IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 9, Issue 2, Ver. VIII (Mar - Apr. 2014), PP 141-152
www.iosrjournals.org

Implementation the Technique of Orthogonal Frequency Division Multiplexing Using 16-Point Fast Fourier Transform and Inverse Fast Fourier Transform

Muhammad Waqas, Muhammad Junaid Khan, Muhammad Abid Saeed
Muhammad Sheraz, Muhammad Tayyab Qaiser
DepartmentofElectricalEngineering,SarhadUniversityofScienceand InformationTechnology,Peshawar Pakistan
DepartmentofCommunicationEngineering,UniversityofOulu,Oulu,Finland
DepartmentofElectricalEngineering,COMSATSUniversity,Abbottabad,Pakistan

Abstract: *Orthogonal FrequencyDivisionMultiplexing(OFDM)isamulti-carriermodulationtechniquewhich dividestheavailable spectrumintomanycarriers.OFDMusesthespectrumefficiently comparedtoFDMAby spacing the channels much closer together and making all carriers orthogonal to one another to prevent interferencebetweenthecloselyspacedcarriers.ThemainadvantageofOFDMistheirrobustnesstochannel fadinginwirelessenvironment. TheobjectiveofthisworkistodesignandimplementanOFDMtransmitter and receiverusingMATLAB.Theworkconcentrates ondevelopingFastFourierTransform(FFT)andInverseFast FourierTransform(IFFT).The workalsoincludesindesigninga mappingmodule,serialtoparallelandparallelto serialconvertermodule.Thedesignuses16-pointsFFTandIFFTfortheprocessingmodulewhichindicatesthat theprocessingblockcontain16inputsdata.AllmodulesareimplementingusingMATLAB.*

Keywords: *Orthogonal FrequencyDivisionMultiplexing(OFDM),FastFourierTransform(FFT),InverseFast FourierTransform(IFFT),CyclicPrefix(CP),Quadrature AmplitudeModulation (QAM),Quadrature Amplitude Demodulation(QAD),Encoder,Decoder*

I. Introduction

Theincreasingroleofmultimediaandcomputerapplicationsincommunications hasintensifiedthe researchinthefieldofWirelessBroadbandMultimediaCommunication Systems(WBMCS).Broadbandsystems refertosystemswithveryhigh datarates.Overthelastfewyears,Ultra-Wideband(UWB) communicationsystems havegainedsignificantinterestfrom industry[1]-[2].Thereasonbehindthisisthatthetechnology promisesto deliververyhighdataratesranging from 110Mbpsatadistanceof10metersupto480Mbpsatadistanceof2 metersina real multipathchannel,whileconsumingverylittlepoweras wellas havinga small sizeandinsignificant weight.Thetransmission ofsuchhighdataratesoverrealchannelsinamultipath environmentimposeslarge bandwidths,thuspushingcarrierfrequenciestoveryhighlevels [3]. Transmittingsuch highdata ratesthat canresist allradiochannelimpairments requiresacarefulchoiceofmodulation technique.OrthogonalFrequencyDivision Multiplexing(OFDM)seemstobea verygoodchoice.OFDMisknownforitshighspectralefficiency,italsooffers inherentresistancetonarrowbandinterference.OrthogonalFrequencyDivisionMultiplexing(OFDM)multicarrier modulation isshowninFigure1.1.TheideaofOFDMistodistributethehighdatastreamtomanylowratedata streamsthataretransmitted inaparallelwayovermanysubchannelswithin thesamebandwidth[4].Thusineach subchannelthesymbol durationislowascomparedtothemaximum delayofthechannelandnowISIcanbe handled[5].

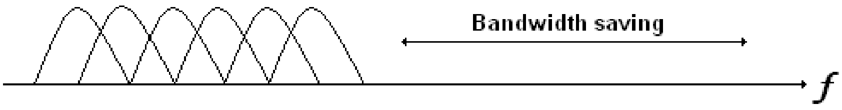


Figure1.1:OrthogonalFrequencyDivisionMultiplexing(OFDM)multicarriermodulation

Inordertoeliminate further the effect ofICIandISI,OFDM introduces whatiscalledtheCyclicPrefix (CP),whichisaguardintervalbetweentwoconsecutiveOFDMsymbols[6].TheCPismade bycopyingthelast partoftime domainOFDMsymbolandappendingittothebeginningoftheOFDM symbolintheguardinterval, itisa cyclicextensionoftheOFDMsymbol[7].TheprocedureisshowninFigure1.2.

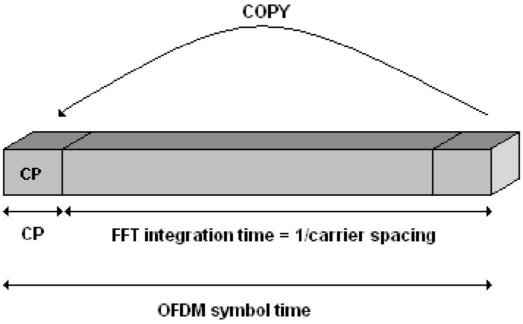
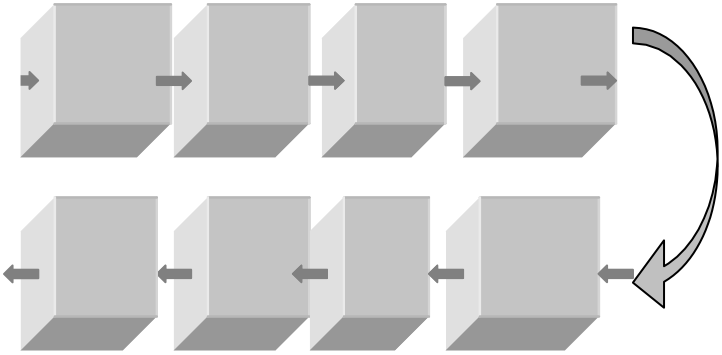


Figure1.2:OFDMSymbolwithCyclicPrefix

InasingleOFDMtransmission allthesubcarriersaresynchronizedtoeachother,restrictingthe transmissiontodigitalmodulation schemes.OFDMissymbolbased,andcanbethoughtofasalargenumberof low bitratecarrierstransmittinginparallel.SincethesemultiplecarriersformasingleOFDMtransmission,they arecommonlyreferredtoas subcarriers,withthetermofcarrierreservedfor describingtheRFcarriermixingthe signal frombaseband[8].TheoverallOFDMmodelisgiveninFigure1.3



Data in
Data out
Data Encoder
Data Deco der
QAM IFFT

QAD FFT
Cyclic
Prefix
Cyclic Prefix Remov

Figure1.3:OFDMModel

II. Methodology

Inmultimediacommunication,ademandemergesforhigh-speed,high-quality digitalmobileportable receptionandtransmission.Areceiverhastocopewitha signalthat is oftenweakerthandesirableandthat contains manyechoes.Simpledigitalsystemsdo notworkwellinthemultipathenvironment.

Foragivenoveralldatarate,increasing thenumberofcarriersreducesthedataratethateachindividual carriermustconvey,andhence lengthensthesymbolperiod.Thismeansthattheinter-symbol interferenceaffectsa smallerpercentageofeachsymbolasthenumberofcarriersandhencethesymbolperiodincreases.Asinglecarrier system,theresponsesofindividual bitsareoverlapping,thuscreatingISI.Inaconventional serialdatasystem,the symbolsaretransmittedsequentially, with thefrequencyspectrumofeach datasymbolallowed tooccupytheentire availablebandwidth.Inaparalleldatatransmission systemseveralsymbolsaretransmittedatthesametime,what offerspossibilities foralleviatingmanyoftheproblemsencounteredwithserialsystems.InOFDM,thedatais dividedamonglargenumberofcloselyspacedcarriers. Theentirebandwidth isfilledfromasinglesourceofdata. Insteadoftransmitting inserialway,dataistransferredinaparallelway[5].Onlyasmallamountofthedatais carriedoneachcarrierandbythisloweringofthebitratepercarrier(notthetotalbitrate),theinfluenceofinter-symbolinterferenceissignificantly reduced.AnimportantpartoftheOFDMsystemdesignthatthebandwidth occupiedisgreaterthanthecorrelationbandwidthofthefadingchannel.Althoughsomeofthecarriersare degraded bymultipathfading,themajorityofthecarriersshouldstillbeadequatelyreceived[9].

Itispossible,however,toarrange thecarriersinanOFDMsignalsothatthesidebandsoftheindividual carriersoverlapandthesignalscanstillbe receivedwithoutadjacentcarrierinterference[10].Inorder todothisthe carriersmustbemathematicallyorthogonal[8]. The receiveractsas abankofdemodulators,translatingeachcarrier downtoDC,theresulting signalthenbeingintegrated overasymbol periodtorecovertheraw data.Iftheother carriersallbeatdowntofrequencieswhich,inthetimedomain,haveawholenumberofcyclesinthesymbol period,thentheintegrationprocess results inzerocontributionfrom allthesecarriers.Thusthecarriersarelinearly independent(i.e.orthogonal).

Mathematically,supposewe havea setofsignalsψ,

$$\int_a^b \Psi_p(t).\Psi_q^*(t)dt=\begin{cases}K & ;for\quad p=q\\ 0 & ;for\quad p\neq q\end{cases}$$

Wherethe*indicatesthecomplexconjugate andinterval[a,b]isasymbol period.Afairlysimplemathematical proofexists,thattheseriessine(mx)form=1,2,…isorthogonalovertheinterval.

Inordertoavoidalargenumberofmodulatorsandfiltersatthetransmitterandcomplementary filtersand demodulatorsatthereceiver,itisdesirabletobeabletousemoderndigitalsignalprocessingtechniques,suchas fastFouriertransform(FFT).Mathematically,eachcarriercanbedescribedasa complexwave.

$$S_c(t)=\quad A_c(t).e^{j[\omega_c t+\phi_c(t)]}\qquad (5.1)$$

Thevaluesoftheparametersareconstantoverthesymboldurationperiod.OFDMconsistsofmanycarriers.Thus thecomplexsignals$S_S(t)$ arerepresentedby:

$$s(t)=\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1}A_N(t).e^{j[\omega_n t+\phi_n(t)]}\qquad (5.2)$$

Where

$$\omega_n=\omega_0+n\Delta\omega$$

Thisisofcourseacontinuous signal.Ifweconsiderthewaveforms ofeachcomponent ofthesignaloverone symbolperiod,thenthevariablestakeonfixedvalues,whichdependonthefrequency ofthatparticularcarrier, andsocanberewritten:

$$\phi_n(t)=\phi_n$$
$$A_n(t)=A_n$$

Ifthesignalissampledusinga samplingfrequencyof1/T,thentheresultingsignalisrepresentedby:

$$s(kT)=\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1}A_n.e^{j[(\omega_0+n\Delta\omega)kT+\phi_n]}\qquad (5.3)$$

$$\tau=NT$$

If we nowsimplifyeq.5.3, withoutalossofgenerality,thenthe signalbecomes:

$$s(kT)=\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1}A_n\,.e^{j\phi_n}.e^{j(n\Delta\omega)kT}\qquad (5.4)$$

NowEq.5.4canbecomparedwiththe generalformoftheinverseFouriertransform:

$$g(kT)=\frac{1}{N}\sum_{n=0}^{N-1} G\left(\frac{n}{NT}\right).e^{j\frac{2\pi nk}{N}} \qquad (5.5)$$

Ineq.5.4,thefunction $A_n e^{j\phi_n}$ isnomorethanadefinitionofthesignal in thesampledfrequencydomain,and s(kT)isthetimedomainrepresentation.Eqs.5.4and5.5areequivalentif:

$$\Delta f=\frac{\Delta\omega}{2\pi}=\frac{1}{NT}=\frac{1}{\tau} \qquad (5.6)$$

This is the same condition that was required for orthogonality. Thus, oneconsequence of maintaining orthogonalityisthattheOFDMsignalcanbedefinedbyusingFouriertransformprocedures.

2.1 TheuseoftheFFTinOFDM

Atthetransmitter,thesignalis definedinthefrequencydomain.Itisasampleddigitalsignal,and itisdefinedsuchthatthediscreteFourierspectrum existsonlyatdiscretefrequencies. EachOFDMcarrier correspondstoone elementofthisdiscreteFourierspectrum.The amplitudesand phasesofthecarriersdependon thedatatobetransmitted. Thedatatransitions aresynchronized atthecarriers,andcanbeprocessedtogether, symbolbysymbol[11].Thedefinitionofthe(N-point)discreteFouriertransform(DFT)is:

$$X_p[k]=\sum_{n=0}^{N-1} x_p[n]e^{-j(2\pi/N)kn} \qquad (5.7)$$

Andthe(N-point)inversediscreteFouriertransforms(IDFT):

$$x_p[n]=\frac{1}{N}\sum_{k=0}^{N-1} X_p[k]e^{-j(2\pi/N)kn} \qquad (5.8)$$

Anaturalconsequenceofthismethod isthatitallowsustogeneratecarriersthatareorthogonal.Themembersof anorthogonalsetarelinearlyindependent.Consideradatasequence($d_0,d_1,d_2,\ldots,d_{N-1}$),whereeachdnisa complexnumber$d_n=a_n+jb_n$.

$$D_m=\sum_{n=0}^{N-1} d_n.e^{-j(2\pi nm/N)}=\sum_{n=0}^{N-1} d_n.e^{-2j\pi f_n t_m} \qquad (5.9)$$

Therealpartofthe vectorD hascomponents;

$$Y_m=\mathrm{Re}\{D_m\}=\sum_{n=0}^{N-1}\left[a_n\cos(2\pi f_n t_m)+b_n\sin(2\pi f_n t_m)\right] \qquad ;k=0,1,2,\ldots,N-1 \qquad (5.10)$$

Ifthesecomponentsareappliedtoalow-passfilterattimeintervals,asignalisobtainedthatclosely approximatesthefrequencydivisionmultiplexedsignal

$$y(t)=\sum_{n=0}^{N-1}\left[a_n\cos(2\pi f_n t_m)+b_n\sin(2\pi f_n t_m)\right] \qquad ;0\le t\le N\Delta t \qquad (5.11)$$

ISItakesplacewhenechoesondifferent-lengthpropagationpathsresultinoverlappingreceivedsymbols [12].ProblemscanoccurwhenoneOFDMsymboloverlapswiththenextone.Thereisnocorrelationbetween twoconsecutive OFDMsymbolsandthereforeinterferencefromonesymbolwiththeotherwillresultina disturbedsignal[13].

Inaddition,oncetheincomingsignalissplitintotherespectivetransmissionsub-carriers,aguardintervalis added betweeneach symbol.Each symbolconsists ofuseful symboldurationT$_S$andaguardinterval□t,inwhich asignalofT$_S$iscyclicallyrepeated.ThisisshowninFigure1.4.

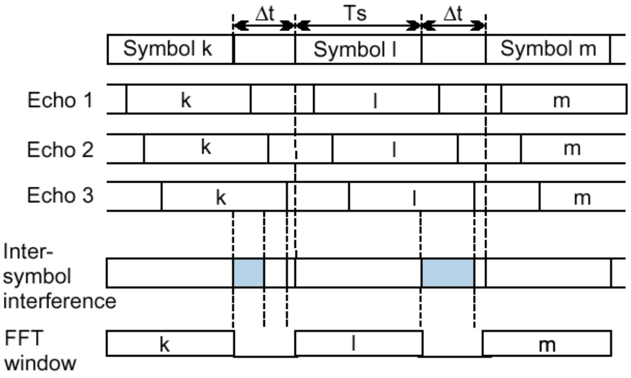


Figure1.4:CombatingISI usingaguardinterval

2.2 *OFDMGenerationand Reception*

OFDMsignalsaretypicallygenerateddigitallyduetothedifficultyincreatinglargebanksof phaselockoscillatorsand receiversintheanalogdomain.Figure 1.5showsthe blockdiagramofatypical OFDM transceiver.Thetransmittersectionconvertsdigital datatobetransmitted,intoamappingofsubcarrieramplitude andphase.Itthentransformsthisspectralrepresentationofthedataintothetimedomainusinganlnverse DiscreteFourierTransform (IDFT).TheInverseFastFourierTransform (IFFT)performsthesameoperationsas anIDFT,exceptthatitismuchmorecomputationallyefficiency,andsoisusedinallpracticalsystems[11].In order totransmittheOFDMsignalthecalculatedtimedomainsignalisthen mixeduptotherequiredfrequency.

Thereceiverperformsthereverseoperation ofthetransmitter, mixingtheRFsignaltobasebandfor processing,thenusingaFastFourierTransform (FFT)toanalyzethesignalinthefrequencydomain.The amplitudeandphaseofthesubcarriersarethenpickedoutand convertedbacktodigitaldata.

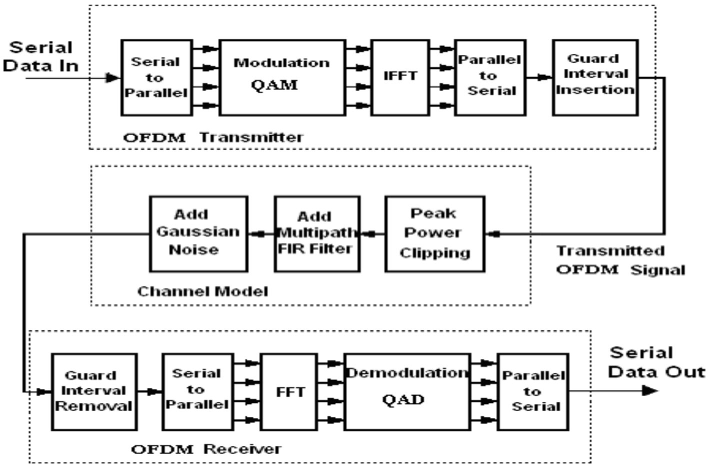


Figure1.5:CompleteOFDMModel,withchannelcharacteristics

2.3 *Serialto ParallelConversion*

Datatobetransmittedistypically intheform ofaserialdatastream.InOFDM,eachsymboltypically transmits40- 4000 bits, andsoaserialto parallelconversionstageisneededtoconverttheinputserialbitstream tothedatatobetransmittedineachOFDMsymbol.Thedataallocatedtoeachsymboldependsonthemodulation scheme used andthenumber ofsubcarriers.For asubcarriermodulationof16-QAMeachsubcarriercarries4bits ofdata,andsofora transmissionusing100subcarriersthenumberofbitspersymbolwouldbe 400[14].

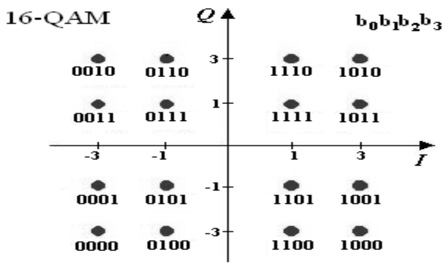
2.4SubcarrierModulationMapping

TheOFDMsubcarrierscanbemodulated byusing16-QAM[15].Theconversion canbeperformed accordingtothegraycodeconstellationmappings,withtheinputbitb$_0$ beingtheearliestinthestream.The outputvaluesdareformedbymultiplyingtheresultingvalue(I+jQ)byanormalizationfactorK$_{MOD}$ asdescribedas$d$□□I□jQ□□K_{MOD}.ThenormalizationfactorK$_{MOD}$ for16-QAMis1/√10.In16-QAMb$_0$b$_1$determinestheI$_{out}$valueandb$_2$b$_3$determinestheQ value,as illustratedinTable1.1.

Table1.1:16-QAMencodingTable.

Inputbits(b$_0$b$_1$)	I-out	Inputbits(b$_2$b$_3$)	Q-out
00	-3	00	-3
01	-1	01	-1
11	1	11	1
10	3	10	3

Onceeachsubcarrierhasbeenallocatedbitsfortransmission,theyaremappedusingamodulation schemetoasubcarrieramplitude andphase,whichisrepresented byacomplex In-phaseandQuadrature-phase (IQ)vector.Figure1.6showsanexampleofsubcarriermodulationmapping.Thisexampleshows16-QAM, which maps4 bitsforeachsymbol.



Inthereceiver,mappingthe receivedIQvector back tothedatawordperforms subcarrierdemodulation. Duringtransmission,noiseanddistortionbecomesaddedtothesignalduetothermalnoise,signalpower reduction andimperfectchannelequalization.Figure1.7showsanexampleofareceived16-QAMsignalwitha SNRof18dB.EachoftheIQpointsisblurredinlocationduetothechannelnoise.ForeachreceivedIQvector the receiverhas to estimate the most likelyoriginal transmissionvector. This isachievedby findingthe transmission vectorthatisclosesttothereceivedvector.Errorsoccurwhenthenoiseexceedshalfthespacing betweenthetransmissionIQpoints,makingitcrossovera decisionboundary.

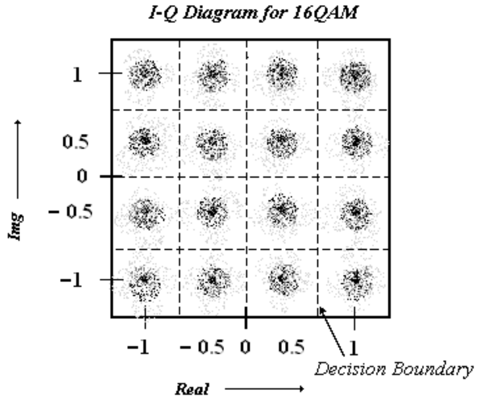
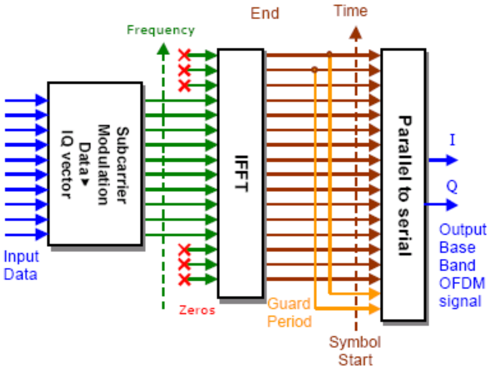


Figure1.7:IQplotfor 16-QAMdata withaddednoise.

2.5 FrequencytoTimeDomainConversion

Afterthesubcarriermodulationstageeachofthedatasubcarriersissettoanamplitudeandphase basedonthedatabeingsentandthemodulation scheme;allunusedsubcarriersaresettozero.Thissetsupthe OFDMsignalinthefrequencydomain.AnIFFTisthenusedtoconvertthis signaltothetimedomain,allowingit tobetransmitted[16].Figure1.8showstheIFFTsectionoftheOFDMtransmitter.Inthefrequency domain, beforeapplying theIFFT,eachofthediscretesamples oftheIFFTcorrespondstoanindividual subcarrier.Most ofthesubcarriers aremodulatedwithdata.Theoutersubcarriers areun-modulated andsettozeroamplitude. Thesezerosubcarriersprovideafrequency guardbandbeforetheNyquistfrequencyandeffectively actasan interpolationofthe signalandallowsfora realisticrolloffintheanaloganti-aliasingreconstructionfilters.



III. Simulation results

Dataencoderproduces binarycodesforanyapplied signalthatiswecansaythatitperformsAnalog to Digitalconversion.Asperformedthedigital processing,forthiswerequiredigital datatobeapplied.Theapplied datawas notindigital format sodata encoderisusedforconvertingnon-digitaldata to digital form. The encoders usedaredifferent forallthreetypes ofinputdata.Theencoder outforTextandimage isshowninFigure 1.9and 1.10respectively.

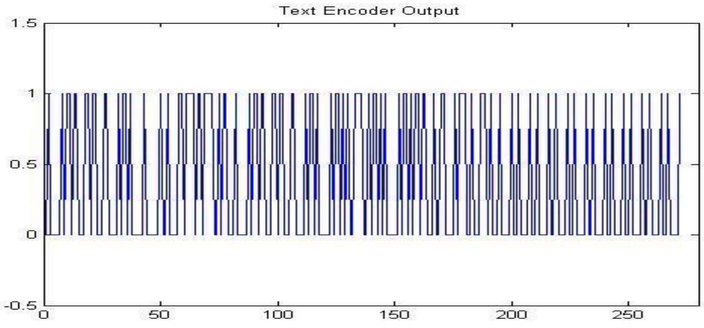


Figure1.9:TextEncoderOutput

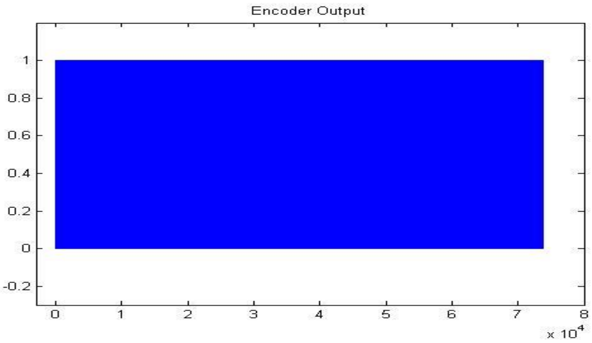


Figure1.10:ImageEncoderOutput

3.1.SubCarrierModulation(QAM)

Onceeachsubcarrierhasbeenallocatedbitsfortransmission, theyaremappedusingamodulation schemetoasubcarrieramplitude andphase,whichisrepresented byacomplexIn-phaseandQuadrature-phase (IQ)vector.Figure1.11showsanexample ofsubcarrier modulationmapping.Thisexampleshows16-QAM, which maps4 bitsforeachsymbol.

Inthereceiver,mappingthereceivedIQvectorbacktothedatawordperforms subcarrier demodulation.During transmission, noiseanddistortionbecomes addedtothesignalduetothermalnoise,signal power reductionandimperfectchannelequalization.Figure1.12showsanexampleofareceived16-QAMsignal withaSNRof18dB.EachoftheIQpointsisblurredinlocation duetothechannelnoise.ForeachreceivedIQ vectorthereceiverhastoestimatethemostlikelyoriginaltransmissionvector.Thisisachievedbyfindingthe transmissionvectorthatisclosesttothereceivedvector.Errorsoccurwhenthenoiseexceedshalfthespacing betweenthetransmission IQpoints,makingitcrossoveradecisionboundary.ThesimulatedresultofQAMis showninFigure1.13.

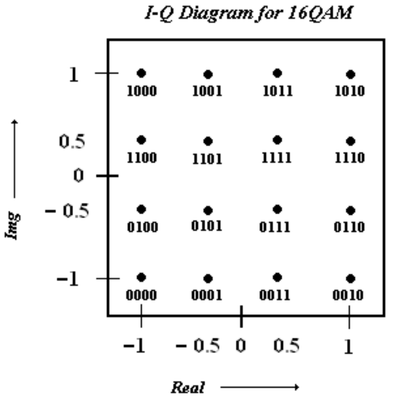


Figure1.11:ExampleIQmodulationconstellation(16-QAM,withgraycodingofthedatatoeachlocation)

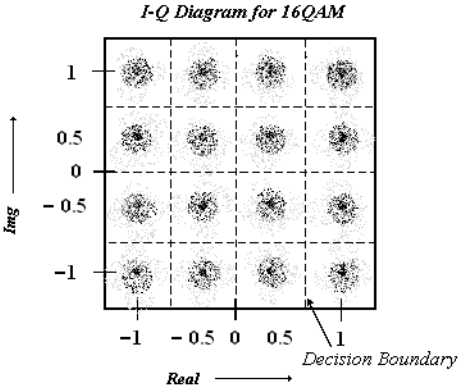


Figure1.12:IQplotfor16-QAMdata withaddednoise.

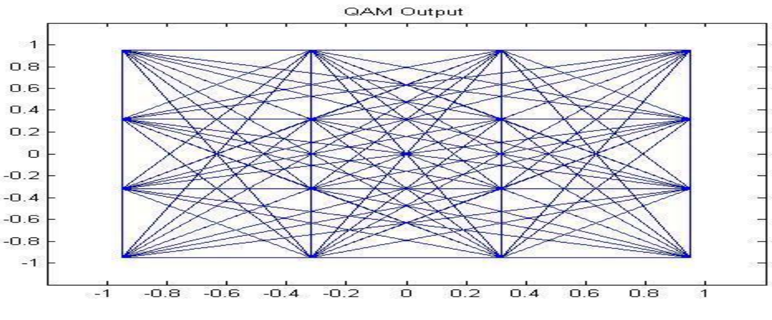


Figure1.13:16-QAMOutput

3.2 *InverseFastFourierTransform(IFFT)*

InthisstagetheInverseFastFourierTransformtakesplace.Thesignalistransformedfromfrequency domaintoitstimedomainanddifferentorthogonalsubcarriers aresetup.Itisthemostimportantstagein theOFDMtransmitter; itisthestagewhichgivesustheconceptoforthogonality.TheIFFTfortextand imageare showninFigure1.14andFigure1.15respectively.

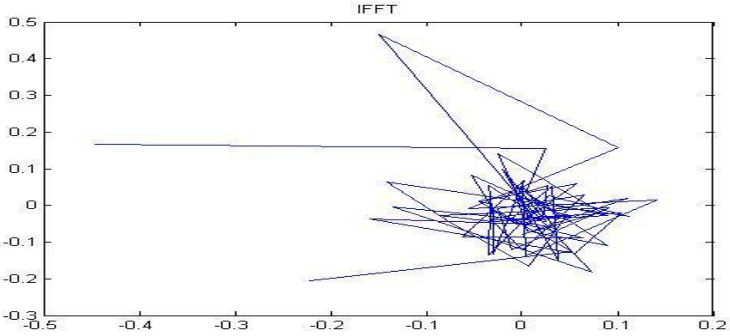


Figure1.14:IFFTfortextdata

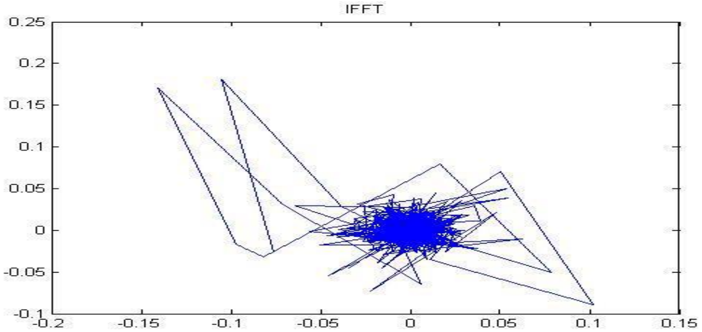


Figure1.15:IFFTforimageData

3.3FastFourierTransform(FFT)

Atthereceivingendthesignalisagaintransformedfromtimedomain tofrequencydomain.TheFFT fortextandimageare showninFigure1.16and1.17accordingly.

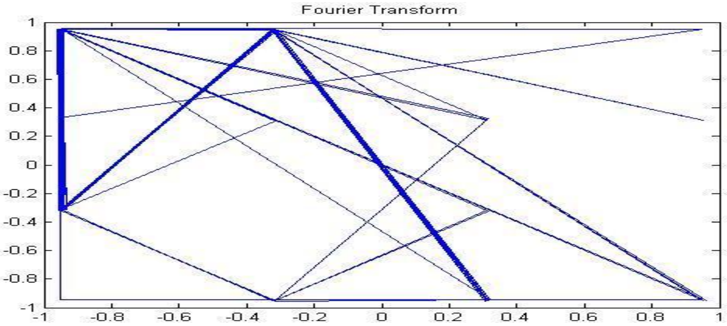


Figure1.16:FFT fortextdata

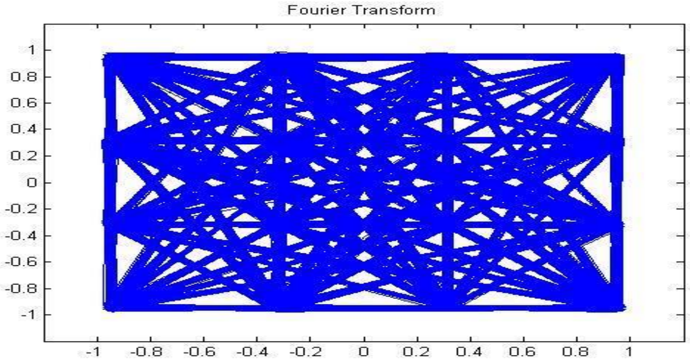


Figure1.17:FFT forImagedata

3.4Subcarrierdemodulation(QAD)

QuadratureAmplitudeDemodulation(QAD)isusedtodemodulatethesignalfromsubcarriers.For thisweuse.ItistheexactreverseofQAMasshowninFigure1.18and1.19respectively.

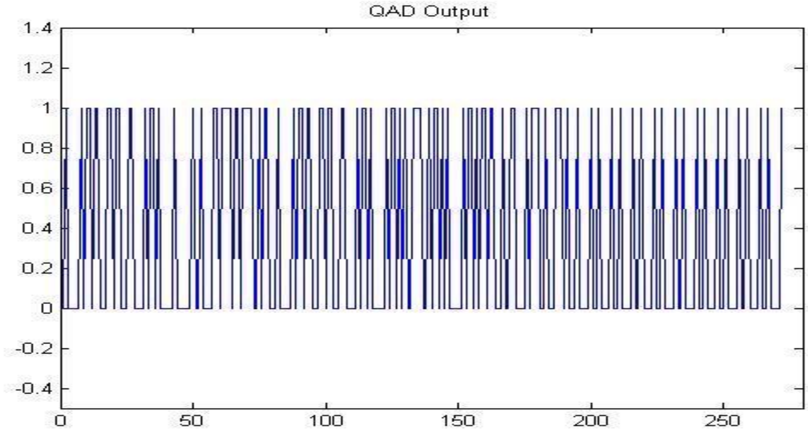


Figure1.18:QADdemodulationforTextdata

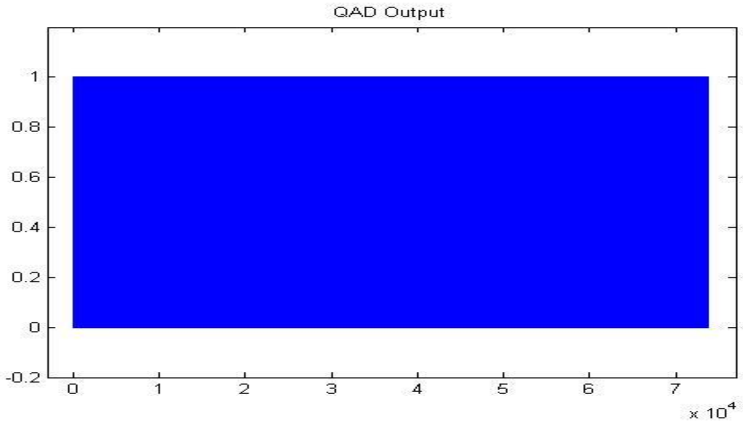
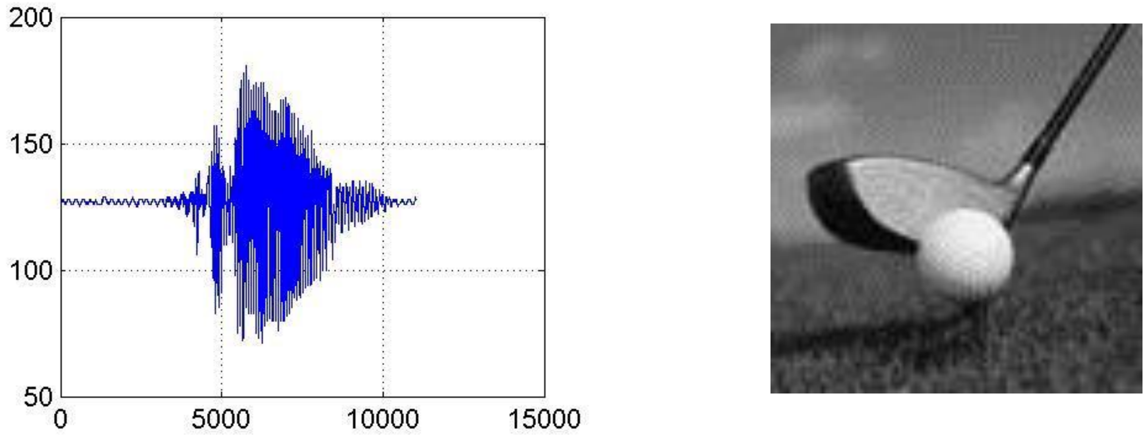


Figure1.19:QADdemodulationforImagedata

3.5DataDecoder

Thedemodulatedsignalisthenappliedtothedataencoder,whichconvertsthebinaryencodeddata intonormalform.ThisisourrequiredoutputwhichisshowninFigure1.20.

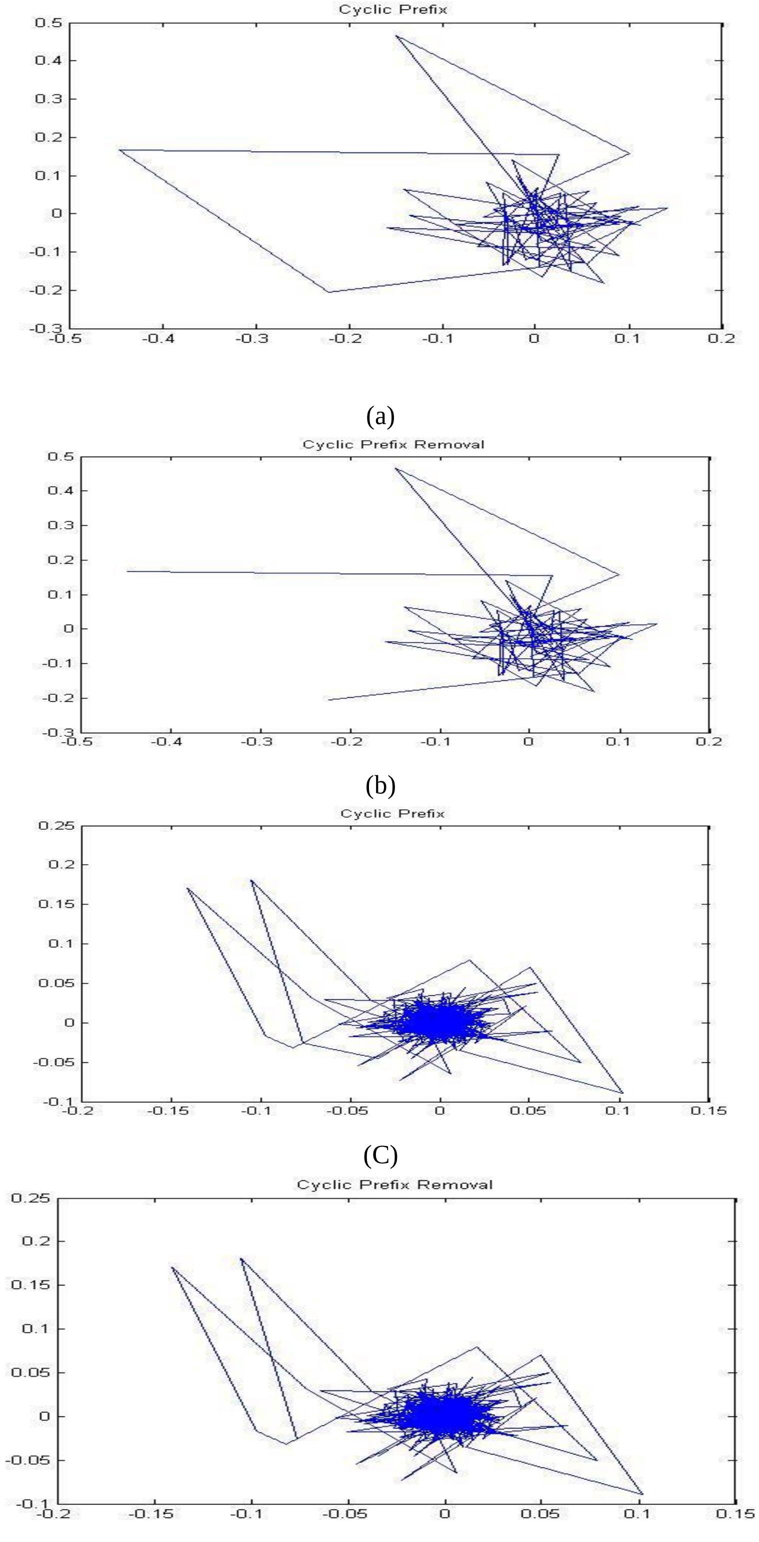


(a) (b) (c)AllahistheSupremePower.

Figure1.20:Receivedinformation,(a)AudioSignal,(b)Image,(c)Text

3.6CyclicPrefix

AllthecyclicprefixandcyclicprefixremovalfortextandimageareshowninFigure1.21



(a)

(b)

(C)

(d)

Figure1.21:(a)cyclicprefixfortextdata(b)cyclicprefixremovalfortextdata (C)Cyclicprefixforimagedata(d) CyclicprefixremovalforImagedata

IV. Conclusion

The purposeofthisworkistogive someinsightintothe poweroftheOFDMtransmissionscheme.Herenotonly thetransmissionschemeisitselfdiscussed, butalsosomeoftheproblems thatwerepresentincommunicationas wellasthetechniquestocorrectthem.

Thismodelfulfillsalmostallthebasicbuilding blocksofacommercial OFDMsystemforboththetransmitting sideandthereceivingsidesoperationsusingMATLAB.WeperformedarealtimesimulationofOFDMmodel, byapplyingthreedifferent typesofdata,whichareText,ImageandAudio.Textwasfeddirectly throughkey boardandwasstoredinacharactertypedataarray.Wegotdifferent imagesfrom systemmemoryandappliedto ourmodel.Themodel issupportingonly gray scaledimages,forthisweconvertedtheRGBimage tograyscaled image.We got audiodata fromexternalsideusinga microphone. OFDMprove torevolutionizemobile communications byallowingittobemorereliableandrobustwhilemaintainingthehighdataratethatdigital communication demands.Toachievehighspectrum efficiency,parameterssuchascyclicprefix,numberof carriers,andconstellationmustadapttothecurrentsituationofthecommunicationchannel.Hereitisshownthat suchflexibilitycanbeobtainedwithareasonableamountofextrahardware.Theflexibility alsocontributestoa largersetofpossibleapplications andthuslargerfabricationvolumesandlowerprice.Theonlyextrasourceof powerconsumptionduetotheflexibilityistheleakagepowerintheunusedpartsofthedesign.TheOFDM modelhavebeenimplemented bysimulation andimplementedinrealtimeoperationbyusingDigitalSignal processorKit(DSK).Thesimulation onOFDMmodel canbeextendedbyintroducing multipatheffectsand channel'sandsystem'snonlinearitieswhichmakestheOFDM simulationa fullfunctionalpractice.

References

[1] HuilinXu, Chia-Chin Chong, Guvenc I, Watanabe F., "*High-Resolution TOA Estimation with Multi-Band OFDM UWB Signals,*" IEEE Int. Conference, Beijing, pp-4191-4196, May, 2008.

[2] Batra, A. Balakrishnan, J. Dabak, A., "Multi-band OFDM: a new approach for UWB," *DSPS R&D Center, Texas Instrum., Dallas, TX, USA, Circuits and System,2004. ISCAS'04, Proceedings of the 2004 International Symposium*, Volume: 5, pp- 365-368.

[3] Michal Litwin, "*Orthogonal Frequency Division Multiplexing (OFDM) Transceiver Design,*" Master Thesis, Dept. of Electrical Engineering Program, Cornell University, August, 2010.

[4] Guillermo Acosta, "*OFDM Simulation Using Matlab,*" Smart Antenna Research Laboratory, August, 2000

[5] P. G. Lin, "*OFDM Simulation in MATLAB,*" Dept. of Electrical Engineering, California Polytechnic State University, San Luis Obispo, June, 2010.

[6] Shaoping Chen, "*ICI and ISI analysis and mitigation for OFDM systems with insufficient cyclic prefix in time-varying channels,*"IEEE Consumer Electronics Society, Dept. of Electron. & Information Eng., South-Central Nat. Univ., China, Feb. 2004

[7] Magnus, S. J.J Van de Beek, P. O. Borjesson, "*Timing and Frequency Synchronization in OFDM System using Cyclic Prefix*", Div. of Signal Processing, Lulea University of Technology S-971-87 Lulea, Sweden.

[8] Charan Langton, "*Orthogonal Frequency Division Multiplexing (OFDM)*", Intuitive Guide to Principles of Communication, pp. 1–22, 2004.

[9] Islam, Mohammed Safiqul, BaraiGouri Rani, Mahmood, Atiq. *"Performance analysis of different modulation schemes using OFDM techniques in Rayleigh fading channel,"* International Journal of Fundamental Physical Sciences, Mar. 2011, Vol. 1 Issue 1, p22-27. 6p.

[10] Y. Chiu, D. Markovi, H. Tang, and N. Zhang, "*OFDM Receiver Design,*" 2000

[11] J. Kuo, C. Lin, and A. A. Wu, *"VLSI Design of a Variable-Length FFT / IFFT Processor for OFDM-Based Communication Systems,"* EURASIPJournalonAppliedSignalProcessing, 1306–1316c, pp. 1306–1316, 2003

[12] Zhi-QuanLuo ; Davidson, T.N. ; Giannakis, G.B. ; Wong, Kon Max, *"Transceiver optimization for block-based multiple access through ISI channels"*, IEEE Tran. Vol. 52 , Issue: 4 , pp- 1037 - 1052 April, 2004

[13] Le Van Ninh, Trinh Anh Vu, Huu Tue Huynh, Fortier, P. *"New Cyclic Prefix Based Symbol Timing and Carrier Synchronization for OFDM.*" Communications, 2006 23rd Biennial Symposium pp-198 - 203, 2006

[14] Haithamj.H., M. F. M. Salleh, "*Performance Analysis of QAM-Modulation Parameters on FFT-OFDM System over Doppler Frequency Fading Channels,*" Int. Journal of Info. and Comm. Tech., Vol. 3, Issue 1, pp-40-52, April 2011

[15] Y. Shao, N. Chi, J. Fan, and W. Fang, *"Generation of 16-QAM-OFDM Signals Using Selected Mapping Method and Its Application in Optical Millimeter-Wave Access System,"* IEEE Photonics Technology Letters, vol. 24, no. 15, pp. 1301–1303, 2012.

[16] Cortes, A. Velez, I. Sevillano, J.F. Irizar, A. *"An approach to simplify the design of IFFT/FFT cores for OFDM systems"*, IEEE Transactions, Vol. 52 Issue 1, pp-26-32, Feb.2006