E-E 423 COMMUNICATION SYSTEMS
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November 24, 1986

Communication Link Design Problem

Problem Statement

Design a microwave communications link between Gonzaga University and Spokane Community College. Because of obstructions between the two schools, it will be necessary to transmit through a repeater on a tower mountain approximately 7.5 miles from SCC and 8.0 miles from G.U. You are required to consider two designs: 1) one in which a passive repeater is utilized and 2) another in which an active repeater is utilized.

Specifications

Carrier frequencies: f_c = 6.725 GHz for 6.675 passive repeater

f_{c1} = 6.675 GHz } for active repeater
f_{c2} = 6.775 GHz }

Noise bandwidth: 10MHz
SNR at destination: >50dB
Consider only one-way link from G.U. to SCC.

Assumptions

Transmitter power (both at G.U. and repeater): <+20dBm

Receiver Noise Figure (including losses both at SCC and repeater): 8dB

Fading losses (total): < 8dB

Antenna Noise Temperature: 290°K

Antenna Efficiency: 55% $\quad G = \dfrac{2.2\pi A}{\lambda^2}$

Report

The only system components you must specify are antenna sizes and transmitter power levels. Clearly write up your design showing a block diagram with component specifications. You should give signal and noise levels at four points along the link (receiver inputs and transmitter outputs) and mathematically verify that the SNR specification at the destination is satisfied. Discuss the relative advantages and disadvantages of the two designs.

Due Date: December 5, 1986 (no exceptions)
Worth: 100 points toward homework grade.

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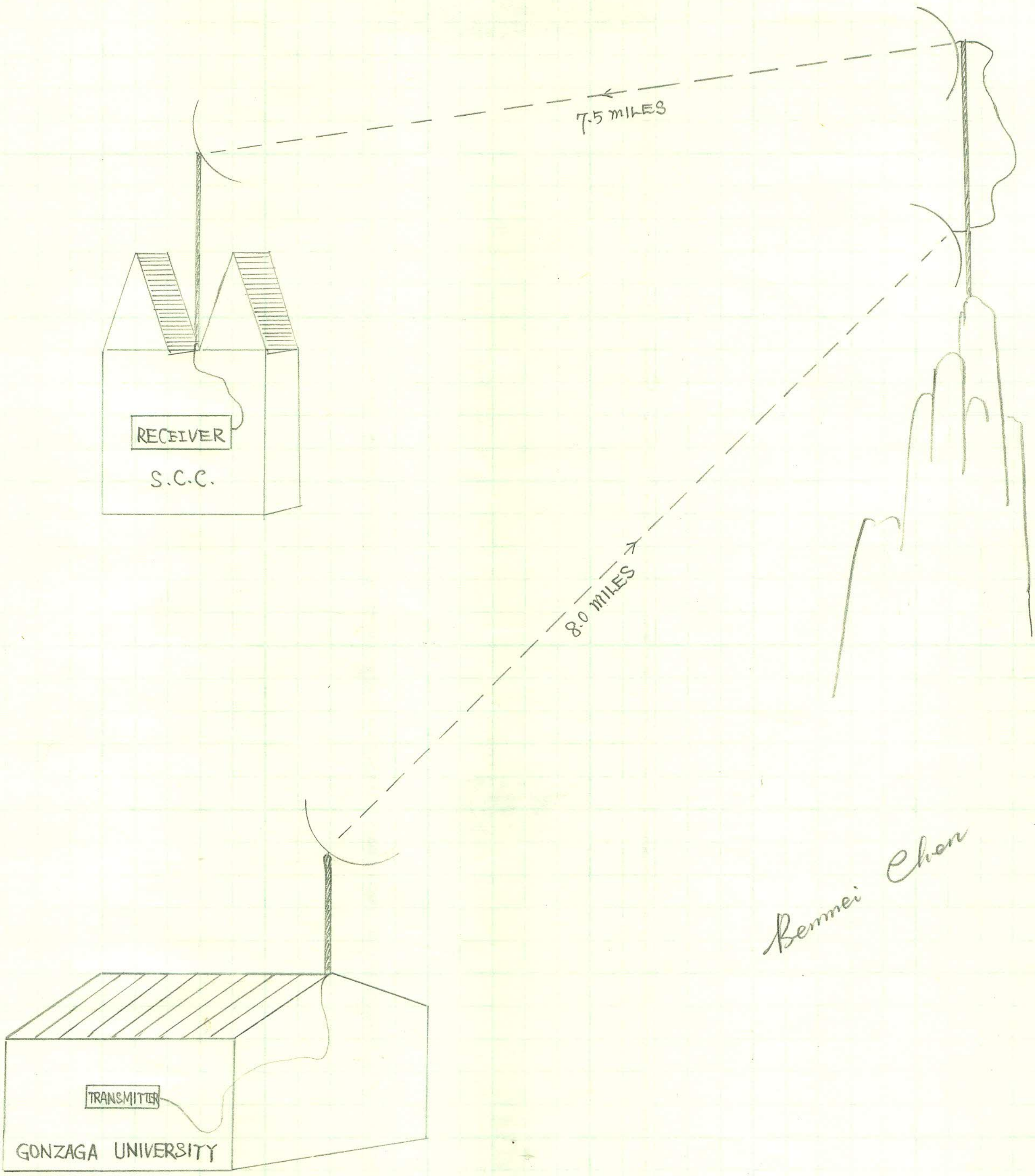

Communication Link Design Problem.

Benmei Chen

November 30, 1986

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DESIGN 1 : THE LINK WITH ACTIVE REPEATER

1. GIVENS AND THE PARAMETERS USED IN DESIGN

CARRIER FREQUENCIES : $f_{c1} = 6.675$ GHz

$f_{c2} = 6.775$ GHz

NOISE BANDWIDTH = 10 MHz

SNR AT DESTINATION : > 50 dB

TRANSMETTER POWER (BOTH AT G.U. AND REPEATER) : $< +20$ dBm

RECEIVER NOISE FIGURE (BOTH AT SCC AND REPEATER) : $F = 8$ dB

FADING LOSSES (TOTAL) = $F_L < 8$ dB $= 6.31$

FADING LOSSES FROM G.U. TO REPEATER = $F_{L1} \approx 6.31/2 = 5$ dB

FADING LOSSES FROM REPEATER TO SCC = $F_{L2} \approx F_L/2 = 5$ dB

ANTENNA NOISE TEMPERATURE = $290°K$

ANTENNA EFFICIENCY = 55% $\quad G = \frac{2.2\pi A}{\lambda^2}$

P_{T1} = TRANSMITTER POWER AT G.U.

P_R' = SIGNAL POWER AT THE INPUT OF RECEIVER OF REPEATER.

P_{T2} = TRANSMITTER POWER AT REPEATER.

P_R = RECEIVED POWER AT S.C.C.

α_1 = SIGNAL LOSS FROM G.U. TO REPEATER

α_2 = SIGNAL LOSS FROM REPEATER TO S.C.C.

d_1 = THE DISTANCE FROM G.U. TO REPEATER = 8 miles

d_2 = THE DISTANCE FROM REPEATER TO SCC = 7.5 miles

T_0 : $290°K$

G_{AR} : THE POWER GAIN OF THE ACTIVE REPEATER.

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2. BLOCK DIAGRAM

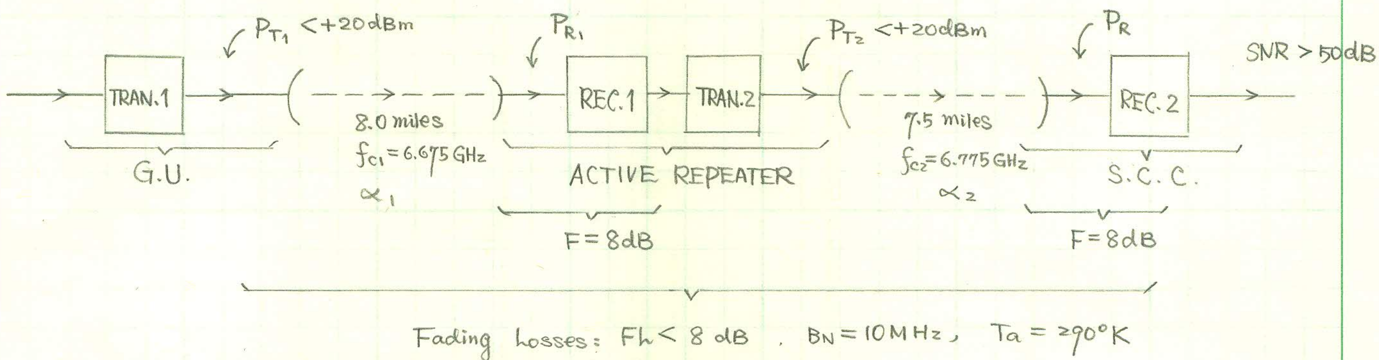


FIG. A1 BLOCK DIAGRAM FOR THE LINK WITH ACTIVE REPEATER

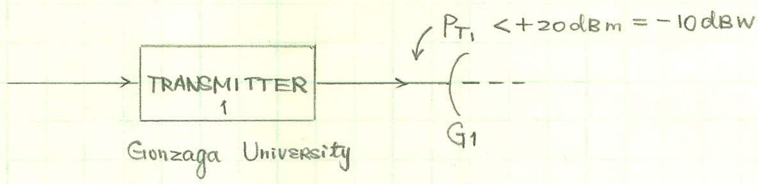


FIG. A2 TRASMITTER 1 AT G.U.

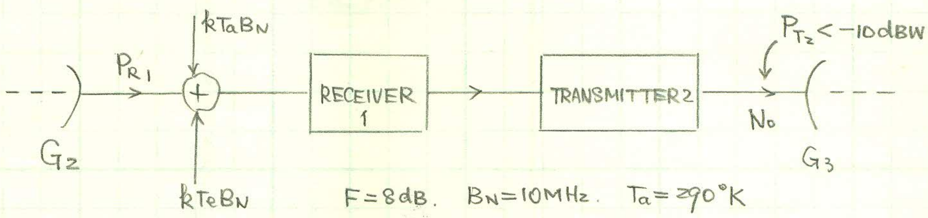
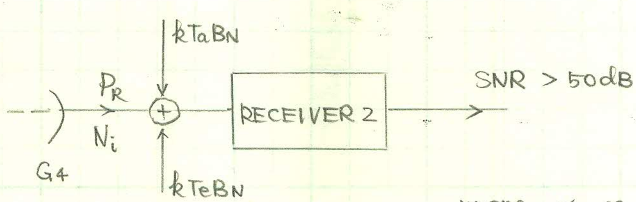


FIG A3 TRANSMITT 2 AND RECEIVER 1 (REPEATER)

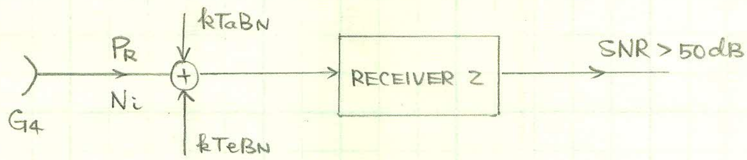


WHERE N_i IS NOISE FROM REPEATER

FIG A4 RECEIVER 2 AT S.C.C

3. DESIGN PROCEDURE :

a) CONSIDER THE RECEIVER AT S.C.C.: FROM FIG A4 ON PAGE 2, WE HAVE



$$F = 8\text{dB}\ .\quad B_N = 10\ \text{MHz}\ ,\quad T_a = 290°\text{K}$$

$$T_e = (F-1)T_0 = (6.3096-1)\times 290° = 1539.7763°\text{K}$$

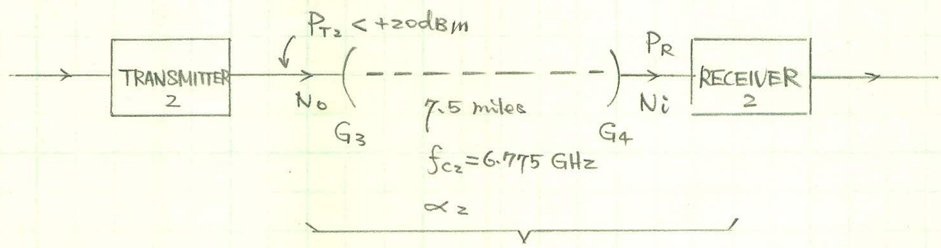
$$SNR = P_R\ /(N_i + kT_aB_N + kT_eB_N)$$

$$P_R = SNR \times (N_i + kT_aB_N + kT_eB_N)$$

$$\geq 10^5 \times (N_i + 1.38\times10^{-23}\times290\times10^7 + 1.38\times10^{-23}\times1539.7763\times10^7)$$

$$= 2.5251\times10^{-8} + 10^5 N_i \quad w \qquad ----- \quad (1)$$

b) CONSIDER THE LINK FROM THE REPEATER TO S.C.C.



Fading Losses : $FL_2 \doteq FL\ (\text{TOTAL})/_2 < 5\text{dB}$

$$\propto_2 = 36.6 + 20\log_{10} f_{c_2} + 20\log_{10} d_2 \qquad (f \text{ in MHz},\ d \text{ in miles})$$

$$= 36.6 + 20\log_{10} 6.775\times10^3 + 20\log_{10} 7.5$$

$$= 130.72\ \text{dB}$$

Because $\propto_2$ is greater enough. we can assumpt $N_i < k(T_a+T_e)B_N = 2.5251\times10^{-13}$ W

LET $P_R = 5\times10^{-8}$ W $= -73.01$ dBW.

AND $P_{T_2} = 19$ dBm $= -11$ dBW < 20dBm

WE CAN ALSO SELECT THE SAME SIZE FOR THE ANTENNA G_3 AN G_4.

$$P_R = P_{T2} * G_3 * G_4 / (\alpha_2 * Fh_2)$$

$$P_R\ (dB) = P_{T2}\ (dB) + G_3\ (dB) + G_4\ (dB) - \alpha_2\ (dB) - Fh_2\ (dB)$$

$$-73.01\,dB = -11\,dB + 2G_3\ (dB) - 130.72\,dB - 5\,dB$$

$$G_3 = 36.86\,dB = 4847.30$$

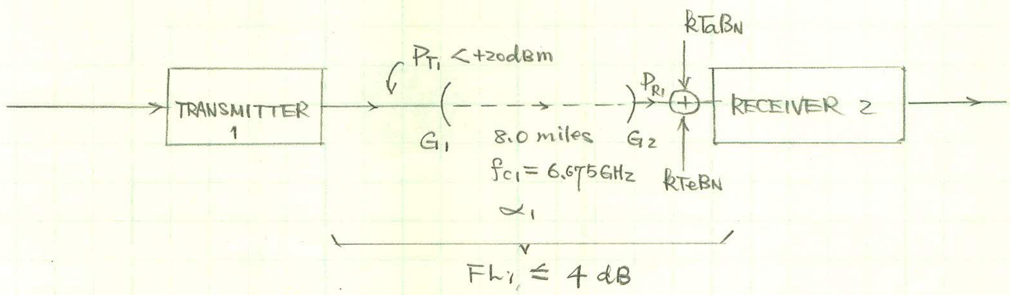
$$G_3 = \frac{2.2\pi A}{\lambda^2} = \frac{2.2\pi A f_{c2}^2}{c^2}$$

$$A = \frac{G_3 \cdot c^2}{2.2\pi f_{c2}^2} = \frac{4847.30 \times (3\times 10^8)^2}{2.2 \times 3.1416 \times (6.775\times 10^9)^2} = 1.3752\ m^2$$

$$A = \pi R^2$$

$$R = \sqrt{A/\pi} = \sqrt{1.3752/3.1416} = 0.66\ m$$

C) CONSIDER THE LINK FROM G.U. TO REPEATER.



WE ; NOW, SELECT ANTENNA G1 AN G2 WITH DIAMETER = 1.5 m. $\{G \approx G_3\}$

$$G_1 = G_2 = 2.2\pi A f_{c1}^2 / c^2 = 37.82\ dB$$

LET $P_{T_1} = -11\,dBW < +20\,dBm$.

$$\alpha_1 = 36.6 + 20\log_{10} f_{c1} + 20\log_{10} d_1$$

$$= 36.6 + 20\log_{10} 6.675\times 10^3\ \text{MHz} + 20\log_{10} 8\ \text{miles}$$

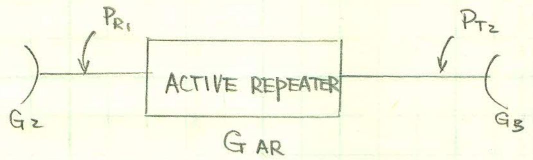
$$= 131.15\ dB$$

$Fh_1 = \frac{1}{2} \times Fh$ (TOTAL FADING LOSSES) = 5 dB

$$P_{R1}\ (dB) = P_{T1}\ (dB) + G_1\ (dB) - \alpha\ (dB) - Fh_1\ (dB) + G_2\ (dB)$$

$$= -11\,dB + 37.82\,dB - 131.15\,dB - 5\,dB + 37.82\,dB = -71.51\,dBW$$

d) CONSIDER THE POWER GAIN OF REPEATER:



$P_{R1} = -71.51$ dBW

$P_{T2} = -11$ dBW

$G_{AR} = -11 - (-71.51) = 60.51$ dB

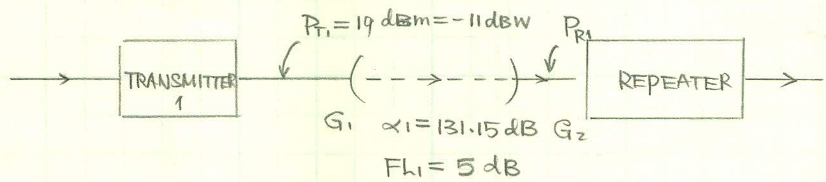
4. CONCLUTION: ANTENNA SIZE: DIAMETER = 1.5 m FOR ONE AT G.U., ONE FOR RECEIVING AT REPEATER

DIAMETER = 1.3 m FOR ONE AT S.C.C, ONE FOR TRASMITTING AT REPEATER

TRANSMITTER POWER = 19 dBm AT G.U.; REPEATER POWER GAIN: 60 dB.

5. VERIFICATION: LOOKING BACK AT THE FIG A1. ON PAGE 2 AND THE COMPONETS ABOVE, WE VERIFY THE DESIGN STEP BY STEP AS BELOW:

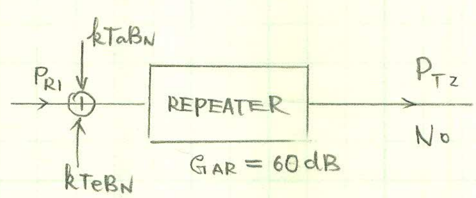
a) FROM G.U. TO REPEATER



$$G_1 = G_2 = \frac{2.2 \times \pi A}{\lambda} = \frac{2.2 \times 3.1416^2 \times 0.75^2 \times 6.675^2 \times 10^{18}}{9 \times 10^{16}} = 6046.5 = 37.82\,\text{dB}$$

$$P_{R1} = P_{T1} + G_1 - \alpha_1 - FL_1 + G_2 = -11 + 37.82 - 131.15 - 5 + 37.82 = -71.52 \text{ dBW}$$

b) REPEATER



$$P_{T2} = P_{R1} + G_{AR} = -71.52 + 60 = -11.52 \text{ dBW} = 18.48 \text{ dBm} < +20 \text{ dBm}$$

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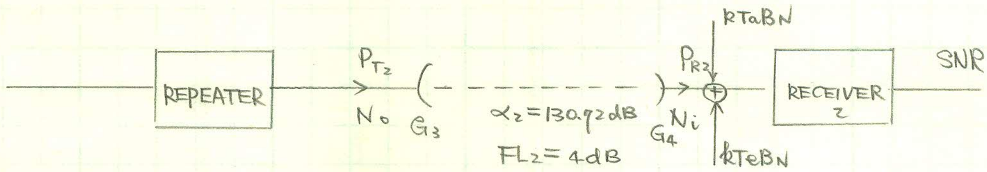
$$N_o = G_{AR} \cdot k(T_a + T_e)B_N = 10^{6.0} \times 1.23 \times 10^{-23} \times (290 + 1539.78) \times 10^{7} = 2.525 \times 10^{-7} = -65.98 \text{ dBW}$$

c) FROM THE REPEATER TO S.C.C.



$$G_3 = G_4 = \frac{2.2 \times \pi^2 \times 0.65^2 \times (6.775 \times 10^9)^2}{9 \times 10^{16}} = 4678.7 = 36.70 \text{ dB}$$

$$N_i = N_o + G_3 - \alpha_2 - FL_2 + G_4$$

$$= -65.98 + 36.70 - 130.72 - 5 + 36.70 = -128.30 \text{ dB} = 1.48 \times 10^{-13}$$

$$P_{R2} = P_{T_2} + G_3 - \alpha_2 - FL_2 + G_4$$

$$= -11.52 + 36.70 - 130.72 - 5 + 36.70 = -73.84 \text{ dB} = 4.1305 \times 10^{-8} \text{ W}$$

$$SNR = P_{R2} / (N_i + k(T_a + T_e)B_N)$$

$$= 4.1305 \times 10^{-8} / [1.48 \times 10^{-13} + 1.38 \times 10^{-23} \times 1829.78 \times 10^7]$$

$$= 4.1305 \times 10^{-8} / 4.0051 \times 10^{-13}$$

$$= 103131.0081 = 50.134 \text{ dB} > 50 \text{ dB}.$$ (VERIFIED!)

6. SIGNAL AND NOISE LEVELS AT FOUR POINTS ALONG THE LINK:

POINTS / LEVELS (dBm)	G.U. TRANS. OUTPUT	REPEATER REC. INPUT	REPEATER TRANS. OUTPUT	S.C.C. REC. INPUT
SIGNAL	19 dBm	−41.52 dBm	18.48 dBm	−43.84 dBm
NOISE	—	−95.98 dBm	−35.98 dBm	−93.93 dBm

7. IMPROVEMENT

IF WE WANT TO GET SNR MUCH GREATER THAN 50 dB AT DESTINATION WITH THE SAME TRANSMITTER POWER LEVEL, WE MUST INCREASE THE AREAS OF FIRST TWO ANTENNAS AND DECREASE G_{AR}. 121

e.g. CHANGING DIAMETER = 2 m FOR FIRST TWO ANT. AND $G_{AR} = 55$ dB, WE HAVE SNR = 51.40 dB AT S.C.C.

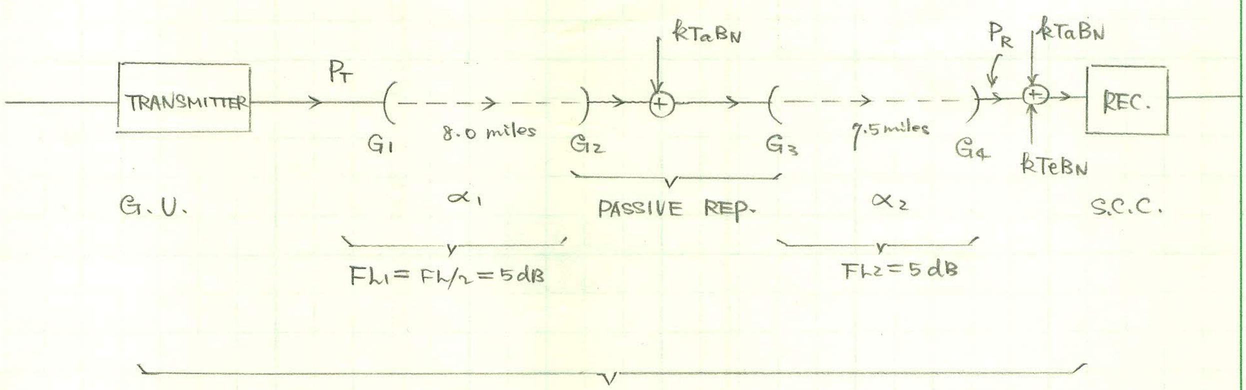
DESIGN 2 : THE LINK WITH PASSIVE REPEATER.

1. GIVENS AND THE PARAMETERS USED IN DESIGN

$$f_{c1} = f_{c2} = f_c = 6.725 \text{ GHz}$$

THE OTHERS ARE THE SAME AS THOSE IN DESIGN 1.

2. BLOCK DIAGRAM



$f_c = 6.725$ GHz , $B_N = 10$ MHz , $F_h \leq 8$ dB , $T_e = (F-1)T_o = 1539.77\ °K$

FIG 1 ___ BLOCK DIAGRAM FOR THE LINK WITH PASSIVE REPEATER

2. DESIGN PROCEDURE:

FROM THE FIG. 1 ON PAGE 7, WE HAVE

$$SNR = P_R / N$$

$$= P_R / [N_i + k(T_a + (F-1)T_0) B_N] \quad \cdots\cdots (1)$$

WHERE, $T_a = 290°K$, $T_0 = 290°K$, $F = 8dB = 6.31$, $B_N = 10MHz$

$$N_i = N_0 * G_3 * G_4 / \alpha_2 \cdot FL_2 \quad , \quad N_0 = kT_aB_N$$

$$P_R = P_T * G_1 * G_2 * G_3 * G_4 / (\alpha_1 * \alpha_2 * FL)$$

LET US SELECT THE SAME SIZE FOR ALL THE FOUR ANTENNA, SO,

$$G_1 = G_2 = G_3 = G_4 = G$$

REWRITE THE EQUATION (1), WE HAVE

$$SNR = P_T \times G^4 / \{(\alpha_1 \alpha_2 \times FL) * [kB_N(G^2 \cdot T_a/\alpha_2 FL_2 + F \cdot T_0)]\} \cdots (2)$$

$$\alpha_1 = 36.6 + 20\log_{10} f_c + 20\log_{10} d_1 \quad (f_c \text{ IN MHz}, d_1 \text{ IN miles})$$

$$= 36.6 + 20\log_{10} 6.725\times10^3 + 20\log_{10} 8 = 131.22 \text{ dB}$$

$$= 1.323\times10^{13}$$

$$\alpha_2 = 36.6 + 20\log_{10} f_c + 20\log d_2$$

$$= 36.6 + 20\log_{10} 6.725\times10^3 + 20\log_{10} 7.5$$

$$= 130.66 \text{ dB} = 1.1628\times10^{13}$$

$$FL = 8dB = 10^{.8} = 6.31$$

$$FL_2 = 5dB = 3.1623$$

$$F = 8dB = 10^{.8} = 6.31$$

LET $SNR = 50 dB = 10^5$

LET $P_T \triangleq 19 \text{ dBm} = -11 \text{ dBW} = 0.0794$

NOW, REWRITE EQATION (2), WE GET

$$G^4 - 1331553.73\,G^2 - 3.0873\times10^{20} = 0$$

$$G = 132557.0823 = 51.22 \text{ dB}.$$

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$$G = \frac{2.2\pi A}{\lambda^2}$$

$$A = \frac{G \times c^2}{2.2\pi \times f_c^2} = \frac{132551.4118 \times (3\times10^8)^2}{2.2\times3.1416\times(6.675\times10^9)^2} = 38.74 \ m^2$$

$$R = \sqrt{A/\pi} = \sqrt{38.74/3.1416} = 3.5 \ m$$

3. CONCLUTION : ANTENNA SIZE : DIAMETER = 7 m FOR ALL FOUR ANTTENNA.

TRANSMITTER POWER = 19.5 dBm AT G.U.

4. VERIFICATION :

$G = G_1 = G_2 = G_3 = G_4 = 51.22$ dB

$P_t = 19.5$ dBm $= -10.5$ dBW

$\alpha_1 = 131.22$ dB

$\alpha_2 = 130.66$ dB , $FL = 8$ dB

$P_R = P_t + G_1 - \alpha_1 + G_2 + G_3 - \alpha_2 + G_4 - FL$ (IN dB)

$= -10.5 + 51.22 - 131.22 + 51.22 + 51.22 - 130.66 + 51.22 - 8$

$= -75.5$ dBW

$N_o = kT_aB_N = 1.38\times10^{-23}\times290\times10^7 = -133.98$ dB

$N_i = N_o + G_3 - \alpha_2 - FL_2 + G_4$

$= -133.98 + 51.22 - 130.66 - 5 + 51.22 = -167.20$ dBW $= 1.91\times10^{-17}$ W

$N = N_i + k[(F-1)T_o + T_a]B_N$

$= 1.9\times10^{-17} + 1.38\times10^{-23}\times1829.776\times10^7$

$= 2.525\times10^{-13}$ W $= -125.98$ dB

$SNR = P_R - N$ (IN dB)

$= -75.5 - (-125.98)$

$= 50.48$ dB > 50 dB. (VERIFIED !!)

5. SIGNAL AND NOISE LEVELS AT THE TRNS. OUTPUT AND REC. INPUT :

$P_T = 19.5$ dBm ; $P_R = -45.5$ dBm , $N_{iR} = -95.98$ dBm

COMPARE :

FROM THE DESIGNS WE GOT, WE ARE EASY TO FIND OUT THAT: IN DESIGN 1, THE LINK WITH ACTIVE REPEATER, WE ONLY NEED TO USE 1.5m-DIAMETER ANTENNAS FOR TRANSMITTING AT G.U. AND RECEIVING AT THE REPEATER, AND 1.3m-DIAMETER ANTENNAS FOR TRANSMITTING AT THE REPEATER AND RECEIVING AT S.C.C., HOWEVER, WE NEED TO EMPLOY A 60dB-POWER-GAIN REPEATER.

IN DESIGN 2, WE DON'T NEED TO USE A ACTIVE REPEATER WITH RECEIVER AND TRANSMITTER. BUT, WE MUST USE FOUR 7m-DIAMETER ANTENNAS IN THE LINK.

IT SEEMS THAT DESIGN 1 IS MORE REASONABLE THAN DESIGN 2.