Digitalne komunikacije i OFDM postupak

1.6.2004

Zavod za elektroakustiku

Predmet: Prijamnici

Communication toolbox i Communication Blockset

- Kolekcije funkcija za istraživanje, razvoj, dizajniranje sustava, analizu i simulaciju u komunikacijskom području:
- izvor signala
- analiza signala
- kodiranje signala izvora informacije
- modulacija i demodulacija
- različiti modeli kanala(AWGN, Rayleighev..)

Sadržaj:

- Communication toolbox i Communication blockset u Matlabu (vrste kanala, baseband i passband modulacija)
- OFDM postupak (upotreba, realizacija i svojstva)
- Realizacija pojednostavljenog OFDM-a pomoću Communication Blockseta u Simulinku, te simulacija cijelog postupka pomoću funkcija pisanih u Comm. Toolboxu

Spektralna korisnost modulacijskih postupaka

Bits per Hertz

- Baseband binary data
  - 2 bits/Hertz
  - Alpha α is filter factor 0.25 gives 1.6 bit/Hz
- Binary phase shift keying BPSK
  - 1 bit/Hertz
  - Upper and lower sidebands as baseband
- Quadrature phase shift keying QPSK
  - 2 bits/Hertz

Spektralna korisnost modulacijskih postupaka

More bits per Hertz

- 16 Quadrature Amplitude Modulation
  - 16 QAM
  - 4 bits/Hertz
- 64 Quadrature Amplitude Modulation
  - 64 QAM
  - 6 bits/Hertz

Osjetljivost na šum za pojedine modulacijske postupke

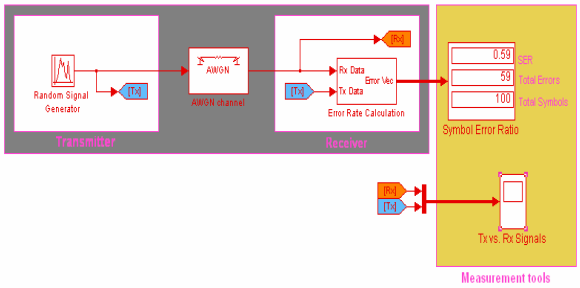
Energy per Bit / Noise Density

- E/N0 = Energy per bit / Noise density
- Additive White Gaussian Noise AWGN
- Un-coded error rate 10^{-4}
- BPSK or QPSK 8.5 dB
- 16 QAM 15.5 dB
- 64 QAM 21.7 dB

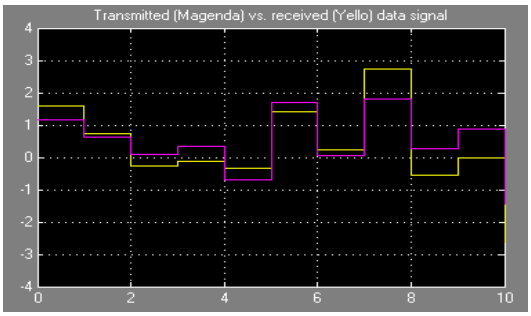
Vrste kanala

- Analogni kanal: utjecaj bijelog šuma se simulira najčešće dodavanjem AWGN bloka
- AWGN je diskretni model kanala jer je analogni signal određen svojom rezolucijom u Matlabu
- Digitalni kanal se simulira tako da digitalni šum mijenja 0 u 1 ili obratno

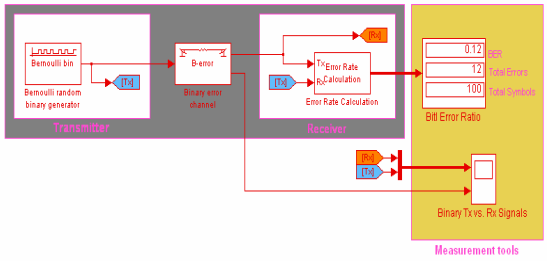
Primjer jednostavnog analognog kanala



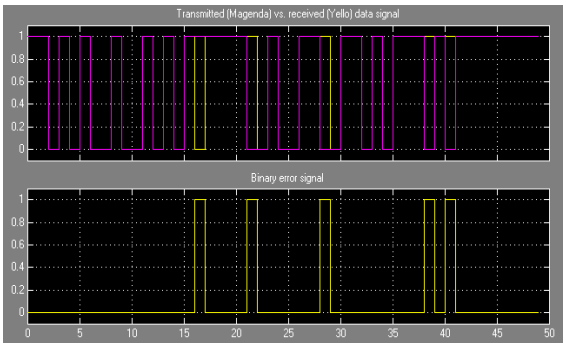
Rezultati simulacije



Jednostavan digitalni kanal

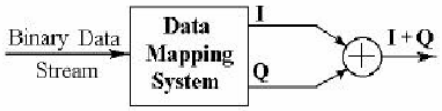


Rezultati simulacije

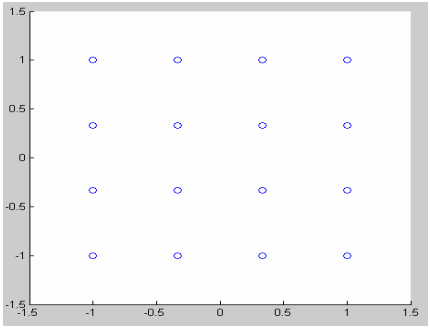


Modulacija u Matlabu

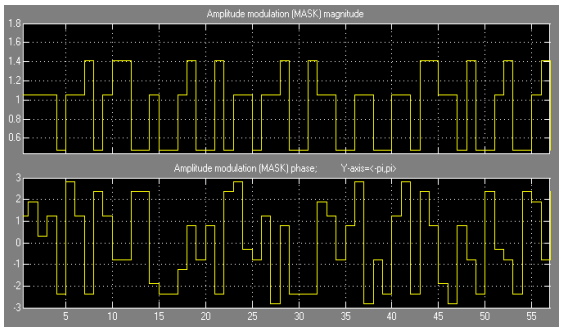
- Baseband modulacija: izlaz je kompleksna ovojnica signala (I-kofazna komponenta,Q-kvadraturna komponenta)



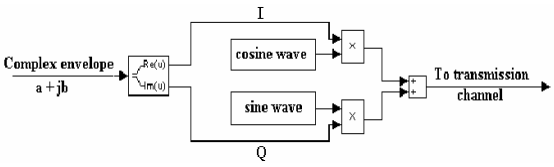
Primjer 16-QAM



16-QAM baseband

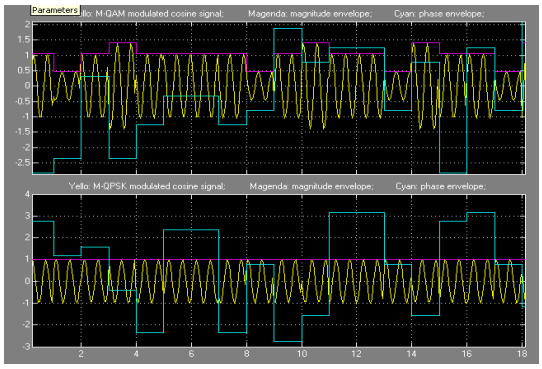


Passband modulacija

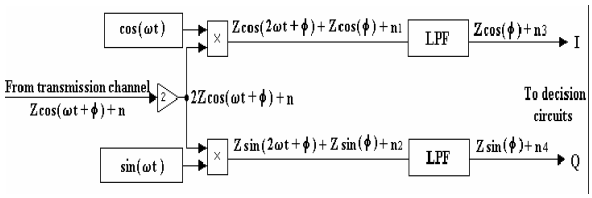


$$\sqrt{I(m)^2 + Q(m)^2} \cdot \cos(2 \cdot \pi \cdot F_C \cdot t + arctg(\frac{Q(m)}{I(m)}))$$

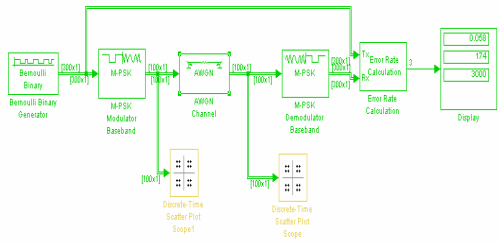
Passband modulacija(16-QAM 16-PSK)



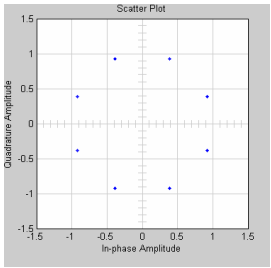
16-QAM demodulator

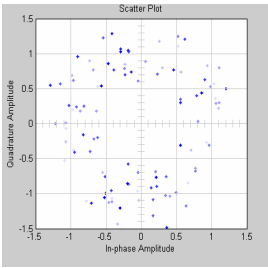


Jednostavan odašiljač i prijamnik



Rezultati simulacije





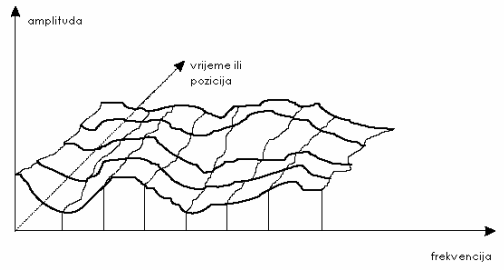
OFDM postupak

- OFDM postaje odabrana tehnika za bežični prijenos
- Sustavi koji koriste OFDM:
- WLAN (802.11a), paketna komunikacija (48 podnosioca, 4 pilot tona, područje oko 5GHz,pojas 20MHZ, 54Mbit/s)
- DAB (192-1500 podnosioca)
- ADSL(1.536Mbit/s), VHDSL (100Mbit/s)
- DRM(Digital Radio Mondiale)

UVOD:

- Multimedijske komunikacije postavljaju velike zahtjeve s obzirom na kvalitetu usluge(QoS)
- “Radio okolina” nestabilna (višestruke refleksije, Dopplerov efekt
- Tokovi podataka su 4kbit/s za govor do 20Mbit/s za HDTV
- Eliminiranje utjecaja kanala pomoću adaptivne ekvilizacije na strani prijema

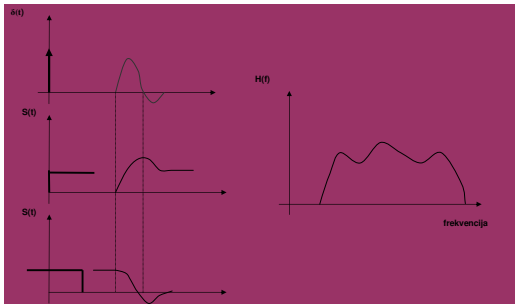
Karakteristika kanala



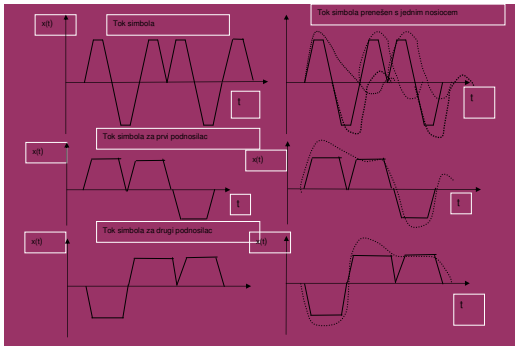
Razvoj OFDM postupka

- 60 ih godina u vojnim komunikacijama
- Veliki broj generatora, modulatora na odašiljačkoj strani te velik broj demodulatora na prijamnoj strani, skupo
- Kompletna digitalna realizacija upotrebom FFT algoritma, jeftinije

Prijenos sa više podnosilaca



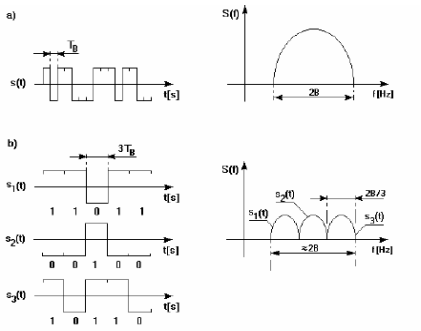
Prijenos sa više podnosilaca



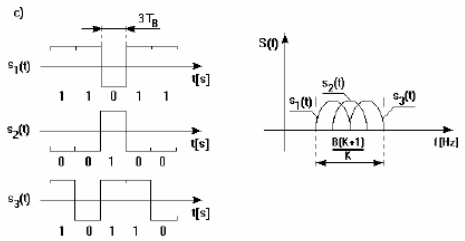
Prijenos s više podnosilaca

- u konvencionalnom načinu prijenosa svaki simbol okupira cijeli pojas
- FDM i OFDM istovremeno se odašilje nekoliko simbola na većem broju podnosilaca
- Kanal se dijeli na više podkanala koji imaju ravnu frekvencijsku karakteristiku
- Ako je feding na pojedinoj frekvenciji jako izražen doći će do gubitka simbola, zato se uvode dodatni simboli na strani odašiljača pa se postupak naziva COFDM

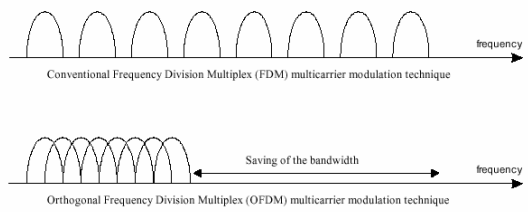
Konvencionalni prijenos i FDM



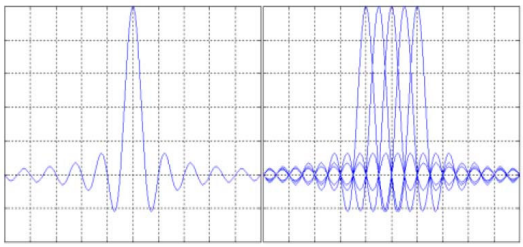
OFDM



FDM i OFDM

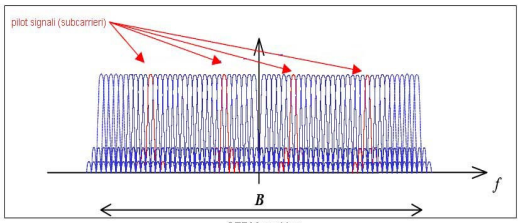


OFDM postupak



a) Frekvencijski spektar za vrijeme trajanja jednog OFDM simbola na jednom podkanalu
b) Frekvencijski spektar za vrijeme trajanja jednog OFDM simbola na više susjednih podkanala

OFDM postupak



OFDM spektar

Matematički opis OFDM-a

- Pojedinačni podnosilac u simboličnom kompleksnom zapisu:

$$s_c(t) = A_c \cdot e^{j[\omega_c t + \phi_c(t)]}$$

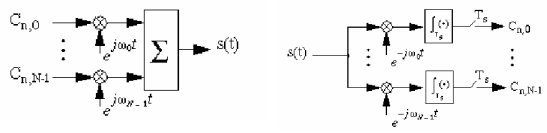
- Svi podnosioci za vrijeme trajanja simbola u simboličnom kompleksnom zapisu:

$$S_s(t) = \sum_{n=0}^{N-1} A_n(t) \cdot e^{j[\omega_n t + \phi_n(t)]}$$

$$s(t) = \sum_{n=0}^{N-1} [(a_n \cos(2\pi f_n t) + b_n \sin(2\pi f_n t)]$$

fn= f0+ n/Tb , n=0,1,....N-1.

Klasični OFDM postupak



$$s(t) = \sum_{n=-\infty}^{n=\infty} \left(\sum_{k=0}^{N-1} C_{n,k}\, g_k(t - n \cdot T_S)\right)$$

$$g_k(t) = \begin{cases} e^{j2\pi f_k t} & , t \in [0, T_S] \\ 0 & \end{cases} \quad f_k = f_0 + \frac{k}{T_S} \quad , k = 0, \ldots, N-1$$

modulator

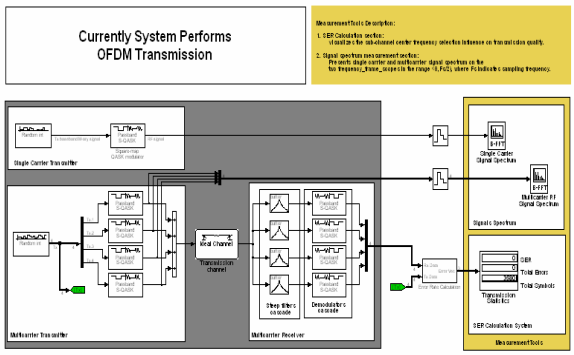
$$C_{n,k} = \frac{1}{T_s} \cdot \int_{nT_s}^{(n+1)T_s} s(t) \cdot g_k^*(t)\, dt$$

demodulator

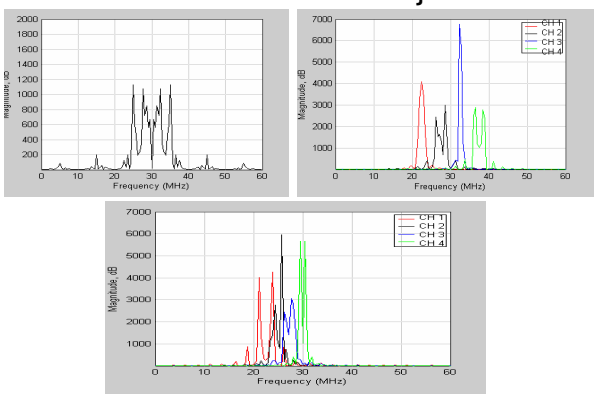
Simulacija

- Klasični BPSK: F_c=30MHz, R=10Msym/s, Osnovni pojas B=10MHz, Bandwidth BW=20MHZ nakon modulacije
- FDM : K=4 , R=2,5Msym/s, SB=2.5MHZ, SBW=5MHZ, BW=20MHz
  OFDM :K=4 , R=2.5Msym/s, SB=2.5MHZ SBW=5MHz, BW'=12.5MHZ

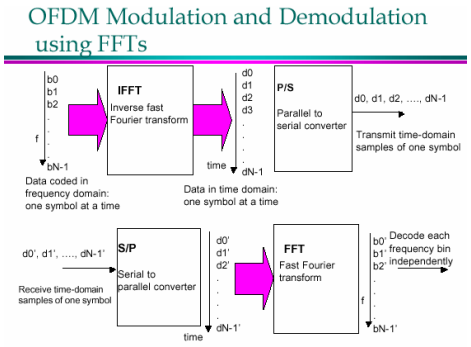
Model u Simulinku



Rezultati simulacije

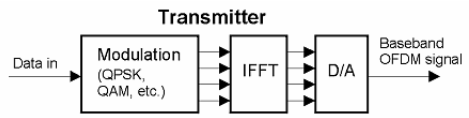


OFDM pomoću DSP



OFDM postupak pomoću IFFT

- Upotreba IFFT transformacije na odašiljačkoj strani odnosno FFT na prijamnoj strani



OFDM pomoću IFFT-a

$$s_c(t) = A_c \cdot e^{j[\omega_c t + \phi_c(t)]}$$

$$S_s(kT) = \sum_{n=0}^{N-1} A_n \cdot e^{j[\omega_n kT + \phi_n]} \qquad S_s(kT) = \sum_{n=0}^{N-1} A_n \cdot e^{j[(\omega_0 + n\Delta\omega)kT + \phi_n]}$$

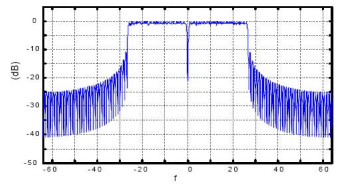
$$S_s(kT) = \sum_{n=0}^{N-1} A_n \cdot e^{j[(n\Delta\omega)kT + \phi_n]} = \sum_{n=0}^{N-1} A_n \cdot e^{j\phi_n} \cdot e^{j[(n\Delta\omega)kT]}$$

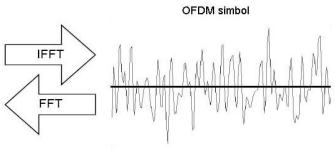
$$\Delta f = \frac{\Delta\omega}{2\pi} = \frac{1}{NT} = \frac{1}{Ts}$$

OFDM pomoću IFFT-a

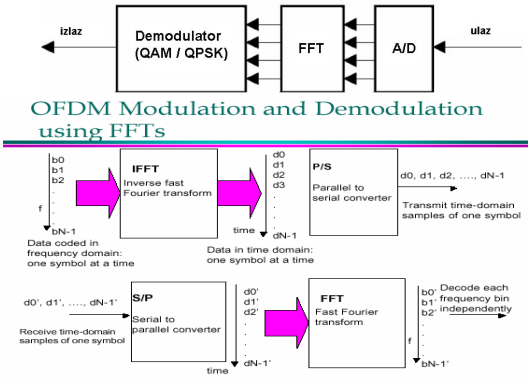
- Na izlazu iz IFFT sklopa dobijemo niz diskretnih uzoraka signala x(0), x(1),...x(N-1), i njega možemo promatrati kao jedan okvir (frame) podataka.
- Da bi dobili kontinuirani signal ide se na D/A konvertor , te poslije D/A konvertora se ide na passband prijenos odnosno na visoku frekvenciju F_c oko koje se formiraju podnosioci.

OFDM pomoću IFFT





OFDM baseband prijamnik

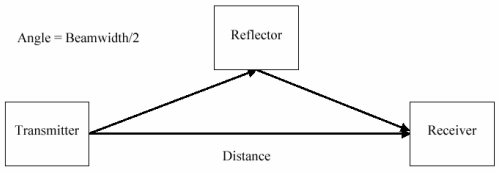


Utjecaj kanala

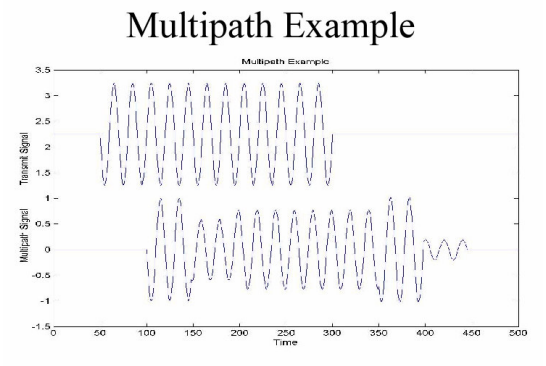
- r(t)=h(t)*s(t)
- h(t)- impulsni odziv realnog kanala
- s(t)- odaslani signal
- r(t)- primljeni signal
- Kanal nije idealan i dolazi do ISI-a
- Promatrati kroz IFI (Inter Frame Interference)
- Uvođenje zaštitnog intervala za uklanjanje IFI-a

Utjecaj refleksija

Multipath Geometry



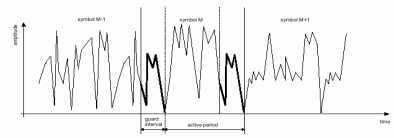
Utjecaj refleksija



Utjecaj kanala

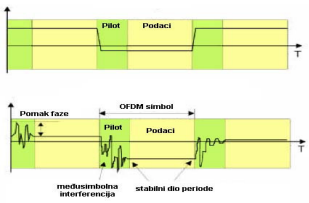
- Zbog širenja elektromagnetskog vala sa više putova dolazi do intersimbolne interferencije (ISI) može se gledati kao i interferencija među okvirima (IFI), pa se kao zaštita u prijenosu koristi zaštitni interval.
- Zaštitni interval se može dobiti umetanjem dodatnih nula na početak okvira te njihovim uklanjanjem na strani prijema.
- Bolji način zaštite je periodičko proširenje simbola tako da se simbol proširi na kraju sam sa sobom i takva metoda se naziva cikličko proširenje simbola.

Proširenje intervala T_s



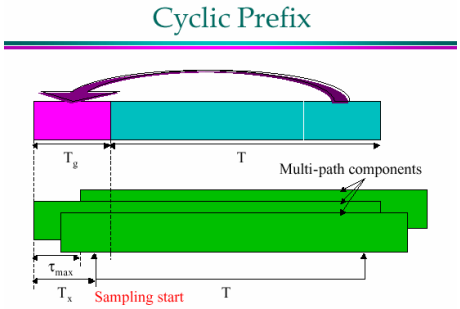
Tsymbol=Ts+Tg

Tg=Ts/4

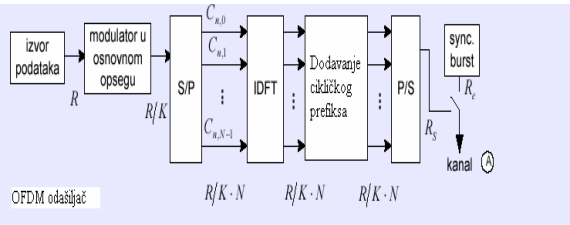


Pilot se dodaje za potrebe procjene kanala i sinhronizacije okvira

Ciklički prefiks i višestazna propagacija

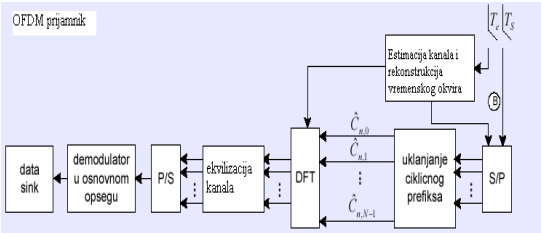


OFDM blok shema baseband odašiljača



R=20kbit/s , K=4, N=5, (Xn(0),Xn(1),...Xn(N-1)) →xn(0),xn(1),..... xn(N-1)).

OFDM blok shema baseband prijamnika



IEEE 802.11a standard

802.11a OFDM Parameters

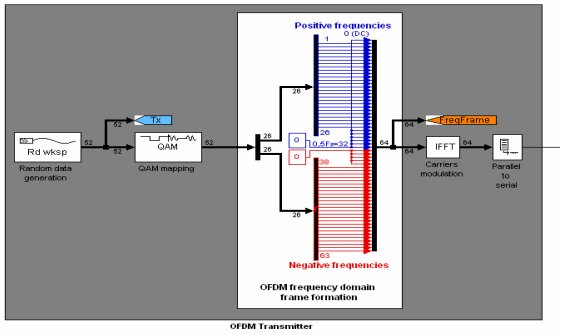
- Total Number of Frequencies 64
- Number of Subcarriers Used 52
- Number of Pilots 4
- Number of Data Subcarriers 48
- Subcarrier Spacing 312.5 kHz
- -3 dB bandwidth 16.56 MHz
- Channel spacing 20 MHz

IEEE 802.11a standard

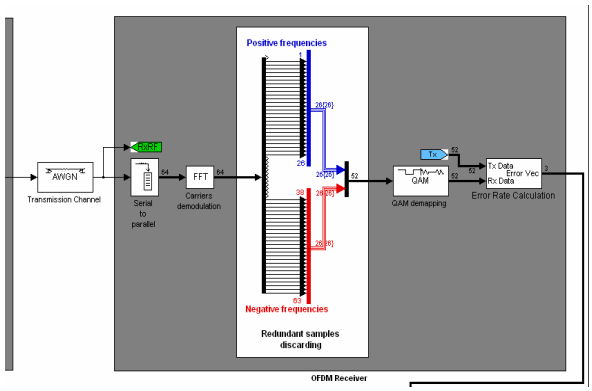
802.11a OFDM Parameters

- OFDM Signal Duration 4 usec
- Cyclic Prefix 800 nsec
- Complex sample rate 20 Msps
- Data Samples 64
- Guard Samples 16
- FFT Complex Tones 64

Simulacija OFDM u IEEE 802.11



Simulacija IEEE 802.11a



Prednosti OFDM-a

- Efikasno korištenje spektra jer omogućuje preklapanje pojaseva podnosilaca
- Podjelom na više uskopojasnih podkanala

sa ravnim fedingom, otporniji na frekvencijski selektivan feding

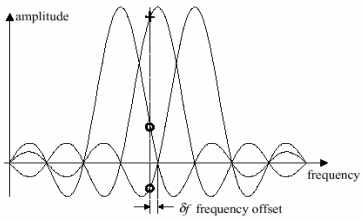
-uvođenje zaštitnog intervala sa cikličkim prefiksom

-jednostavnija ekvilizacija kanala

-dobra zaštita od međukanalne interferencije

-mogućnost primjene u NLS sustavima(Non Line of Sight)

Nedostaci OFDM-a



ICI (Inter Carrier Interference) se javlja u slučaju greške u sinhronizaciji podnosioca na odašiljačkoj strani

Nedostaci OFDM-a

- Osjetljiv na offset frekvencije podnosioca
- Ako su podaci koji ulaze u IDFT blok korelirani na određeni način, izlaz iz bloka može biti amplitude n, to povećava PAPR(Peak To Average Power Ratio)

Primjena kod DRM-a

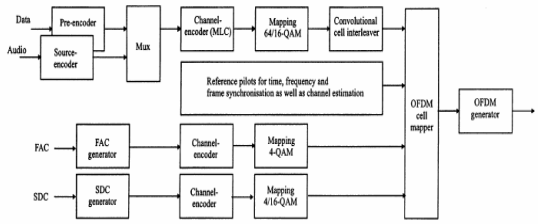


Fig. 1. DRM system overview.

DRM

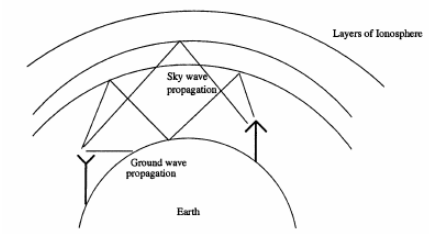


Fig. 3. Wave propagation in the AM bands.

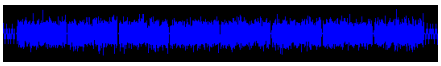
OFDM kao Toolbox u Matlabu za simulaciju prijenosa različitih tipova podataka

- www.skydsp.com

Orginalni signal

Parameter	Value
FFT size	2048
Number of Carriers	800
Guard Period	512 samples
Guard Type	Half cyclic extension, half zero amplitude
Sample rate of OFDM signal	44.1kHz
Bandwidth	17.5kHz

OFDM sa QPSK modulacijom



Parameter	Value
Multipath	None
Peak Power Compression	None
Input Data Wave Format	4.33sec, Mono, 11kHz, 8bit
OFDM signal length	15.26sec

Utjecaj odnosa S/N u kanalu na kvalitetu prijema

Parameter	Result
SNR	12dB
Bit Error Rate	0.000277
RMS phase error	12.1 degrees
Total Number of errors	53

Primljeni signal

Utjecaj odnosa S/N u kanalu na kvalitetu prijema

Parameter	Result
SNR	4dB
Bit Error Rate	0.1591
RMS phase error	33.31 degrees
Total Number of errors	3.044e+004

Primljeni signal