S-72.3220 RADIOTIETOLIIKENNEJÄRJESTELMÄT
Tentti 5.9.2007
Osa A. Ilman lähteitä suoritettavat tehtävät (2)

Tentti koostuu kahdesta osasta. Kun olet suorittanut osan A, jätä vastaukset tentin valvojalle, jolloin saat 3 tehtävää käsittävän B-osan tehtäväpaperin. Nämä tehtävät saat suorittaa vapaavalintaisten lähteiden kanssa. Ajankäytöstä päätät itse 3 h kokonaisajan puitteissa. Poistua saat kuitenkin vasta tunnin kuluttua tentin alkamisesta.

1. Vastaa lyhyesti muutamalla lauseella seuraaviin osatehtäviin. Käytä tarvittaessa kuvia:

a) Ketä katsotaan ensimmäisenä lähettäneen radiosignaaleja Atlantin yli?
b) Mitkä taajuudet muodostavat VHF-kaistan?
c) Millä taajuuksilla vaikuttaa ilmakehän kohina eniten?
d) Mitä kuvaa AM/PM-konversio?
e) Miten määrittelee ITU radiotietoliikennejärjestelmän epäkäytettävyys?
f) Radiovastaanottimen herkkyys on –90 dBm, lähettimen lähtötehotaso on 40 dBm, ja vastaanotettu mediaanitaso on –60 dBm. Kuinka suuri on tasahäipymisvara?
g) Mitä kertoo radiovastaanottimen signature?
h) Miksi monitiehäipyminen on pienempi ongelma kiinteissä point to area radioverkoissa kuin matkapuhelinverkoissa?
i) Miten määrittelee ITU lähetinantennin korkeus, kun kantama > 15 km?
j) Montako GEO-satelliittia tarvitaan päiväntasaajan täydelliseksi peittämiseksi?

2. Kiinteillä radioyhteyksillä käytetään käytetään yhä enemmän mm-aaltoja.
a) Minkälaisia etenemishäviöitä on otettava huomioon sadevaimennuksen lisäksi yli 30 GHz taajuudella toimivan radiolinkkihypyn suunnittelussa?
b) Hahmottele sateen aiheuttaman katkoajan ennustaminen esim. proseduurin vuokaavion avulla. Vain periaatteet tarvitsee selostaa, tarkkoja algoritmeja ei vaadita, saa toki esittää.

S-72.3220 RADIOTIETOLIIKENNEJÄRJESTELMÄT
Tentti 5.9.2007
Osa B. Lähteiden kanssa suoritettavat tehtävät (4, joista 3 parhaiten suoritettua otetaan huomioon tenttiarvosanassa)

3. 1 MHz (kohina)kaistanleveydellä toimivan spektrianalysaattorin tuloon redusoitu kohinataso on –85 dBm, kun lähteen kohinalämpötila on 290 K.

a) Laske tämän spektrianalysaattorin kohinaluku.

b) Käyetään esivahvistinta, jonka kohinaluku on 2 dB. Kuinka suuri pitää tämän esivahvistimen vahvistuksen olla, jotta sen tuloon redusoitu kohinataso olisi –100 dBm? $kT_o = 4 \cdot 10^{-21}$ W/Hz

4. Lyhyen kantaman radiotietoliikennejärjestelmä Bluetooth toimii ISM-kaistalla, ja suurin kantoaaltotaajuus on 2.484 GHz. Luokka II-lähetimen maksimitehotaso on 4 dBm, ja vastaanottimen herkkyysvaatimus on –70 dBm. Kuinka suuri on maksimikantama, jos yhteydellä on vapaan tilan eteneminen, ja lähetys- ja vastaanottoantennijärjestelmien nettovahvistus on 0 dB?

5. Pahimpana kuukautena antaa radiojänteeltä mitattu kanavamalli seuraavat ennustekaavat tasahäipymän ja selektiivisen häipymän aiheuttamille katkostodennäköisyyksille ilman diverstiyä ja diversityn kanssa:

$$P_{o,SF} = P_{SF} W \tau e^{-B/4,5}, \qquad P_{o,FF} = r \cdot 10^{-FFM/10}$$
$$P_{o,SF,div} = P_{SF} e^{-B/2,8} W \tau, \; P_{o,FF,div} = q \cdot 10^{-FFM/5}$$

kanavamallin parametriarvot ovat: • P_{SF} = 0,02 • r = 0,15 • q = 7,5 • τ = 6,3 ns	vastaanottimen häipymäsietoparametrit ovat:: • FFM = 35 dB • B on M-signaturen korkeus = 5/25 dB • W on signaturen leveys = 32/12 MHz Signature on sama sekä minimi- että ei-minimivaiheisessa kanavassa. Arvot pätevät ilman korjainta ja korjaimella varustetulle vastaanottimelle

Laske katkoparannus

a) korjaimella,

b) diversityllä,

c) korjaimella ja diversityllä.

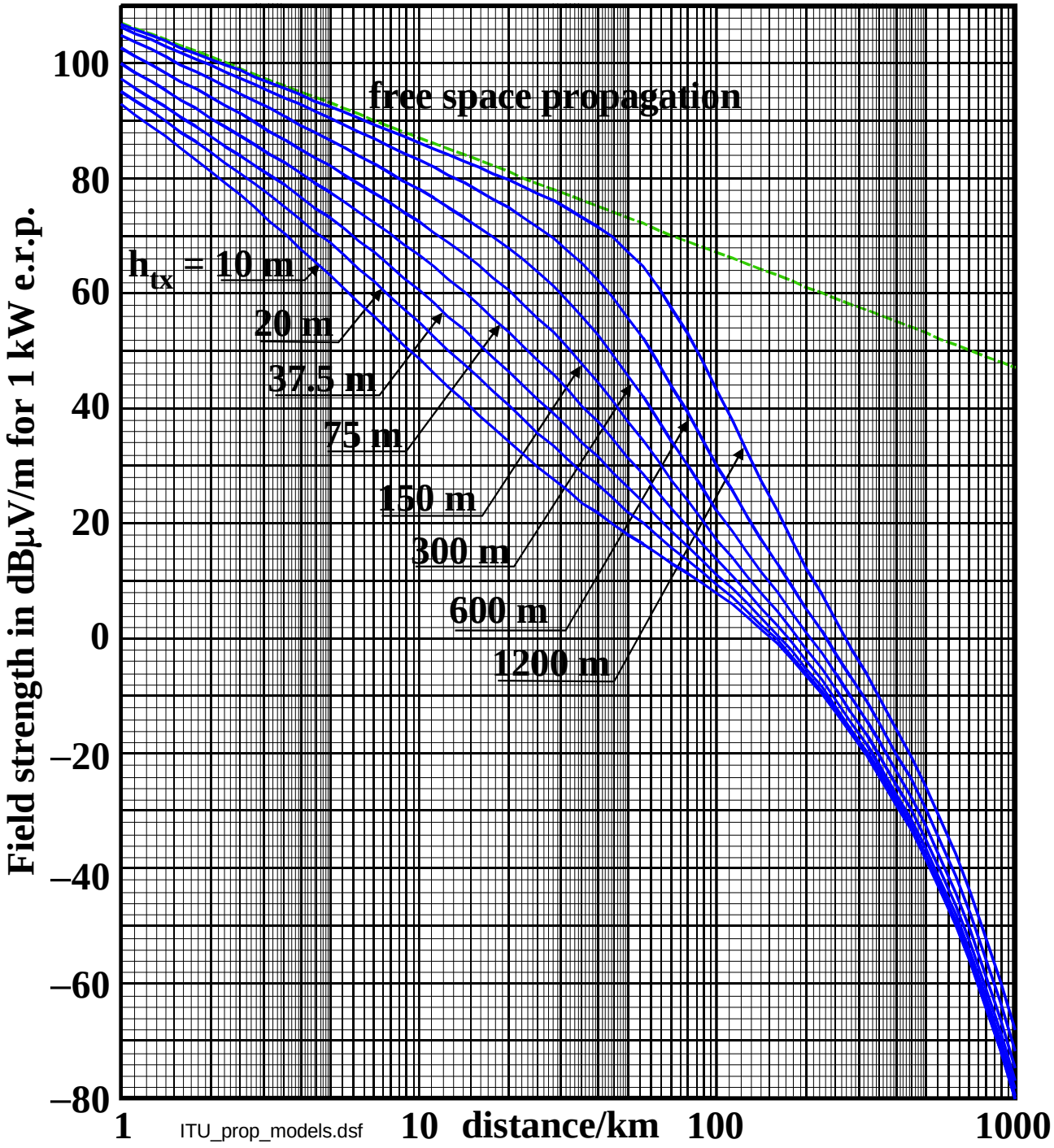
6. Hyvänlaatuisen FM-ääniohjelman vastaanotto vaatii 54 dBμV/m sähkökentän tason ja suojaussuhteeksi interferenssisignaalin normaalietenemisen aikana 51 dB (50 % ajasta) ja poikkeuksellisen troposfäärietenemisen aikana 37 dB (1 % ajasta). Oletetaan kaikkien lähettimien lähetystasoksi 10 kW EIRP ja lähetystaajuudeksi 100 MHz ja tehollisseksi lähetysantennin korkeudeksi 300 m. Vastaanotinantenn korkeus oletetaan vastaavan sitä arvoa, jolla suosituksessa ITU-R Rec. 1546 olevat sähkökentän tasokäyrät ovat voimassa.

a) Millä etäisyydellä lähettimestä peittotodennäköisyys annetuilla vaatimuksilla on 50 % suosituksen ITU-R Rec. 1546 mukaan?

b) Kuinka suuri tulee samantaajuisen kanavan lähettimen olla, jotta suojaussuhdevaatimus interferenssin normaalietenemisellä täyttyy 50 % todennäköisyydellä peittoalueen rajalla lähettimillä yhdistävällä suoralla suosituksen ITU-R Rec. 1546 mukaan?

c) Kuinka suuri tulee samantaajuisen kanavan lähettimen olla, jotta suojaussuhdevaatimus interferenssin poikkeuksellisella troposfäärietenemisellä täyttyy 50 % todennäköisyydellä peittoalueen rajalla lähettimillä yhdistävällä suoralla suosituksen ITU-R Rec. 1546 mukaan?

Received field strength at 600 MHz over land paths as function of distance for different transmitter antenna heights exceeded 50% of time. Receiver antenna height 10 m (equal to representative height of ground cover)



S-72.3220 RADIO COMMUNICATION SYSTEMS
Examination 5.9.2007
Part A. Two tasks to be done without literature

The exam consists of two parts. When you have done the tasks in Part A (*closed books*) you give the answers to the exam supervisor, and then you will get Part B (*open books*) including 4 problems (the 3 best performed are considerd for the exam grade). You decide yourself the time you spend on each part, but the total exam duration is 3 h. You can leave the exam room at earliest 1 hour after the start of the exam.

1. Answer the following questions with one or a few sentences. Use figures when needed.

a) Who has been considered to be the first to transmit radio signals across the Atlantic ocean?
b) Which frequencies comprise the VHF-band?
c) On which frequencies has atmospheric noise its largest impact?
d) What does AM to PM conversion describe?
e) How does ITU define non-availability of a radio communication system?
f) The sensitivity level of a radio receiver is –90 dBm, the transmitter output power level is 40 dBm, and the median received level –60 dBm. How large is the flat fade margin?
g) What does the radio receiver signature tell?
h) Why is multipath fading a smaller problem in fixed point to area radio networks than in mobile radio networks?
i) How does ITU define transmitter antenna height for ranges > 15 km?
j) How many GEO-satellites are needed for full coverage of the Equator?

2. Fixed radio links are more and more using mm-waves.
a) What kind of propagation losses must be taken into account in the planning of a mm-wave radio link hop above 30 GHz in addition to rain attenuation?
Give an outline to the estimation of outage caused by rain e.g. as a flow diagram of the procedure. Only the principles are required not the exact algorithms, thus not forbidden in your answer.

S-72.3220 RADIO COMMUNICATION SYSTEMS
Examination 5.9.2007
Part B. 4 tasks to be done with arbitrary literature. The three best performed are considered for the exam grade.

3. The noise level reduced to the input of a spectrum analyzer with 1 MHz (noise) bandwidth is –85 dBm, when the source has a noise temperature of 290 K.

a) Calculate the noise figure of this spectrum analyzer.

b) A pre-amplifier with 2 dB noise figure is used. How large should the gain of this pre-amplifier be to give a noise level reduced to the pre-amplifier input of –100 dBm? $kT_o = 4 \cdot 10^{-21}$ W/Hz

4. The short range radio communication system Bluetooth is working in the ISM-band and the maximum carrier frequency is 2.484 GHz. A class II transmitter has a maximum power level of 4 dBm, and the receiver sensitivity requirement is –70 dBm. How large is maximum range if free space propagation occurs, and the net gain of both transmitter and receiver antenna systems is 0 dB.

5. During the worst month the measured channel model of a radio hop gives the following prediction formulas for the outage probability caused by frequency selective fading and flat fading respectively without and with diversity:

$$P_{o,SF} = P_{SF} W \tau e^{-B/4.5}, \qquad P_{o,FF} = r \cdot 10^{-FFM/10}$$

$$P_{o,SF,div} = P_{SF} e^{-B/2.8} W \tau, \; P_{o,FF,div} = q \cdot 10^{-FFM/5}$$

the parameter values of the channel models are: • P_{SF} = 0.02 • r = 0.15 • q = 7.5 • τ = 6.3 ns	the fade tolerance parameters of the receiver are: • FFM = 35 dB • B is the M-signature height = 5/25 dB • W is the signature width = 32/12 MHz The signature is the same in both minimum phase and non minimum phase channel. The two signature values are without and with equalizer

Calculate the outage improvement:

a) using equalizer only,

b) using diversity only,

c) using both equalizer and diversity.

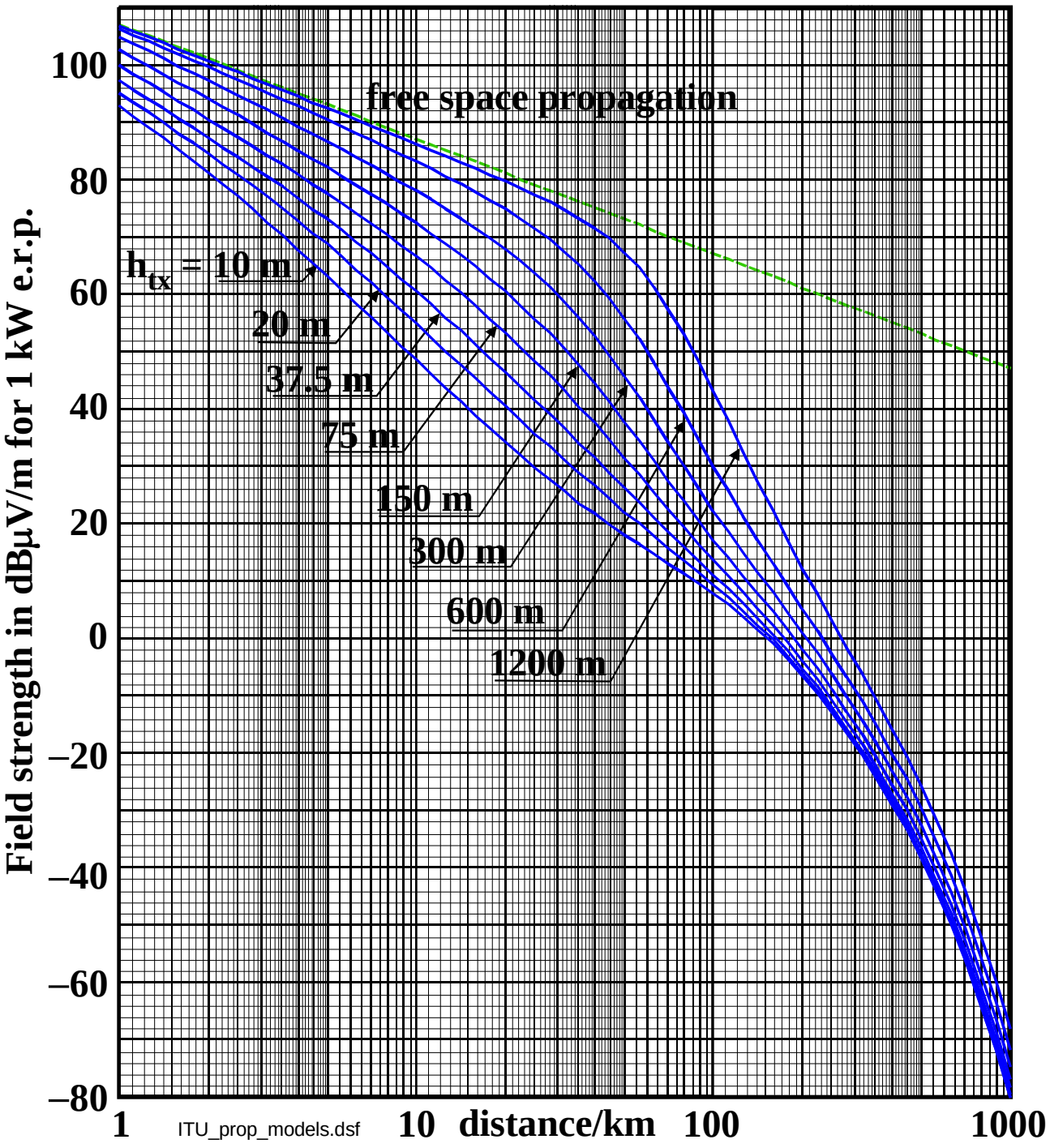
6. High-quality FM-audio reception requires an electrical field strength level of 54 dBμV/m and a cochannel protection ratio of 51 dB during standard interference propagation (50 % of time) and 37 dB during aexceptional tropospheric propagation (1 % of time). It is assumed that all transmitter transmit 10 kW EIRP at 100 MHz and the effective transmitter antenna height is 300 m. The receiver antenna height corresponds to the assumptions for the field strength level curves in ITU-R Rec. 1546.

a) At which distance from the transmitter the coverage probability under the above requirement is 50 % according to ITU-R Rec. 1546?

b) How large should the cochannel transmitter distance be that the protection ratio requirement is fulfilled with 50 % probability during standard interference propagation on the line connecting the transmitters at the coverage border according to ITU-R Rec. 1546?

c) How large should the cochannel transmitter distance be that the protection ratio requirement is fulfilled with 50 % probability during exceptional tropospheric interference propagation on the line connecting the transmitters at the coverage border according to ITU-R Rec. 1546?

Received field strength at 600 MHz over land paths as function of distance for different transmitter antenna heights exceeded 50% of time. Receiver antenna height 10 m (equal to representative height of ground cover)



1. Answer the following questions with one or a few sentences. Use figures when needed.

a) Who has been considered to be the first to transmit radio signals across the Atlantic ocean?
Marconi

b) Which frequencies comprise the VHF-band?
30 – 300 MHz

c) On which frequencies has atmospheric noise its largest impact?
Below 1 MHz

d) What does AM to PM conversion describe?
The output phase shift for a given imput amplitude in a non-linear RF power amplifier

e) How does ITU define non-availability of a radio communication system?
When the bit error rate (of a 64 kbit/s channel) exceeds 0.001 for more than 10 consecutive seconds

f) The sensitivity level of a radio receiver is –90 dBm, the transmitter output power level is 40 dBm, and the median received level –60 dBm. How large is the flat fade margin?
30 dB

g) What does the radio receiver signature tell?
How deep 2-path channel notch the receiver tolerates as function of the notch frequency.

h) Why is multipath fading a smaller problem in fixed point to area radio networks than in mobile radio networks?
Due to use of directive antennas the delay spread is lower than in mobile networks with omnidirectional antennas..

i) How does ITU define transmitter antenna height for ranges > 15 km?
It is the antenna height above the median terrain height on the distance interval 3 ... 15 km from the transmitter site.

j) How many GEO-satellites are needed for full coverage of the Equator?
3

2. Fixed radio links are more and more using mm-waves.

a) What kind of propagation losses must be taken into account in the planning of a mm-wave radio link hop above 30 GHz in addition to rain attenuation?

b) Give an outline to the estimation of outage caused by rain e.g. as a flow diagram of the procedure. Only the principles are required not the exact algorithms, thus not forbidden in your answer.

SOLUTION

a) Free space loss
Atmospheric gas losses
Precipitation losses other than rain losses (snow, fog)
(Radome losses)
(Possible antenna feeder losses)
(Connector losses)

b) Determination of rain rate exceeded 0.01 % of time on the actual geographic location of the hop

↓

Calculation of the rain attenuation exceeded 0.01 % of time on the used frequency

↓

Calculation of the effective hop length reduction factor

↓

Calculation of the reference hop length for the actual rain rate

↓

Calculation of the rain attenuation exceeded 0.01 % of time

↓

Prediction of rain outage based on the previous rain attenuation value and the receiver flat fade margin

3. The noise level reduced to the input of a spectrum analyzer with 1 MHz (noise) bandwidth is –85 dBm, when the source has a noise temperature of 290 K.

a) Calculate the noise figure of this spectrum analyzer.

b) A pre-amplifier with 2 dB noise figure is used. How large should the gain of this pre-amplifier be to give a noise level reduced to the pre-amplifier input of –100 dBm? $kT_o = 4 \cdot 10^{-21}$ W/Hz

SOLUTION

a)

$$P_n = FkT_oB \rightarrow F = \frac{P_n}{kT_oB} = \frac{10^{-11.5}}{4 \cdot 10^{\cdot 21} \cdot 10^6} = \frac{10^{3.5}}{4} = 790.6 \leftrightarrow 29.0 \text{ dB}$$

b)

$$P_{n,sys} = F_{sys}kT_oB$$

$$\rightarrow F_{sys} = \frac{P_{n,sys}}{kT_oB} = \frac{10^{-13.0}}{4 \cdot 10^{\cdot 21} \cdot 10^6} = \frac{10^{2.0}}{4} = 25 \leftrightarrow 13.98 \text{ dB}$$

$$F_{sys} = F_{pa} + \frac{F-1}{G_{pa}}$$

$$\rightarrow G_{pa} = \frac{F-1}{F_{sys} - F_{pa}} = \frac{10^{2.9} - 1}{10^{1.398} - 10^{0.2}} = 33.88 \leftrightarrow 15.3 \text{ dB}$$

4 The short range radio communication system Bluetooth is working in the ISM-band and the maximum carrier frequency is 2.484 GHz. A class II transmitter has a maximum power level of 4 dBm, and the receiver sensitivity requirement is -70 dBm. How large is maximum range if free space propagation occurs, and the net gain of both transmitter and receiver antenna systems is 0 dB

SOLUTION

$$P_{tx} - S = L_{fs} - G_{tx} - G_{rx} = 92.45 + 20\lg d + 20\lg f$$

$$= 92.45 + \underbrace{20\lg 2.484}_{7.90} + 20\lg d_{km} = 4 - (-70) = 74$$

$$\rightarrow d = 10^{0.1(74-92.45-7.90)} = 10^{-1.3175} = 0.0481 \text{ km}$$

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5. During the worst month the measured channel model of a radio hop gives the following prediction formulas for the outage probability caused by frequency selective fading and flat fading respectively without and with diversity:

$$P_{o,SF} = P_{SF} W \tau e^{-B/4.5}, \qquad P_{o,FF} = r \cdot 10^{-FFM/10}$$

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the parameter values of the channel models are: • P_{SF} = 0.02 • r = 0.15 • q = 7.5 • τ = 6.3 ns	the fade tolerance parameters of the receiver are: • FFM = 35 dB • B is the M-signature height = 5/25 dB • W is the signature width = 32/12 MHz The signature is the same in both minimum phase and non minimum phase channel. The two signature values are without and with equalizer

Calculate the outage improvement:

a) using equalizer only,
b) using diversity only,
c) using both equalizer and diversity.

SOLUTION

a)

$$P_{o,0} = \left(0.15 \cdot 10^{-0.1 \cdot 35} \right)^{0.75} + 0.02 \cdot 32 \cdot 0.0063 \cdot e^{-5/4.5} \Big)^{0.75} \Big)^{4/3}$$

$$= \left(4.74 \cdot 10^{-5} \right)^{0.75} + 132.7 \cdot 10^{-5} \Big)^{0.75} \Big)^{4/3} = 1.474 \cdot 10^{-3}$$

$$P_{o,eq} = \left(0.15 \cdot 10^{-0.1 \cdot 35} \right)^{0.75} + 0.02 \cdot 12 \cdot 0.0063 \cdot e^{-25/4.5} \Big)^{0.75} \Big)^{4/3}$$

$$= \left(4.74 \cdot 10^{-5} \right)^{0.75} + 0.585 \cdot 10^{-5} \Big)^{0.75} \Big)^{4/3} = 6.100 \cdot 10^{-5}$$

$$I_{eq} = \frac{P_{o,0}}{P_{o,eq}} = \frac{1.474 \cdot 10^{-3}}{6.100 \cdot 10^{-5}} = 24.2$$

b)

$$P_{o,div} = \left(\left(7.5 \cdot 10^{-0.2 \cdot 35} \right)^{0.75} + \left(0.02 \cdot 32 \cdot 0.0063 \cdot e^{-5/2.8} \right)^{0.75} \right)^{4/3}$$

$$= \left(\left(0.075 \cdot 10^{-5} \right)^{0.75} + \left(67.61 \cdot 10^{-5} \right)^{0.75} \right)^{1.33} = 6.82 \cdot 10^{-4}$$

$$I = \frac{P_{o,0}}{P_{o,div}} = \frac{1.474 \cdot 10^{-3}}{6.82 \cdot 10^{-4}} = 2.16$$

c)

$$P_{o,div} = \left(\left(7.5 \cdot 10^{-0.2 \cdot 35} \right)^{0.75} + \left(0.02 \cdot 12 \cdot 0.0063 \cdot e^{-25/2.8} \right)^{0.75} \right)^{4/3}$$

$$= \left(\left(7.5 \cdot 10^{-7} \right)^{0.75} + \left(2.00 \cdot 10^{-7} \right)^{0.75} \right)^{4/3} = 1.142 \cdot 10^{-6}$$

$$I = \frac{P_{o,0}}{P_{o,div+eq}} = \frac{1.474 \cdot 10^{-3}}{1.142 \cdot 10^{-6}} = 1291$$

6. High-quality FM-audio reception requires an electrical field strength level of 54 dBμV/m and a cochannel protection ratio of 51 dB during standard interference propagation (50 % of time) and 37 dB during exceptional tropospheric propagation (1 % of time). It is assumed that all transmitter transmit 10 kW EIRP at 100 MHz and the effective transmitter antenna height is 300 m. The receiver antenna height corresponds to the assumptions for the field strength level curves in ITU-R Rec. 1546.

a) At which distance from the transmitter the coverage probability under the above requirement is 50 % according to ITU-R Rec. 1546?

b) How large should the cochannel transmitter distance be that the protection ratio requirement is fulfilled with 50 % probability during standard interference propagation on the line connecting the transmitters at the coverage border according to ITU-R Rec. 1546?

c) How large should the cochannel transmitter distance be that the protection ratio requirement is fulfilled with 50 % probability during exceptional tropospheric interference propagation on the line connecting the transmitters at the coverage border according to ITU-R Rec. 1546?

SOLUTION

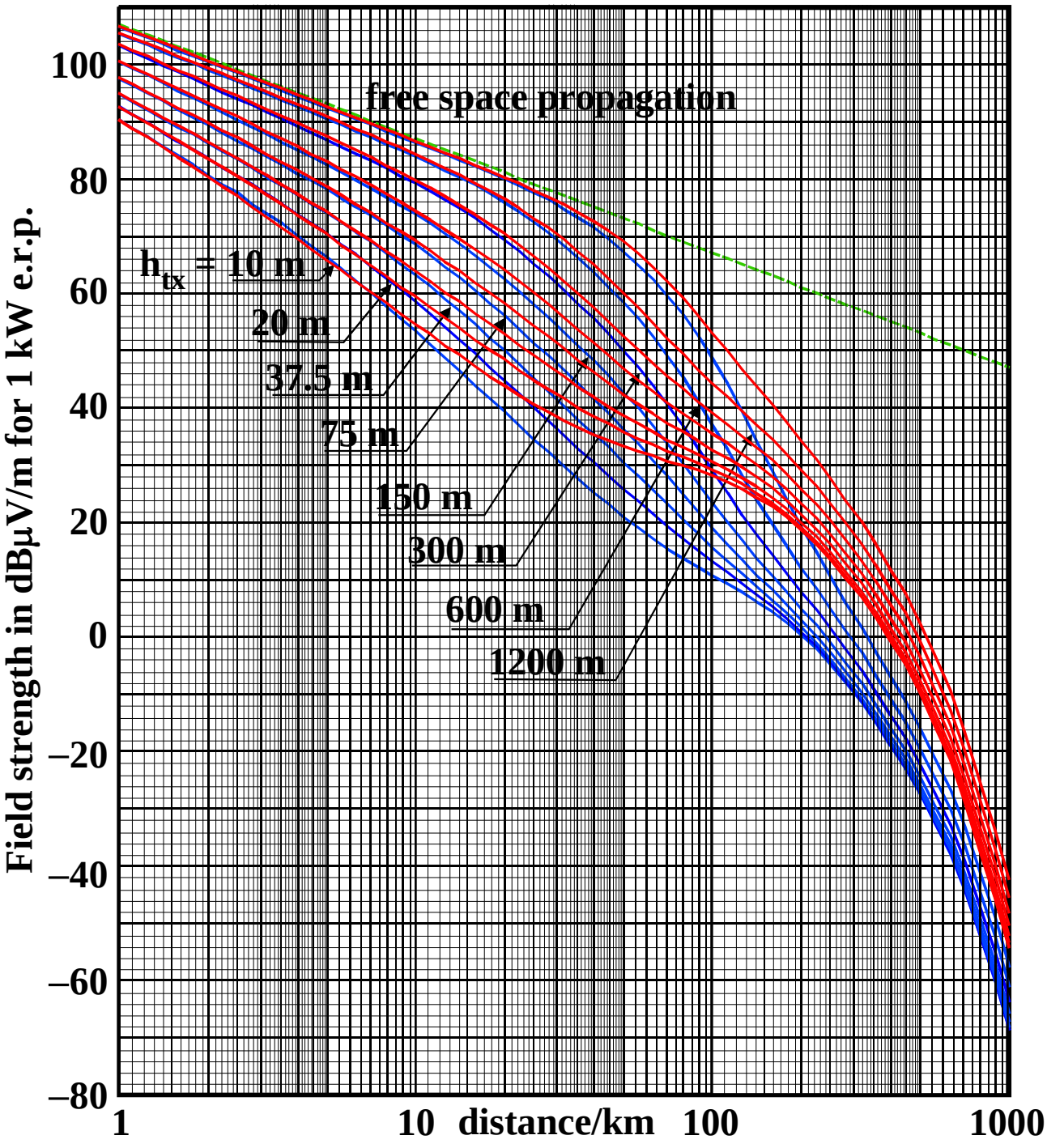
a) As the graph gives the field strength level with 1 kW EIRP a transmitted EIRP of 10 kW means that the maximum range is form th graph at 10 dB lower field strength level than the required or for 44 dBμV/m. From the curve for 50 % coverage probability a maximum range of about 63 km is obtained.

b) The CIR requirement during standard propagation means that the allowed interference field at the coverage border must be at maximum 44 – 51 = –7 dBμV/m. From the same curve a minimum range of about 338 km is determined. Thus the minimum distance between two co-channel transmitters is 63 + 338 = 401 km.

c) The CIR requirement during adverse tropospheric propagation means that the allowed interference field at the coverage border must be at maximum 44 – 37 = +7 dBμV/m. From the curve for 1 % coverage probability a minimum range of about 385 km is determined. Thus the

minimum distance between two co-channel transmitters is 63 + 385 = 448 km.

Received field strength at 100 MHz over land paths as function of distance for different transmitter antenna heights exceeded 50% and 1% of time. Receiver antenna height 10 m (equal to representative height of ground cover)



Received field strength at 100 MHz over land paths as function of distance for different transmitter antenna heights exceeded 50% and 1% of time. Receiver antenna height 10 m (equal to representative height of ground cover)