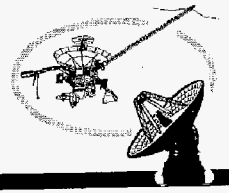

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DYNAMIC TELEMETRY BIT RATES FOR DEEP SPACE COMMUNICATIONS

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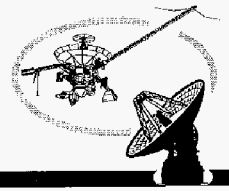
DYNAMIC TELEMETRY BIT RATES



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CONCEPT

- DUE TO VARIATIONS IN THE RECEIVING ANTENNA GAIN TO SYSTEM TEMPERATURE RATIO (G/T), THE SUPPORTABLE DATA RATE CHANGES OVER A TRACKING PASS
- CURRENTLY, CHANGES IN DATA RATES ARE IN LARGE STEPS, CAUSING THE RECEIVERS AND DECODERS TO GO OUT OF LOCK
  - RESULTS IN LOSS OF DATA
  - DATA RATES DESIGNED TO MAXIMIZE DATA RETURN OVER A PASS, MINIMIZING RATE CHANGES
- IF DATA RATE CHANGES COULD BE DONE WITHOUT LOSING LOCK, DATA RETURN COULD BE INCREASED
  - GALILEO WAS FIRST MISSION TO REALLY TAKE ADVANTAGE OF THIS
- TO PREVENT LOSS OF LOCK, DATA RATE CHANGES MUST BE SMALL ENOUGH TO ALLOW THE LOOPS TO TRACK

DYNAMIC TELEMETRY BIT RATES

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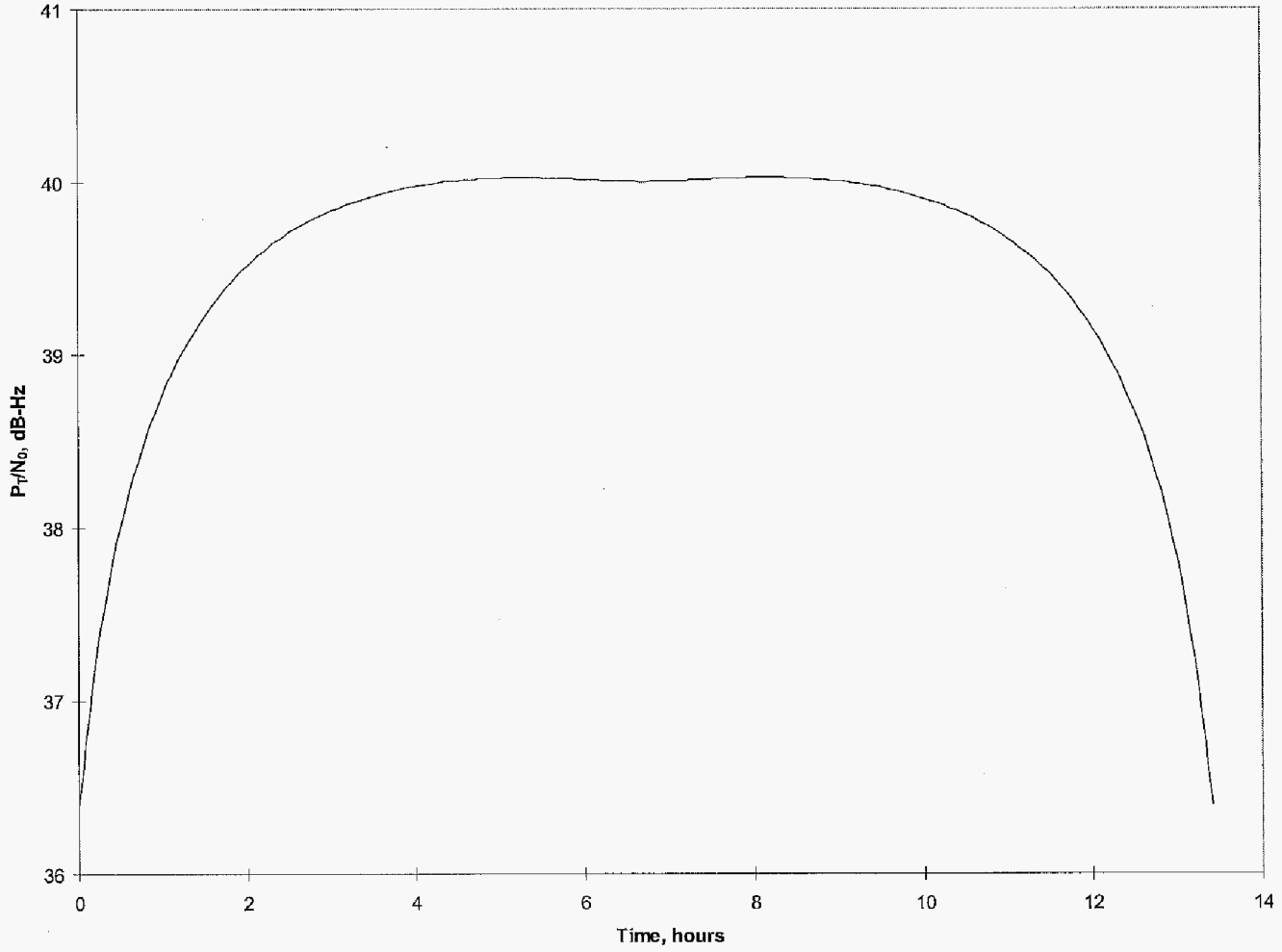
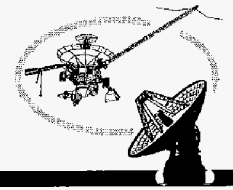
P_T/N_0 EXAMPLE



DYNAMIC TELEMETRY BIT RATES



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CONDITIONS SIMULATED

- THE FOLLOWING LINK WAS SIMULATED
  - RATE 1/2 CONVOLUTIONAL CODING
  - REED SOLOMON CODING
  - 10232 BIT FRAME
  - THRESHOLD BER = 10^{-3}
  - X-BAND DOWNLINK
- TRACKING LOOPS (CARRIER, SUBCARRIER, SYMBOL) THIRD ORDER
- SUBCARRIER FREQUENCY AND SYMBOL RATE SYNCHRONOUS
  - SPACECRAFT TRANSPONDING MODEM IMPLEMENTATION
  - SUBCARRIER FREQUENCY ASSUMED TO BE FIVE TIMES THE SYMBOL RATE
- MAXIMUM LOOP BANDWIDTH ON SUBCARRIER AND SYMBOL LOOPS 50 Hz
- COMPARISON IS DONE AGAINST THE SINGLE DATA RATE THAT GIVES THE LARGEST DATA RETURN OVER THE PASS

DYNAMIC TELEMETRY BIT RATES

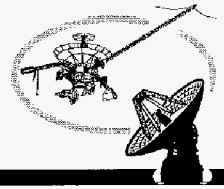
CONSTRAINTS

- TO ACHIEVE THE REQUIRED PERFORMANCE, THE FOLLOWING CONSTRAINTS MUST BE MET:
  - BIT SNR $\geq$ 2.98 dB
  - CARRIER LOOP SNR $\geq$ 10 dB
  - SUBCARRIER LOOP SNR $\geq$ 20 dB
  - SYMBOL LOOP SNR $\geq$ 15 dB
- PEAK OF ANY TRANSIENT RESPONSE LESS THAN 0.1 RADIANS
- BANDWIDTH LIMITATION OF 50 Hz ON THE SUBCARRIER AND SYMBOL LOOPS ALSO CONSTRAIN RESULTS
- PHASE NOISE EFFECTS ON NARROW BANDWIDTHS NOT CONSIDERED

DYNAMIC TELEMETRY BIT RATES

TRANSIENT ANALYSIS

- OUR THIRD ORDER LOOP HAS A TRANSIENT RESPONSE TO A FREQUENCY STEP OF:
  - $\phi_1(t) = (2\pi\Delta f)(23)/(20B)[2 - 2\cos(20Bt/23) + \sin(20Bt/23)]\exp(-20Bt/23)$
  - WHERE
    - B IS THE LOOP BANDWIDTH
    - Δf IS THE FREQUENCY STEP
- NOW, ASSUME A SERIES OF FREQUENCY STEPS, T SECONDS APART:
  - $\phi(t) = \Sigma\ \phi_1(t + nT)$
- WE CONSTRAIN $\phi(t)$ TO BE LESS THAN 0.1 RADIANS
  - FOR A GIVEN B AND T, THIS LIMITS Δf
  - BIT RATE IS CONSTRAINED BY LIMITS ON BIT SNR, CARRIER LOOP SNR, SUBCARRIER LOOP SNR, AND SYMBOL LOOP SNR



DYNAMIC TELEMETRY BIT RATES

COMPARISON

- WE COMPARE TWO DIFFERENT RATE VARIATION SCHEMES:
  - RATE CHANGES EVERY SYMBOL (T IS SYMBOL TIME, HALF THE BIT TIME)
  - RATE CHANGES ONCE EVERY FRAME (T IS FRAME TIME, 2*10232*SYMBOL TIME)
- THE BEST SINGLE RATE ALSO COMPARED
- METRIC IS DATA RETURN, IN BITS, OVER THE ENTIRE PASS PERIOD
- LOOK AT:
  - IMPROVEMENT AT FIXED P_T/N_0
  - IMPROVEMENT AS FUNCTION OF P_T/N_0

DYNAMIC TELEMETRY BIT RATES

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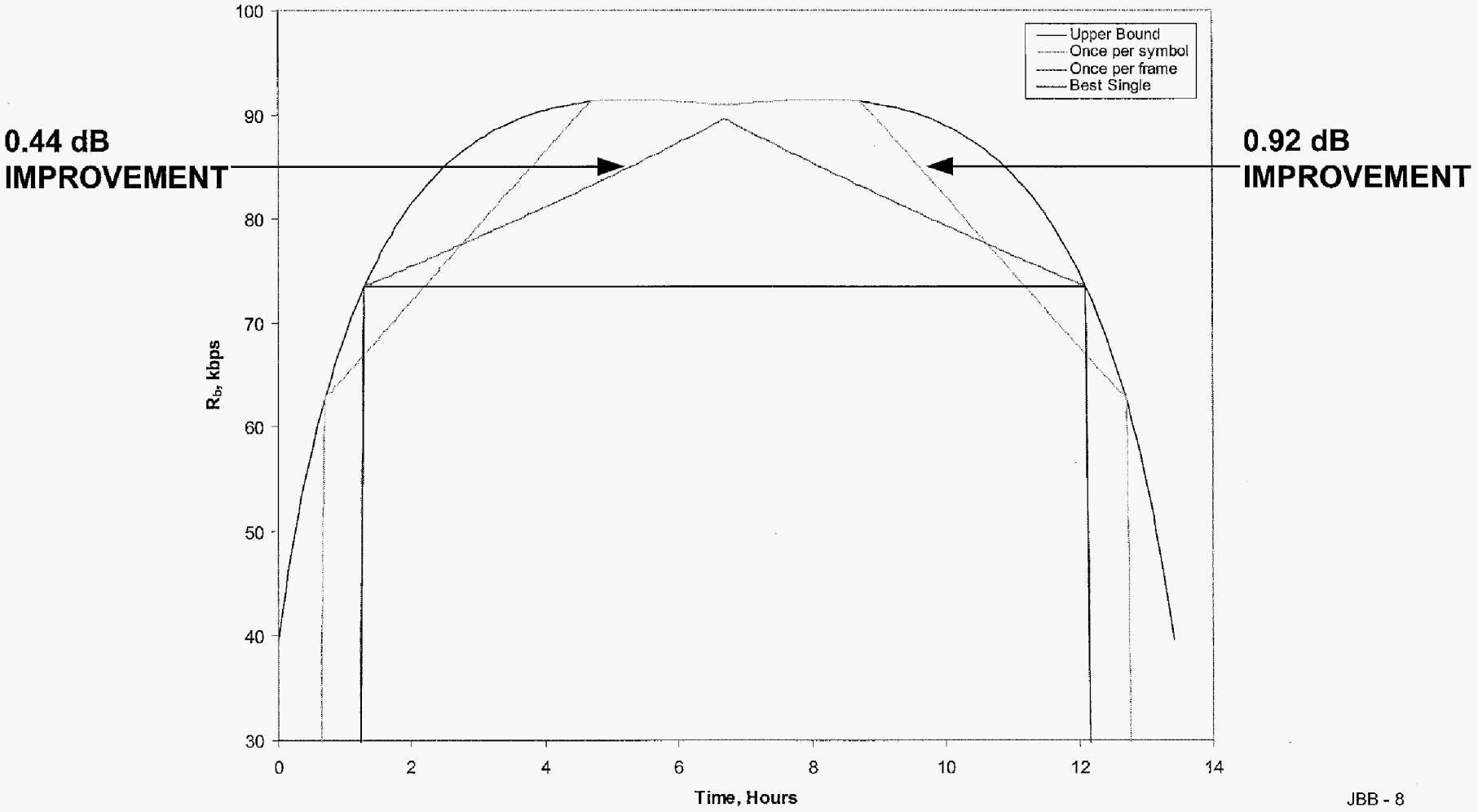
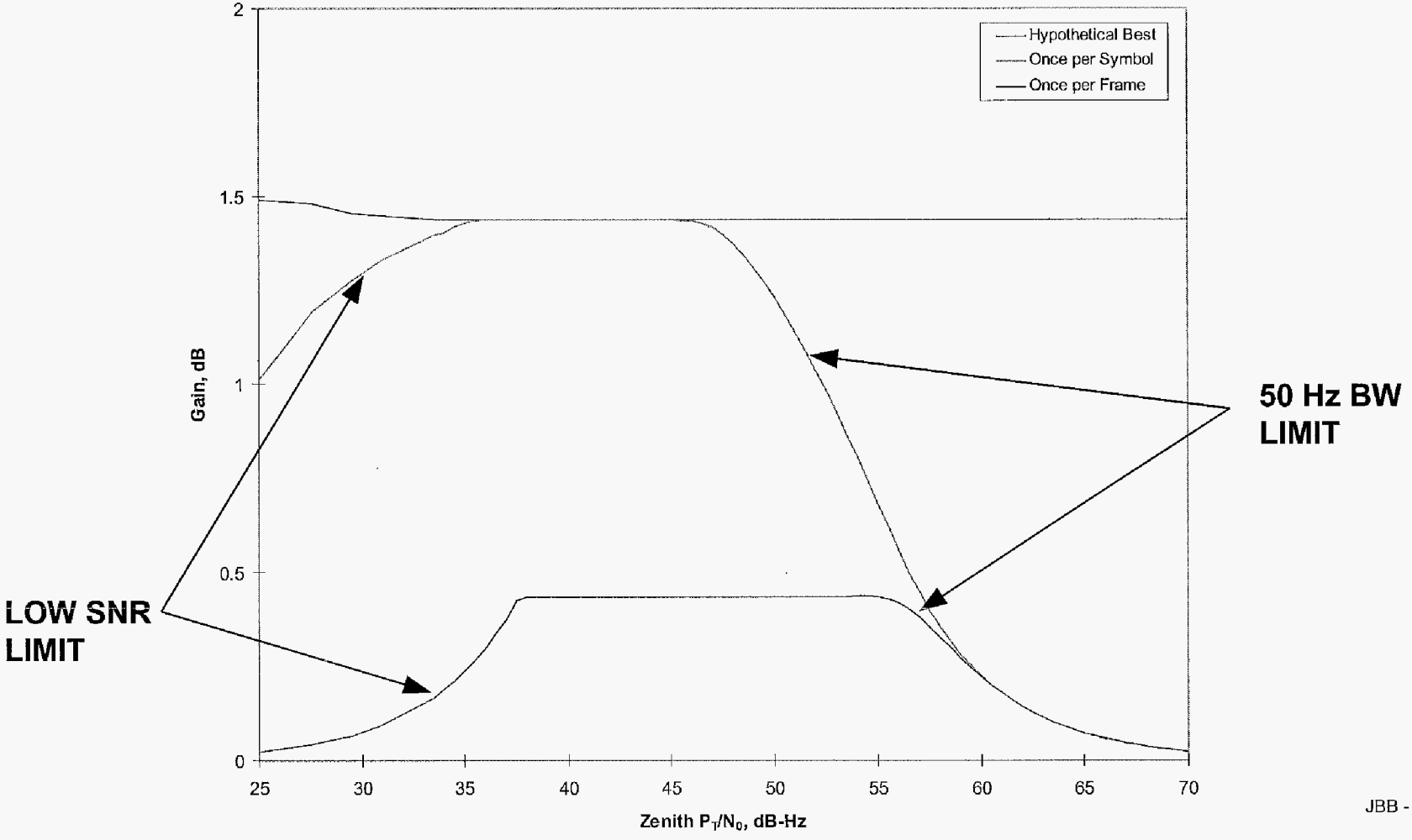
P_T/N_0 = 53 dB-Hz

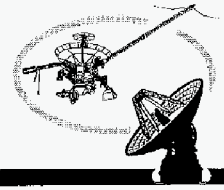


DYNAMIC TELEMETRY BIT RATES

RATE IMPROVEMENT VERSUS P_T/N_0



DYNAMIC TELEMETRY BIT RATES



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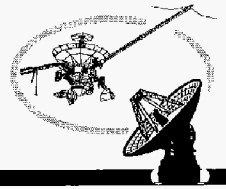
OPERATIONAL ISSUES

- ACQUISITION
  - SINCE SYMBOL RATE IS TIME VARYING, ACQUISITION IS COMPLICATED
  - EITHER PREDICTION OF RATE OR A PERIOD OF TIME AT A FIXED RATE IS REQUIRED
- OPERATIONAL COMPLEXITY
  - TRACKING ANTENNA PROFILE MUST BE PROGRAMMED INTO SPACECRAFT
  - REQUIRES MORE SEQUENCING ACTIVITIES
- PROFILE MATCHING DURING HANDOVERS
  - AS ONE ANTENNA'S G/T DECREASES, THE OTHER'S INCREASES
  - INCREASES PLANNING COMPLEXITY



DYNAMIC TELEMETRY BIT RATES

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CONCLUSIONS

- CHANGING THE BIT RATE AS P_T/N_0 CHANGES CAN SIGNIFICANTLY INCREASE THE DATA RETURN FOR A PASS
  - AS MUCH AS 1.4 dB
- SMALL CHANGES IN RATE EVERY SYMBOL GIVES A BETTER IMPROVEMENT THAN A LARGER CHANGE ONCE EVERY FRAME
- DATA RETURN INCREASE MUST BE TRADED OFF WITH INCREASED MISSION OPERATIONS COMPLEXITY