

ECEN5533 Design Project #2 (80 points)

U.S. Sprawl has just announced plans to construct a high speed satellite link between Matsue, Japan and Cape Town, South Africa. In a recent press conference announcing Sprawl's decision, CEO Dudley Doright stated "At the moment, there is admittedly little need for a high bandwidth communications link in this region. However we feel if we build it, they will come."

Your employer, MegaMoron Communications Inc. (the world's premier communications construction company), has decided to submit a proposal for this system. As an esteemed member of the technical staff, you have been tasked to determine specifications for a portion of this design.

Preliminary investigation has yielded the following information:

*The information source is to be located at Matsue, Japan (N35° Latitude, E133° Longitude). The information sink will be located at Cape Town, South Africa (S34° Latitude, E18° Longitude). The signal is to be broadcast up to an ACME geosynchronous satellite and then beamed back down to the sink.

*Two independent digital signals will be provided that must be transmitted over this system using either time division multiplexing (TDM) or frequency division multiplexing (FDM).

*You will need to specify one transmitting & one receiving antenna, and the configuration of your transmitting and receiving hardware. If FDM is chosen both signals can be injected into the same transmitting antenna and extracted from the same receiving antenna, or you could install two transmitting antennas at the source and two receiving antennas at the sink.

*You will need to specify the type of ACME satellite relay to lease. The ACME satellite is located 35,780 Km above the equator at E59° Longitude. This satellite has a 38,490 Km slant range from Cape Town and appears 31 degrees above the horizon. It has a 41,190 Km slant range from Matsue and appears 4 degrees above the horizon.

*You will need to specify one transmitter, one receiver, and one satellite transponder per transmitted signal. You will be moving one high speed signal if TDM is chosen, and two slower speed signals if FDM is chosen.

*A 13m cable is required to connect the receiving antenna to the information sink. *Any electronics not installed at the sink are considered to be installed outside.*

*A 29m cable is required to connect the information source to the transmitting antenna. *Any electronics not installed at the source are considered to be installed outside.*

*You've got *two* 53.7 Mbps data signals to transport, one from the Matsue Telephone Central Office, and one from Freida's Internet Service.

*The binary digital signals provided at Matsue are both zero mean, ten milliwatt, 100 mvp, NRZ-L, base band, random binary square waves.

*Two clean zero mean, ten milliwatt, 100 mvp, NRZ-L base band binary bit streams should be provided as output at the Cape Town receiver site.

*Maximum acceptable end-to-end P(bit error) of an uncompressed received data signal at Cape Town is $7.8 \cdot 10^{-5}$.

*Allowable RF modulation schemes are M-ary ASK, PSK, or FSK, M being some power of 2. The same scheme must be used on both the uplink and downlink. The cost for M-ary

hardware, $M > 2$, is the same as the cost for binary hardware and is built into the costs for the transmitter power amp (where binary is converted to M-ary if desired) and the receiver Matched Filter Detector (where M-ary is converted back to binary, if desired).

*RF Center Frequencies: 7.1 - 16.7 GHz for any radio link. Two center frequencies must be chosen, one for the uplink, and one for the downlink. These frequencies must be offset by a minimum of $6R_s$ Hz, where R_s is the combined symbol rate at the transmitter, in symbols/second (note: symbols/second = baud). For example, if 2 binary FDM signals are transmitted, or a single binary TDM signal is transmitted, and no compression or FEC is used, the combined symbol rate will be 107.4 Mbaud (107.4 Mbps in this case since the symbol is a binary bit), and the center frequencies must be offset by at least 644.4 MHz.

Even if you use FDM, only specify a single center frequency for the uplink, and a single center frequency for the downlink, and use that frequency in your calculations. In reality your FDM signals would be offset above and below this average (center) frequency.

*RF Antenna Temperatures: Use $(261 + 11.9|f_c \text{ in GHz} - 12.6|^{1.32})$ degrees K for the satellite system in orbit (looking at Matsue). Use $(75 + 2.6|f_c \text{ in GHz} - 12.6|^{1.32})$ degrees K for the antenna temperature at Cape Town (looking at the sky). For example, if the up link center frequency is 16 GHz, the satellite receive antenna temperature will be 320.9 degrees Kelvin. If the down link center frequency is 16 GHz, the earth station receive antenna temperature will be 88.08 degrees Kelvin.

*Other losses = 1.49 dB for the uplink and downlink.

*Available Amplifiers...

GaAs $F = 1.40$ dB $G = 0-35$ dB Freq: 7.1 - 16.7 GHz

IC $F = 12.9$ dB $G = 0-50$ dB Base band or IF

A GaAs amp must be the first amplifier stage in the RF receiver. A GaAs amp must be the last stage in an RF transmitter. Lower cost IC amps may be used in intermediate stages. GaAs amps are assumed to down convert the received RF energy to a lower IF or base band frequency on the receive side of the house, and up convert the IF or baseband energy to a higher RF frequency on the transmitter side of the house.

*Coaxial Cable Losses: $L = 1.19$ dB per 100 meters if you move IF or baseband energy over the cable. Cable loss $L = 3.28 + 0.90(\text{RF Center Frequency in GHz})^{0.50}$ dB per 100 meters if you move RF energy over the cable. For example, if RF energy at a center frequency of 16 GHz is moved over a cable, the loss will be 6.88 dB per 100 meters.

*Satellite Systems: Assume any satellite has properly aimed spot beams with antenna gains equivalent to that of parabolic transmitting and receiving antennas with a 1.74 square meter physical area and efficiency of 0.44. The satellite electronics' noise figure is 1.92 dB. Four satellite systems are available.

The ECONO-RELAY GaAs transponder has a nominal power gain of 60 dB and a maximum power out of 5.6 dBW. I.E. if the input power to the satellite amplifier is < -54.4 dBW, the output power will be 60 dB higher. If the input power to the satellite is > -54.4 dBW, the output power will max out at 5.6 dBW.

The ECONO-REPEATER has a matched filter detector front end that can handle any type of binary or M-ary signaling. This system regenerates the received signal and yields a clean, noise free, RF power out of 5.6 dBW.

The TURBO-RELAY GaAs transponder has a nominal power gain of 93 dB and a

maximum power out of 7.3 dBW. I.E. if the input power to the satellite amplifier is < -85.7 dBW, the output power will be 93 dB higher. If the input power to the satellite is > -85.7 dBW, the output power will max out at 7.3 dBW.

The TURBO-REPEATER has a matched filter detector front end that can also handle any type of binary or M-ary signaling. This system regenerates the received signal and yields a clean RF power out of 7.3 dBW.

*Coherent Matched Filter Detector: Contains a GaAs front end, so can be installed as the first stage in an RF receiver if desired. This GaAs front end can also handle IF frequencies. Has component temperature of 985 degrees Kelvin. Outputs a base band zero mean, ten mwatt, 100 mvp NRZ-L waveform.

Optional Items:

ACME COMPRESS-O-MATIC: A two box system consisting of a real time data compressor at the transmit site and decompression at the receive site. As the signal is compressed it becomes more sensitive to bit errors, hence a smaller end-to-end P(Bit Error) will be required to yield equivalent performance with the uncompressed case. Each box can handle a single input with a bit rate ≤ 60 Mbps. The Compress-O-Matic can compress the bit stream at a user selectable rate up to a 4.6 - 1 ratio. Required end-to-end $P(\text{Bit Error}) = 7.8 \cdot 10^{-5} / (\text{compression ratio})^{2.37}$. For example, a 24.9 Mbps signal input to a system with a 2.3 - 1 compression ratio will output a 10.83 Mbps bit stream which must be delivered with an end-to-end P(Bit Error) of $10.83 \cdot 10^{-6}$. Both compressor and decompression work at baseband. Decompression should follow the Matched Filter Detector at the information sink. Input should be a zero mean, ten milliwatt, 100 mvp, NRZ-L base band bit stream. Outputs the same.

ACME Extra Sensory Perception Forward Error Correction hardware adds a user selectable number of extra parity bits to the transmitted bit stream, allowing the receiver to correct a limited amount of bit errors in real time. The baseband bit rate out of the ESP FEC coder can be a *factor* 1.00 to 1.18 times higher than the baseband bit rate into the coder. Basically, this FEC coder will increase E_b/N_0 via coding (resulting in an increase in the RF bit rate) as an alternative to increasing E_b/N_0 via increasing the received signal power or decreasing the system temperature. There should be an FEC coder for every FEC decoder. If both compression and FEC are used, FEC should follow the compression stage, and precede the final decompression stage. FEC decoders must immediately follow a Matched Filter Detector. Works on a single bit stream at baseband. Input should be a zero mean, ten milliwatt, 100 mvp, NRZ-L base band bit stream. Outputs the same.

The error correcting capabilities of an FEC system can be modeled by increasing the apparent E_b/N_0 seen at the Matched Filter Detector by a value equal to the *Coding Gain*. For this ACME FEC coder, the Coding Gain (in dB) = $(\text{factor} - 1.00)(0.79 \text{ dB} + 0.64 \cdot E_b/N_0)/0.18$ (E_b/N_0 in dB using the increased bit rate).

For example, suppose FEC is not being used, the bit rate is 29.4 Mbps @ $R = 74.68$ dB in the digital link equation), and the received $E_b/N_0 = 9.60$ dB. Inserting FEC with a *factor* of 1.04 will increase the bit rate to 30.58 Mbps, meaning R now = 74.85 dB in the digital link equation, and E_b/N_0 for the higher rate *coded* bit stream now decreased to 9.43 dB. The Bit Error Rate for the coded bit stream will go up. However, the FEC receiver box will fix many of the errors,

increasing the apparent E_b/N_0 that you should use in your Q function equation by $(.2222)(0.79 + 0.64*9.43) = 1.517$ dB, meaning you should use an $E_b/N_0 = 9.43 + 1.517 = 10.95$ dB when using the appropriate Q function equation to calculate the P(BE) for the *data* bits.

ACME COMBINE-A-TRON: A time division multiplexer set capable of combining two digital bit streams into a higher speed output at the transmitter, and recovering the lower speed signals at the receiver. The TDM output bit rate = the sum of the input bit rates. Works at baseband. You need one of these if you go with TDM.

Input to the multiplexer should be two zero mean, ten milliwatt, 100 mvp, NRZ-L base band bit streams. Outputs the same.

Input to the demultiplexer should be a zero mean, ten milliwatt, 100 mvp, NRZ-L base band bit stream. Outputs two of the same.

ACME Freak Couplers: Necessary if you're using Frequency Division Multiplexing. At the transmitter, would be used to combine two IF signals onto one cable, allowing the combined signals to be fed to a single antenna. At the receiver, a coupler will split the received signal and send $\frac{1}{2}$ the power to one output, and the other $\frac{1}{2}$ to a second output.

NOTE: If you believe you need a device and do not see it listed here, contact your MegaMoron's Chief Technical Officer, Dr. George Scheets, for price/performance details.

COSTS (All costs based on the projected 15 year life of the project)

*Compress-O-Matic: \$31,800 for a compression and decompression gear capable of operating on a single baseband bit stream. *If installed outside costs three times as much.*

*Extra Sensory Perception FEC coder: \$15,700 for FEC coder and decoder gear capable of operating on a single baseband bit stream. *If installed outside costs three times as much.*

*Combine-A-Tron: \$25,700 gets you multiplexing gear for the transmit site and demultiplexing gear for the receive site. *If installed outside costs three times as much.*

*Acme Freak Couplers: \$10,100 gets you a pair of couplers, one for the transmitter site and one for the receiver. These cost the same whether they are installed inside or outside.

GaAs Transmitter Power Amps: $\$4,050 + 34(\text{power gain in dB})*(\text{RF center frequency in GHz})$. For example, an amplifier with a gain of 10 dB and RF center frequency of 23.0 GHz will cost $4050 + 34*10*23 = \$11,870$. *A GaAs amp installed outside costs three times as much.* This amplifier will modulate and up convert a base band or IF signal to your desired RF center freq & must be the last amplifier before any transmitting antenna.

Electricity costs: $\$61(\text{power out of the above GaAs transmitter Power Amp, in watts})$.

GaAs Low Noise Receiver Front End Amps/Mixer: $\$10,700 + \$13.90(\text{power gain in dB})*(\text{RF center frequency in GHz})$. For example, an amplifier with a gain of 10 dB and an RF center frequency of 23.0 GHz would cost $10700 + 13.9*10*23 = \$13,897$. *A GaAs amp installed outside costs three times as much.* This amplifier will demodulate and down convert an RF signal to base band or IF & must be the first amplifier after any receiving antenna.

IC Amps: $\$0.52(\text{power gain in dB})$. Input and output can be either IF or baseband signals. *An IC amp installed outside costs three times as much.*

*Coherent Matched Filter Detector: Cost is \$3,090. *If installed outside costs three times as much.*

Earth Station Antennas: Parabolic Efficiency = 0.67. Cost = $\$83(\text{antenna diameter in meters})^{2.88}$. For example, a 32m diameter parabolic would cost \$1.794 Million.

*Satellite Transponders: If you go with TDM you will need to lease one transponder, FDM will require two.

ACME ECONO-RELAY \$806,000

ACME ECONO-REPEATER \$574,000

ACME TURBO-RELAY \$1,397,000

ACME TURBO-REPEATER \$2,338,000

*Bandwidth Cost: $\$0.0031 \times (\text{total symbol rate moved on uplink in symbols/second})$. Paid to Federal Communications Commission & Satellite provider. For example, if you move two uncompressed binary signals, the cost will be $0.0031 \times 107,400,000 = \$332,940$. If you go to a 4-ary signal with 2 bits per symbol, the symbol rate will be cut in half, reducing the bandwidth cost to \$166,470.

*Cable Costs: $\$140(\text{length in meters})$ at the receiver. $\$140(\text{length in meters}) + \$3.1(\text{power being carried in watts})$ at the transmitter. For example a 29 meter cable at the transmitter carrying a kilowatt of power would cost \$7,160.

*System M (margins): Lower margins result in increased outages due to fading, weather, and/or equipment problems. A real-world system with a low initial cost and low margin would tend to be unusable more often than a system with a higher margin and more expensive initial cost. The Margin Cost accounts for low margin designs that will cost U.S. Sprawl future revenue. Define M in the following equation as the *minimum* of the uplink and downlink margins. If you are using a *relay* which is not operating in the saturated region, the uplink and downlink margins must be the same. Margin Cost = $\$7.76M \times (1 / \text{minimum } |M \text{ in dB}| \text{ in any hop})$. For example, if you choose a minimum margin of 5 dB, the estimated amount of lost revenues to U.S. sprawl, and hence the Margin cost, is \$1.552 million dollars.

*Sun Margin: Twice a year near the vernal & autumnal equinox, the Sun will get behind a geosynchronous satellite and appear in the field of view of an earth based down link antenna. The result each time is a potential 20-30 minute disruption in communications for 2-3 days that will cost U.S. Sprawl revenue. As a system designer, you have two options; (A) Accept these outages & the resulting revenue losses. We will reflect this by requiring an additional \$30K margin cost over the project life. (B) Design the system to work when the Sun is in the receive antenna field of view (i.e. over-design the system for the 359-361 days of the year that the sun is not in the receive antenna field of view). Do this by adding the Sun Noise Temperature of 7,940 degrees Kelvin to the downlink RF antenna temperature calculated earlier and design your system using this result as the antenna temperature.

Rules of Engagement

You may work in two person teams if you so desire.

The low bid will be that design with the lowest cost over the life of the system. The low bid designer(s) will receive 20 extra credit points. The 2nd lowest bid designer(s) will receive 15 points, the 3rd lowest bid designer(s) will receive 10 points. All remaining designs with cost < the average class cost will receive 5 points extra credit. Only working bids will be considered for the above. The instructor reserves the right to modify these rules in the even of a tie, and to deduct points for gross over designs.

Your documentation should include one MegaMoron Link & Cost form or a very similar equivalent, and block diagrams which clearly show your system configuration. Make your final report short and sweet. DO NOT GIVE ME A RUNNING COMMENTARY OF YOUR

DERIVATION, I will dock you points if you do so.

-----MegaMoron RF Relay Link Form-----

All values except P(Bit Error) should be in dB

- 1) Input Power -20.0 dBW
 - 2) Transmitter Cabling Loss
 - 3) Transmitter Power Amp Gain
 - 4) Transmitter Antenna Gain
 - 5) Uplink Path Loss
 - 6) Other Losses on the Uplink -1.49 dB
 - 7) Satellite Receiver Antenna Gain
 - 8) Uplink Margin
 - 9) Satellite Power Gain
 - 10) Satellite Transmitter Antenna Gain
 - 11) Downlink Path Loss
 - 12) Other Losses on the Downlink -1.49 dB
 - 13) Downlink Margin
 - 14) Receiver Antenna Gain
 - 15) Bit Rate
 - 16) Receiver System Temperature
 - 17) Boltzmann's Constant +228.6 dB
 - 18) Coding Gain
-
- 19) (E_b/N_0) at receiver
(sum of lines 1-18)

20) P(Bit Error) at receiver

-----MegaMoron Regenerative Repeater Link Form-----

All values except P(Bit Error) should be in dB

1) Input Power -20.0 dBW

2) Transmitter Cabling Loss

3) Transmitter Amp Gain

4) Transmitter Antenna Gain

5) Uplink Path Loss

6) Other Losses, Uplink -1.49 dB

7) Satellite Receiver Antenna Gain

8) Uplink Margin

9) Bit Rate

10) Satellite Receiver System Temperature

11) Boltzmann's Constant

12) (Eb/No) at satellite
(sum of lines 1-11)

13) Uplink P(Bit Error)

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1) Satellite Power Out

2) Satellite Transmitter Antenna Gain

3) Downlink Path Loss

4) Other Losses, Downlink -1.49 dB

5) Earth Receiver Antenna Gain

6) Downlink Margin

- 7) Bit Rate
- 8) Earth Receiver System Temperature
- 9) Boltzmann's Constant
- 10) Coding Gain
- 11) (E_b/N_0) at ground
(sum of lines 1-10)
- 12) Downlink P(BE)
- 13) End-to-End P(BE)

----- MegaMoron Cost Form -----

Transmitter Electronic costs

- GaAs Power Amp
- IC amplifiers

Transmitter Electricity costs

Transmitter Antenna Cost

Transmitter Cable Cost

Receiver Electronic Cost

- GaAs LNA
- Matched Filter Detector
- IC amplifiers

Receiver Antenna Cost

Receiver Cable Cost

Combinatron or Freak Coupler

Compress-o-matic

Forward Error Correction

Satellite Transponder Cost

Bandwidth Cost

Margin Cost

Sun Margin Cost

TOTAL COST:

Additional Information:

Uplink Center Frequency:

Downlink Center Frequency:

Type of Modulation:

Transmitted Symbol Rate:

Type of Multiplexing:

Comment: Note that though there is a line for cable loss and amplification gain at the transmitter, unlike the first design problem there are not separate lines for these two values at the receiver. That's because their effect shows up in the System Temperature.

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