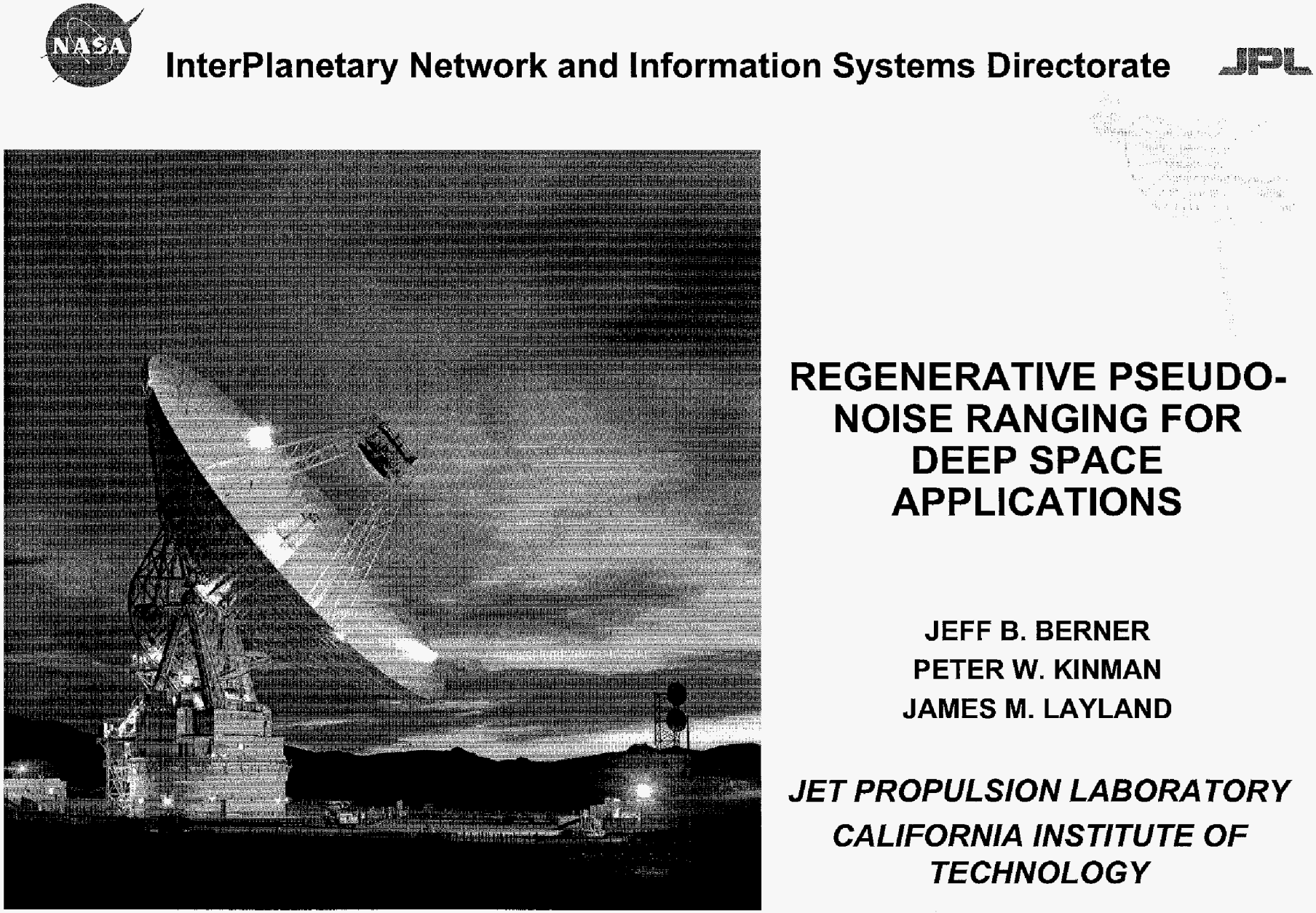

InterPlanetary Network and Information Systems Directorate

REGENERATIVE PSEUDO-NOISE RANGING FOR DEEP SPACE APPLICATIONS

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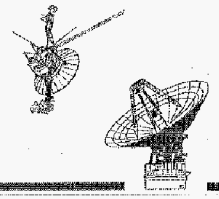
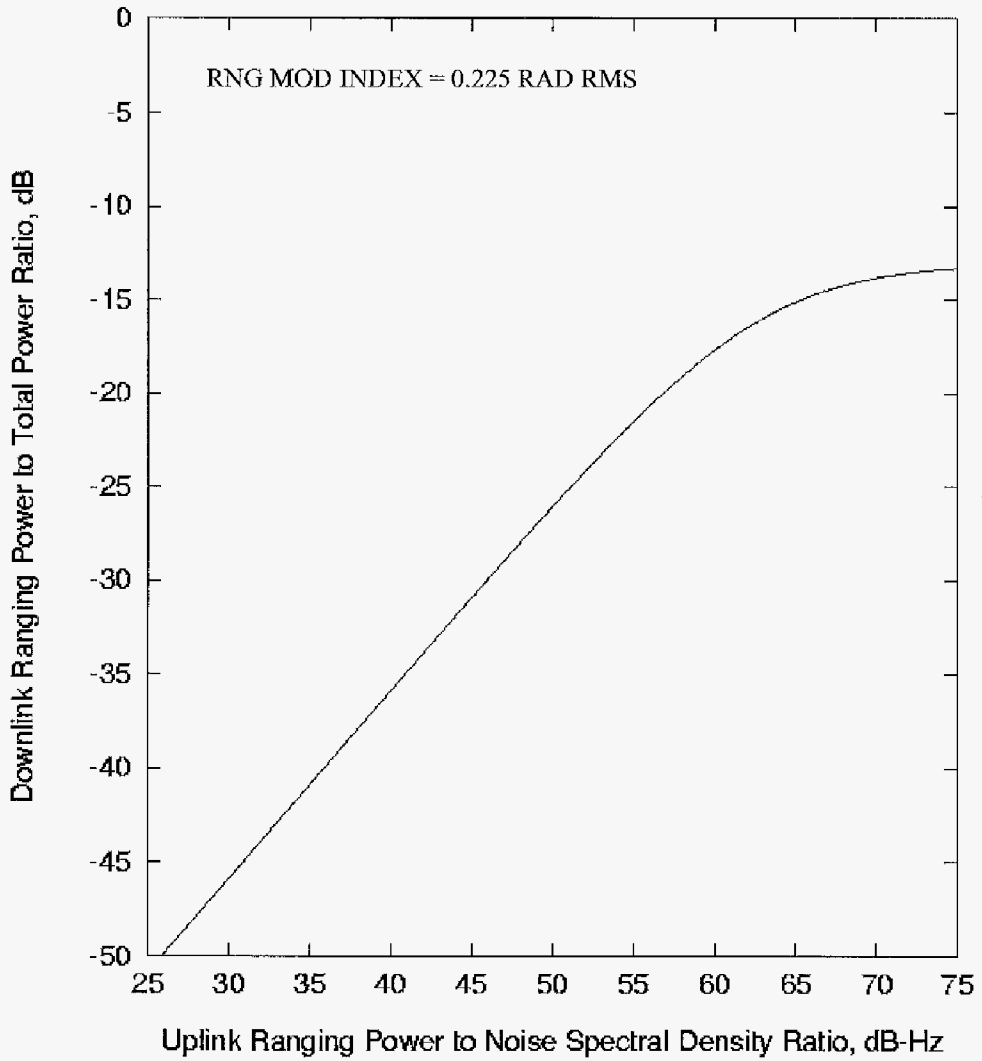
CURRENT RANGING DESIGN

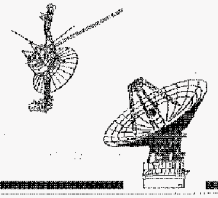


- RANGING SIGNAL IS MODULATED ONTO THE UPLINK
- SPACECRAFT DEMODULATES THE RANGING SIGNAL AND FILTERS IT WITH A 1.5 MHz FILTER
  - 1.5 MHz OF NOISE IS INCLUDED WITH THE SIGNAL
- DOWNLINK CARRIER IS MODULATED BY THE FILTERED RANGING SIGNAL
  - NOISE DEGRADES THE DOWNLINK
- GROUND EQUIPMENT DEMODULATES THE RANGING SIGNAL FROM THE CARRIER AND CORRELATES IT WITH THE REFERENCE
  - INTEGRATION TIME IS INCREASED TO REDUCE THE NOISE

TURN AROUND DEGRADATION

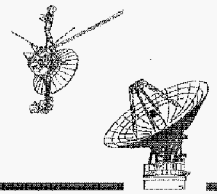


SEQUENTIAL RANGING



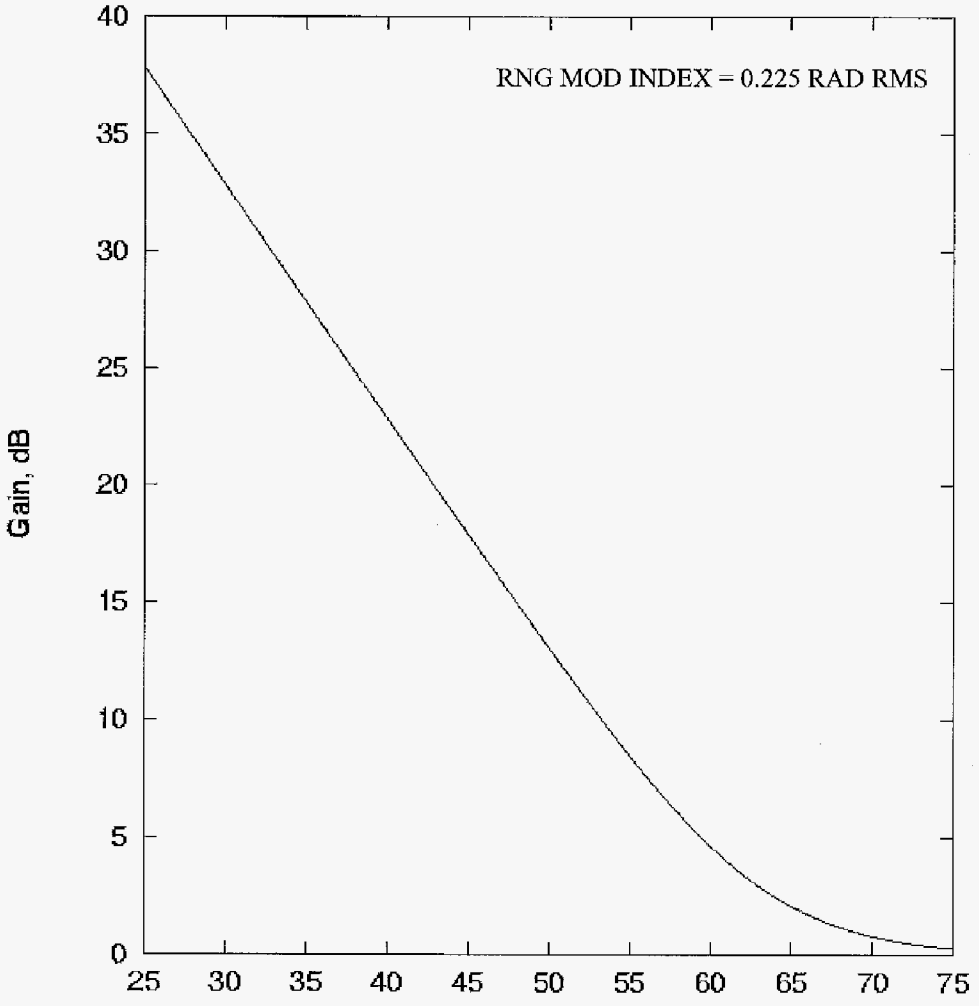
- SERIES OF SQUARE WAVE TONES SENT
  - FREQUENCY OF EACH TONE HALF THE FREQUENCY OF THE PREVIOUS ONE
  - HIGHEST FREQUENCY TONE CALLED THE CLOCK COMPONENT
  - TOTAL NUMBER OF COMPONENTS (N) DEPENDS ON THE AMBIGUITY TO BE RESOLVED
- CLOCK SENT FOR PERIOD OF TIME (T1 SECONDS)
  - THEN EACH SUBSEQUENT COMPONENT IS SENT FOR T2 SECONDS
- CLOCK SENT AGAIN FOR DRVID (DIFFERENCED RANGE VS INTEGRATED DOPPLER) MEASUREMENTS
  - T3 SECONDS FOR EACH DRVID MEASUREMENT
  - NDRVID MEASUREMENTS
- TOTAL TIME FOR 1 RANGE MEASUREMENT (CYCLE TIME) IS
  - (2+T1) + (1+T2)*(N-1) + NDRVID*(2+T3) + 1
- SINCE EACH COMPONENT MUST BE CORRELATED AND INTEGRATED SEPARATELY, ALL ACQUISITIONS MUST START AT BEGINNING OF SEQUENCE

REGENERATIVE RANGING

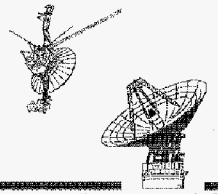


- INSTEAD OF JUST FILTERING THE RECEIVED SIGNAL PLUS NOISE, THE RANGING SIGNAL IS TRACKED ON THE SPACECRAFT
- ONCE THE SPACECRAFT LOCKS TO THE RANGING SIGNAL, THE REGENERATED SIGNAL IS USED TO MODULATE THE DOWNLINK CARRIER
  - THIS ALLOWS SIGNIFICANT REDUCTION IN THE NOISE ON THE SIGNAL, FROM 1.5 MHz TO THE SIGNAL TRACKING LOOP BANDWIDTH
- THIS REQUIRES THAT THE SPACECRAFT HAVE SOME KNOWLEDGE OF WHAT THE RANGING SIGNAL LOOKS LIKE AND THAT THERE IS ENOUGH SNR TO LOCK
- SEQUENTIAL SIGNAL IS NOT A GOOD CANDIDATE, DUE TO LONG CYCLE TIMES AND VARIABLE PARAMETERS
  - BEGINNING TIME OF SEQUENCE MUST BE KNOWN, WHICH WOULD COMPLICATE OPERATIONS SIGNIFICANTLY

REGENERATIVE RANGING GAIN

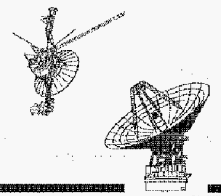


PN CODE DESCRIPTION



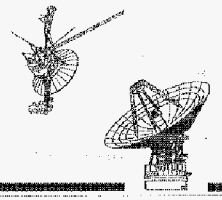
- PSEUDO-NOISE (PN) RANGING PROVIDES AN EASIER SIGNAL TO LOCK TO
- PN SIGNAL IS GENERATED BY OR'ING THE CLOCK COMPONENT WITH THE RESULT OF AND'ING 5 PN SEQUENCES
  - SEQUENCES OF LENGTH 7, 11, 15, 19, 23
  - RESULTING SEQUENCE IS 1,009,470 CHIPS LONG
  - CLOCK RATE IS APPROXIMATELY 1 MHz
    - RESULTING CYCLE TIME IS 0.5 SECONDS (2 CHIPS PER CLOCK CYCLE)
    - CLOCK IS FREQUENCY COHERENT WITH THE UPLINK CARRIER
- PN SIGNAL LOOKS LIKE A SQUARE WAVE AT 1 MHz, WITH A FEW ERRORS
- CORRELATION PROCESS CAN START AT ANY POINT IN THE SEQUENCE
  - NO KNOWLEDGE OF START TIME REQUIRED
- CORRELATION CAN BE DONE AGAINST EACH OF THE SUBSEQUENCES, SO ONLY 75 CORRELATIONS NEED TO BE DONE

SPACECRAFT DESIGN/OPERATION



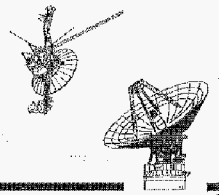
- MINIMUM UPLINK Pr/N0 IS 27 dB-Hz
  - REQUIRES 18 SECONDS INTEGRATION TIME FOR PROBABILITY OF ACQUISITION TO BE GREATER THAN 0.999
  - STRONGER SIGNALS REQUIRE LESS INTEGRATION TIME
- DUE TO FREQUENCY COHERENCY OF RANGING SIGNAL WITH UPLINK CARRIER, ACQUISITION PROCESS IS STRAIGHT FORWARD
  - LOCK TO UPLINK CARRIER
  - CHIP TRACKING LOOP LOCKS TO CHIPS, USING SCALED CARRIER REFERENCE TO GET THE CLOCK FREQUENCY
    - SINCE ONLY PHASE NEEDS TO BE TRACKED, A FIRST ORDER PHASE LOCKED LOOP IS USED TO TRACK THE CLOCK (CHIP) PHASE
- ONCE THE CHIPS ARE IN LOCK, THE SIGNAL IS INTEGRATED AND CORRELATED AGAINST THE PN SEQUENCE
- WHEN OFFSET IS DETERMINED, PN SEQUENCE USED TO MODULATE DOWNLINK CARRIER
- CORRELATIONS CONTINUE TO BE DONE
  - AGREEMENT USED AS LOCK INDICATION

USES OF IMPROVEMENT



- THE GAIN IN RECEIVED RANGING POWER CAN BE USED IN SEVERAL WAYS:
  - REDUCE THE INTEGRATION TIME ON THE GROUND (TO REDUCE THE TRACKING TIME DEVOTED TO RANGING), GIVING THE SAME MEASUREMENT VARIANCE
  - KEEP THE INTEGRATION TIME ON THE GROUND THE SAME, REDUCING THE VARIANCE ON THE MEASUREMENT
  - REDUCE THE DOWNLINK RANGING MODULATION INDEX, KEEPING THE INTEGRATION TIME ON THE GROUND THE SAME, PROVIDING MORE POWER FOR TELEMETRY

MARS GLOBAL SURVEYOR (MGS) EXAMPLE



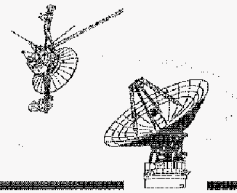
CURRENT

NUMBER OF COMPONENTS	18
NUMBER OF DRVID	0
T1 (SEC)	20
T2 (SEC)	10
T3 (SEC)	0
CYCLE TIME (SEC)	210
UPLINK Pr/N0 (dB-Hz)	44.9
DOWNLINK Pr/N0 (dB-Hz)	10.0

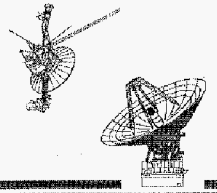
WITH REGENERATION

SPACECRAFT INTEGRATION TIME (SEC) (ASSUMING 0.999 PROB. OF ACQ.)	0.5
DOWNLINK Pr/N0 GAIN (dB)	17.6

CASSINI EXAMPLE



	VENUS CRUISE	SATURN
CURRENT		
NUMBER OF COMPONENTS	10	10
NUMBER OF DRVID	0	0
T1 (SEC)	1248	47
T2 (SEC)	60	1
T3 (SEC)	0	0
CYCLE TIME (SEC)	1800	70
UPLINK Pr/N0 (dB-Hz)	35.8	61.8
DOWNLINK Pr/N0 (dB-Hz)	-8.4	12.0
WITH REGENERATION		
SPACECRAFT INTEGRATION TIME (SEC) (ASSUMING 0.999 PROB. OF ACQ.)	2.3	0.5
DOWNLINK Pr/N0 GAIN (dB)	24.7	3.3



CONCLUSION

- PSEUDO-NOISE REGENERATIVE RANGING INCREASES THE GROUND RECEIVED Pr/N0
  - FOR CERTAIN PHASES OF MISSIONS, SIGNIFICANT INCREASES IN RANGING PERFORMANCE CAN BE ACHIEVED
  - THE IMPROVEMENT CAN BE USED TO REDUCE TRACKING TIME OR TO REDUCE THE VARIANCE ON THE MEASUREMENT
- USING PSEUDO-NOISE RANGE CODES SIMPLIFIES THE IMPLEMENTATION ON THE SPACECRAFT TRANSPONDER