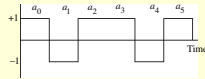


Discrete Multitone Transmission

- Binary data are normally transmitted serially as a pulse train as indicated below



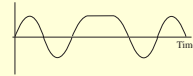
- However, in order to faithfully extract the information transmitted, the receiver requires complex equalization procedure to compensate for channel imperfection and to make full use of the channel bandwidth

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Discrete Multitone Transmission

- For example, the pulse train shown in the previous slide arriving at the receiver may appear as indicated below



- To alleviate the problems encountered with the transmission of data as a pulse train, frequency-division multiplexing with overlapping subchannels have been proposed

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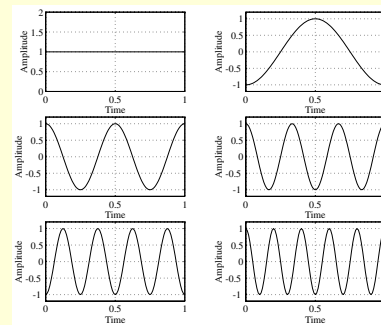
Discrete Multitone Transmission

- In such a system, each binary digit a_r , $r = 0, 1, \dots, N-1$, modulates a subcarrier sinusoidal signal $\cos(2\pi r t / T)$ as indicated in the next slide, for the transmission of the data shown in Slide 1
- The modulated subcarriers are summed and transmitted as one composite analog signal

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Discrete Multitone Transmission



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Discrete Multitone Transmission

- At the receiver, the analog signal is passed through a bank of coherent demodulators whose outputs are tested to determine the digits transmitted
- This is the basic idea behind the multicarrier modulation/demodulation scheme for digital data transmission

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Discrete Multitone Transmission

- A widely used form of multicarrier modulation is the discrete multitone transmission (DMT) scheme in which the modulation and demodulation processes are implemented via the discrete Fourier transform (DFT), efficiently realized using FFT methods
- This approach leads to an all-digital system, eliminating the arrays of sinusoidal generators and the coherent demodulators

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Discrete Multitone Transmission

- We outline next the basic idea behind the DMT scheme
- Let $\{a_k[n]\}$ and $\{b_k[n]\}$, $0 \leq k \leq M-1$, be two real-valued data sequences operating at a sampling rate of F_T that are to be transmitted
- A new set of complex sequences $\{\alpha_k[n]\}$ of length $N = 2M$ is defined next as shown in the next slide

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Discrete Multitone Transmission

$$\alpha_k[n] = \begin{cases} a_0[n], & k = 0, \\ a_k[n] + jb_k[n], & 1 \leq k \leq \frac{N}{2} - 1, \\ b_0[n], & k = \frac{N}{2}, \\ a_{N-k}[n] + jb_{N-k}[n], & \frac{N}{2} - 1 \leq k \leq N-1 \end{cases}$$

- Apply an inverse DFT to transform the above sequences into a new set of signals given by

$$u_\ell[n] = \frac{1}{N} \sum_{k=0}^{N-1} \alpha_k[n] W_N^{-\ell k}, \quad 0 \leq \ell \leq N-1$$

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Discrete Multitone Transmission

where $W_N = e^{-j2\pi/N}$

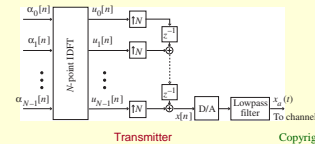
- **Note:** The method of generation of the complex sequence set $\{\alpha_k[n]\}$ ensures that its IDFT $\{u_\ell[n]\}$ will be a real sequence
- Each of these N signals is then up-sampled by a factor of N and time-interleaved, generating a composite signal $\{x[n]\}$ operating at a rate of NF_T that is assumed to be equal to $2F_c$

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Discrete Multitone Transmission

- The composite signal $\{x[n]\}$ is then converted into an analog signal $x_a(t)$ by passing it through a D/A converter, followed by an analog reconstruction filter
- The analog signal $x_a(t)$ is then transmitted over the channel



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Discrete Multitone Transmission

- At the receiver, the received analog signal $y_a(t)$ is passed through an analog anti-aliasing filter and then converted into a digital signal $\{y[n]\}$ by an S/H circuit, followed by an A/D converter operating at a rate of $NF_T = 2F_c$
- The received digital signal is then deinterleaved by a delay chain containing $N-1$ unit delays, whose outputs are next down-sampled by a factor of N , generating the set of signals $\{v_\ell[n]\}$

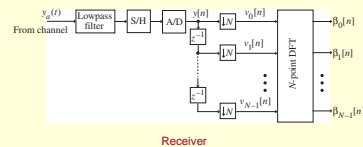
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Discrete Multitone Transmission

- Applying the DFT to these N signals, we finally arrive at N signals $\{\beta_k[n]\}$ given by

$$\beta_k[n] = \sum_{\ell=0}^{N-1} v_\ell[n] W_N^{\ell k}, \quad 0 \leq k \leq N-1$$



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Discrete Multitone Transmission

- If the channel's frequency response is assumed to have a flat passband, and the analog reconstruction and anti-aliasing filters are assumed to be ideal lowpass filters, it can be shown that

$$v_k[n] = u_{k-1}[n], \quad 0 \leq k \leq N-2$$

$$v_0[n] = u_{N-1}[n]$$

- Or, equivalently,

$$\beta_k[n] = \alpha_{k-1}[n], \quad 0 \leq k \leq N-2$$

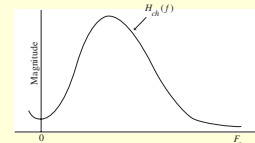
$$\beta_0[n] = \alpha_{N-1}[n]$$

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Discrete Multitone Transmission

- Transmission channels, in general have a bandpass frequency response $H_{ch}(f)$
- In some cases, in the passband of the channel, the magnitude response drops very rapidly outside its passband as indicated below



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Discrete Multitone Transmission

- For reliable digital data transmission over such a channel and its recovery at the receiving end, the channel's frequency response needs to be compensated by essentially a highpass equalizer at the receiver
- However, such an equalization also amplifies high-frequency noise that is invariably added to the data signal as it passes through the channel

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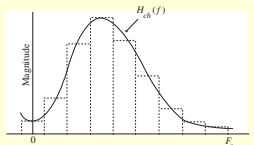
Discrete Multitone Transmission

- For a large value of the DFT length N , the channel can be assumed to be composed of a series of contiguous narrow-bandwidth bandpass subchannels
- If the bandwidth is reasonably narrow, the corresponding bandpass subchannel can be considered to have an approximately flat magnitude response as indicated by the dotted lines in the figure in the next slide

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Discrete Multitone Transmission



- The subchannel can then be approximately characterized by a single complex number given by the value of its frequency response at $\omega = 2\pi k / N$

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Discrete Multitone Transmission

- The values can be determined by transmitting a known training signal of unmodulated carriers and generating the channel's frequency response
- The real data samples at the outputs of the receiver are then divided by these complex numbers to compensate for channel distortion

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