

ELEMENTS OF A DIGITAL COMMUNICATION SYSTEM

Vj g"cpnf{uku"cpf "f guki p"qh"fi ki kcn'eqo o wplecvkp"u{ ugo u0"

Kpxqkxgu"vj g"vcpuo kuukp"qh"lphqto cvkp"kp"fi ki kcn'hqto "Itqo "c"uqwteg" vj cv'i gpgtcvgu"vj g"lphqto cvkp"vq"ppg"qt"o qtg"fgv'kpcv'kpu0"

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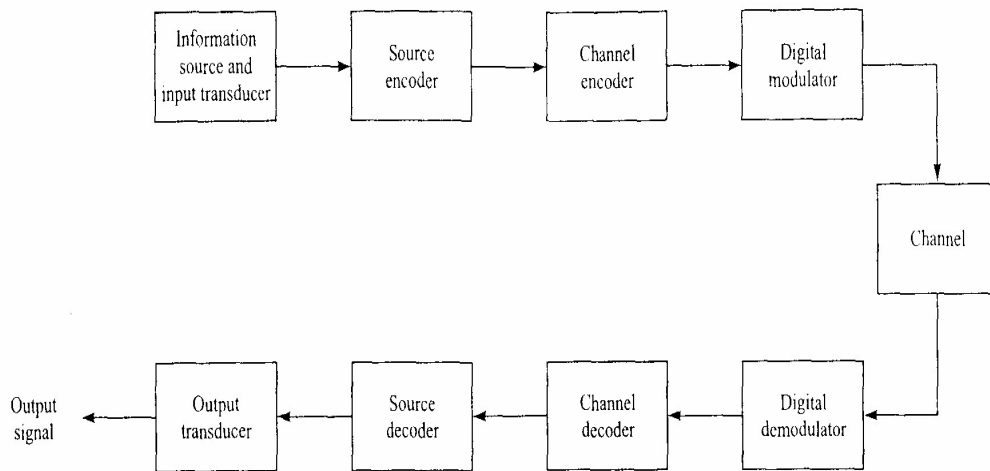
1.1 ELEMENTS OF A DIGITAL COMMUNICATION SYSTEM

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Hki wtg"308/3'kmwutcvgu"vj g"hwpevkp'cn'f kci tco "cpf "vj g'dcule"grgo g'p'u'qh" c"fi ki kcn'eqo o wplecvkp"u{ ugo 0"

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HK WTG"308/3"Dcule"grgo g'p'u'qh"fi ki kcn'eqo o wplecvkp"u{ ugo 0"

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Vj g"uqwteg"qwr w'o c{ "dg"gkj gt "cp"cp'cqi "uki pcn"uwej "cu"cp"cw'kq"qt" xlf gq"uki pcn"qt"fi ki kcn'uki pcn"uwej "cu"vj g"qwr w'qh"fi v'grv' r g"o cej kpg." vj cv'ku'f kuetgv'kp"vo g"cpf "j cu"fi h'kpg'pwo dgt"qh'qwr w'ej ctcevtu0"

"

"

Kp"fi ki kcn'eqo o wplecvkp"u{ ugo . "vj g"o guci gu'r tqf wegf "d{ "vj g"uqwteg" ctg"eqpxgtvgf "kpq"fi ugs wpeg"qh'dk'pct{ "fi ku0"

"

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Vj g"r tqegu"qh'ghkkgpvn{ "eqpxgt vpi "vj g"qwr w'qh'gkj gt"cp"cpmqi "qt"
f ki kcn'uqwtg"kpq" c"ugs wpeg"qh'dkpt { "f ki ku"ku"ecmgf "uqwtg"gpqf kpi "
qt"fcv"eqo r tguakp0"
"

Vj g"ugs wpeg"qh'dkpt { "f ki ku"htqo "vj g"uqwtg"gpqf gt."y j lej "y g"ecm'vj g"
kphqto cvkq"ugs wpeg."ku'r cuugf "v'vj g"ej cppgn'gpqf gt0"
"

Vj g" r wtr qug" qh" vj g" ej cppgn' gpqf gt" ku" vq" kptqf weg." k" c" eqpvtqmgf "
o cppgt."uqo g'tgf wpf cpe { "k"vj g"dkpt { "kphqto cvkq"ugs wpeg"vj cv'ecp"dg"
wugf "cv"vj g"tgegkxgt "vq"qxgteqo g" vj g"ghgew"qh'pqkug"cpf "kpvtht'gpeg"
gpqwpvgtgf "k"vj g"vcpuo kulkq"qh'vj g"uki pcn'vj tqwi j "vj g"ej cppgn0"
"

Vj ku' kpetgcug" vj g" tgrkcdkx{ " qh" vj g" tgegkxgf " fcv" cpf " ko r tqxgu" vj g"
hkf grkx{ "qh'vj g'tgegkxgf " uki pcn0"
"

Vj g"dkpt { "ugs wpeg"cv'vj g"qwr w'qh'vj g"ej cppgn'gpqf gt"ku'r cuugf "v'vj g"
digital modulator, y j lej "ugtxgu"cu"vj g"kvthceg"v'vj g"eqo o wplecvkq"
ej cppgn0"
"

Ukpeg"pgctn{ "cm'vj g"eqo o wplecvkq" ej cppgn" gpqwpvgtgf " k"r tcevleg"
ctg"ecr cdrg" qh'vcpuo kxkpi "grgevkcn'uki pcn"*y cxghqto u+."vj g"r tko ct { "
r wtr qug" qh" vj g" f ki kcn" o qf wcvqt" ku" vq" o cr " vj g" dkpt { " kphqto cvkq"
ugs wpeg"kpq"uki pcn'y cxghqto u0 " "
"

Vq"grcdqtcvg" qp"vj ku'r qkpv."ngv"wu"uwr r qug" vj cv'vj g"eqf gf "kphqto cvkq"
ugs wpeg" ku"vq"dg"vcpuo kwgf "qpg"dk'cv'c"vko g"cv'uqo g"wpkqto "tcvg"t"
dku" r gt" ugeqpf " *dkulu-0 Vj g" f ki kcn" o qf wcvqt" o c { " uko r n{ " o cr " vj g"
dkpt { " f ki k' 2" kpq" c" y cxghqto " u_i(t) cpf " vj g" dkpt { " f ki k' 3" kpq" c"
y cxghqto "u." *v+0 k" vj ku" o cppgt."gcej "dk'htqo "vj g"ej cppgn' gpqf gt" ku"
vcpuo kwgf "ugr ctvgn{ 0Y g"ecm'vj ku"*binary modulation*.

Cngtpevkgxg{."vj g"o qf wcvqt"o c { "vcpuo kv"8"eqf gf "kphqto cvkq"dku'cv'c"
vko g"d { "wukpi "O " = 2^h f kpkp'ev'y cxghqto u"u_i*v+."i = 0, 1, ..., M - 3."qpg"
y cxghqto "hqt"gcej "qh'vj g"4⁰"r quukdn g" d/dk' ugs wpegu0 "Y g" ecnn' vj ku"
M-ary modulation (M > 2).

P qvg"vj cv'c"pgy "d/dk'ugs wpeg"gpvgtu"vj g"o qf wcvqt"gxgt { "b/R ugeqpf u0"
J gpeg."y j gp"vj g"ej cppgn'dk'tcv"t"ku'hkzgf."vj g"co qwpv'qh'vko g"cxckrdrg"vq"
vcpuo kv'qpg"qh'vj g"M y cxghqto u"eqttgur qpf kpi "vq" c"d/dk'ugs wpeg"ku"b
vko gu'vj g"vko g'r gkqf k" c"u{ ugo "vj cv'wugu"dkpt { "o qf wcvkq0"
"

Vj g'communication channel is vj g'rj {ulecn'o gf kwo "vj cv'ku'wugf "vq'ugpf "vj g" uki pcn'ltqo "vj g"vcpuo kwgt "vq"vj g"tgegkxgt'k y ktgruu"vcpuo kuukqp."vj g" ej cppgn'o c{"dg'vj g"cw qur j gtg"tgg'ur ceg+0" "

Qp" vj g" qvj gt" j cpf." vgrj qpg" ej cppgn" wuwmf " go r m{" c" xctkvf " qh" rj {ulecn'o gf k." kpmf kpi "y ktg" rpgu." qr v'ecn'hdgt" ecdrgu." cpf "y ktgruu" *o ketqy cxg'tcf kq+0"

Y j cvxgt" vj g" rj {ulecn' o gf kwo " wugf" hqt" vcpuo kuukqp" qh" vj g" kphqto cvkqp." vj g" guugpv'ecn' hgcwtg" ku' vj cv' vj g" vcpuo kwgf " uki pcn' ku' eqttw vgf " kp" c" tcpf qo " o cppgt" d{ "c" xctkvf " qh" r quukdr" o gej cpluo u." uwej " cu" cf f kxg" thermal noise i gpgtcvgf " d{ " grgevtqpk" f gxlegu=" o cp/ o cf g" pqkug." g0 " cwqo qdkrg" ki pkvqp" pqkug=" cpf " cw qur j gtle" pqkug." g0 " grgevtlecn'ki j v'kpi " f kiej cti gu'f v'kpi "vj wpf gtuvqto u0 "

Cv' vj g" tgegkxkpi " gpf " qh" c" f ki kcn' eqo o v'kcvkqp" u{ uvo . " vj g" digital demodulator r tgeguugu" vj g" ej cppgn/eqttw vgf " vcpuo kwgf " y cxghqto " cpf " tgf wegu" vj g" y cxghqto u" vq" c" ugs wpep" qh" pwo dgtu" vj cv' tgr tgu'gv' guko cvgu'qh'vj g"vcpuo kwgf " f cv'u{ o dqn' *dkpct { "qt'O /ct { +0" "

Vj ku' ugs wpep" qh" pwo dgt u"ku'r cuugf " vq"vj g"ej cppgn' f geqf gt. "y j lej " cwgo r wu" vq" tgeqputwev' vj g" qtki kpcn' kphqto cvkqp" ugs wpep" ltqo " npqy rgi g"qh'vj g"eqf g" wugf "d{ "vj g"ej cppgn'gpeqf gt "cpf " vj g'tgf wpf cpe{ " eqpvkpgf "kp"vj g'tgegkxgf "f cv0 "

C'o gcuwtg'qh)j qy "y gni'vj g'f go qf wrcvt"cpf "f geqf g t'r gthqto "ku'vj g'htg / swge{ " y kj " y j lej " gttqtu" qeew" kp" vj g" f geqf gf " ugs wpep0' O qtg" r tgekugf ." vj g" cxgtci g" r tqdcdkk\ " qh" c" dk/gttqt" cv' vj g" qwr w' qh' vj g" f geqf gt" ku" c" o gcuwtg" qh' vj g' r gthqto cpeg" qh' vj g" f go qf wrcvt" f geqf gt" eqo dkpcvqp0' "

k\ i gpgtcn" vj g" rtqdcdkk\ " qh" gttqt" ku" c" h'pvcvqp" qh" vj g" eqf g" ej ctcevtkukcu."vj g" v' r gu'qh'y cxghqto u'wugf " vq"vcpuo k'vj g'kphqto cvkqp" qxgt" vj g" ej cppgn" vj g" vcpuo kwgt" r qy gt." vj g" ej ctcevtkukcu" qh' vj g" ej cppgn' *k0 "vj g"co qwpv"Qh"pqkug."vj g"O cwtg"qh' vj g"kvgt'htgpeg+." cpf " vj g'o gvj qf "qh) f go qf wrcvqp"cpf "f geqf kpi 0' "

Vj g" uqwtg" f geqf gt" ceegr wu" vj g" qwr w' ugs wpep" ltqo " vj g" ej cppgn' f geqf gt" cpf ." ltqo " npqy rgi g" qh' vj g" uqwtg" gpeqf kpi " o gvj qf " wugf ." cwgo r wu"vq"tgeqputwev'vj g'qtki kpcn'uki pcn'ltqo "vkr"uqwtg0' "

Dgecwug" qh'ej cppgn'f geqf kpi " gttqtu" cpf " r quukdr" f kvvt v'kqp" kvqf wegf " d{ "vj g"uqwtg"gpeqf gt."cpf "r gtj cr u."vj g"uqwtg" f geqf gt."vj g"uki pcn'cv' vj g"

qwr w'qh'vj g'uqwtg'f geqf gt'ku'cp'cr r tqzko cvkqp'v'j g'qtki kpcn'uqwtg"
qwr w' Vj g'f khgt gpeg" qt "uqo g'hwpevkqp" qh'vj g'f khgt gpeg "dgvy ggp" vj g"
qtki kpcn' uki pcn' cpf " vj g" tgeqputwevgf " uki pcn' ku" c" o gcuwtg" qh' vj g"
f kvqt vkqp'kvqf wegf "d{ " vj g'f ki kcn'eqo o wplecvkqp'u{ uvg0 "

1.2 COMMUNICATION CHANNELS AND THEIR CHARACTERISTICS

"

Vj g" eqo o wplecvkqp" ej cppgn' r tqxkf gu" vj g" eqppgevkqp" dgvy ggp" vj g"
vcpuo kvgt'cpf "vj g'tgegkxgt0 "

"

Vj g"rj {ukecn' ej cppgn' o c{ "dg" c"r ckt" qh'y ktgu" vj cv' ectt{ " vj g" grgevtkecn'
uki pcn'qt'cp'qr vkecn'hdgt'vj cv' ecttktgu" vj g" kphqto cvkqp" qp" c"o qf wrcvgf "
rki j v' dgco . " qt'cp"wpf gty cvgt" qegcp" ej cppgn'kp'y j lej "vj g" kphqto cvkqp"
ku"vcpuo kvgf " ceqwvkecmf . " qt"htgg"ur ceg"qxgt"y j lej "vj g" kphqto cvkqp /
dgctkpi "uki pcn'ku'tcf kvgf "d{ 'wug'qh'cp'cpvgppc0 "

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Qvj gt" o gfk" vj cv' ecp" dg"ej ctcevgtkf gf " cu"eqo o wplecvkqp" ej cppgn'
ctg"f cv" uqtcig" o gfk." uwej "cu"o ci pgvke" vcr g." o ci pgvke" f kumi." cpf "
qr vkecn'f kumi0 "

"

Qpg" eqo o qp" r tqdrgo " kp" uki pcn' vcpuo kuukqp" vj tqwi j " cp{ " ej cppgn' ku"
cf f kxg'pqkug0"

"

Cf f kxg'pqkug"ku"i gpgtcvgf " kvgtpcmf " d{ "eqo r qpgpw"uwej "cu"tgukvqtu"
cpf "uqrf /ucvg" f gxlegu" wugf "v"ko r ngo gpv" vj g" eqo o wplecvkqp" u{ uvg0 0
Vj ku'ku'uqo gvko gu'ecmgf *thermal noise* .

Qvj gt'uqwtg'u'qh'pqkug'cpf "kvgtthgtgpeg" c{ "ctkug"gzvgtpcmf "v'vj g'u{ uvg0 . "
uwej "cu'kvgtthgtgpeg"htqo "qvj gt'wugtu" qh'vj g'ej cppgn0"

"

Y j gp"uwej "pqkug"cpf "kvgtthgtgpeg"qeewr { "vj g'uco g'htgs wgepe{ "dcpf "cu"vj g"
f guktgf " uki pcn" vj gkt" ghgev" ecp" dg"o kpk0 k gf " d{ "vj g" r tqrgt" f guki p" qh'
vj g'vcpuo kvgf "uki pcn'cpf "ku" f go qf wrcvqt "cv'vj g'tgegkxgt0"

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Qvj gt'v' r gu'qh'uki pcn' gi tcf cvkqpu'vj cv'o c{ "dg" gpeqwpvgf "kp"vcpuo kuukqp"
qxgt"vj g'ej cppgn'ctg"uki pcn'cvgpwcvkqp." co r kvwf g" cpf "r j cug" f kvqt vkqp."
cpf "o wkr cvj " f kvqt vkqp0"

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Vj g'ghgeu'qh'pqkug"o c{ "dg"o kpk0 k gf "d{ "kpetgculpi "vj g'r qy gt'kp"vj g'vcpuo
o kvgf "uki pcn0J qy gxgt."gs vkr o gpv'cpf "qvj gt'r tcevtkecn'eqputckpu'iko kv'vj g"
r qy gt'rgxgn'kp"vj g'vcpuo kvgf "uki pcn0"

"

Cpqj gt"dcule"rko kcvkp"ku"j g"cxckrdrg"ej cppgn'dcpf y kf vj 0' "

"

C"dcpf y kf vj "eqputckp" ku"uwcm{ "f wg"vq" vj g'rj {ulecn' rko kc vqpu"qh'vj g"
o gf kwo "cpf "vj g"grgevtqple"eqo r qpgpv"wgf "vq"ko r ngo gpv'vj g"vcpuo kvgt"
cpf "vj g"tgegkgt0'

"

Wireline channels.

Vj g"vgrj j qpg'pgw qtnlo cngz"gzvpu"vq"wg"qh'y ktg"rpgu" hqt"xqlkg"uki pc n'
vcpuo kuukp."cu'y gm'cu'f cvc"cpf "xkf gq"vcpuo kuukp0' "

"

Vy kvgf" rck" y ktg" rpgu" cpf" eqczkcn' ecdrg" ctg" dculecm{ " i wkf gf "
grgevtqo ci pgle"ej cppgn'vj cv'r tqxkf g'tgrvkg"o qf guv'dcpf y kf vj u0' "

"

Vgrj j qpg" y ktg"i gpgtcm{ " wugf "vq"eqppgev"e"ewwqo gt"vq"e"egpvtcn'qhkg"
j cu'c"dcpf y kf vj "qh'ugxgtenj wptgf "nkuj gtv| "*mJ | +0"

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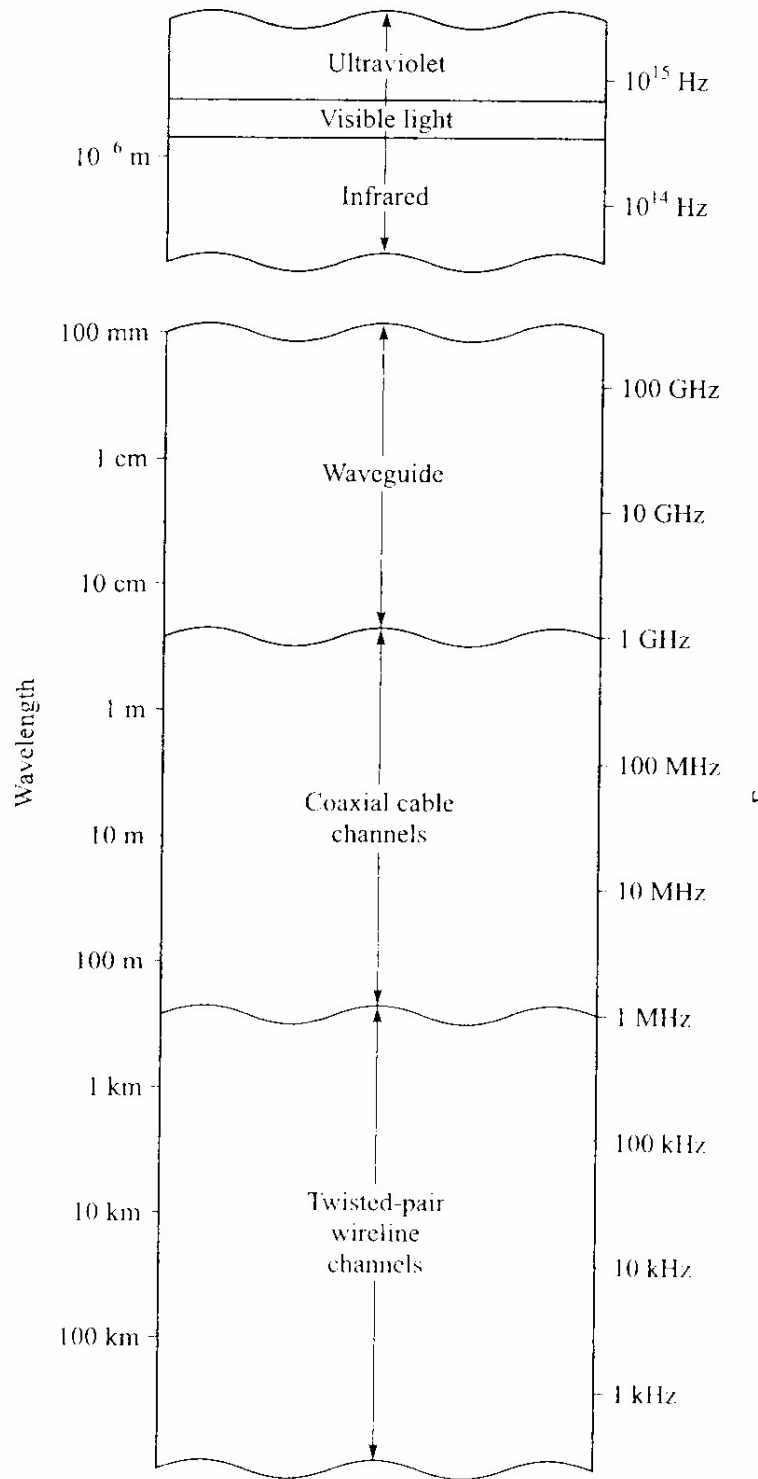
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Hki wtg" 304/3" kmwutcvgu" yj g" htgs wpe{ " tpci g" qh" i wk gf" grgevtq /
o ci pgke"ej cppgn. "y j kej "lpenmf g'y cxgi wk gu'cpf "qr vcecihdgtu0



"
"

Hk WTG"304/3" Htgs wpe{ "tpci g"ht"i wk gf" y kt g'ej cppgn0

"

Uki pcni"tcpuo kwgf "y tqwi j "uwej "ej cppgnu"ctg"fkvqt vgf "kp"dqj "co r rkwf g"
cpf "r j cug"cpf "hwt vj gt"eqttwr vgf "d{ "cf f kxg"pqkug0"
"

Vy kwgf /r ckt "y kgrkpg" ej cppgnu" ctg" cnuq" r tqpg" vq" etquwcm" kpvghgt gpeg"
htqo "r j { ulecm{ "cf lcegpv"ej cppgnu0"
"

"

Fiber-optic channels.

Qr vkecn' hkdgtu" qhgt " vj g" eqo o wplecvkqp" u{ uogo " f guki pgt" c" ej cppgn'
dcpf y kf vj " vj cv"ku"ugxgten"qtf gtu"qh"o ci pkwf g"rti gt"vj cp"eqczken'ecdng"
ej cppgnu0 " "
"

Vj g"tcpuo kwgt "qt"o qf wrcvt "kp" c' hkdgt /qr vke"eqo o wplecvkqp"u{ uogo "ku" c"
rki j v'uqwtg ."gkxj gt" c'rki j v/go kvkpi "f kvf g"*NGF +"qt" c'rcugt0 " "
"

Kphqto cvkqp" ku"tcpuo kwgf "d{ " xct { kpi " *o qf wrcvki "+" vj g"kvgpukv{ "qh"vj g"
rki j v'uqwtg"y kj "vj g"o guci g"uki pcn0 Vj g"rki j v'r tqrci cvgu" vj tqwi j " vj g"
hkdgt"cu" c'rki j v'y cxg"cpf "ku"co r rkhgf " r gkqf kcm{ "kp"vj g" ecug"qh" f ki kcn'
tcpuo kvkqp." kv" ku" f gvgevgf " cpf " tgi gpgtcvgf " d{ " tgr gcvtu+" cmpi " vj g"
tcpuo kvkqp"r cvj "vq"eqo r gpucvg"ht"uki pcn'cwgpcvkqp0 " "
"

Cv"vj g"tgegkgt." vj g"rki j v'kvgpukv{ "ku" f gvgevgf " d{ " c"r j qvqf kvf g." y j qug"
qwr w" ku" cp" grgevtkecn' uki pcn' vj cv' xctkgu" kp" f kgev' r tqrci cvkqp" vq" vj g"
r qy gt" qh"vj g"rki j v'ko r kpi kpi "qp"vj g"r j qvqf kvf g0 Uqwtgu" qh"pqkug" kp"
hkdgt/qr vke"ej cppgnu"ctg"r j qvqf kvf gu" cpf "grgevtqple"co r rkhgtu0"
"

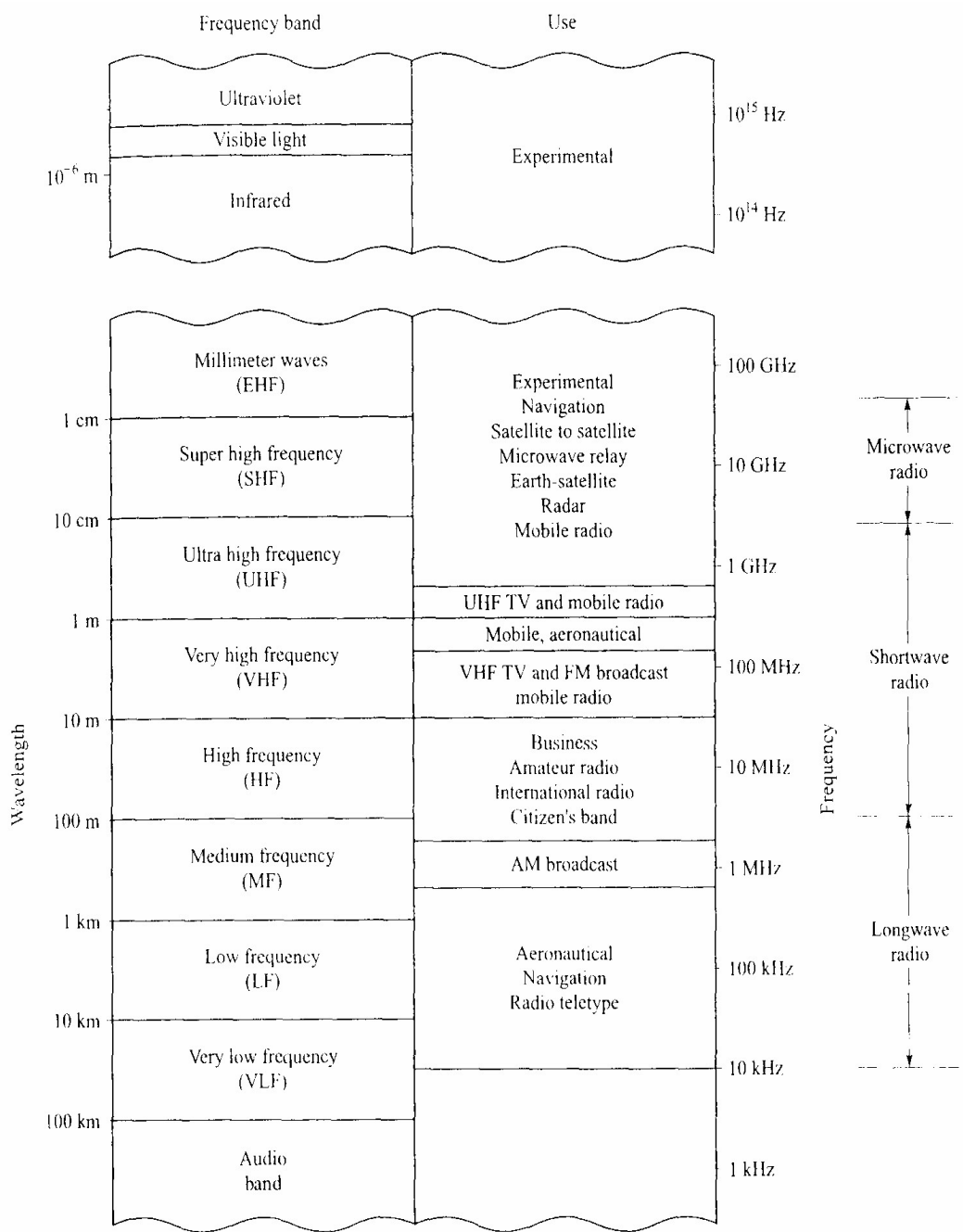
Wireless electromagnetic channels.

Grgevtqo ci pgle" gpgti { " ku" eqwr rnf " vq" vj g" r tqrci cvkqp" o gf kwo " d{ " cp"
cpvppc"y j lej "ugtxgu"cu"vj g'tcf kvqt0"
"

Vj g"r j { ulecn'uk g"cpf "vj g"eqphki wcvkqp"qh"vj g"cpvppcf gr gpf "r tko ctk{ "qp"
vj g" htgs wpe{ " qh" qr gtcvkqp0 Vq" qdvkqp" ghkkgpv" tcf kvkqp" qh"
grgevtqo ci pgle" gpgti { ." vj g" cpvppc" o wuv" dg" rpi gt" vj cp." 3 B2" qh" vj g"
y cxgrpi vj 0"
"

Eqpugs wgpv{ ." c" tcf kv" ucvkqp" tcpuo kvkpi " kp" vj g" co r rkwf g/o qf wrcvgf "
*CO +htgs wpe{ "dcpf ."uc{ "cv'fc = 3"O J | "eqttgur qpf kpi "vq" c'y cxgrpi vj "qh"
" = c/fc = 522"o gvgtu" *o +. "tgs wkt gu"cp"cpvppc"qh"cv'ngcu"52"o 0"
"
"
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"

HK WTG'304 Htgs wqpe {"t cpi g'ht'y kt gnuu'gngv tqo ci pgve'ej cpgnu'0'

"

"

Vj g'o qf g'qh'r tqr ci cvkp"qh'gngv tqo ci pgve'y cxgu'lp'y g'cvo qur j gtg"cpf"
lp"htgg"ur ceg"o c {"dg"u wdf kxf gf "lpvq"y tgg"ecvgi qtkgu."pco gn {"i tqwvf/
y cxg" r tqr ci cvkp." um{/y cxg" r tqr ci cvkp." cpf" rkpq/ql/uk j v' *NQU"
r tqr ci cvkp0"

"

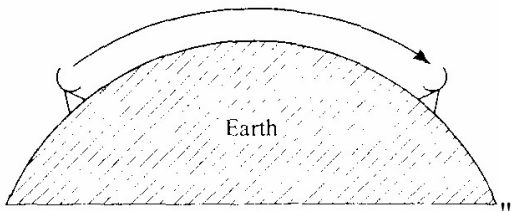
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Kp"vj g"xgt {"mgy "htgs wgpe {"*XNH"cpf "cwf kq"htgs wgpe {"dcpf u."y j gtg"vj g"
y cxgrgpi vj u" gzeggf " 32" n0 ." vj g" gctvj " cpf " vj g" kppqur j gtg" cev" cu" c"
y cxgi wkf g'hqt"grgextqo cipgve"y cxg'r tqr ci cvkq0' "

Kp" vj g"ug" htgs wgpe {" tpci gu." eqo o wplecvkqp" uki pcnu" rtcevekcm {"
r tqr ci cvg"ctqwpf "vj g"i mtdg0'Hqt" vj ku'tgcuqp." vj g"ug"htgs wgpe {"dcpf u"ctg"
r tko ctkn {"wugf "vq"r tqxkf g'pcxki cvkqpcn'ckf u'htqo "uj qtg"vq"uj kr u'ctqwpf "vj g"
y qtrf 0'"

Vj g'ej cppgn'dcpf y kf vj u'cxckrdng"kp"vj g"ug" htgs wgpe {"dcpf u"ctg'tgrvkgm {"
uo cm" *wuwcm {" 3/32" r gtegpv" qh" vj g" egpvt" htgs wgpe {"+" cpf " j gpeg" vj g"
kphqto cvkqp"vj cv'ku'tcpuo kwgf "vj tqwi j "vj g"ug'ej cppgn'ku'qh'tgrvkgm {"umqy "
ur ggf "cpf "i gpgtcm {"eqphkpgf "vq"i ki ken'tcpuo kuukp0'"

C" f qo kpcpv' v'r g" qh" pqlug" cv' vj g"ug" htgs wgpeku" ku" i gpgt cvf " htqo "
vj wpf gtuvqto " cevkxk {"ctqwpf " vj g"i mtdg." gur gekcm {" kp"tqr kecn'tgi kqpu0'
Kpvgthtgpeg'tguwmu'htqo "vj g"o cp {"wugtu'qh'vj g"ug'htgs wgpe {dcpf u0'
"
"
"



HK WTG'304/5"kmwutcvkqp"qh'i tqwpf/y cxg'r tqr ci cvkqp"
"
"

I tqwpf /y cxg'r tqr ci cvkqp." cu" kmwutcvf "kp" Hki 0'304/5." ku"vj g" f qo kpcpv"
o qf g"qh"r tqr ci cvkqp" hqt"htgs wgpeku" kp"vj g"o gf kwo " htgs wgpe {" *O H"
dcpf "205 /5"O J | +0"
"

Vj ku'ku"vj g"htgs wgpe {"dcpf "wugf "hqt"CO "dtqcf ecukpi "cpf "o ctkko g'tcf kq"
dtqcf ecukpi 0'"
"

Kp"CO "dtqcf ecukpi ." vj g'tpci g'y kj "i tqwpf /y cxg'r tqr ci cvkqp"qh'gxgp"vj g"
o qtg'r qy gthwntcf kq'ucvqpu'ku'iko kgf "vq"cdqw'372"n0 0'
"

Cwo qur j gtle"pqlug."o cp/o cf g"pqlug."cpf "vj gto cn'pqlug"htqo "grgextqple"
eqo r qpgpw" cv' vj g" tgegkxt" ctg" f qo kpcpv' f kmwtdcpegu" hqt" uki pcn'
vtcpuo kuukp"kp"vj g'O H'dcpf 0'
"
"

"

Um{y cxg" r tqr ci c\kqp." cu" kmwutcvgf" kp" Hki 0' 304/6." tguwmu" htqo " vcpuo kwgf "uki pcn'dgkpi 'tghrgevfg '*dgpv'qt'tghrcevfg +htqo 'vj g'kqpqr j gtg." y j lej "eqpuku"qh"ugxgtcn'rc{gtu"qh"ej cti gf "r ctv\ngu"tcpi kpi "kp"cnkwwf g" htqo '72'v'622"no "cdqxcg'vj g'uwt\hceg"qh'vj g'gctvj 0"

"

F wtkpi "vj g'f c{ vko g'j qwtu."vj g'j gcvkpi "qh'vj g'my gt'cvo qur j gtg'd{ "vj g'uwp" ecwugu'vj g'htqo c\kqp"qh'vj g'my gt'rc{gtu"cv'cnkwwf gu" dgrny "342"no 0"

"

Vj gug"my gt"rc{gtu."gur gekm{ "vj g'F/rc{gt."ugtxcg"vq"cdutd"htgs wpekgu" dgrny "4"O J | ."vj wu'ugxgtgn{ "rko k\kpi "um{y cxg"r tqr ci c\kqp"qh"CO "tcf kq" dtqcf ecuv0"

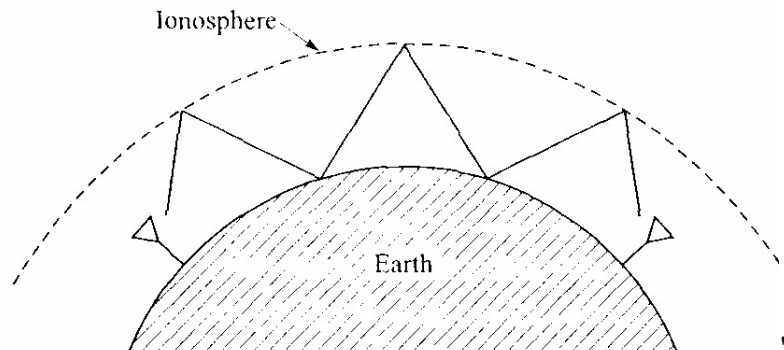
"

J qy gxgt."f wtkpi "vj g'pli j wko g'j qwtu."vj g'grgvtqp"f gpukv{ "kp"vj g'my gt" rc{gtu"qh'vj g'kqpqr j gtg" f tqr u"uj ctr n{ "cpf "vj g'htgs wpe{ "cdutr v\kqp" vj cv'qeevtu'f wtkpi "vj g'f c{ vko g'ku'uki pkh\ecpv{ "tgv wvgf 0" "

"

Cu" c" eqpugs wpeg." r qy gthwi' CO " tcf kq" dtqcf ecuv' uvc\kpu" ecp" r tqr ci cvg" qxgt" rcti g'f kv\pegu" xlc"um{ "y cxg"qxgt"vj g'H/rc{gt"qh'vj g' kqpqr j gtg."y j lej "tcpi gu"htqo "362"v'622"no "cdqxcg'vj g'uwt\hceg"qh'vj g' gctvj 0"

"



"

HK WTG'304 /6"kmwutcvkqp"qh"um{y cxg'r tqr ci c\kqp0

"

C" htgs wpgv{ " qeewtkpi " r tqdrgo " y kj " grgvtqo ci pgv\ " y cxg" r tqr ci c\kqp" xlc"um{ "y cxg"kp"vj g'j ki j "htgs wpe{ " *J H"tcpi g'ku"signal multipath.

Uki pcn' o wnkrcvj " qeewtu" y j gp" vj g' vcpuo kwgf " uki pcn' cttkxgu" cv' vj g' tgegkxgt'xlc"o wnkrg'r tqr ci c\kqp" r cvj u'cv'f khgtgpv'f gnc{u0" "

"

"

K' i gpgtcmf " tguwmu" kp" kpvgtu{o dqn' kpvgtgtgpeg" k' c" f ki kcn' eqo o wplecvkqp"u{uvg0 0' "

O qtgqxtg." yj g" uki pcn' eqo r qpgpvu" cttkxkpi " xlc" f khtgtpv" r tqr ci cvkqp" r cvj u"o c{ "cf f" f gutwvwxgnf ." tguwnkpi " kp" c" r j gpqo gpqp" ecngf "signal fading, y j kej "o quv'r gqr ng" j cxg" gzt r gt kpegf " y j gp" r kuvkpi " vq" c" f kuvcpv" tcf kq" ucvkqp" cv' pki j v' y j gp" umf " y cxg" ku" yj g" f qo kpcpv" r tqr ci cvkqp" o qf g' C' f f kxg" pqlug" kp" yj g" J H' t' cpi g" ku" c" eqo dkpcvqp" qh" cvo qur j gtle" pqlug" cpf " yj gto cn' pqlug0 "

Umf /y cxg" kppqur j gtle" r tqr ci cvkqp" egcugu" vq" gz kuv" cv' htgs wgpelgu" cdqxtg" cr r tqzko cvgnf "52'O J | ." y j kej "ku" yj g" gpf "qh' yj g" J H' d' cpf 0' "

J qy gxgt." k' ku" r quukdng" vq" j cxg" kppqur j gtle" uecwgt" r tqr ci cvkqp" cv' htgs wgpelgu" kp" yj g" t' cpi g" 52/82" O J | ." tguwnkpi " htqo " uki pcn' uecwgtkpi " htqo " yj g" ny gt " kppqur j gtg0' "

K' ku" cnuq" r quukdng" vq" eqo o wplecvg" qxgt" f kuvpegu" qh' ugxtcn' j wpf tgf " o kgu" d{ "wug" qh' tqr qur j gtle" uecwgtkpi " cv' htgs wgpelgu" kp" yj g" t' cpi g" 62/522" O J | 0' "

"Vtqr quecwgt" tguwmu" htqo " uki pcn' uecwgtkpi " f wg" vq" r ctvknngu" kp" yj g" cvo qur j gtg" cv' cnkwwf gu" qh' 32" o kgu" qt " hguu0' "

I gpgtcmf ." kppqur j gtle" uecwgt" cpf " vqr qur j gtle" uecwgt" kpxqkxg" ncti g" uki pcn' r tqr ci cvkqp" nquugu" cpf " tgs wktg" c" ncti g" co qwpv' qh' v' t' cpuo kwgt" r qy gt " cpf " tgrvwxgnf " ncti g" cpvppcu0' "

Htgs wgpelgu" cdqxtg" 52" O J | " r tqr ci cvg" yj tqwi j " yj g" kppqur j gtg" y kj " tgrvwxgnf " rkwg" nquu" cpf " o cnng" ucvgmkng" cpf " gzt cvgtt gutkcn' eqo o wplecvkqp" r quukdng0' "

J gpeg." cv' htgs wgpelgu" kp" yj g" xgt { " j ki j " htgs wgpelgu" { " *XJ H" j cpf " cpf " j ki j gt. " yj g" f qo kpcpv" o qf g" qh' gngvtqo ci pgvle" r tqr ci cvkqp" ku" NQU" r tqr ci cvkqp0' Hqt" vgtt gutkcn' eqo o wplecvkqp" u{uvg0 u." yj ku" o gcpu" yj cv' yj g" v' t' cpuo kwgt" cpf " tgegkxgt " cpvppcu" o wuv' dg" kp" f kt gev' NQU" y kj " tgrvwxgnf " rkwg" qt " pq" qduv wvkvqp0' "

Hqt" yj ku" tgcup. " vgrxkukqp" ucvkqp" v' t' cpuo kwkpi " kp" yj g" XJ H" cpf " wmtc" j ki j " htgs wgpelgu" { " *WJ H" cpf u" o qwpv' yj gkt" cpvppcu" qp" j ki j " vqy gtu" vq" cej kxg" c" dtqcf " eqxgtci g' ctgc0' "

"
"
"

Vj g" f qo kpcpv" pqlug" rko kkpj " vj g" r gthqto cpeg" qh" c" eqo o wplecvkqp"
u{uvg "kp"XJ H' cpf "WJ H' tcepi gu" ku"vj gto cni" pqlug" i gpgtcvgf " kp" vj g"
tgegkgt'htqpv'gpf "cpf " equo le"pqlug"r lengf "wr "d{ "vj g"cpvgppc0" "

Cv'htgs wpekgu"kp"vj g"uwr gt"j ki j "htg s wpe{ "U G+"dcpf "cdqyg"32" I J | ."
cwo qur j gtle "eqpf kkpup'r r{ "c"o clqt "tqng"kp"uki pcnr tqr ci cvkqp0" "

Hqt" gzco r ng." cv"32" I J | ." vj g" cwgpwcvkqp" tcepi gu" htqo " cdqw" 2025"
f gekdgn" r gt" nkrqo gygt " f D lno + " kp" rki j v' tclp" vq" cdqw" 208" f D lno " kp"
j gcx{ "tclp0" "

Cv'322" I J | ." vj g" cwgpwcvkqp" tcepi gu'htqo " cdqw" 208" f D lno " kp" rki j v' tclp"
vq" cdqw" 8" f D lno " kp" j gcx{ "tclp0" "


J gpeg. "kp" vj ku"htgs wpe{ " tcepi g. " j gcx{ " tclp" kptqf wegu" gzvtgo gn{ " j ki j "
r tqr ci cvkqp" mquugu" vj cv' ecp" tguwr" kp" ugtxleg" qwci gu" *vqcn' dtgcnf qy p"
kp" vj g" eqo o wplecvkqp" u{uvg +0" "

Cv'htgs wpekgu" cdqyg" vj g" gzvtgo gn{ " j ki j " htgs wpe{ " *GJ H+" dcpf. " y g"
j cxg" vj g" kphctgf " cpf " xlkudng" rki j v' tgi kpu" qh" vj g" grgevtqo ci pgve"
ur gevwo . " y j lej " ecp" dg" wugf " vq" r tqxf g" NQU" qr vech' eqo o wplecvkqp" kp"
htgg" ur ceg0' Vq" f cvg. " vj gug" htgs wpe{ " dcpf u" j cxg" dggp" wugf " kp"
gzr gtko gpvcn' eqo o wplecvkqp" u{uvg u. " uwej " cu" ucvgmkg/vq/ucvgmkg"
rkpm0' "

Underwater acoustic channels.
"

Grgevtqo ci pgve" y cxgu" f q" pqv' r tqr ci cvg" qxgt" mpi " f kucpegu" wpf gt"
y cvgt "gzegr v'cv'gzvtgo gn{ "ny "htgs wpekgu0" "

Vj g" cwgpwcvkqp" qh' grgevtqo ci pgve" y cxgu" kp" y cvgt " ecp" dg" gzt r tguugf " kp"
vto u" qh' vj g" skin depth, y j lej " ku" vj g" f kucpeg" c" uki pcn' ku" cwgpwcvgf " d{ "
3lg0" "

Hqt" ugcy cvgt. " vj g" unkp" f gr vj " " ? " 472" I  y j gt g/ " ku" gzt r tguugf " kp" J | "
cpf " " ku" kp" o 0" "

Hqt" gzco r ng." cv'32" nJ | ." vj g" unkp" f gr vj " ku" 40" o 0' kp" eqpvtcuw. " ceqwvke"
uki pcn' r tqr ci cvg" qxgt" f kucpegu" qh' vgpu" cpf " gxgp" j wpf tgf u" qh' nkrq/
o gygtu0'
"
"
"

Cp" wpf gty cvgt" ceqwuke" ej cppgn' ku" ej ctcevgtk gf " cu" c" o wnr cvj " ej cppgn' f wg" vq" uki pcn' tghgevkqpu" htqo " vj g" umhceg" cpf " vj g" dqwqo " qh" vj g" ugc0"

Dgecwug" qh" y cxg" o qvkqp." vj g" uki pcn' o wnr cvj " eqo r qpgpw" wpf gti q" vko g/xct { kpi "r tqr ci cvkqp" f gr { u'vj cv'tguwn'kp" uki pcn' hcf kpi 0' "

Vj g" uqwpf " xgmekv{ " ku" pqo kpcmf " cdqw" 3722" o lu." dw" vj g" cewcn' xcwng" y km' xct { "gkj gt" cdqxg" qt" dgmjy " vj g" pqo kpcn' xcwng" f gr gpf kpi " qp" vj g" f gr vj " cvy j kej " vj g" uki pc n'r tqr ci cvgu0"

Co dkpvp' qegcp" ceqwuke" pqkug" ku" ecwugf " d{ "uj tko r ." hkuj ." cpf " xctkqu" o co o cnu' P gct" j ctdqtu." vj gtg" ku" cnuq" o cp/o cf g" ceqwuke" pqkug" kp" cf f kkkqp" vq" vj g" co dkpvp' pqkug0"

Kp" ur kvg" qh" vj ku" j quvkv" gpvktqpo gpv." kv" ku" r quukdr" vq" f guki p" cpf " ko r ngo gpv' ghlekpv" cpf " j ki j n{ " tgrkdr" wpf gty cvgt" ceqwuke" eqo o wplecvkqp" u{ uvgu u" hqt" vtcpuo kvkpi " f ki kcn' uki pcn' qxgt" rcti g" f kvcpegu0"

Storage channels.

O ci pgle" vcr g." kpenf kpi " f ki kcn' cvf kvcr g" cpf " xkf gvcr g." o ci pgle" f kumi" wugf " hqt" uvtkpi " rcti g" co qwpw" qh' eqo r wgt" f cvc." qr vkecn' f kumi" wugf " hqt" eqo r wgt" f cvc" uvtkci g." cpf " eqo r cev' f kumi" ctg" gzco r ngu" qh" f cvc" uvtkci g" u{ uvgu u" vj cv' ecp" dg" ej ctcevgtk gf " cu" eqo o wplecvkqp" ej cppgn0' "

Vj g" r tqegu" qh' uvtkpi " f cvc" qp" c" o ci pgle" vcr g" qt" c" o ci pgle" qt" qr vkecn' f kumi" ku" gs vlxcrgpv" vq" vtcpuo kvkpi " c" uki pcn' qxgt" c" vgrj qp" qt" c" tcf kv" ej cppgn0' "

Vj g" tgcfdcem' r tqegu" cpf " vj g" uki pcn' r tqegu" kpi " kvxkvgf " kp" uvtkci g" u{ uvgu u" vq" tgeqxt" vj g" uvtkgf " kvhqtto cvkqp" ctg" gs vlxcrgpv" vq" vj g" hvpevkqpu" r gthqtto gf " d{ " c" tgekvgt" kp" c" vgrj qp" qt" tcf kv" eqo o wplecvkqp" u{ uvgu " vq" tgeqxt" vj g" vtcpuo kvgf " kvhqtto cvkqp0' "

Cffkvxg" pqkug" i gpgtcvgf " d{ " vj g" grgestqple" eqo r qpgpw" cpf " kvvgtgtgpeg" htqo " cf lcegpv' vtcem" ku" i gpgtcv{ " r tguvp' kp" vj g" tgcfdcem' uki pcn' qh' c" uvtkci g" u{ uvgu . " luv' cu" ku" vj g" ecug" kp" c" vgrj qp" qt" c" tcf kv" eqo o wplecvkqp" u{ uvgu 0' "

"

"

Vj g"co qwpv'qh'f cv"vj cv'ecp"dg"uvtgf "ku"i gpgtcm{ "rko kvgf "d{ "vj g"ukl g" qh'vj g"f km'qt" vr g"cpf "vj g'f gpukv{ " *pwo dgt"qh'dku" uvtgf "r gt" us wctg" kpej + " vj cv' ecp" dg"cej kxgf "d{ "vj g"y tkgltgcf "grgestqple" u{ ugo u"cpf" j gcf u0"

"

"

Ej cppgn' eqf kpi " cpf " o qf wrcvqp" ctg" guugpvkn' eqo r qpgpw" qh'c"y gm/ f guki pgf " f ki kcn' o ci pgke" qt" qr vkn' uvtci g" u{ ugo 0' k" vj g" tgcfdcm' r tqegu." vj g" uki pcn' ku" f go qf wrcvgf " cpf " vj g" cf f gf " tgf wpf cpe{ " kvtqf wegf " d{ " vj g" ej cppgn' gpeqf gt" ku" wugf " vj" eqttgev' gttqtu" k" vj g" tgcfdcm' uki pcr0"

"

"

1.3 MATHEMATICAL MODELS FOR COMMUNICATION CHANNELS

"

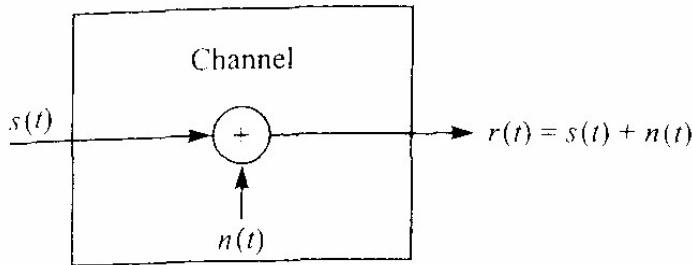
Vj g"o cvj go vkn' o qf gn' hqt" vj g" ej cppgn' ku" wugf " k" vj g" f guki p" qh' vj g" ej cppgn' gpeqf gt" cpf " o qf wrcvt "cv' vj g' vcpuo kvgt "cpf " vj g' f go qf wrcvt " cpf " ej cppgn' f geqf gt "cv" vj g' tgegkgt 0"

"

The additive noise channel.

Vj g'uko r rguv" o cvj go vkn' o qf gn' hqt" c" eqo o wplecvqp" ej cppgn' ku' vj g" cf f kxg' pqlug' ej cppgn' kmwv cvgf " k" Hki 0305 /30"

"



"

Hk WTG'305/3 "Vj g"cf f kxg' pqlug' ej cppgn'

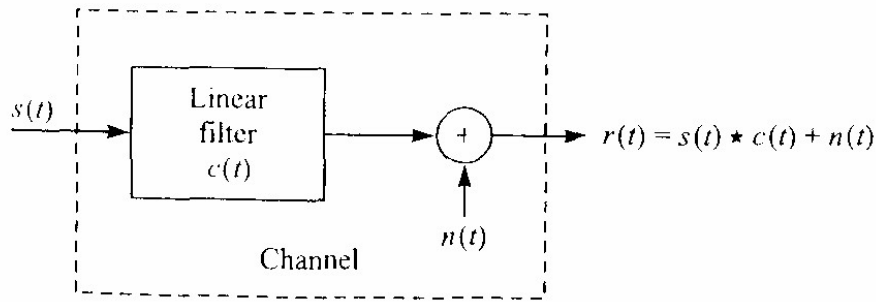
"

k" vj ku" o qf gn" vj g" vcpuo kvgf " uki pcn' u* v+ " ku" eqttw vgf " d{ " cp" cf f kxg" tcpf qo " pqlug" r tqegu" p* v+ 0' Rj { ukecm{ . " vj g" cf f kxg" pqlug" r tqegu" o c{ " ctug" htqo " grgestqple" eqo r qpgpw" cpf " co r nktu" cv' vj g' tgegkgt " qh' vj g" eqo o wplecvqp" u{ ugo " qt" htqo " kvgt hgt gpeg" gpeqwpvgtgf " k" vcpuo kvqp " cu' k" vj g' ecug' qh' tcf k' uki pcn' vcp uo kvqp + 0'

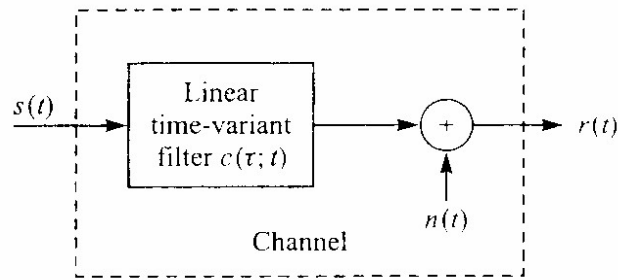
"

"

"



HK WTG'305/4"Vj g"rpgct'hkngt"ej cpgnly kj "cf f kxg"pqkug0"



HK WTG'305/5"Nkpgct"ko g/xctkcpv'hkngt"ej cpgnly kj "cf f kxg"pqkug0"

The linear tim e-variant filter channel.

Rj { ulecn'ej cpgnu"uwej "cu"wpf gty cvgt"ceqwvke"ej cpgnu"cpf "kppur j gte" tcf kq"ej cpgnu"vj cv'tguwn"kp"ko g/xctkcpv"o wnr cvj " r tqr ci cvkqp"qh'vj g" vcpuo kwgf "uki pcn'o c{"dg"ej ctcevtk gf "o cvj go cvkcm("cu"ko g/xctkcpv' rpgct'hkngtu0"

Uwej "rpgct'hkngtu"ctg"ej ctcevtk gf "d{"c"ko g/xctkcpv"ej cpgni"ko r wug" tgur qpug" $c(t; t)$, y j gtg" $c(t; t)$, ku"vj g"tgur qpug" qh'vj g"ej cpgni'cv"ko g"t f wg"vq"cp"ko r wug"cr r rkgf "cv"ko $g' - t$.

Vj wu."t"tgr tgugpw"vj g"\$ci g\$"*gr ug /ko g+"xctkdr0' Vj g"rpgct"ko g/xctkcpv'hkngt"ej cpgnly kj "cf f kxg"pqkug"ku"mwutcvgf "kp"Hki 0'305/50'Hqt" cp'kpr w'uki pcn'u"v."vj g"ej cpgni'qwr w'uki pcn'ku"

$$r(t) = s(t) * c(\tau; t) + n(t)$$

$$= \int_{-\infty}^{\infty} c(\tau; t)s(t - \tau) d\tau + n(t)$$

"5+"

Gzco r ngu

"

Evaluation of Line of Site (LOS) The antenna for a television (TV) station is located at the top of a 1,500-foot transmission tower. Compute the LOS coverage for the TV station if the receiving antenna (in the fringe area) is 20 feet above ground.

Solution: " , we find that the distance from the TV transmission tower to the radio horizon is

$$d_1 = \sqrt{2h} = \sqrt{2(1,500)} = 54.8 \text{ miles}$$

The distance from the receiving antenna to the radio horizon is

$$d_2 = \sqrt{2(20)} = 6.3 \text{ miles}$$

Then, the total radius for the LOS coverage contour (which is a circle around the transmission tower) is

$$d = d_1 + d_2 = 61.1 \text{ miles} \quad "$$

"

Maximum Telephone Line Data Rate A computer user plans to buy a higher-speed modem for sending data over his or her analog telephone line. The telephone line has a signal-to-noise ratio (SNR) of 25 dB and passes audio frequencies over the range from 300 to 3,200 Hz. Calculate the maximum data rate that could be sent over the telephone line when there are no errors at the receiving end.

Solution: In terms of a power ratio, the SNR is $S/N = 10^{(25/10)} = 316.2$ (see dB in Chapter 2), and the bandwidth is $B = 3,200 - 300 = 2,900$ Hz. " , we get

$$R = B \log_2 \left(1 + \frac{S}{N} \right) = 2,900 [\log_{10} (1 + 316.2)] / \log_{10}(2),$$

or

$$R = 24,097 \text{ bits/s}$$

Consequently, a 28.8-kbit/s modem signal would not work on this telephone line; however, a 14.4-kbit/s modem signal should transmit data without error. "

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1.4 A HISTORICAL PERSPECTIVE IN "THE DEVELOPMENT OF DIGITAL COMMUNICATIONS

"

Vj g" grgwtk" vrgi tr j " y cu" f gxgnr gf " d{ " Uco wgn' O qtug" cpf " y cu" f go qpwtcvf "k"3: 590"

"

O qtug" f gxkugf " vj g" xctkcdng/rgpi vj " dlpct{ " eqf g" k" y j lej " ngwtu" qh' vj g" Gpi rkuj " cr j cdg'vtg'tgr tg ugpvfg "d{ "c"ugs wpeg"qh'f qu'cpf "f cuj gu"eqf g" y qtf u"0"

"

P gctn{ " 62" { gctu" rvtg." k" 3: 970' Go krg" Dcw qv' f gxkugf " c" eqf g" hqt" vrgi tr j { " k" y j lej " gxgt{ " ngwt" y cu" gpeqf gf " kvq" hz gf /rgpi vj " dlpct{ " eqf g' y qtf u'qh'rgpi vj "70' "

"

K" vj g" Baudot code, dlpct{ " eqf g" grgo gpw" ctg" qh" gs wcn' rgpi vj " cpf " f guki pcvfg "cu" o ctn'cpf "ur ceg0"

"

P { s wku' *3; 46+ " y j q" kpxguki cvfg " vj g" r tqdng " qh" f gvto kpkpi " vj g" o czko wo "uki pcnpi "tcv" vj cv'ecp"dg" wugf "qxgt" c" vrgi tr j "ej cppgn'qh'c" i kxgp'dcpf y kf vj "y kj qw' kvgt/u{ o dqnlkvgtgtpgpeg0"

"

J g" hqtto wrcvfg " c" o qf gn' qh' c" vrgi tr j " u{ uvgo " k" y j lej " c" vtcpuo kvfg " uki pcn'j cu'vj g' i gpgtcnlhqtto "

"

""

" " " " $s(t) = \sum_n a_n g(t - nT)$ "*38+ "

"

y j gtg""

i *v' tgr t gupvu' c' dcuke' r wug" uj cr g""

} cpi "ku" vj g" dlpct{ " f cv" ugs wpeg" qh' } Õ3; " vtcpuo kvfg " cv' c" tcv" qh' 3 IV" dkulu0"

P { s wku' ugv' qw' vq" f gvto kpg" vj g" qr vko wo "r wug" uj cr g" vj cv' y cu' dcpf / rko kvfg "vq' Y "J | "cpf "o czko k gf "vj g" dkv' tcv" wpgt "vj g' eqpwtckpv' vj cv' vj g" r wug" ecwugf "pq" kvgt/u{ o dqnlkvgtgtpgpeg" cv' vj g" uco r kpi " vko g" mV. ""k ? "2. Õ3. Õ4. 000"

"

J ku" uwf lgu" rgf " j ko " vq" eqpenmf g" vj cv' vj g" o czko wo " r wug" tcv" ku" 2W r wugulu0Vj ku' tcv' ku' pqy "ecmgf "vj g" Nyquist rule.

"

QUESTIONS

30 C"egmwrct" vgrgr j qpg" egm'ukg"j cu"cp"cpvgppc" mjecvzf "cv"vj g"vqr "qh"e"
82/hv' vqy gt0' C" v'r kecn' egmwrct" vgrgr j qpg" wugt" j cu" j ku" qt" j gt"
cpvgppc" mjecvzf "6"hv'cdqyg"vj g"i tqwvf 0' Y j cv'ku"vj g"NQU"tcf kwu"qh"
eqxgtci g'hqt"vj ku'egm'ukg"vq"cf kucpv'wugtA "

40 Cp"cpcri " vgrgr j qpg" rpg"j cu"cp"UP T"qh"67"fD"cpf "r cuugu" cwf kq"
htgs wgpelgu" qxgt"vj g"tcpi g"qh"522"vq"5.422"J | 0'C"o qf go "ku"vq"dg"
fguki pgf" vq" vtcpuo kv' cpf" tgegkxg" f cvc" uko wncpgqwan(" *k0" hwn"
f wr rnz +qxgt"vj ku'hp'g'y kj qw'gttqtu0"

*c+"K"vj g"htgs wpe{ "tcpi g"522"vq"3.422"J | "ku" wugf "hqt"vj g" vtcpuo kwgf "
uki pcn"y j cv'ku"vj g"o cz ko wo "vcpuo kwgf "f cvc"tcvga"

*d+"K"vj g"htgs wpe{ "tcpi g"3.722"vq"5.422"J | "ku" wugf "hqt"vj g"uki pcn "dgkpi "
uko wncpgqwan("tg egkxgf ."y j cv'ku"vj g"o czko wo "tgegkxgf "f cvc"tcvga" "

*e+"K" vj g" y j qng" htgs wpe{ " tcpi g" qh" 522" vq" 5.422" J | " ku" wugf "
uko wncpgqwan(" hqt" vtcpuo kvkpi " cpf" tgegkxkpi ." y j cv' ctg" vj g"
o czko wo "vcpuo kvkpi "cpf "tgegkxkpi "f cvc"tcvga "