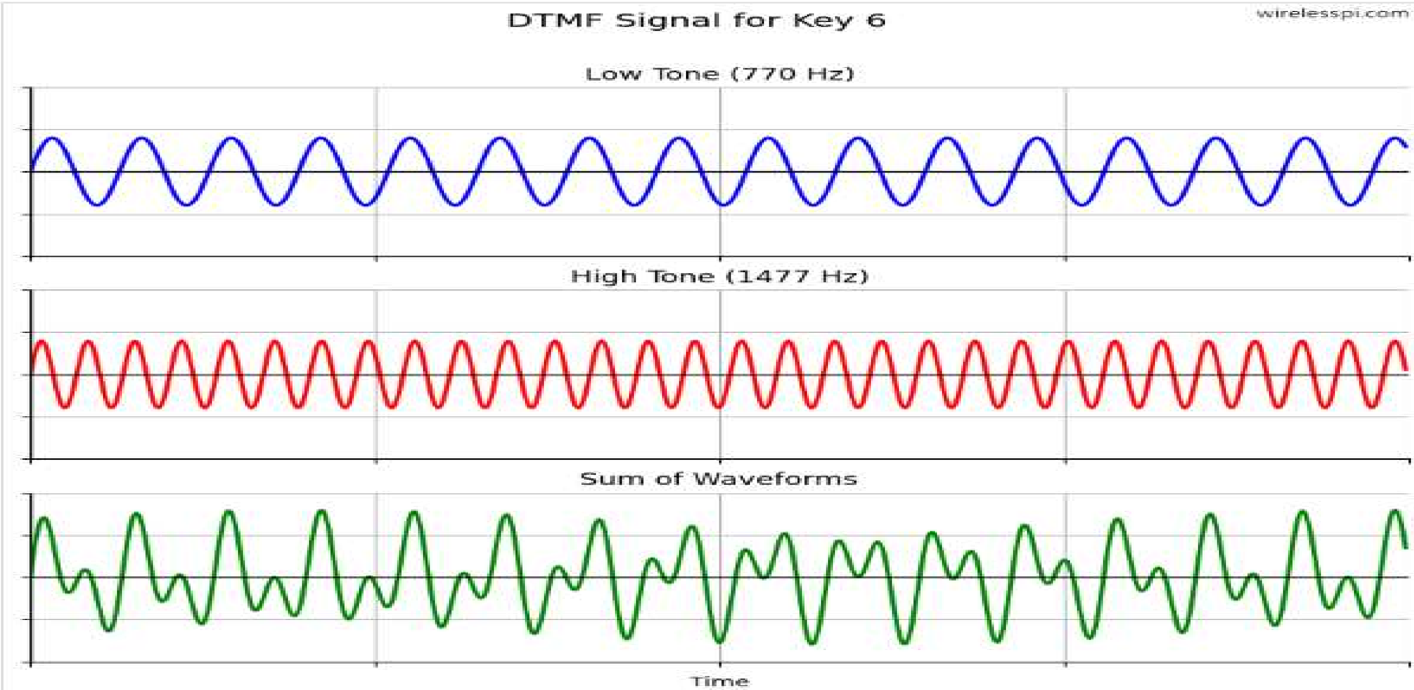
In addition, there are 4 tones in a high group of frequencies (corresponding to each column in the keypad above).

$$1209, 1336, 1477, 1633 \quad \text{Hz}$$

The last column showing letters A through D are missing in the above figure because they are rarely used.

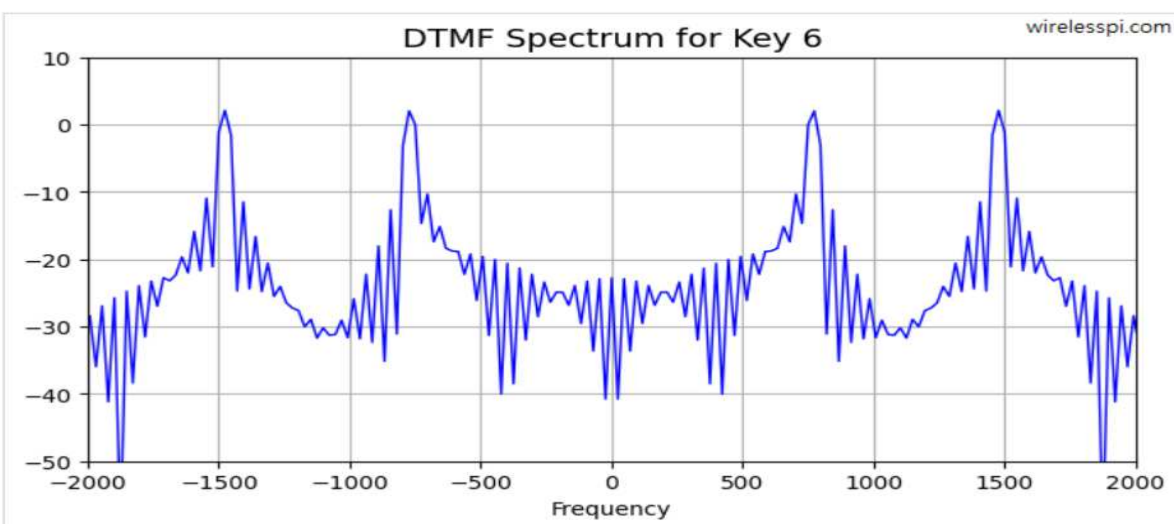
Each key press generates two tones, or sinusoids: one from the low frequency group (row) and the other from a high frequency group (column). For example, pressing the number 6 generates a sum of two sinusoids, one at 770 Hz and the other at 1477 Hz.

How to Generate and Detect Dual Tone Multi-Frequency (DTMF) Signals



How to Generate and Detect Dual Tone Multi-Frequency (DTMF) Signals

The spectrum of this signal can be viewed through the FFT command and drawn in the figure below. Clearly, the two spikes at ± 770 Hz and ± 1477 Hz indicate the presence of the two tones corresponding to key 6.



Notice in the above figure that computational complexity of taking a [Discrete Fourier Transform (DFT)] is high due to N frequencies involved. In many applications such as spectral analysis and wireless communications, this is exactly what is needed. However, in applications like DTMF detection, an efficient evaluation of a small number of known frequency components is required.

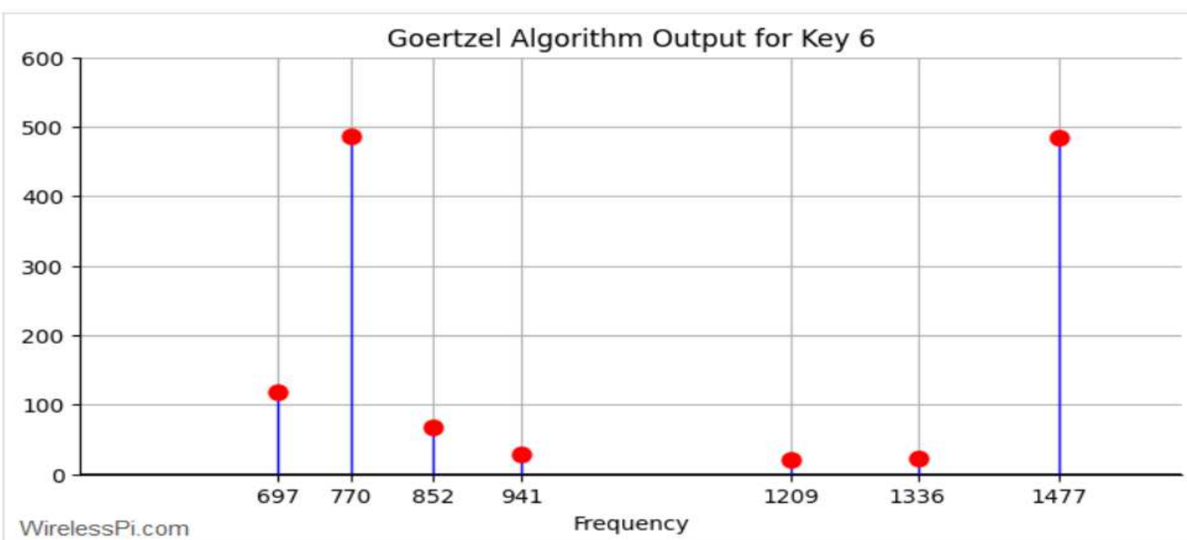
This is why we now move towards Goertzel algorithm for detection of particular tones in a signal.

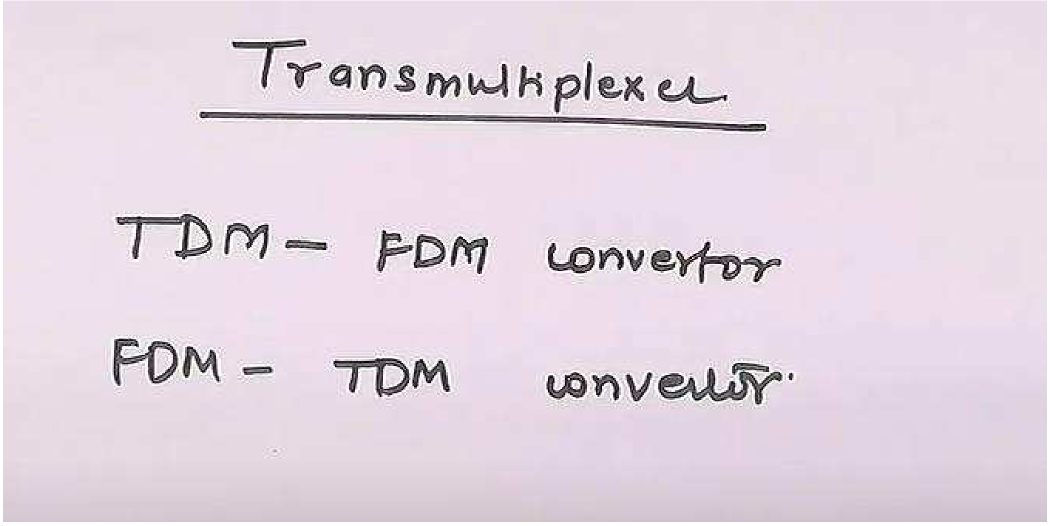
DTMF Signal Detection – The Goertzel Algorithm

As described above, the Goertzel algorithm is a method even faster than the Fast Fourier Transform (FFT) for detection of a tone with a particular frequency in a signal. There is no magic: this is accomplished by focusing only on one target frequency and ignoring the rest of the DFT output.

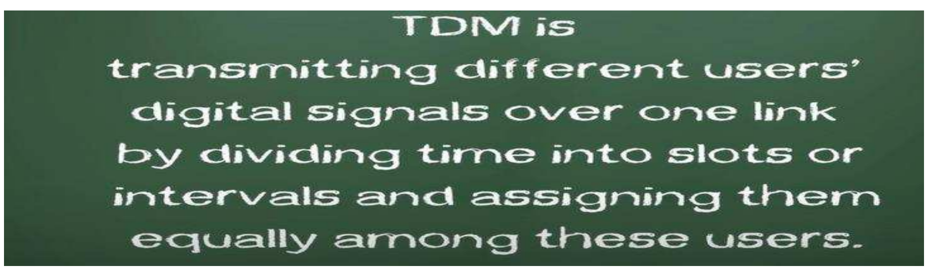
How to Generate and Detect Dual Tone Multi-Frequency (DTMF) Signals

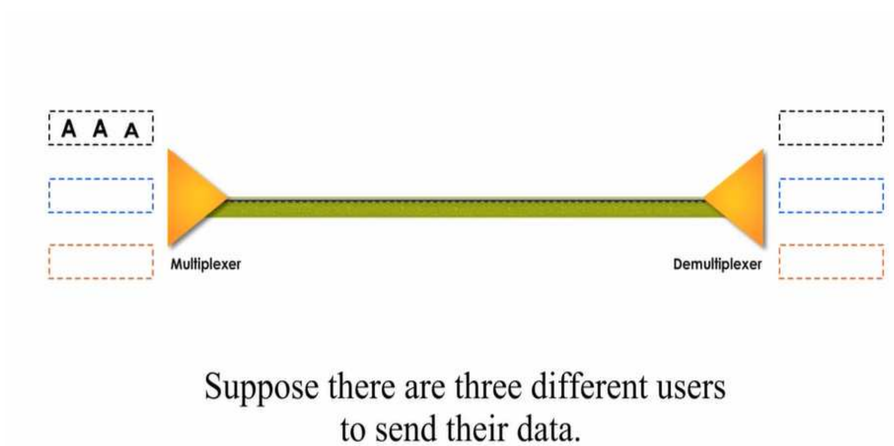
When the code above is run for the signal corresponding to key 6 generated earlier in this article, the output is shown in the figure below. It is clear that the two frequencies 770 Hz and 1477 Hz are present in the signal thus leading to the result that key 6 was pressed at the other end of the line.

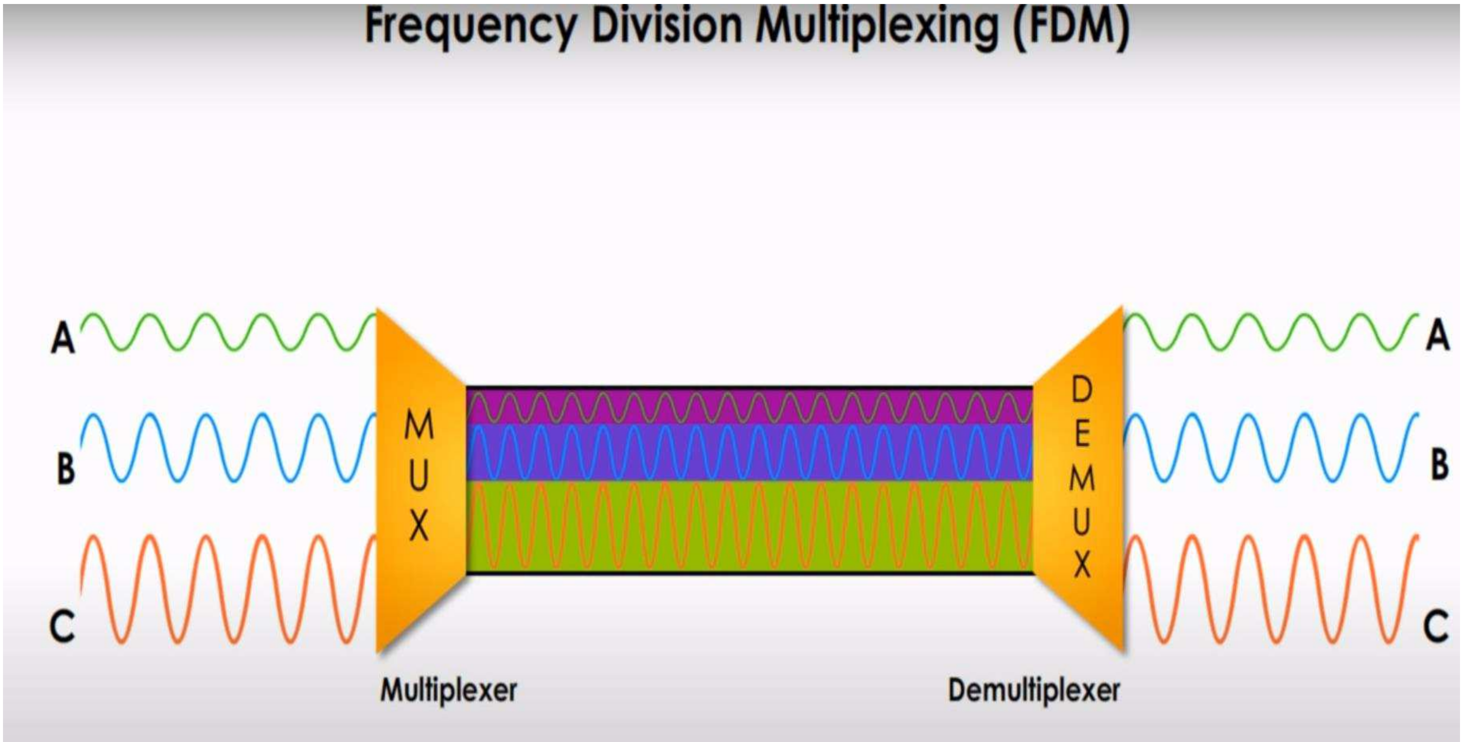


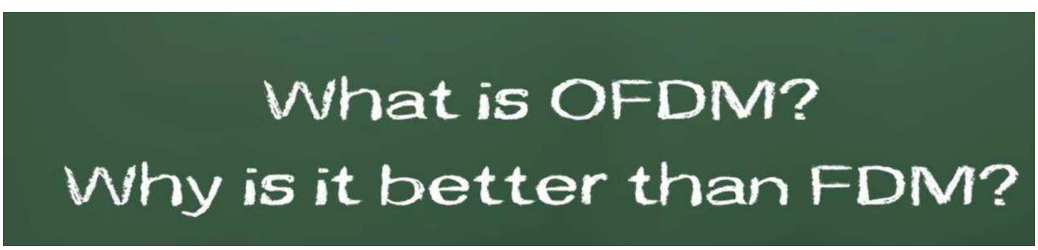


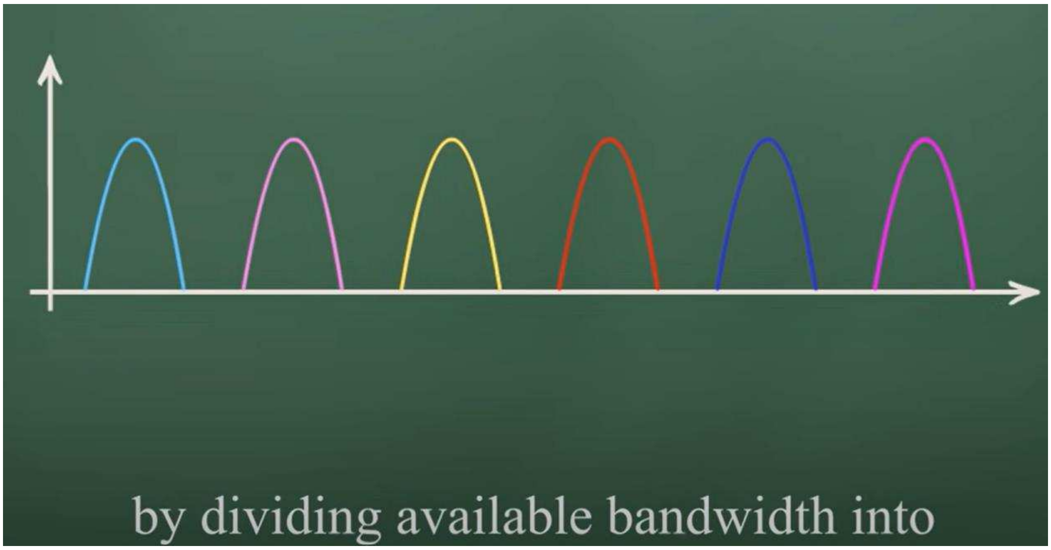
❖ **In transmultiplexing systems digital images (data) are combined into one image (signal) in order to be sent through a single communication channel. At the receiver end the combined image (data) is split to recover the transmitted images**



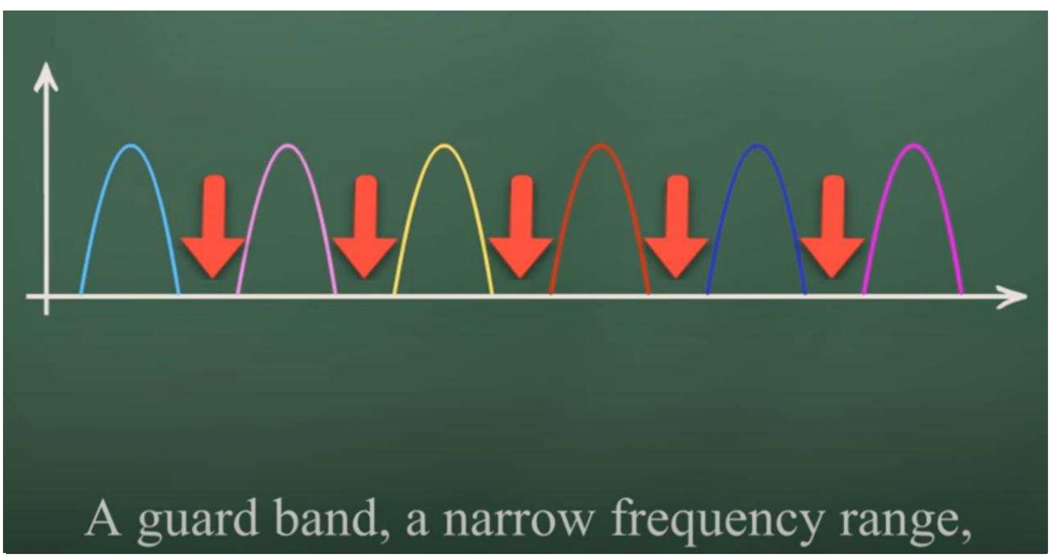



Frequency Division Multiplexing (FDM)
A
B
C
MUX
DEMUX
A
B
C
Multiplexer
Demultiplexer

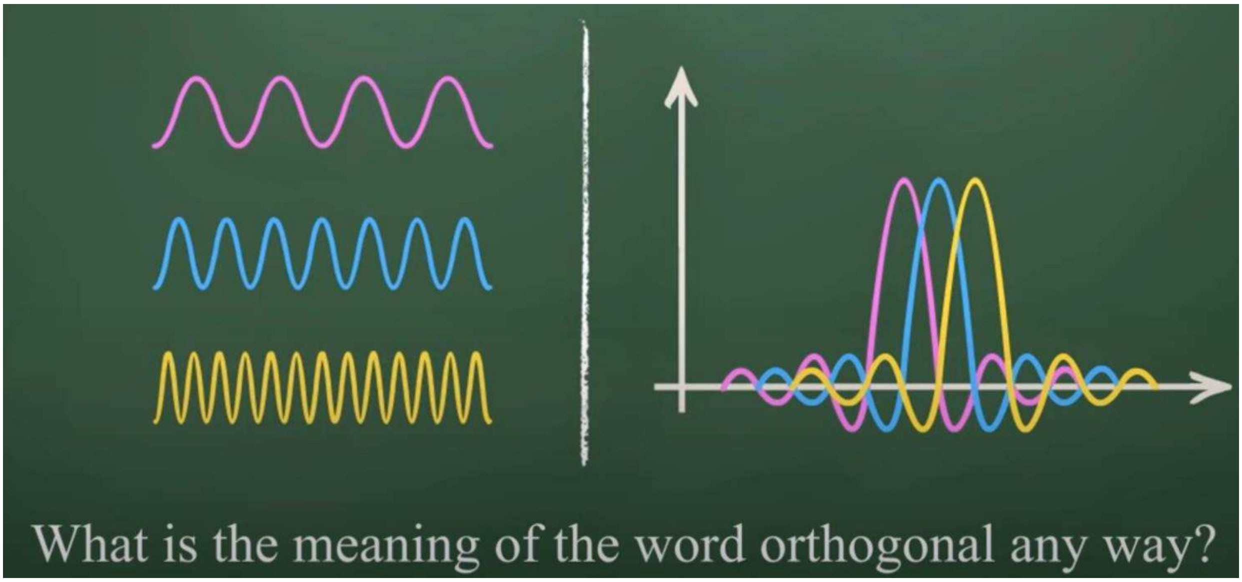

What is OFDM?
Why is it better than FDM?

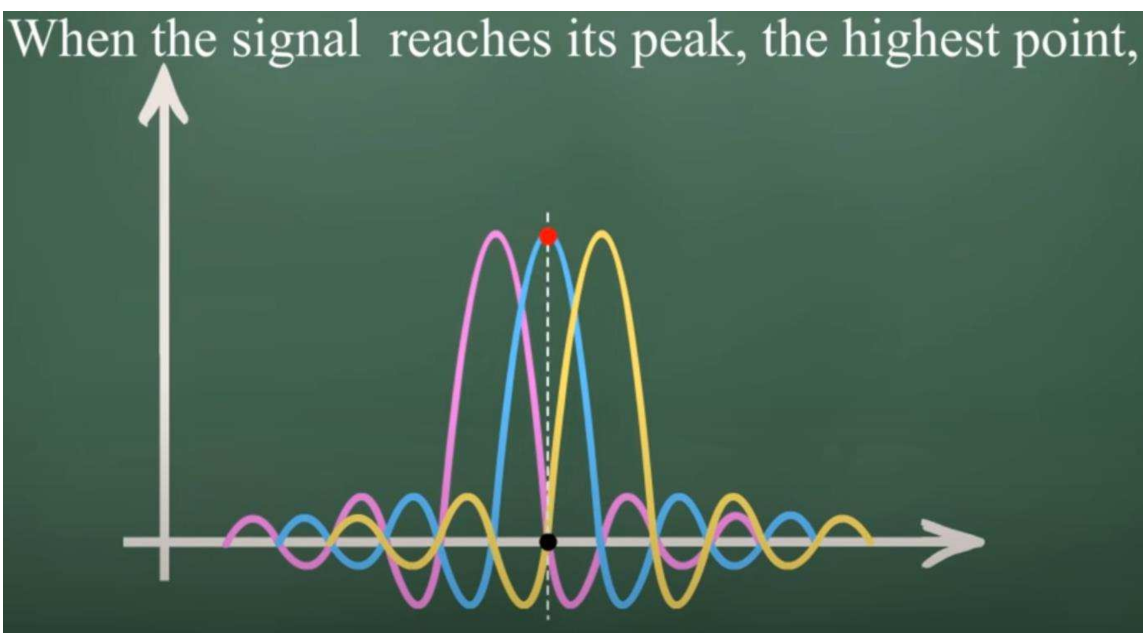


different non-overlapping sub channels.



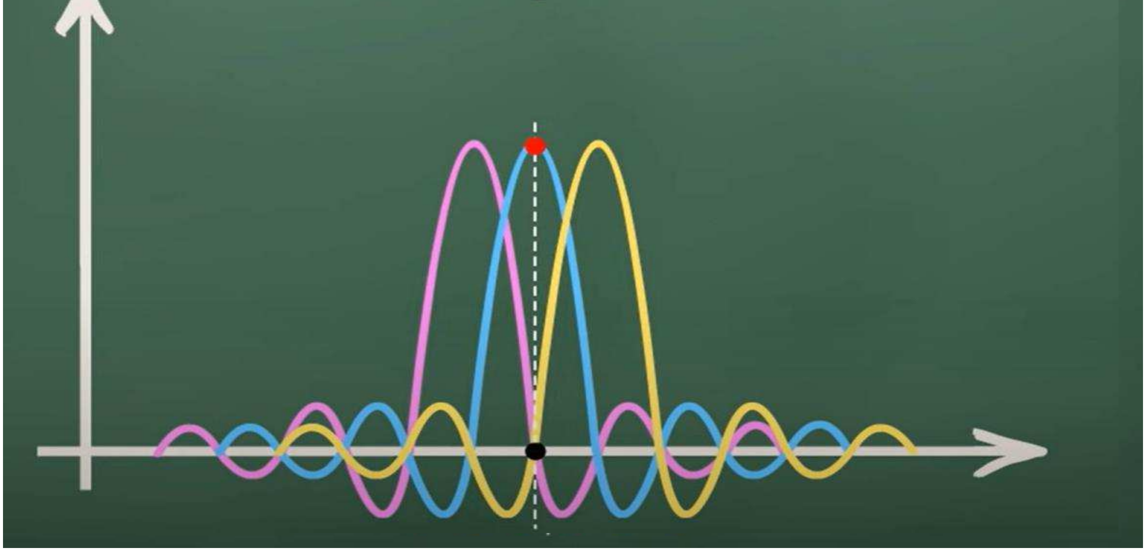
different non-overlapping sub channels.


What is the meaning of the word orthogonal any way?

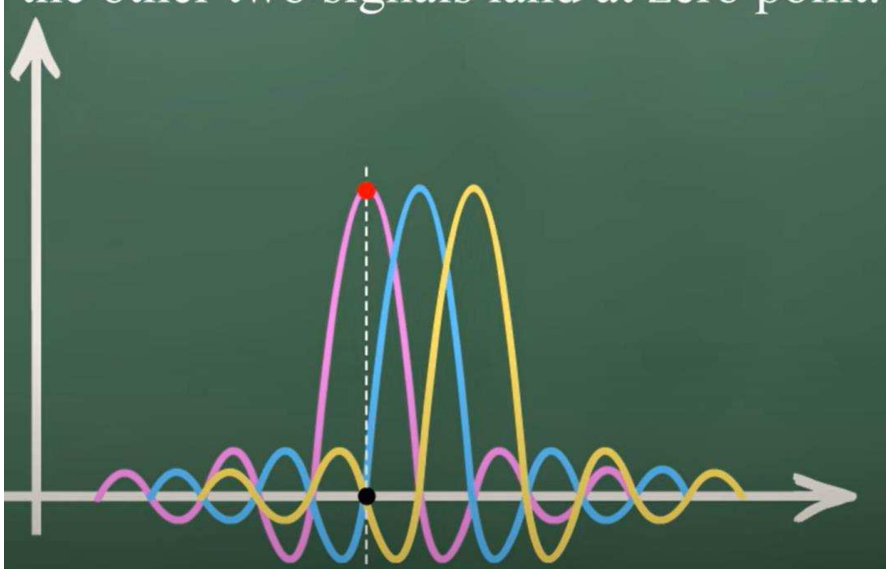

When the signal reaches its peak, the highest point,

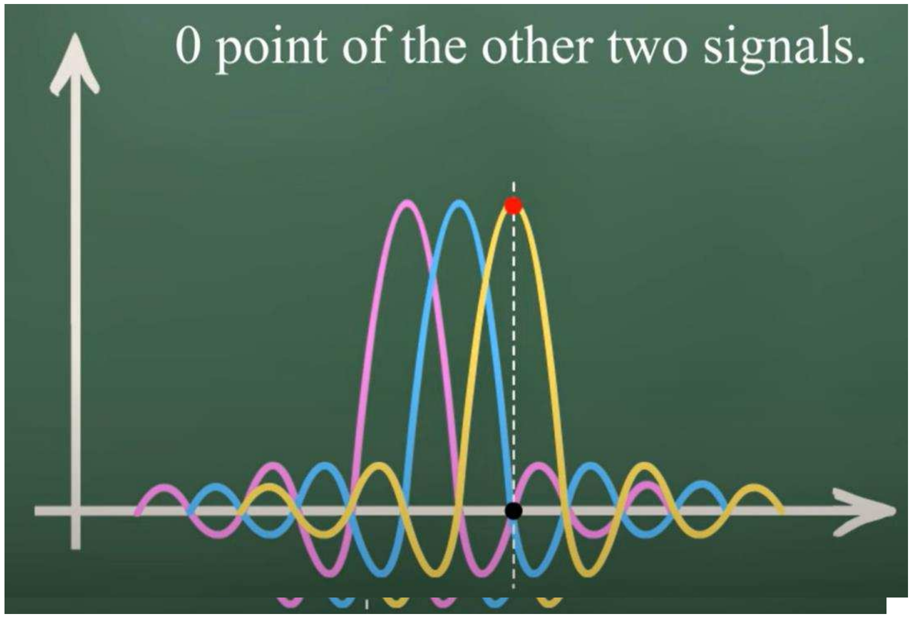
its two neighbors, pink signal and yellow signal

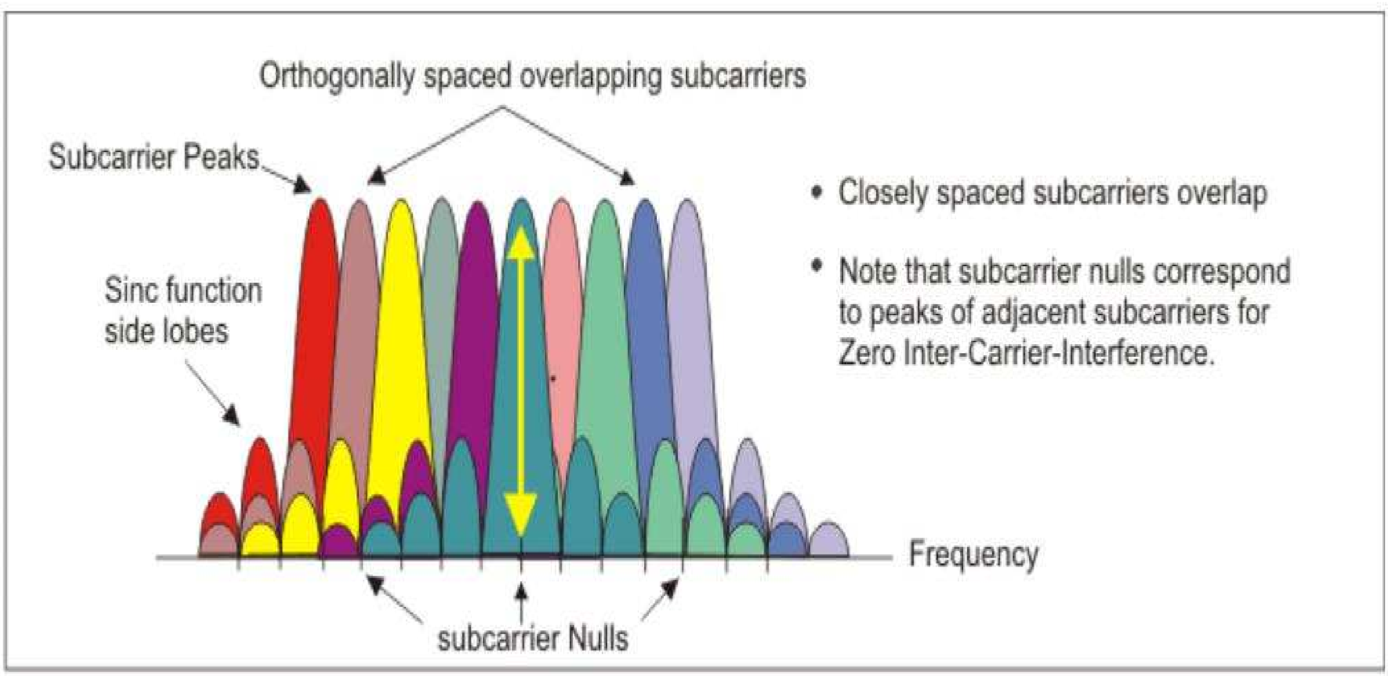
are at their 0 point, or at null.



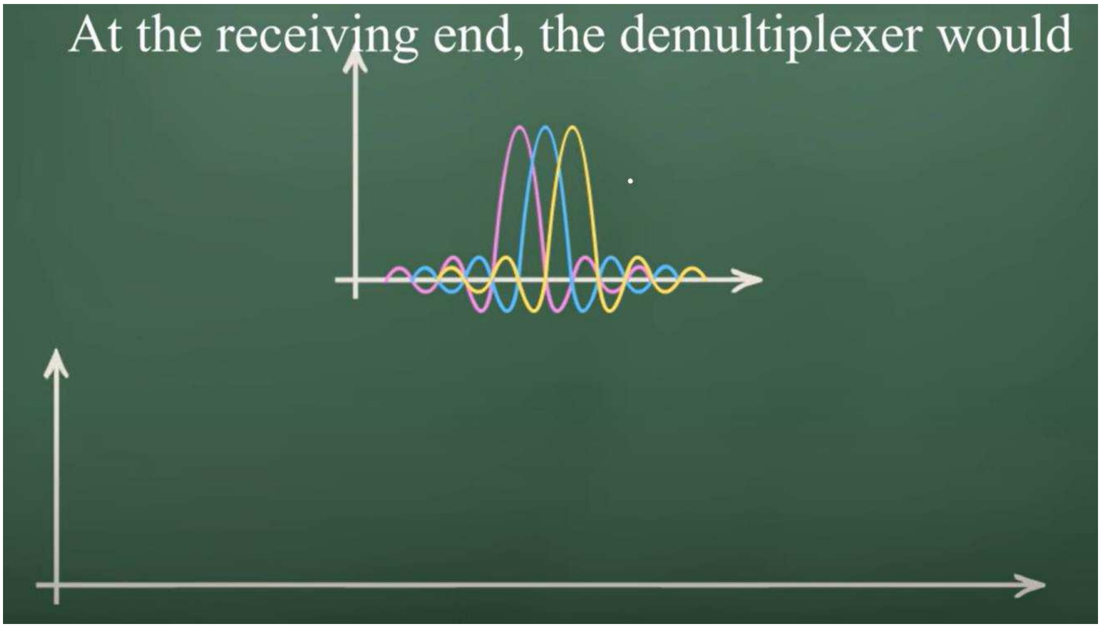
the other two signals land at zero point.

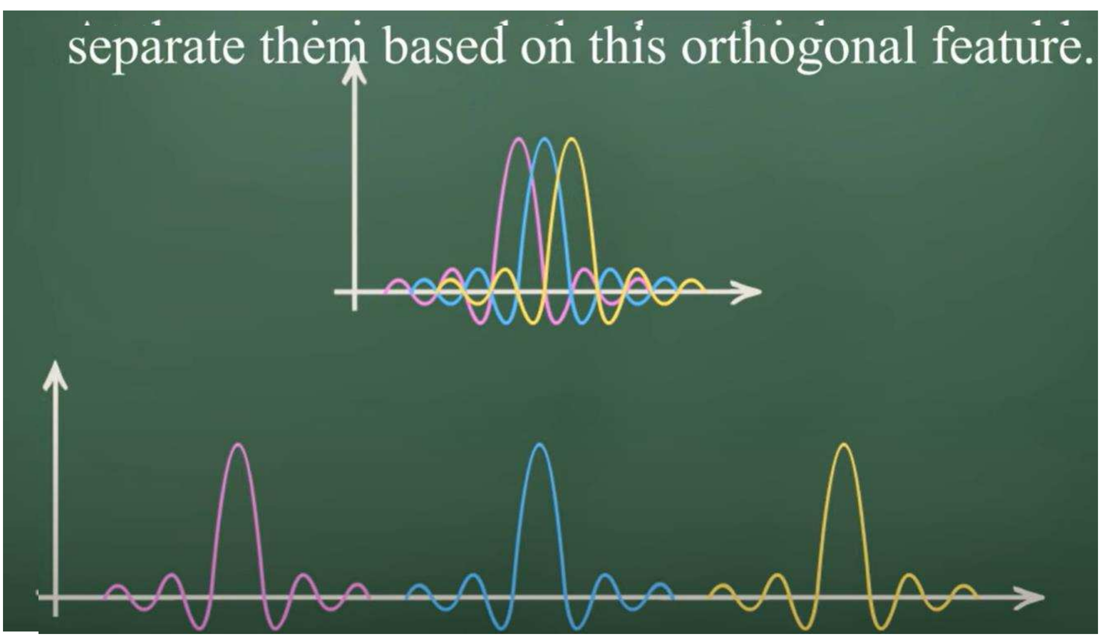






OFDM Signal Frequency Spectra


At the receiving end, the demultiplexer would


separate them based on this orthogonal feature.

OFDM would better utilize the available bandwidth, thus offering higher data transmission rate than FDM.

1970	First patent in the name of OFDM was published [13]
1971	OFDM with DFT was proposed for easier and simple implementation by eliminating the need of banks of subcarrier oscillators [14]
1980	Proposed the use of cyclic prefix in place of guard spaces in OFDM systems to achieve perfect orthogonality among subcarriers [15]
1981	Faster processing of OFDM system achieved by replacing N-point DFT with N/2- point DFT [17]
1990	Different scenarios were proposed where OFDM can be employed [18]
1991	OFDM was studied for applications like ADSL, HDSL and VHDSL [19-20]
1995	OFDM was proposed for use in HDTV [21-22]
1997	OFDM was presented for HiperLAN [23]
1998	OFDM systems were exploited for DVT-B [24]
1999	Symmetric pulses instead of rectangular pulses in OFDM systems were proposed to increase spectral efficiency [25]
	First WLAN (IEEE 802.11a) was proposed having capability of providing data rates up to 54 Mbps [26]
2000	IEEE 802.11b standard was developed to support high data rate operation in the 2.4 GHz band [27]
2003	Family of other WLAN standards summarized [28]
2004	Standard for fixed WMAN/fixed WiMAX/IEEE 802.16d was developed [29]
	Standard for mobile WMAN/mobile WiMAX/802.16e was published [30]
2006	The perspective and challenges for the implementation of MIMO-OFDM wireless systems were discussed [31-32]
2009	Perspectives for LTE as a 4G mobile technology were discussed [33]
2010	OFDM was studied for broadband optical access networks [34]
	The evolution of new version of LTE called as LTE-Advanced was discussed [35]
2012	ITU accepted "LTE-Advanced" and "WirelessMAN-Advanced" as official specifications of IMT-Advanced Standard [36]

2012	ITU accepted "LTE-Advanced" and "WirelessMAN-Advanced" as official specifications of IMT-Advanced Standard [36]
2013	The integration of WiMAX and LTE was proposal [37]
2014	Different hybrid wireless optical broadbandaccess network (WOBAN) technologies were reviewed and compared [38]
2015	MIMO-OFDM was investigated for visible light communication [39]
2017	Opportunities for coexistence of LTE and Wi-Fi were evaluated and analyzed for future 5G Systems [40]
2018	A new architecture for WDM-PON based on optical orthogonal frequency division multiplexing and self-homodyne detection was proposed to lower system complexity and power consumption requirements [41]
	OFDMA was exploited for Light-fidelity (Li-Fi) to support multiuser access using VLC [42]

Wi-Fi generations

Generation	IEEE standard	Adopted	Maximum link rate (Mbit/s)	Radio frequency (GHz)
Wi-Fi 7	802.11be	(2024)	1376 to 46120	2.4/5/6
Wi-Fi 6E	802.11ax	2020	574 to 9608[1]	6[2]
Wi-Fi 6		2019		2.4/5
Wi-Fi 5	802.11ac	2014	433 to 6933	5[3]
Wi-Fi 4	802.11n	2008	72 to 600	2.4/5
*(Wi-Fi 3)**	802.11g	2003	6 to 54	2.4
*(Wi-Fi 2)**	802.11a	1999	6 to 54	5
*(Wi-Fi 1)**	802.11b	1999	1 to 11	2.4
*(Wi-Fi 0)**	802.11	1997	1 to 2	2.4
*(Wi-Fi 0, 1, 2, 3, are unbranded common usage)[4][5][6][7]				

SSID:
MAHE-MIT

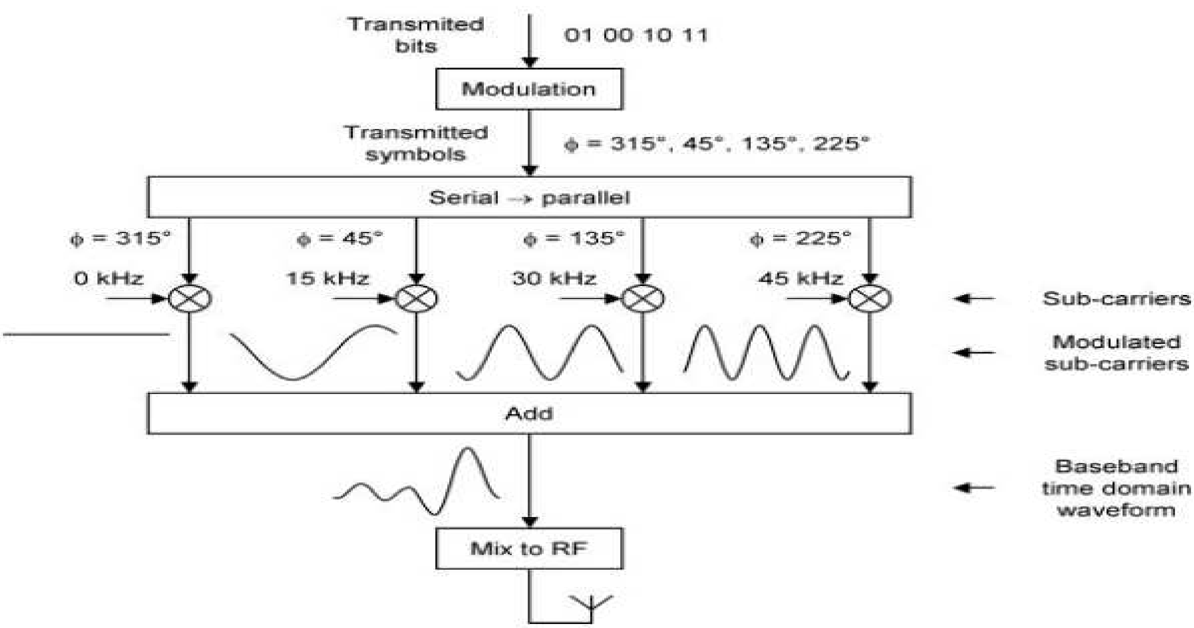
Protocol:
Wi-Fi 5 (802.11ac)

Security type:
Open

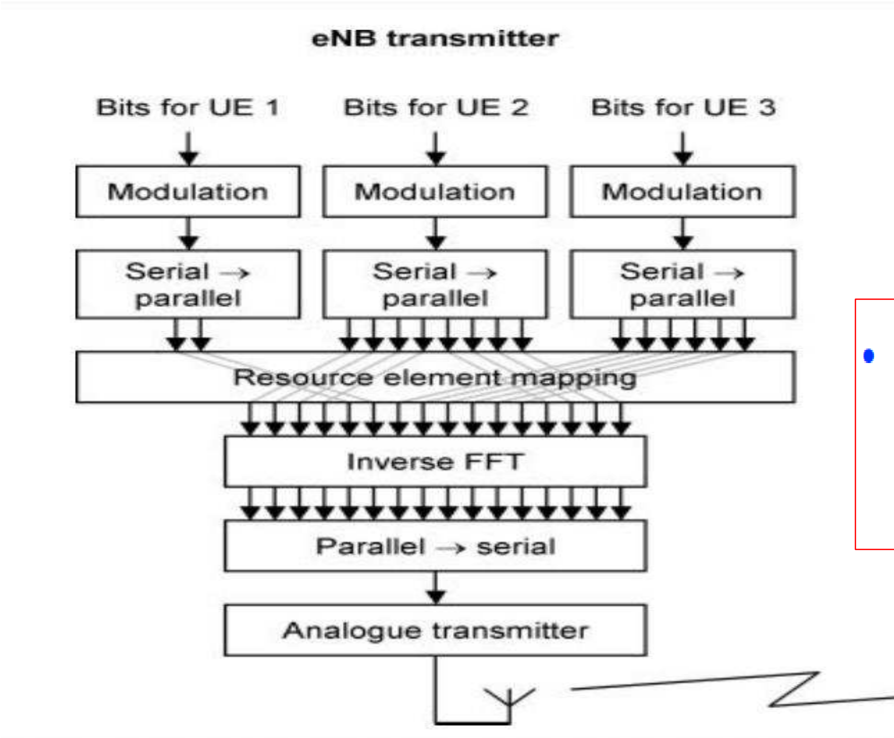
Manufacturer:
Intel Corporation

Description:
Intel(R) Wi-Fi 6 AX201 160MHz

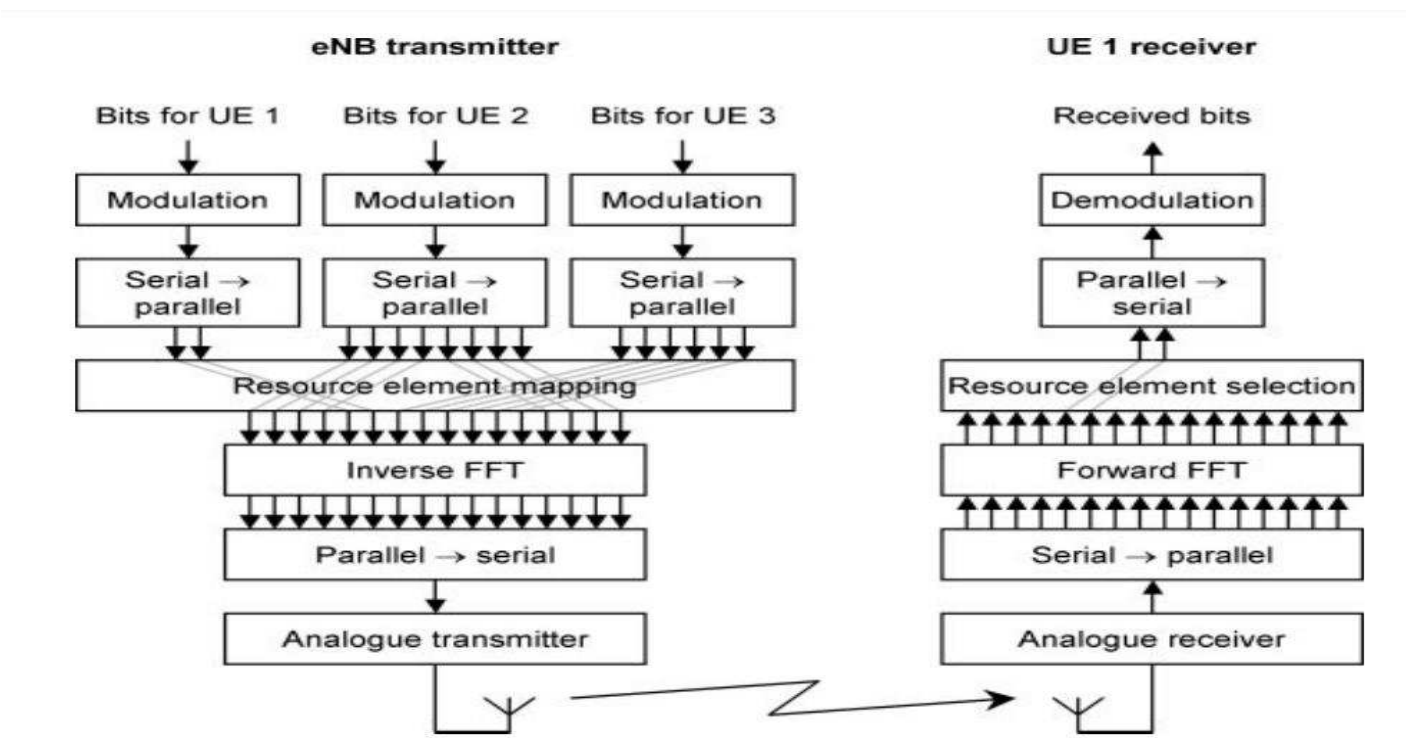
Driver version:
22.170.0.3

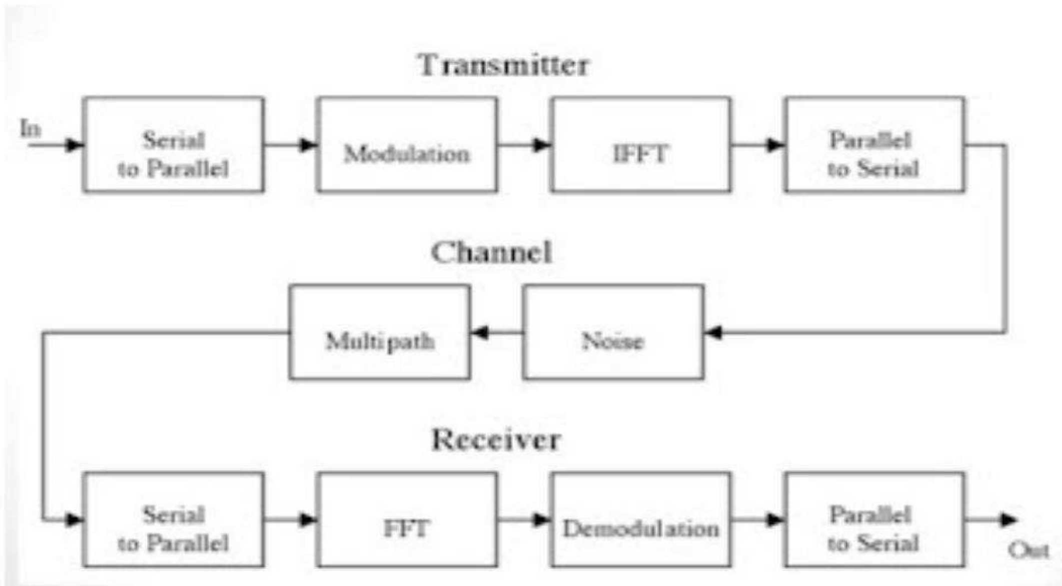


Simple OFDM Generation



- The resource element mapper takes the individual sub-streams and chooses the subcarriers on which to transmit them





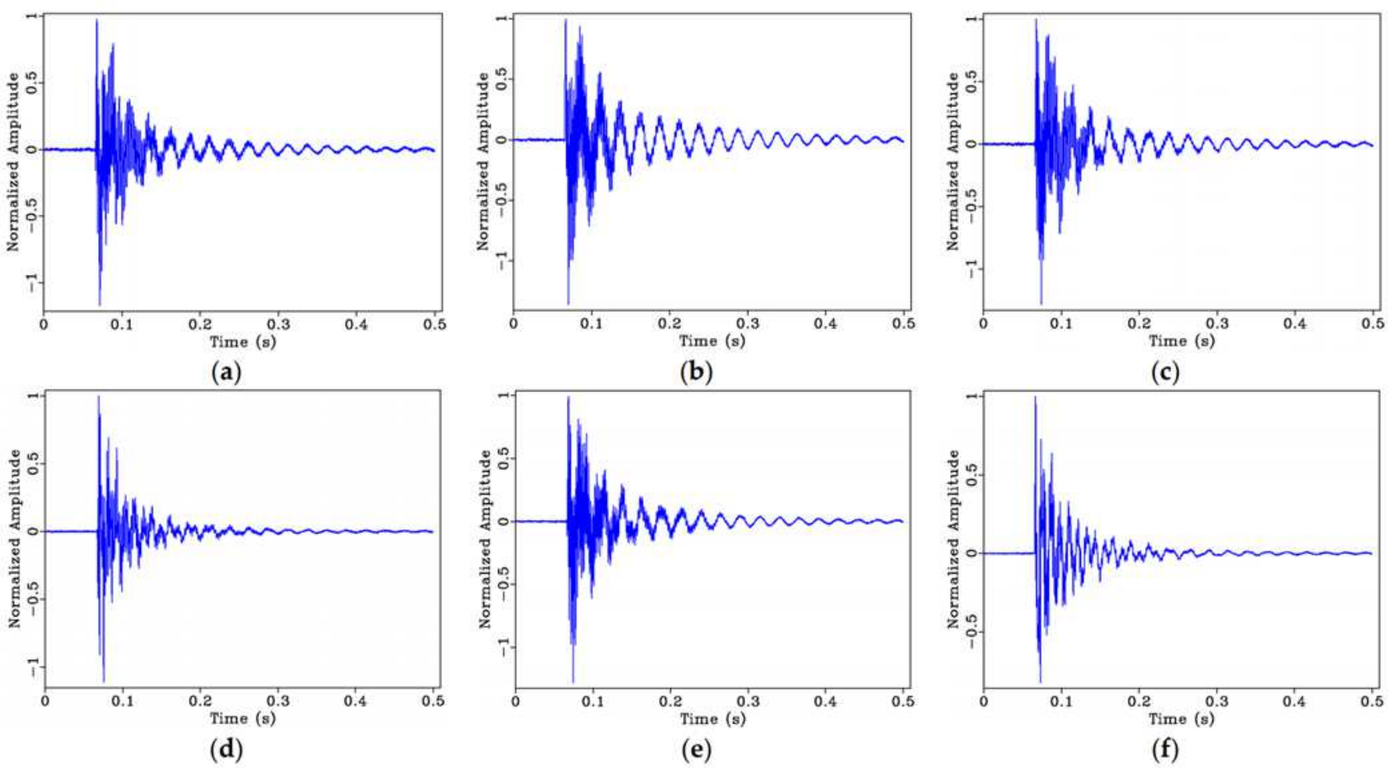
OFDM block diagram

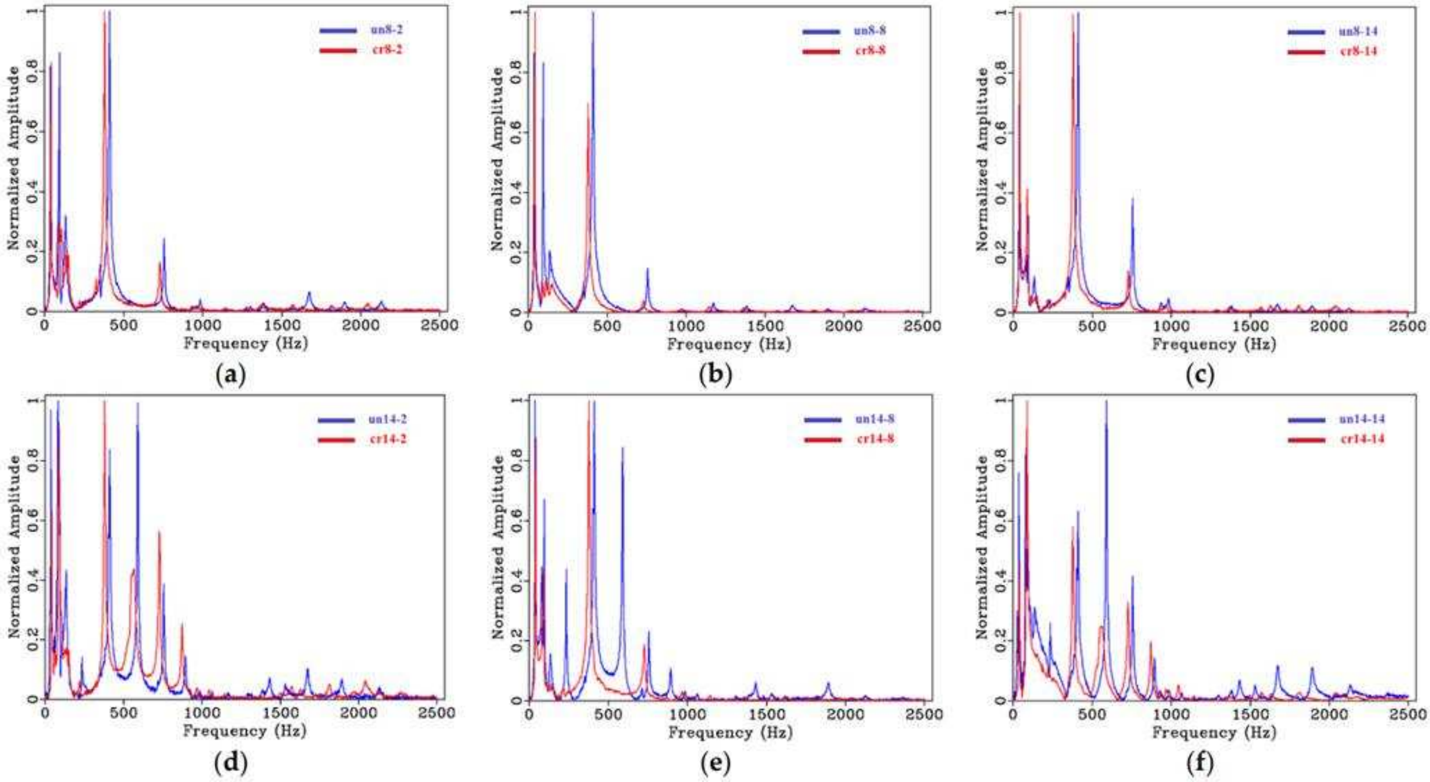
Damage Detection in Reinforced Concrete Member Using Local Time-Frequency Transform Applied to Vibration Measurements

Damage Detection in Reinforced Concrete Member Using Local Time-Frequency Transform Applied to Vibration Measurements

Table 2. Natural vibration frequencies of uncracked and cracked girders (un14-2 and cr14-2).

Modes of Nature Frequency	Frequency (Hz)		Shift (Hz)	Shift in %
	Uncracked	Cracked		
1	38	42	+4	10.5%
2	84	90	+6	7.1%
3	134	140	+6	4.4%
4	236	220	−16	6.8%
5	412	380	−32	7.8%
6	592	566	−26	4.4%
7	758	730	−28	3.7%
8	896	874	−22	2.5%
9	988	968	−20	2%
10	1068	1048	−20	1.9%





DAMAGE IDENTIFICATION OF STRUCTURES USING INSTANTANEOUS FREQUENCY CHANGES

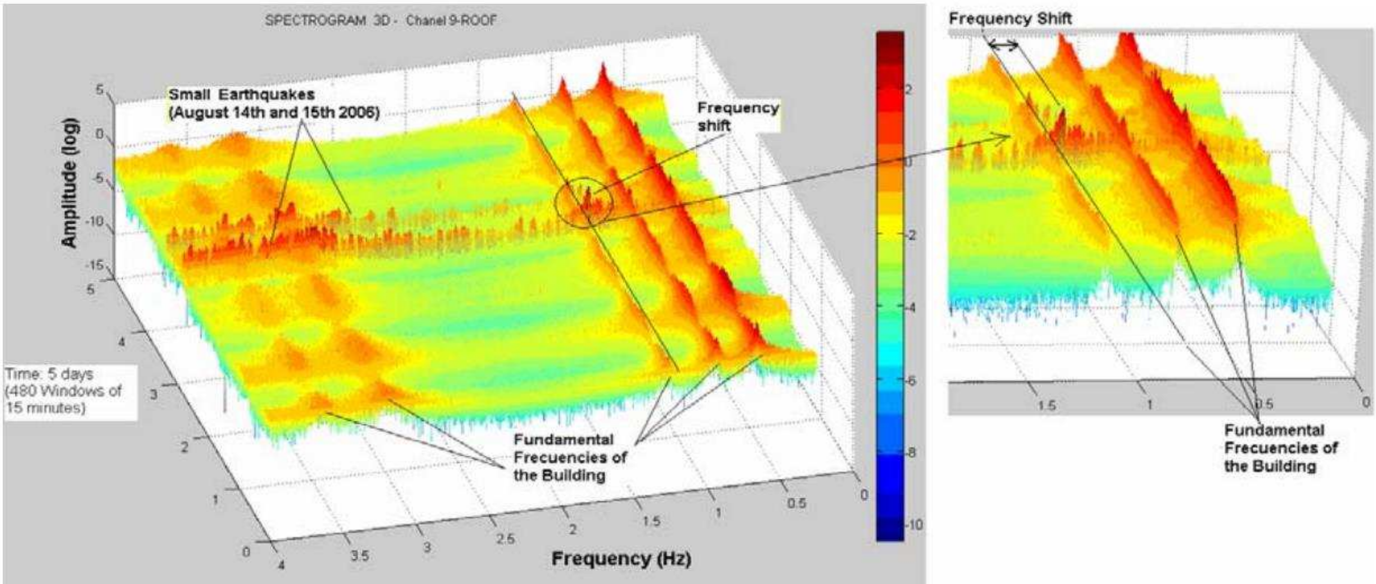


Figure 4: STFT of 5 days continuous recording taken in residential building in San Juan P.R. (3D View).

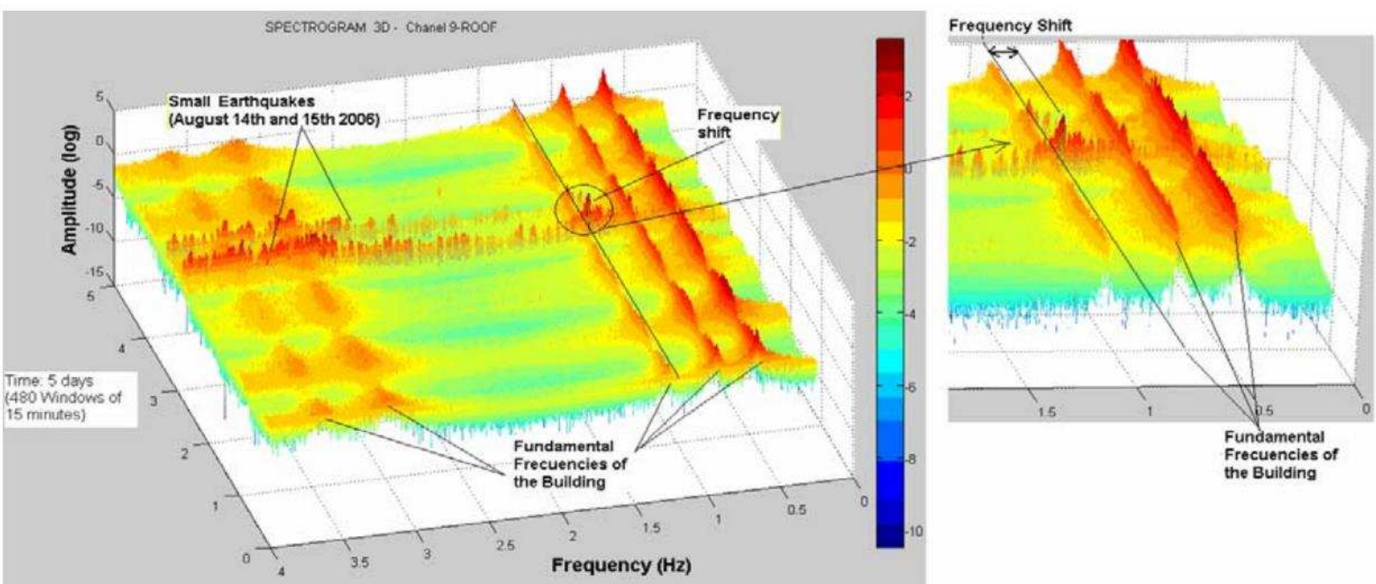


Figure 4: STFT of 5 days continuous recording taken in residential building in San Juan P.R. (3D View).

Figures 3 and 4 shows that the small earthquake of August 14th/2006 produced a temporary shift in frequency of 4% (from 1.27 Hz to 1.22 Hz, the frequency returned to its initial value of 1.27 Hz at the end of the excitation), therefore non damage occur.

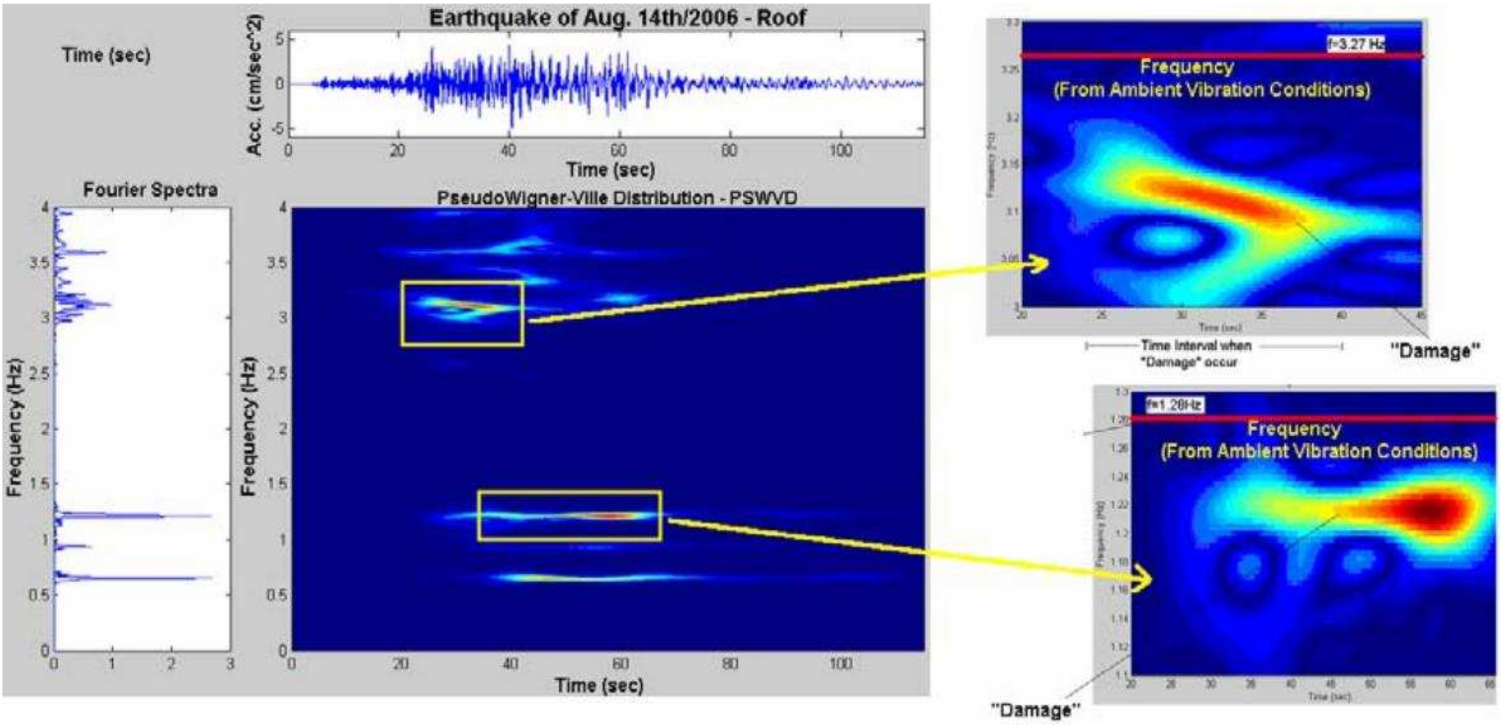


Figure 7: Pseudo Wigner Ville Distribution for a magnitude 5.0 tremor recorded on 14-08-2006 at the roof (26th floor) of a residential building.

COURSE OUTCOMES (COS)

At the end of this course, the student should be able to:		No. of Contac Hours	Marks	Program Outcomes (POs)	PSO	BL (Recommended)
CO1	Evaluate Z-transform for analysis of LTI systems.	12	22	1-3,5	1,2	2-5
CO2	Evaluate discrete fourier tranaform and fast fourier transforms for discrete signals.	10	24	1-3,5	1,2	2-5
CO3	Understand the design of digital filters.	16	34	1-3,5	1,2	2-5
CO4	Understand the structures and implementation of digital filters	6	12	1-3,5	1,2	2-5
CO5	Apply the principles of digital signal processing to real world problems	4	8	1-3,5	1,2	2-5
	Total	**48**	**100**			

45	Applications of DSP-dual tone multi frequency signal detection	CO5
46	Signal compression, transmultiplexers	CO5
47	Oversampling, digital signal processors introduction	CO5
48	Review of applications of digital signal processing	CO5

Fig.1.1 Original image

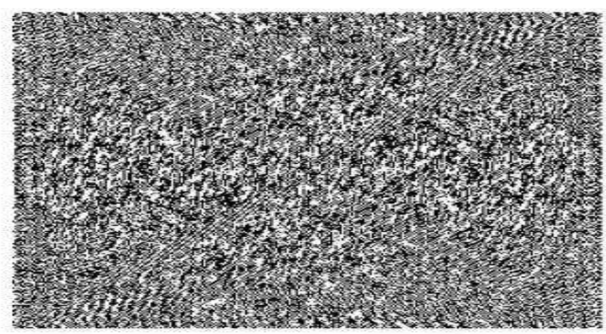


Fig.1.2 Fourier transformed image

- **The Fourier spectrum is obtained by using function abs i.e. S= abs(C). This computes the magnitude of each element of the array.**

- **fft2 puts the zero frequency components at the top left corner. Another function fftshift can be used to make the origin of the transform to the centre of the frequency**

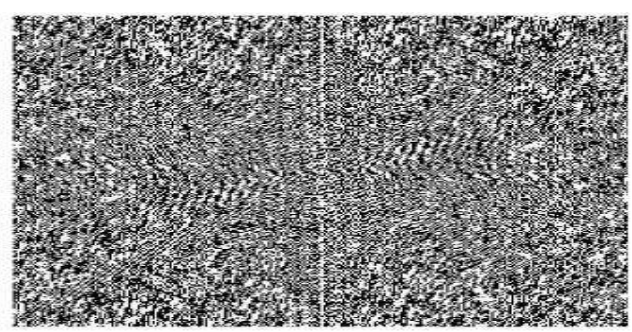
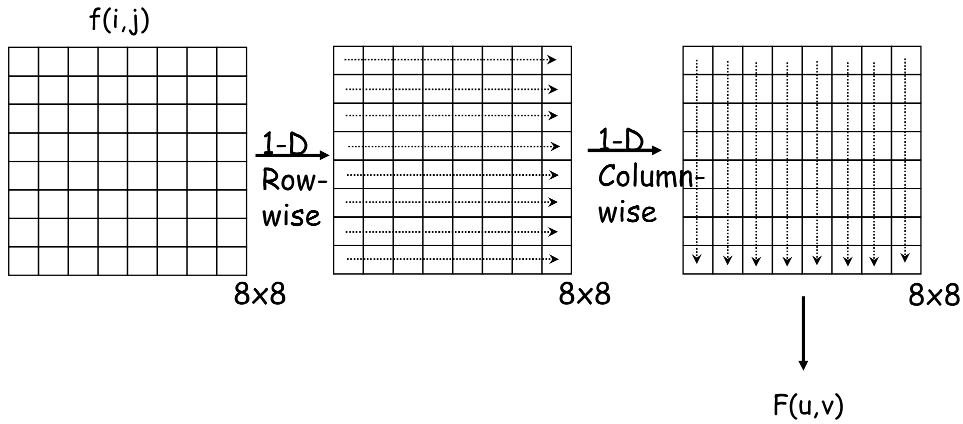


Fig.1.4 Fourier transformed apply

2-D FFT

- Images are two-dimensional; How do you perform 2-D FFT?
  - Two series of 1-D transforms result in a 2-D transform as demonstrated in the figure below



- F(0,0) is called the DC component and the rest of F(i,j) are called *AC components*

2-D Transform Example

- The following example will demonstrate the idea behind a 2-D transform by using our own cooked up transform: The transform computes a running cumulative sum.

f(i,j)

1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1

8x8

My Transform: $F_{my}(\omega) = \sum_{n=\omega}^{8} f(n)$

1-D Row-wise →

8	7	6	5	4	3	2	1
8	7	6	5	4	3	2	1
8	7	6	5	4	3	2	1
8	7	6	5	4	3	2	1
8	7	6	5	4	3	2	1
8	7	6	5	4	3	2	1
8	7	6	5	4	3	2	1
8	7	6	5	4	3	2	1

8x8

1-D Column wise →

$F_{my}(u,v)$

64	56	48	40	32	24	16	8
56	49	42	35	28	21	14	7
48	42	36	30	24	18	12	6
40	35	30	25	20	15	10	5
32	28	24	20	16	12	8	4
24	21	18	15	12	9	6	3
16	14	12	10	8	6	4	2
8	7	6	5	4	3	2	1

8x8

Note that this is only a hypothetical transform. Do not confuse this with DCT

The End