Future Multiple Uplink per Aperture access schemes

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S.Marti, 31/10/2012

Objectives

- Presently a ground station supports a single spacecraft
- Multiplexing techniques used for long time on commercial satellite communications
- Supporting more than one spacecraft simultaneously has advantages:
  - More antenna support hours available
  - More downlink time for each mission
  - Sharing support costs (lower cost per mission)

- Is it possible to support more than one spacecraft simultaneously?
  - Easy for TM downlink
  - More complex for TC uplink and coh RG

The objective was to find how to implement a system that supports more than one spacecraft being transparent to operations.

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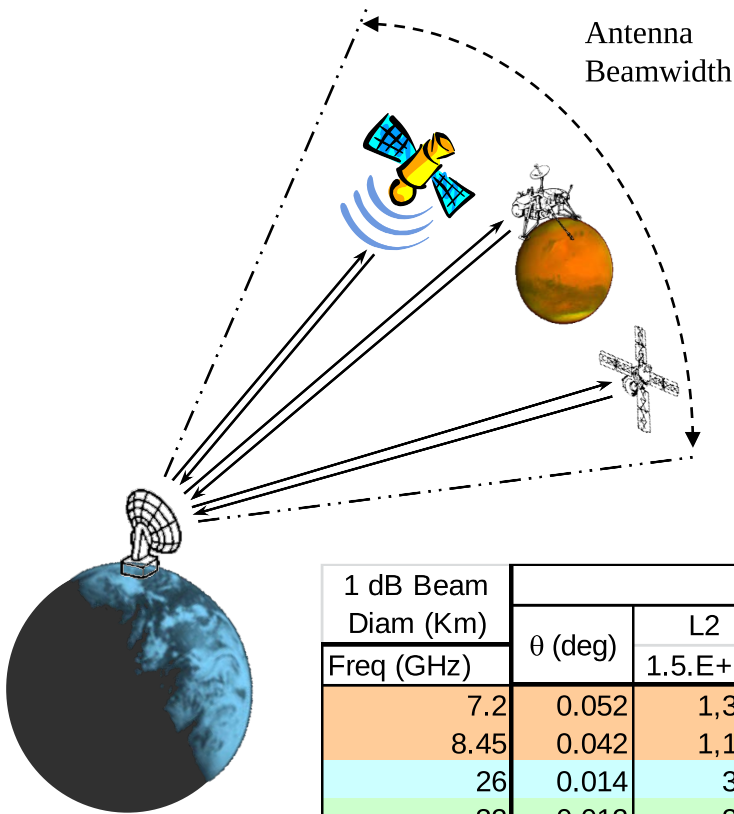
Limits of Multilink



1. All spacecraft shall be inside antenna beamwidth (50 mdeg for 35m @ X Band, 1mm@1m)
2. Not realistic for NE, L1/L2/Moon
3. Ground Station resources (EIRP) shall be distributed between the missions

1 dB Beam Diam (Km)		35 meters						
	θ (deg)	L2	Mercury		Mars		Jupiter	
Freq (GHz)		1.5.E+06	100.E+06	200.E+06	50.E+06	350.E+06	630.E+06	930.E+06
7.2	0.052	1,357	90,478	180,956	45,239	316,673	570,011	841,444
8.45	0.042	1,101	73,388	146,775	36,694	256,857	462,342	682,505
26	0.014	362	24,127	48,255	12,064	84,446	152,003	224,385
32	0.012	302	20,106	40,212	10,053	70,372	126,669	186,988
34.5	0.010	271	18,096	36,191	9,048	63,335	114,002	168,289

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Achievements

- A GSP study was started in November 2011
- Small and short study (100 k€, 10 months) with two scenarios
- Team composed by Callisto (F) and Zelinda (IR)

- The study concluded the optimal solutions considering two scenarios:
  - Short term: where no change on the on board systems is possible (missions already flying or under manufacturing) and limited changes on ground.
  - Long term: Freedom on the design of the communication links (future missions still not designed)

Final solutions have been analysed and the required technological developments identified -> inputs for future TRP, GSTP developments

European Space Agency

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Callisto

02/11/2012

Study Final Presentation
Multiple Satellite Per Aperture
MSPA

MSPA: What Missions?

Mission Type	DSA Beamwidth	Multiple Missions Planned
L1/L2	✗	✔
Venus	✓	✗
Mars	✔	✔
Mercury	✓	✗
Jupiter/Saturn	✓	✗ (NASA ?)

Multiple Orbiter ✓

Orbiter + Lander ✗

MSPA: What Scenarios?

Short Term

Current transponder
Current Modulation

Long Term

New transponder
Alternative Modulation

What Multiplex Schemes?

	Multiplexing level		
	Data	Subcarrier	Carrier
SDM(A)	N/A	N/A	N/A Only one beam
TDM(A)	✓	Difficult to implement	One S/C after the other
FDM(A)	N/A	✓	✓
CDM(A)	✓	N/A	N/A (FHSS only for secure NE comms)

What Multiplex Schemes?

	Multiplexing level		
	Data	Subcarrier	Carrier
SDM(A)	N/A	N/A	N/A Only one beam
TDM(A)	**SC-CCSDS-PT**	Difficult to implement	One S/C after the other
FDM(A)	N/A	**SCFDM**	**CFDM** CFDMA (ATFR)
CDM(A)	**CDM (DSSS)** **CDMA (DSSS)**	N/A	N/A (FHSS only for secure NE comms)

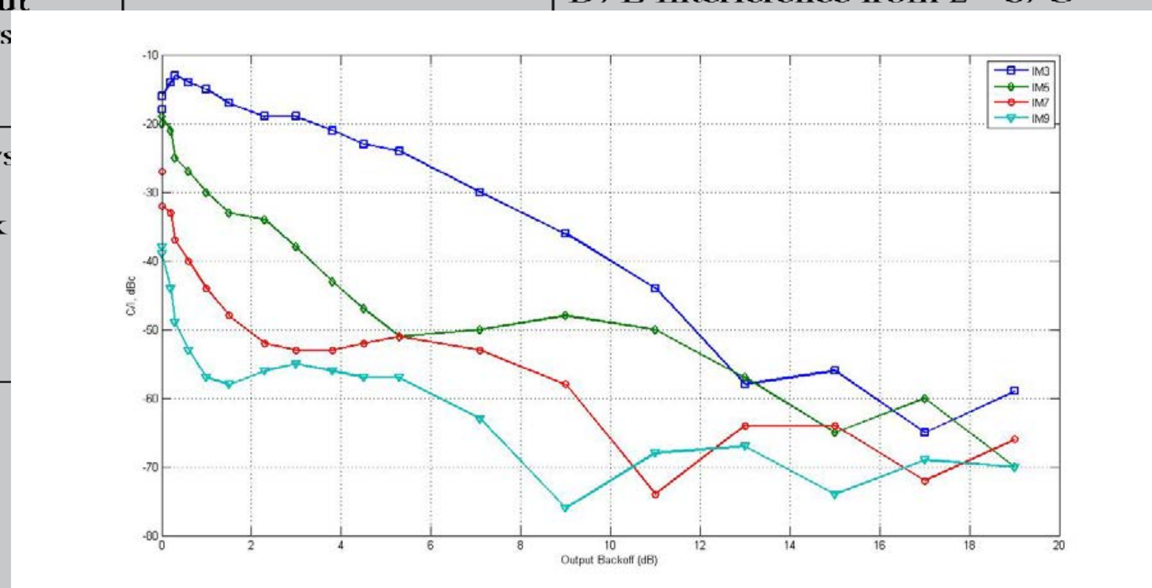
MSPA Study Final Presentation

- Selection of Solutions for detailed investigation (CAL)
- Solution for Short Term Scenario (CAL)
- Solution for Long Term Scenario (ZEL)
- Recommendations to go forward (ZEL)

Short Term Scenario

Option No.	Abbreviation	Description	Pros	Cons
2	CFDMA Uplink CFDMA Downlink	Multiple individual uplink carriers. Multiple downlink carriers (each downlink coherent with one of the uplinks)	Simplicity Independent Flexibility Possibility to use polarisation Diversity on U/L	Intermodulation products (HPA & PIM) Realistically only 2 Users (20kW HPA)
3	SC-CCSDS-PT Uplink SFDMA Downlink	Single uplink multiplexed at data level. Multiple downlink (same carrier frequency but different subcarriers	Easy to Implement	Limited operations Limited TC Throughput D/L Interference from 2nd S/C
4	SFDMA Uplink SFDMA Downlink	Multiple subcarriers the same carrier frequency in uplink downlink		

IM3



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3	SC-CCSDS-PT Uplink SFDMA Downlink	Single uplink multiplexed at data level. Multiple downlink (same carrier frequency but different subcarriers)	Easy to Implement	Limited operations Limited TC Throughput D/L Interference from 2nd S/C needs polarisation diversity to reduce interference D/L Acquisition for 2nd S/C
4	SFDMA Uplink SFDMA Downlink	Multiple subcarriers at the same carrier frequency in uplink and downlink	Relatively Easy to implement	U/L Limited to 2 users U/L Cross Modulation problem D/L Interference from 2nd S/C needs polarisation diversity to reduce interference D/L Acquisition for 2nd S/C

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Long Term Scenario

Option No.	Abbreviation	Description	Pros	Cons
5	SC-CCSDS-PT Uplink CFDMA/ATFR Downlink	Single uplink multiplexed at data level. Multiple downlink with different carriers and turnaround ratios	Easy to Implement on U/L (no major modifications) Very Easy to implement on D/L	Limited operations Limited TC Throughput Continuous U/L sweep. Same U/L bit rate for all. Need as many different Turn Round ratios as users.
6	SC-CCSDS-PT Uplink CDMA Downlink	Single uplink multiplexed at data level. Multiple downlink at the same carrier frequency (Code Division Multiple Access)	Easy to Implement on U/L (no major modifications) CDMA acquisition problem on GS side only. Multiple Access (users) on downlink	Limited operations Limited TC Throughput Continuous U/L sweep. Same U/L bit rate for all. Need to develop CDMA transponder and GS demodulator.
7	CDM Uplink CDMA Downlink	Single uplink Code Division Multiplex using W-H codes. Multiple downlink Code Division Multiple Access	Continuous and simultaneous commanding to all spacecraft. Full S/C Tx power available for TM and ranging.	With limiter -severe AM Without limiter -severe interference between command channels. Continuous U/L sweep or complex acquisition.
8	DSSS CDMA Uplink DSSS CDMA Downlink	Similar to Galileo SS TT&C scheme	Proven for GEO/MEO missions. For Mars link budgets gives adequate margins. U/L Doppler pre-compensation can be used.	Deep Space more challenging for acquisition at C/No< 40dBhz. Need to develop CDMA transponder and GS TTC modem.

Callisto

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Selected for Short Term Scenario

CFDMA Uplink	Multiple individual uplink carriers.
CFDMA Downlink	Multiple downlink carrier each coherent its uplink carrier

Selected for Long Term Scenario

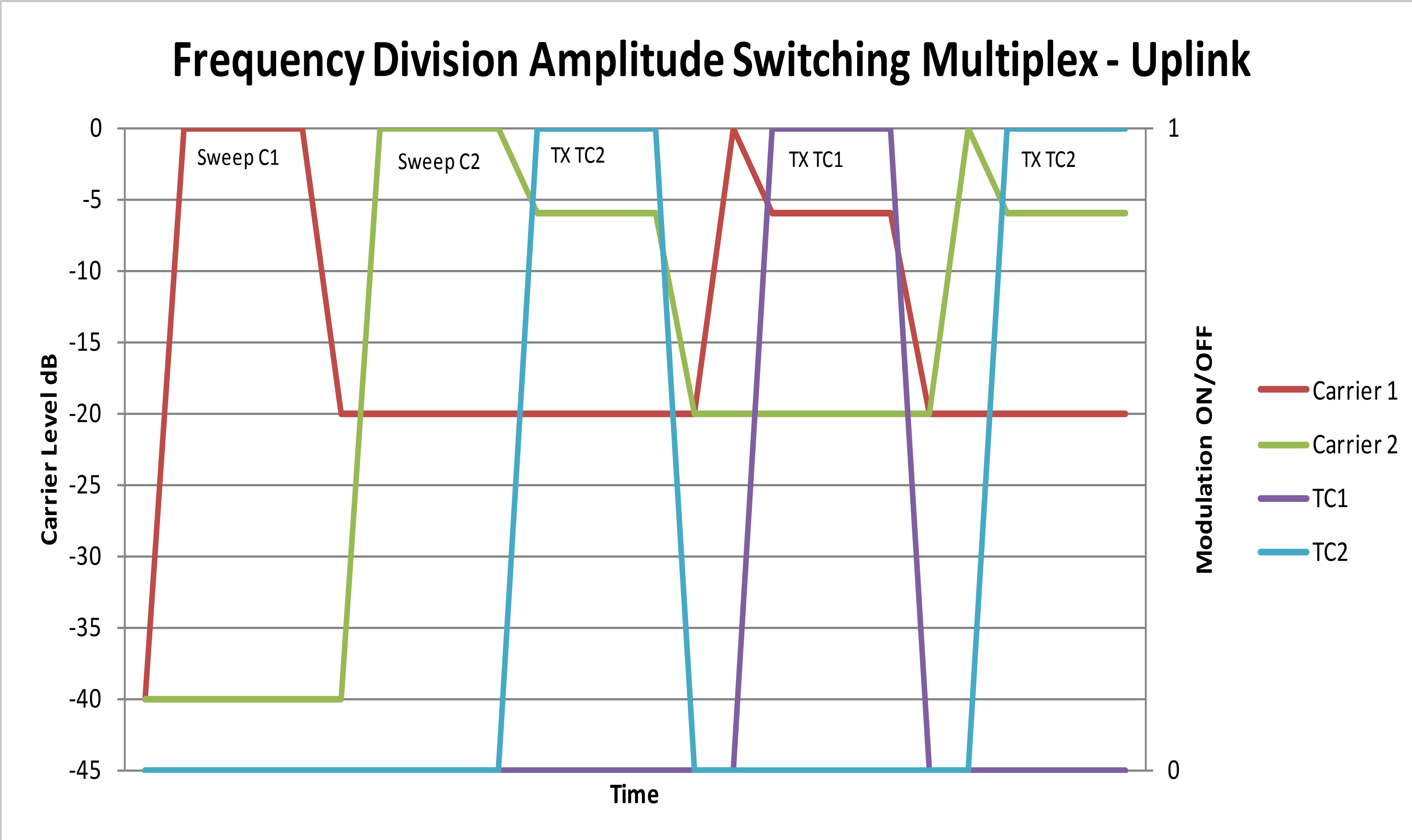
DSSS CDMA Uplink DSSS CDMA Downlink	Similar to Galileo SS TT&C scheme

Short Term Scenario

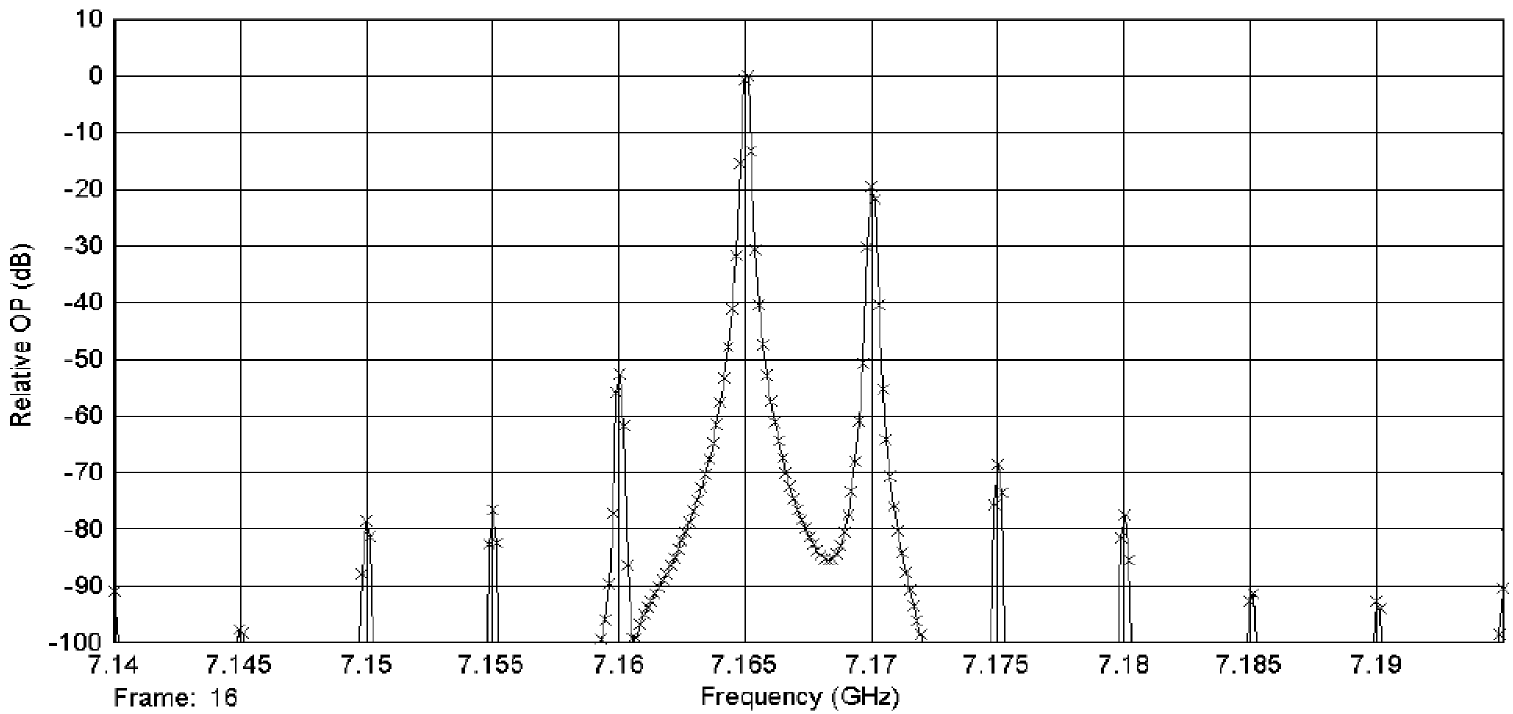
- CFDMA on Uplink
- CFDMA on Downlink
- Problem is Intermodulation on uplink!

Solutions for Intermodulation

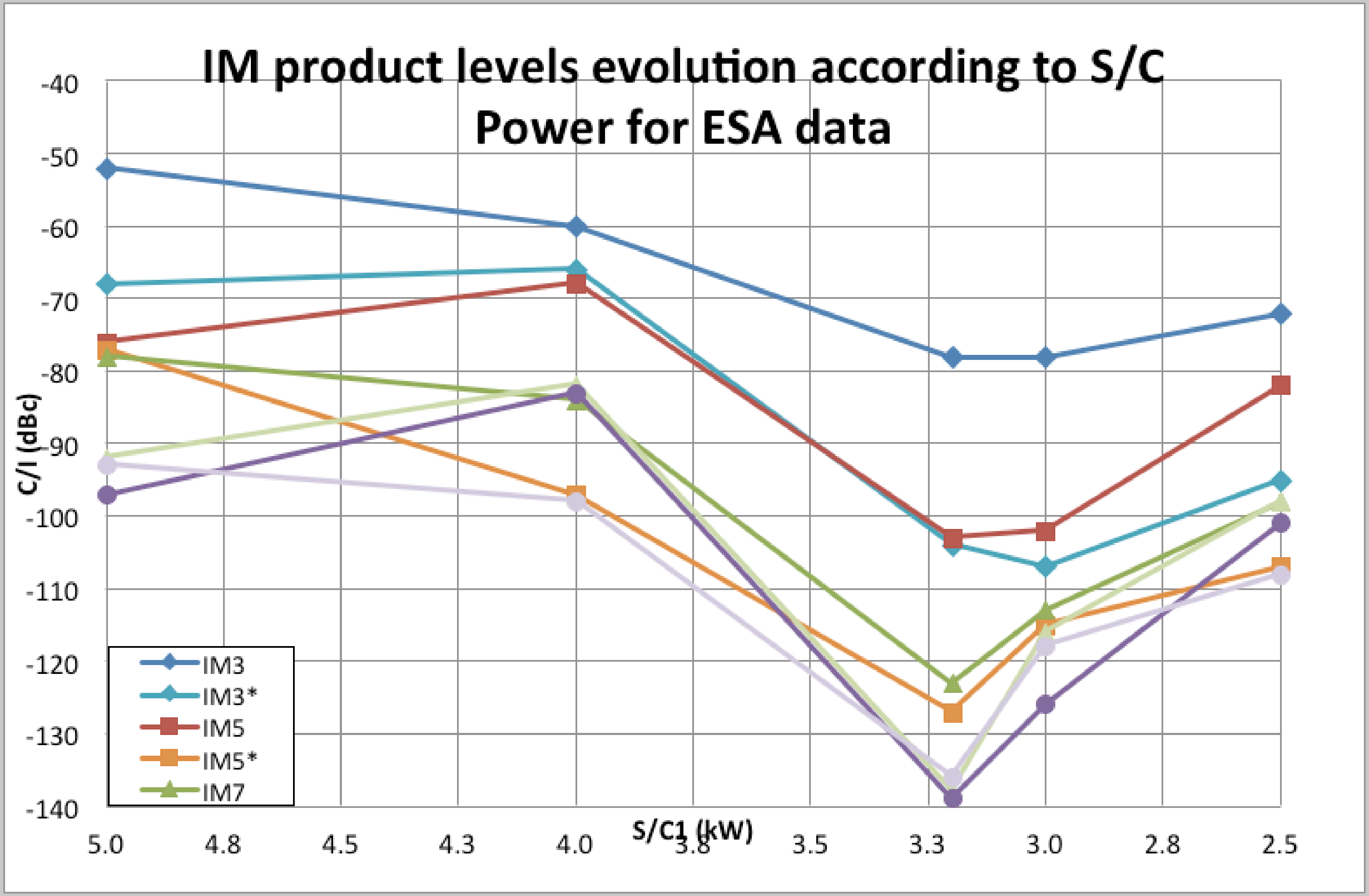
1. Separate HPAs for carrier (but PIM)
2. New Extra HPA (50 KW)
3. Use Linearizer
4. Amplitude Switching of carrier levels…

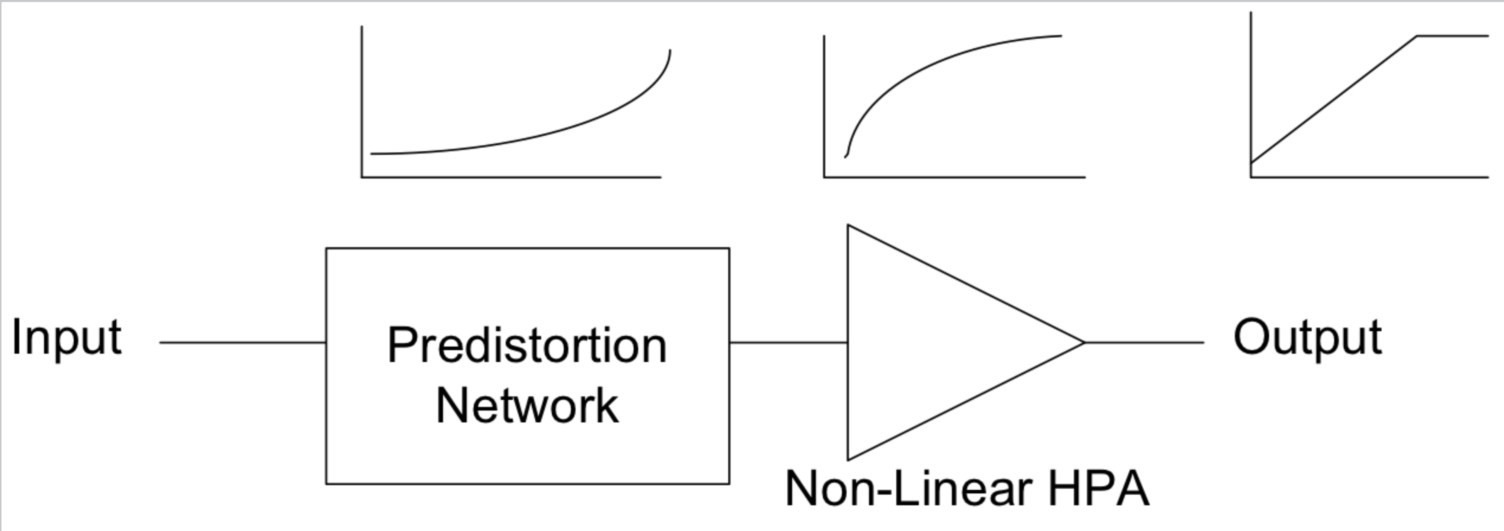

Frequency Division Amplitude Switching Multiplex - Uplink
Sweep C1
Sweep C2
TX TC2
TX TC1
TX TC2
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
Carrier Level dB
1
0
Modulation ON/OFF
Time
Carrier 1
Carrier 2
TC1
TC2

Short Term Scenario



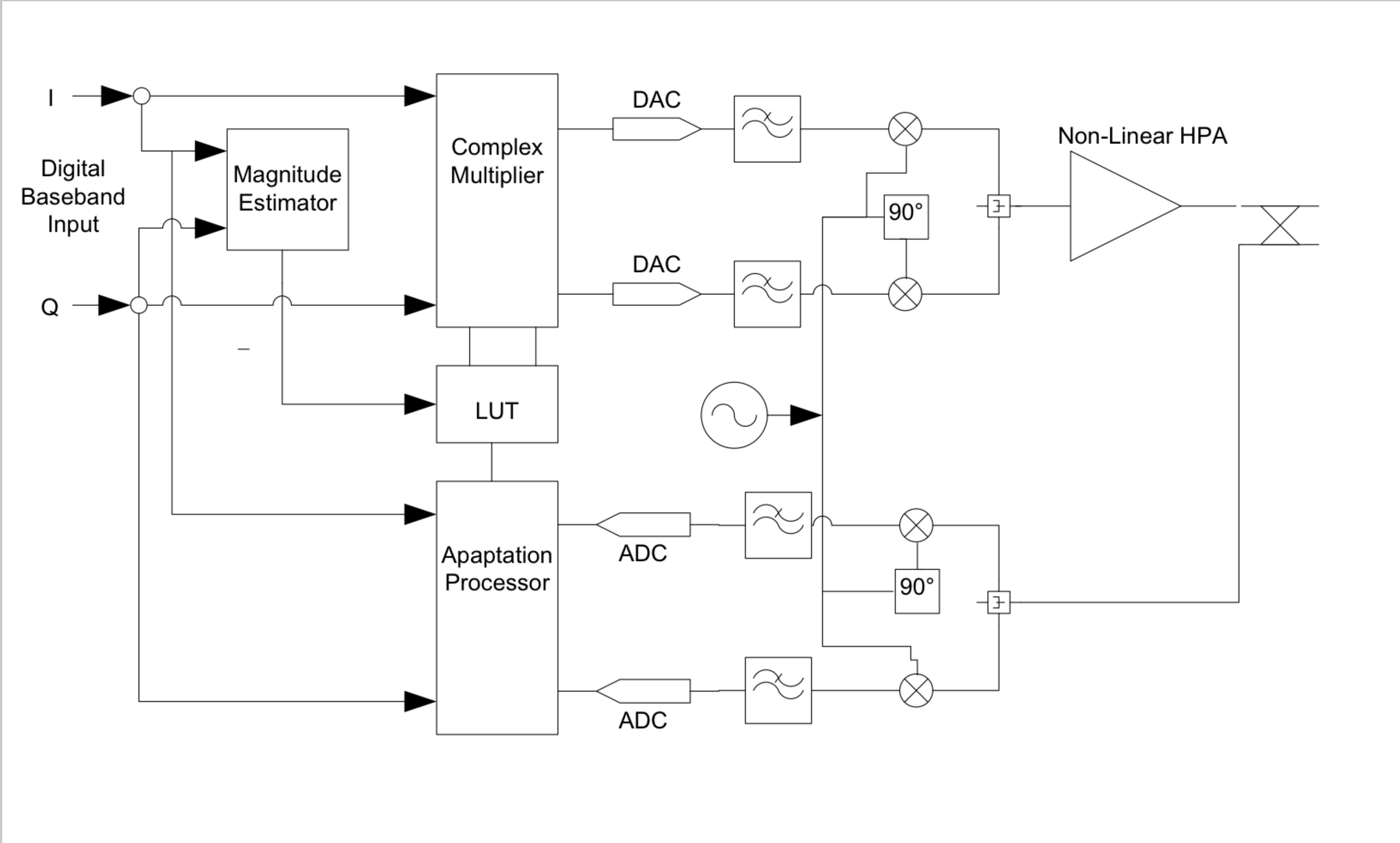
Short Term Scenario





Linearizer – General Principle

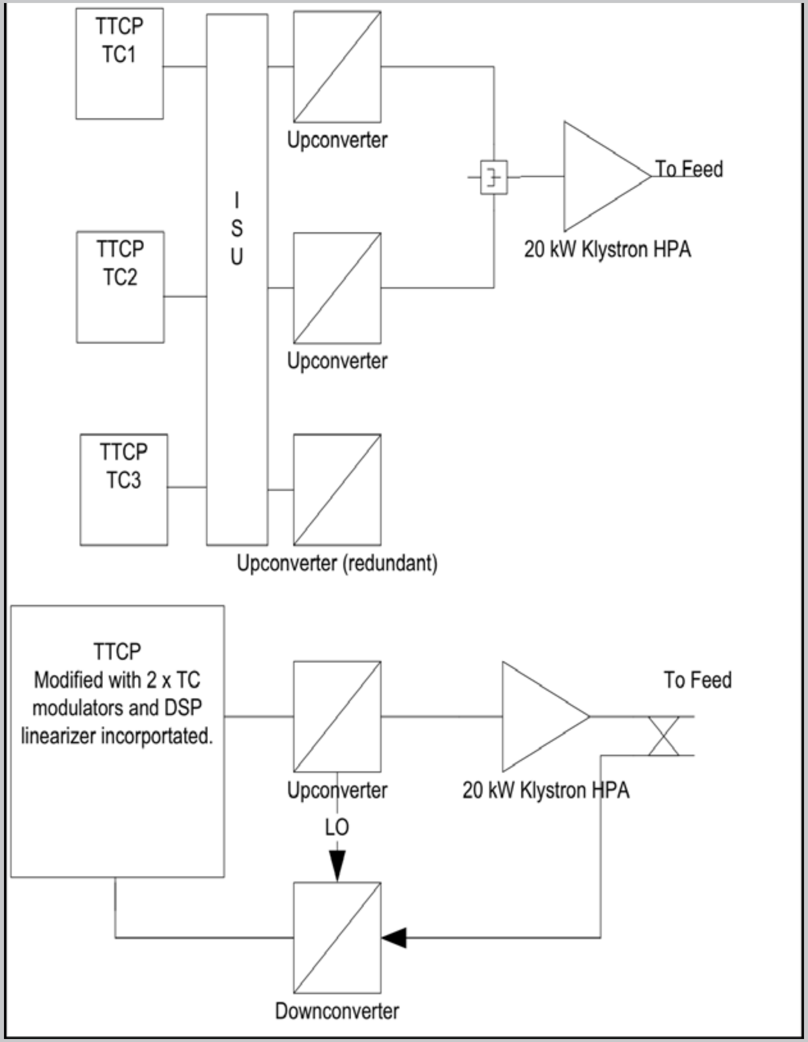
Short Term Scenario



Linearizer – Implemented by DSP at Baseband

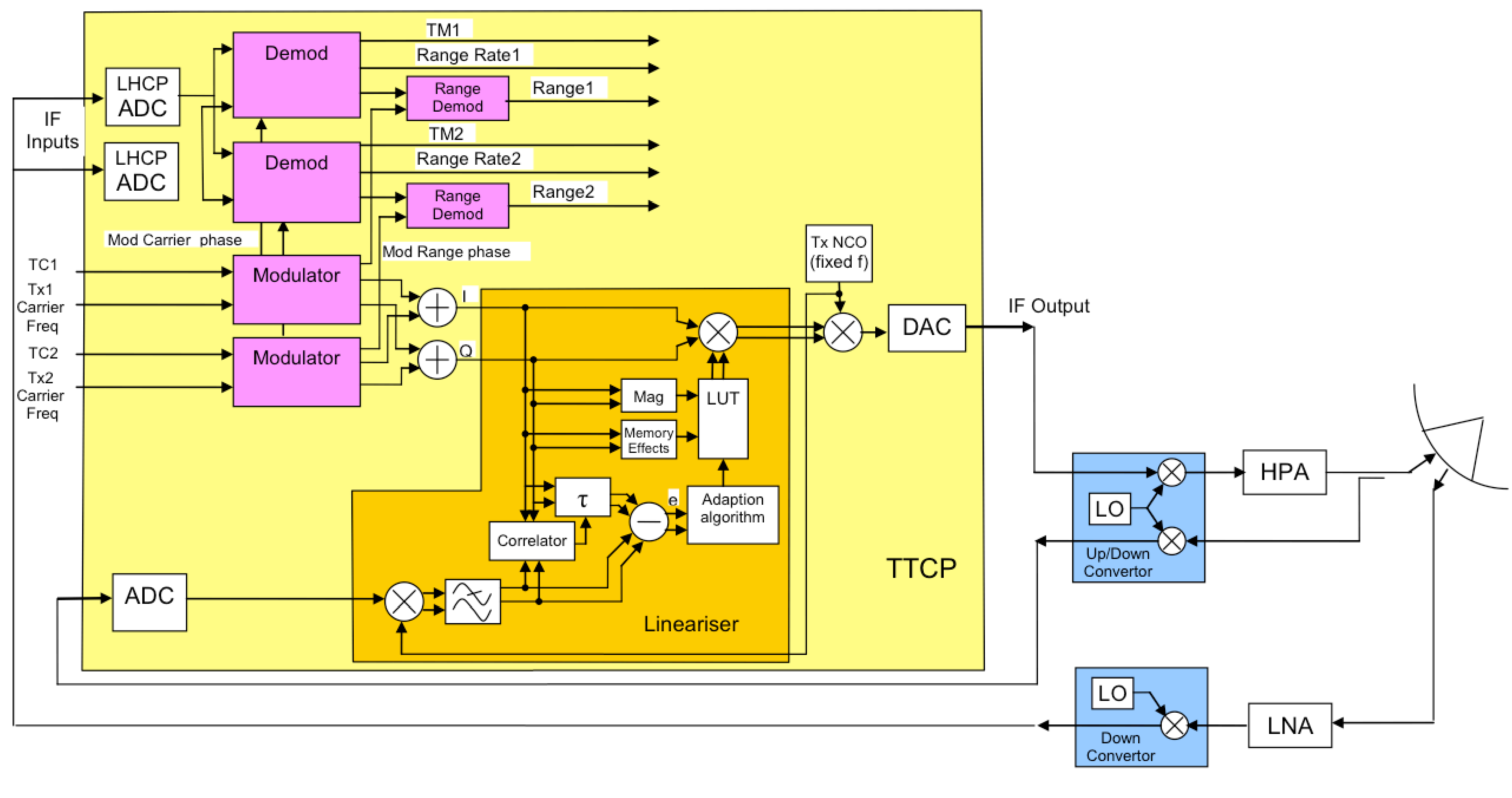
RD	Reported IMP3 reduction	Method	Notes
RD25	>15dB	Pre-distortion without adaption feedback	HPA was TWTA
RD28	Max 10dB min 4dB Max 15dB min 8dB Max 25dB min 8dB Max 15dB	Digital predistortion with adaptation Digital predistortion with adaptation and memory affects Digital predistortion with adaptation and memory affects Digital predistortion with adaptation and memory affects	SSPA various OPBO levels SSPA various OPBO levels TWTA narrow band (10-20 MHz) TWTA wideband (100 MHz)
RD32	10.5dB	Pre-distortion	Klystron (Radar)
RD33	20dB	Digital predistortion with adaptation	Simulation using ADS
RD34	13dB	Digital predistortion with adaptation	SSPA
Lintech	30dB	Pre-distortion without adaption feedback	SSPA

Linearizer – Reported Performance



Implementation in the DSA

Short Term Scenario



Implementation in the DSA

Communications Performance

- 35m DSA to Mars Orbiter – MEX Parameters
- Max Range (370 x 10^6 km)

	Nominal	S/C1	S/C2
GS Tx Power (kW)	5	5	0.05
GS EIRP (dBW)	102	102	82.1
Mod Index (Rad)	1	1	0
S/C Carrier PLL	WIDE	WIDE	WIDE
S/C Carrier PLL Margin (dB)	21	21	4.6
TC Bit Rate (bps)	2000	2000	-
TC Data Margin (dB)	8.2	8.2	N/A

Communications Performance

- 35m DSA to Mars Orbiter – MEX Parameters
- Max Range (370 x 10^6 km)

	Nominal	S/C1	S/C2
GS Tx Power (kW)	5	3	0.03
GS EIRP (dBW)	102	100	79.9
Mod Index (Rad)	1	1	0
S/C Carrier PLL	WIDE	WIDE	WIDE
S/C Carrier PLL Margin (dB)	21	19	2.4
TC Bit Rate (bps)	2000	2000	-
TC Data Margin (dB)	8.2	6.0	N/A

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Zelinda Ireland

02/11/2012

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Long Term Scenario DSSS CDMA

- Modulation scheme
- Space Segment
- Ground Segment

Modulation Scheme based on Galileo TTC

CCSDS 415.1-B-1

- DSSS UQPSK uplink, DSSS OQPSK Downlink
- 1023 Gold Code for Forward Command channel
  - Short enough for rapid acqusition
  - Long enough for low auto & cross correlation (-24 dBC)
  - 100s of balanced codes available
- 256 * 1023 chip truncated maximum length Ranging Code on Uplink @ -10 dBC
- 2047 Gold code for non-coherent downlink
- 256 * 1023 chip coherent downlink
  - Range Ambiguity of ~12,500 km
- Currently used on S-Band links (Gallileo, TDRSS) with 3 Mcps, derivative used on C-Band Galileo Payload & ATV, HTV, ISS link

DSSS Scheme Suitability

- Much greater range of Mars vs Galileo ?

  so lower C/No making acquisition difficult (Galileo C/No > 60 dBHz)

- X-Band versus S-Band?

  so more Doppler & LO uncertainty...

- Greater orbit Dynamics at Mars than MEO

  so more Doppler

- Simultaneous spacecraft access vs Galileo one-at-a-time

  so MAI and Ground station intermodulation

Adapt Galileo Scheme ?

- Different Code families ?
    - Asynchronous CDMA scheme so Gold & Maximum length a good choice
- Command code longer than 1023 ?
    - Reduce auto and cross correlation
    - Longer code length gives more codes

  No real need for change
- Higher Chip rate (than 3 Mcps) ?
    - Greater range accuracy
    - But harder to acquire due to greater chip rate uncertainty.
    - Would need longer range code for same ambiguity

  No real need for change
- Longer Range code ?
    - Not difficult, but 12,500 km is enough ?

Acquisition at Spacecraft

- Key to acquisition is Doppler and LO offset pre-compensation unique to each spacecraft to reduce Carrier and code uncertainty.

One dimensional Search for Code Phase

Max Carrier uncertainty	3000 Hz (+/-)
Max allowed carrier rotation	120 degrees
Therefore Max Coherent Correlation	333.3chips

C/No	Non_Coherent correlations	Acquisition time	Max Code Doppler	
		mS	cps	ppm
30.0				
33.0	20,137	2,237.4	0.22	0.074
36.0	4,465	496.1	1.01	0.336
37.0	2,772	308.0	1.62	0.541
39.0	1,093	121.4	4.12	1.373
42.0	291	32.3	15.48	5.160
45.0	80	8.9	56.18	18.727

Acquisition Strategy

- Propose 3kHz residual Carrier uncertainty, pro-rate code (0.4 ppm @ X-Band).
- Acquisition in ~ 1 second with fully parralel correlator @ C/No> 37 dB.
  (Probability 90% in ½ second => 99% in 1 second)
- Back up: Slow acquisition sweep of carrier and code (~50 Hz/s)
- For emergency retain PCM/BPSK/PM subcarrier mode like Galileo.

CDMA Performance

- Uplink BER comparable with PCM/BPSL/PM at 10 dB carrier suppression.
- Ranging accuracy is comparable with ESA Tone/Code with 1 MHz tone (but smaller ambiguity)
- All S/C Tx power availabe for ranging at all times (not shared with data)
- D/L BER better than PM schemes (no remanent carrier)
- U/L MAI < 0.2 dB (4 uplinks), NLD < 0.2 dB with adequate G/S Back-off
- Delta DOR tones could be inserted in nulls of Tx spectrum

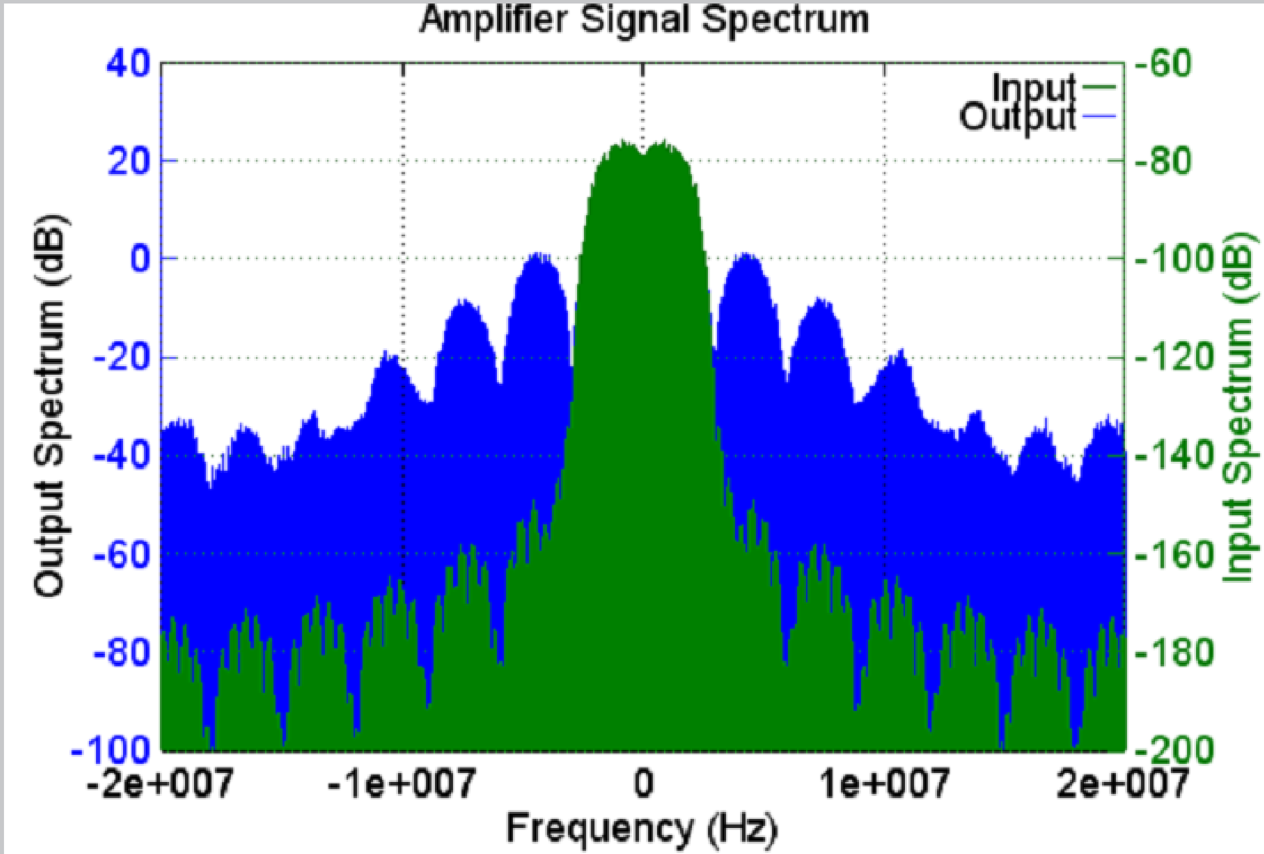
Simulation Model

Galileo TTC is one-satelite-at-a-time, not simultaneous CDMA

- 1024 Chip Sequence, BPSK modulated, No data modulation, allows FFT without leakage, at 3 Mcps sequence is periodic with sequence repition at ~ 3kHz
- 16 Samples per chip (48 Msps)
- 2^21 point FFT so frequency resolution ~ 22 Hz
- 128 FFT bins between harmonics of 3 kHz
- Infinite specturm DSSS signal low pass filtered before HPA

Spectral Regrowth

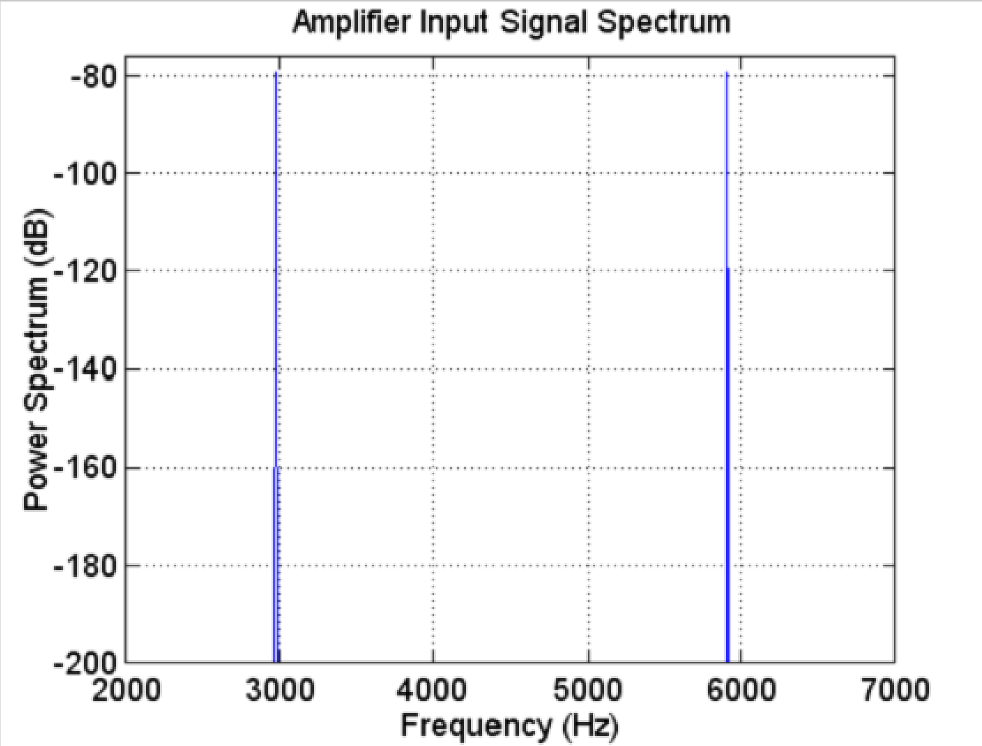
- HPA causes spectral regrowth
(non-compliant to ECSS-E-ST-50-05C / CCSDS 401.0-B-20 spec of -60 dBC in 4 kHz)

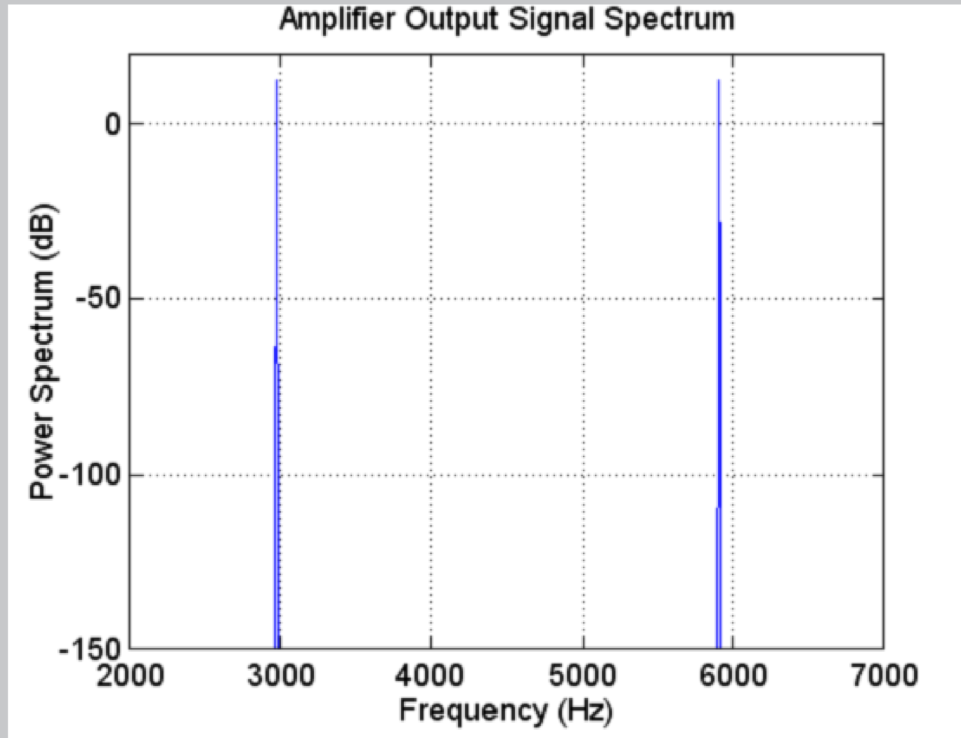


Single DSSS carrier, Nominal output power

(IBO = 0 dB, 6 dB Gain compression)

Intermodualtion - Single DSSS Signal



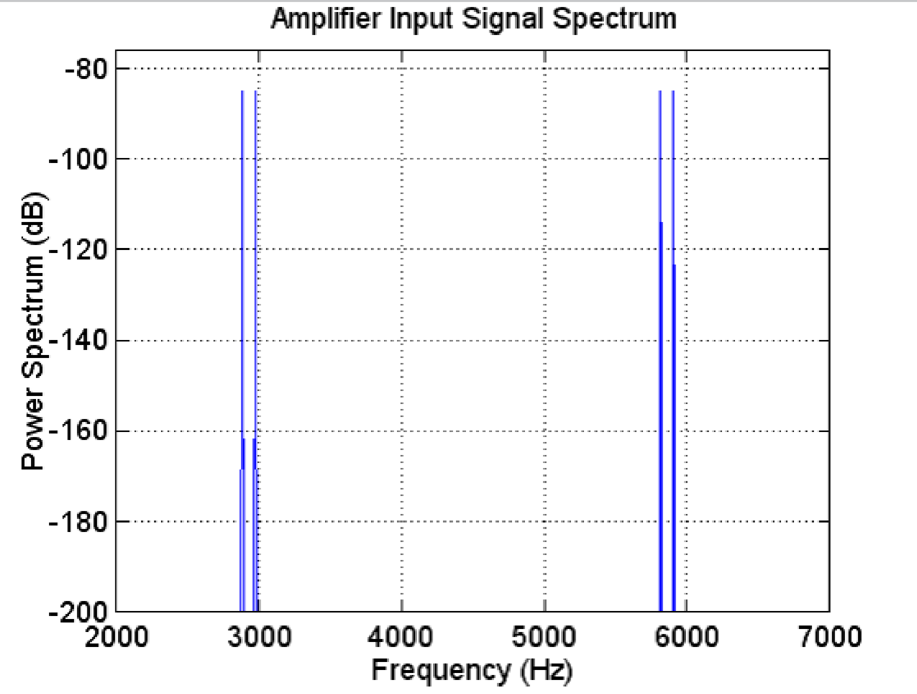


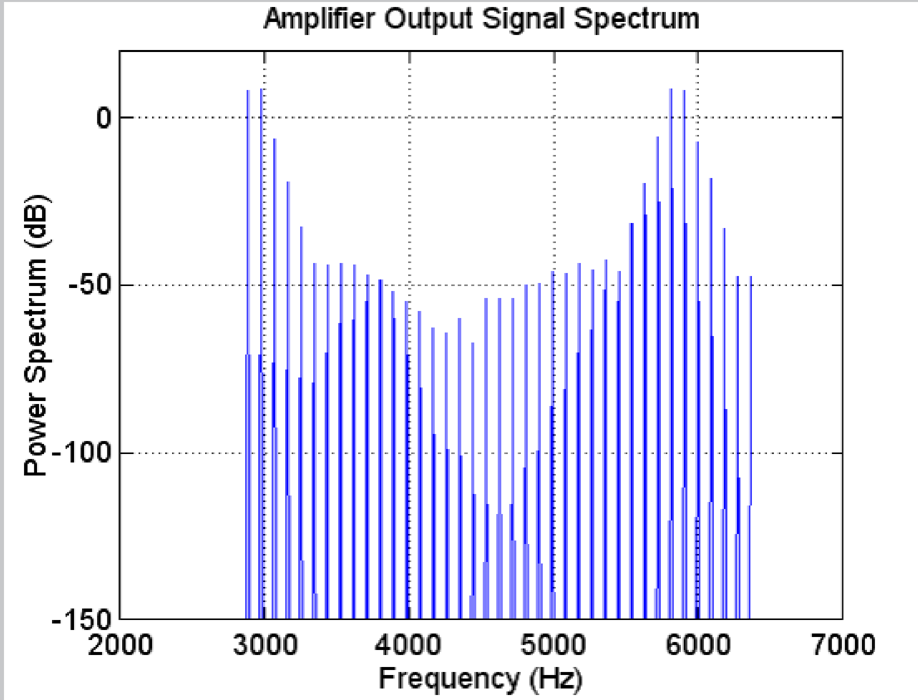
No intermodulation between tones in Single Carrier DSSS signal

Only spectral regrowth

Intermodulation with 2 DSSS Carriers

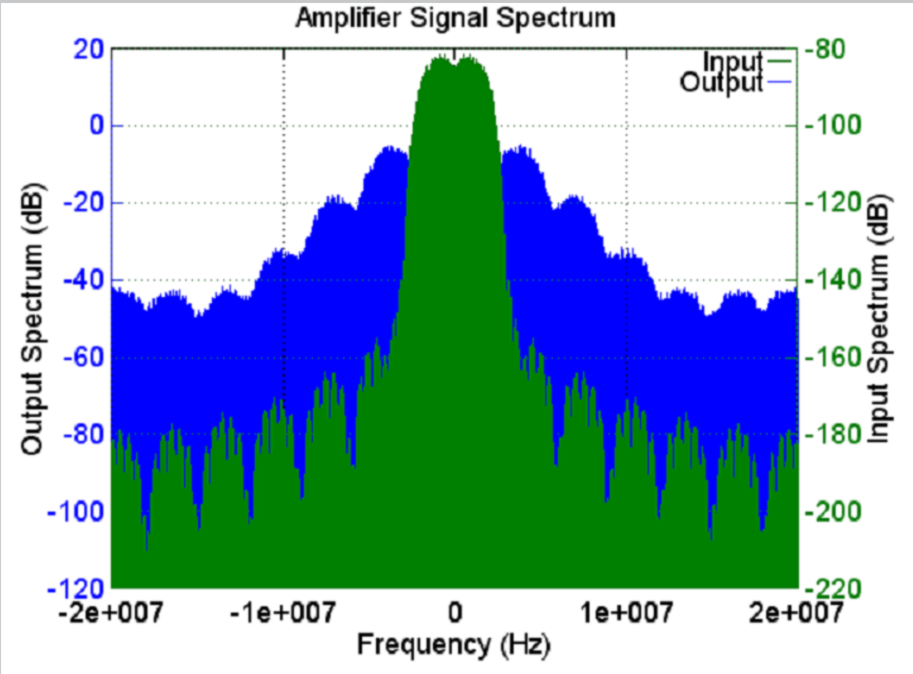
- Two Carriers with 92 Hz offset
- 3 dB input back-off (no hard saturation)



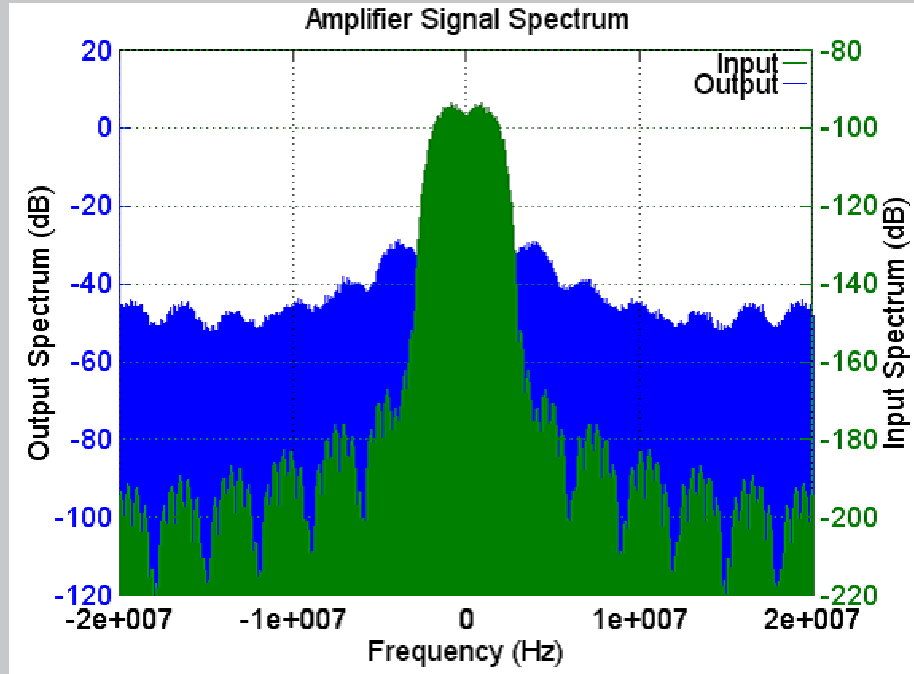


Substantial Intermodulation products within signal spectrum

Spectral Regrowth with 2 DSSS Carriers



IBO 3 dB



IBO 15 dB

To meet -60 dB spec IBO ~ 15 dB needed, OBO ~ 9dB

Output power reduces from 18.5 kW to 2.3 kW (1.1 Kw per carrier)

Zelinda Ireland

HPA Summary

System type	Input Power (dBm)	Total IBO	Output Power (dBm)	Signal power within main lobe (dBm)	IM noise power within main lobe (dBm)	Power in the side lobes (dBm)	C/I (dB)
Single Carrier Unity gain Ideal HPA	-19.5	0.0	-19.5	-19.5	-∞	-83.5	84.3
Single carrier	-19.5	0.0	72.2	72.1	16.6	57.0	40.6
Two carrier	-22.5	3.0	71.1	70.9	56.8	53.3	45.8
	-29.5	10.0	67.7	67.6	43.8	41.1	54.6
	-34.5	15.0	63.7	63.6	33.8	32.1	62.2
Four carrier	-25.5	6.0	69.9	69.8	54.1	48.8	51.7
	-34.5	15.0	63.6	63.6	35.6	33.2	62.3

Ground-station Conclusion

- NLD causes small degradation to U/L BER (< 0.2 dB)
- Non-constant envelope of multi-carrier CDMA signal causes substantial spectral regrowth
- Cannot meet ECSS requirement of -60 dB C/I with "reasonable" BO.

SO

Lineariser Needed ?

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Recommendations to go forward:

- Multiple Rx and Tx channels in TTCP (Rx already foreseen, Tx not)
- Incorporation of DSSS Rx and Tx capabilities in TTCP (already foreseen)
- Development of X-band Dual standard transponder
- Ground station Lineariser for control of out-of-band emissions (in TTCP ?)

Multiple Rx & Tx channel Feasibility

- Multiple Receive channels within the same band (so through same ADC)
  – Dual TM chains foreseen in Phase 2B (begin Q1 2015).

- Multiple Transmit channels within the same band (so through same DAC)
  – Firmware Duplication, probably no hardware change

Short Term :
CFDMA channels could be arranged to fit in same band (so same ADC)

Long Term:
All DSSS CDMA links can in principle use same nominal frequency

Limitation to number of links simultaneously supported in TTCP is FPGA resources for:
Receivers, Transmitters, Doppler Precompensators , Doppler Predictors.

And DPU resources for simultaneously handling TC, TM, Doppler predict files.

DSSS CDMA Road Map

◆ Space segment

- Evaluate performance of exisitng Gallielo S-band transponder at low C/No
- Development based on existing Galileo Dual Standard TTC Transponders (Tesat, Alcatel) – Low risk development.

◆ Ground Segment

- Characterise DSA Klystron for DSSS multicarrier.
- Establish if Linariser necssary
- Single channel Galileo DSSS Rx and Tx implementation within TTCP foreseen in Phase 3 (begin Q2 2016)
- Multiple channels possible subject to FPGA resources

Lineariser Feasability

Short Term :

- Characterise Klystron for Multicarrier
  Establish if IMP can be tolerated with current HPA
  -if not develop lineasiser methods for DSA
- Acesss Performance of COTS linearisers
- Study and Develop lineariser in TTCP.

Long term:

- Sensible to implement in TTCP rather than separate unit
- Useful for both Short (CFDMA) and Long-term (CDMA) solutions
- Needs extra ADC input for HPA feedback (avaiable in TTCP –DS Variant)
- Needs new combined Up/Down Convertor

TTCP Lineariser not currently foreseen ?

Questions ?