

# ECE 6390: Satellite Communications and Navigation Systems

## Solutions to TEST 2 (Fall 2006)

1. **SARSAT:** The orbit is inclined in such a way that, when the rotation of the earth is accounted for, the satellite appears to ride a longitudinal line down the earth. This maximizes location accuracy and coverage.
2. **Rain Attenuation:** Rain drops elongate in the horizontal direction while falling, creating an *anisotropic* conductivity through the atmosphere. A horizontally-polarized wave will experience more reflection and loss because it is aligned with the dimension of the elongated raindrop.
3. **FM Radio Station:** Decreasing index of modulation will result in lower SNR for a given location and, therefore, a smaller coverage area. The only reasonable way to recover the footprint is to increase transmit power and/or transmit antenna gain.
4. **Dish Antennas:**
  - (a) For a constant noise level, the CNR will rise and fall in proportion to the received signal strength. Look at the link budget

$$P_R = P_T + G_T + G_R - 20 \log_{10} \left( \frac{4\pi}{\lambda} \right) - 20 \log_{10} (r) - \text{Additional Loss in dB}$$

There are 3 terms here that exhibit a *strong* dependence on frequency:  $G_T$ ,  $G_R$ , and the reference path loss term. Dish antenna gains  $G_R$  and  $G_T$  each increase proportional to  $f^2$  while reference path loss falls with respect to  $f^2$ . The net increase in CNR with respect to frequency is  $f^2$ . Thus – all other factors assumed equal – the CNR should be 16 dB at 12 GHz and 26 dB at 40 GHz.

- (b) A dish antenna will fail to deliver its increased gains at higher frequencies if there is significant *surface roughness*. Atmospheric effects other than rain are fairly mild at 40 GHz and below.
5. **Rain Fading:** Based on the 10 dB extra link margin and the properties of the 20 GHz link, we can use the regression coefficient table to establish this relationship:

$$10 \text{ dB} > \frac{L}{\sin 45^\circ} k_h R^{\alpha_h} = \frac{1 \text{ km}}{\sin 45^\circ} (0.0751) R^{1.099}$$

We find that the rain rate,  $R$  must be less than 62 mm/hr. It would appear that the target reliability rate,  $X$ , is approximately %99.99 (some people went to great pains to interpolate a precise value for this and I'm not sure why). At this probability, Chicago, New York, and Los Angeles (regions K, K, and E, respectively) will work fine since it does not rain with more than 42 mm/hr at that probability level. Atlanta and Miami, however, are in regions M and N, respectively and will not sustain the link at %99.99. The additional information that vertical polarization will allow the link to work in Atlanta only serves to confirm this calculation.

## 6. Interplanetary Doppler:

This looks like a hard problem unless you realize that the planetary motion is orthogonal to the direction of wave propagation. Thus, there is no need to worry about the speed of Jupiter or Earth around the sun. If we view the satellite orbiting Jupiter as a transmitter, then the maximum Doppler contribution will occur when the satellite's circular orbit velocity is aligned towards or away from Earth:

$$|f_{DT}|_{\max} = \frac{V_T}{\lambda} = 1.052 \text{ MHz} \quad V_T = \sqrt{\frac{GM_J}{R}} = 39,463 \text{ m/s}$$

One more thing to consider: the earth station receiver will be rotating which contributes a Doppler shift at the receiver (maximized at sunset and sunrise):

$$|f_{DR}|_{\max} = \frac{V_R}{\lambda} = 1.24 \text{ kHz} \quad V_R = \frac{2\pi R_E}{T_{\text{day}}} = 465 \text{ m/s}$$

This contribution is significantly less than the transmitter-induced Doppler shift. Based on these numbers, an Earth receiver must be prepared to receive a signal for carrier frequencies in the range of [7998.95, 8001.05] MHz.