Antenna arraying techniques in the Ground Control System for Deep Space Missions (GCS DSM-2015-West)

A.Chebotarev, V.Grachev

OSC «SDB MEI»

Basic Antenna arraying techniques

1. Radio Interferometry and VLBI methods for space communication and navigation

   NEO, LEO, GEO and deep space crafts

2. Radio Interferometry and VLBI observations of the

   Extragalaxy radio sources,

   Space crafts,

   satellites of GLONASS/GPS/Galileo

3. Radar Radio Interferometry and VLBI observations of the

   planets and asteroids

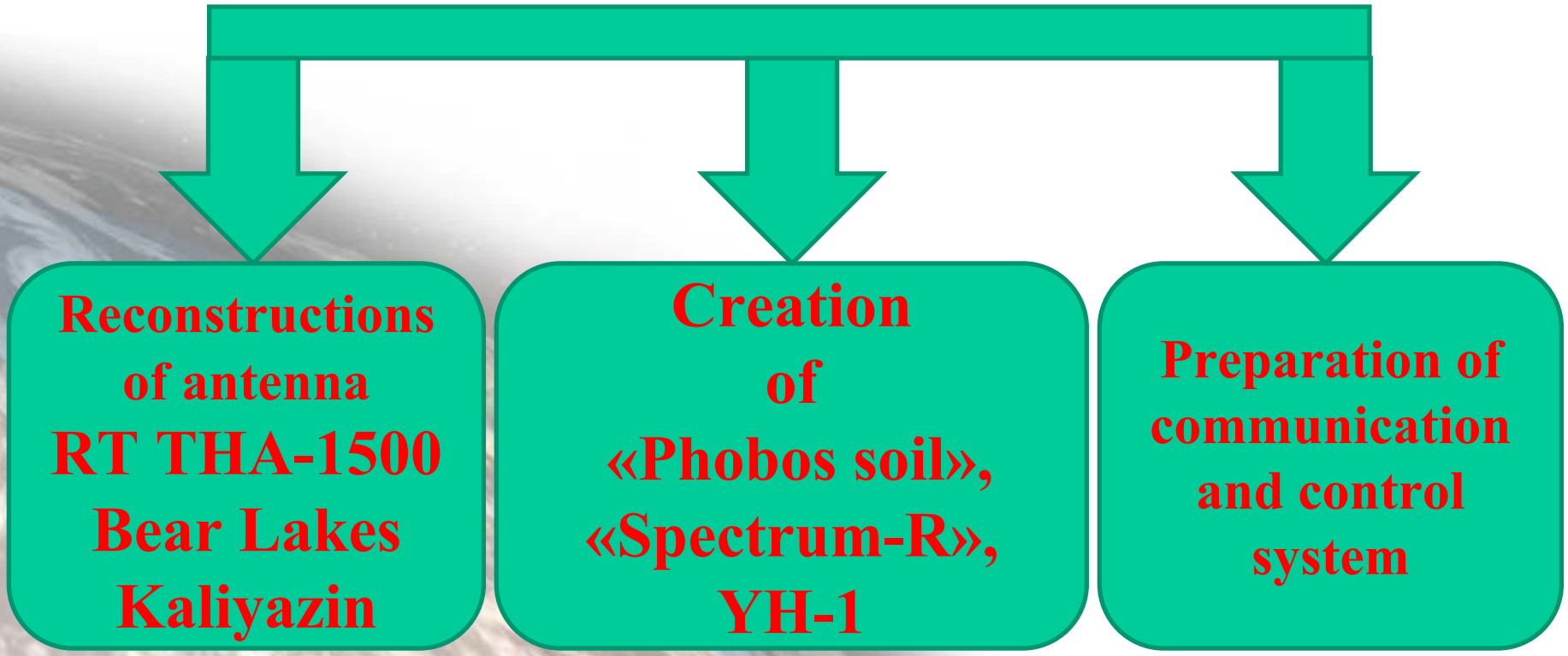
   Space crafts, satellites and space debris

General goals for Antenna arraying in the Ground Control System

To provide the seven GCS DSM Data Types:

1. **Frequency & Timing Data Type,**
2. **Tracking Data Type,**
3. **Telemetry Data Type,**
4. **Command Data Type,**
5. **Monitor Data Type,**
6. **Radio Science Data Type,**
7. **Radio Interferometry and Very Long Baseline Interferometry Data Type, VLBI**

General goals for «GCS DSM-2015-West»



ОКБ МЭИ

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Technology resources of State Ground Control System

Radioastron

Phobos soil

CPP «RITM»- Local antenna array

Evpatiriya Ussuriysk RT-70

Compound interferometer

Phased array

VLBI-network

п. «Bear Lakes» RT-64

п. «Kaliyazin» RT-64

64-meter antenna in Bear Lakes and Kaliyazin and 70 meter antenna in Ussuriysk

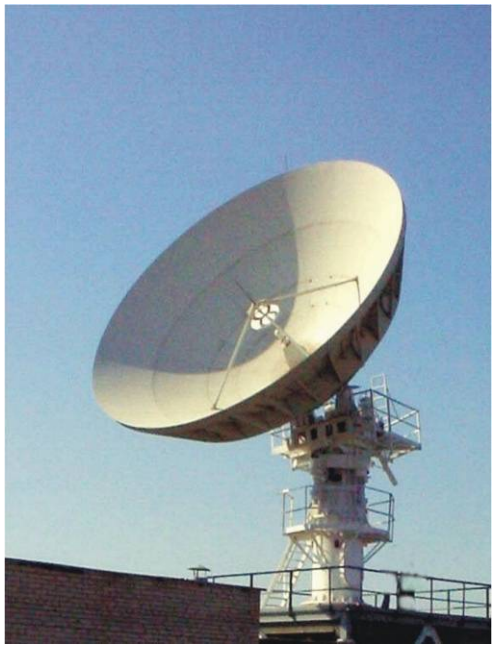
Комплекс П-2500 в Уссурийске

Correlating-phased array «RITM»

RITM-M

SDB MEI antennas

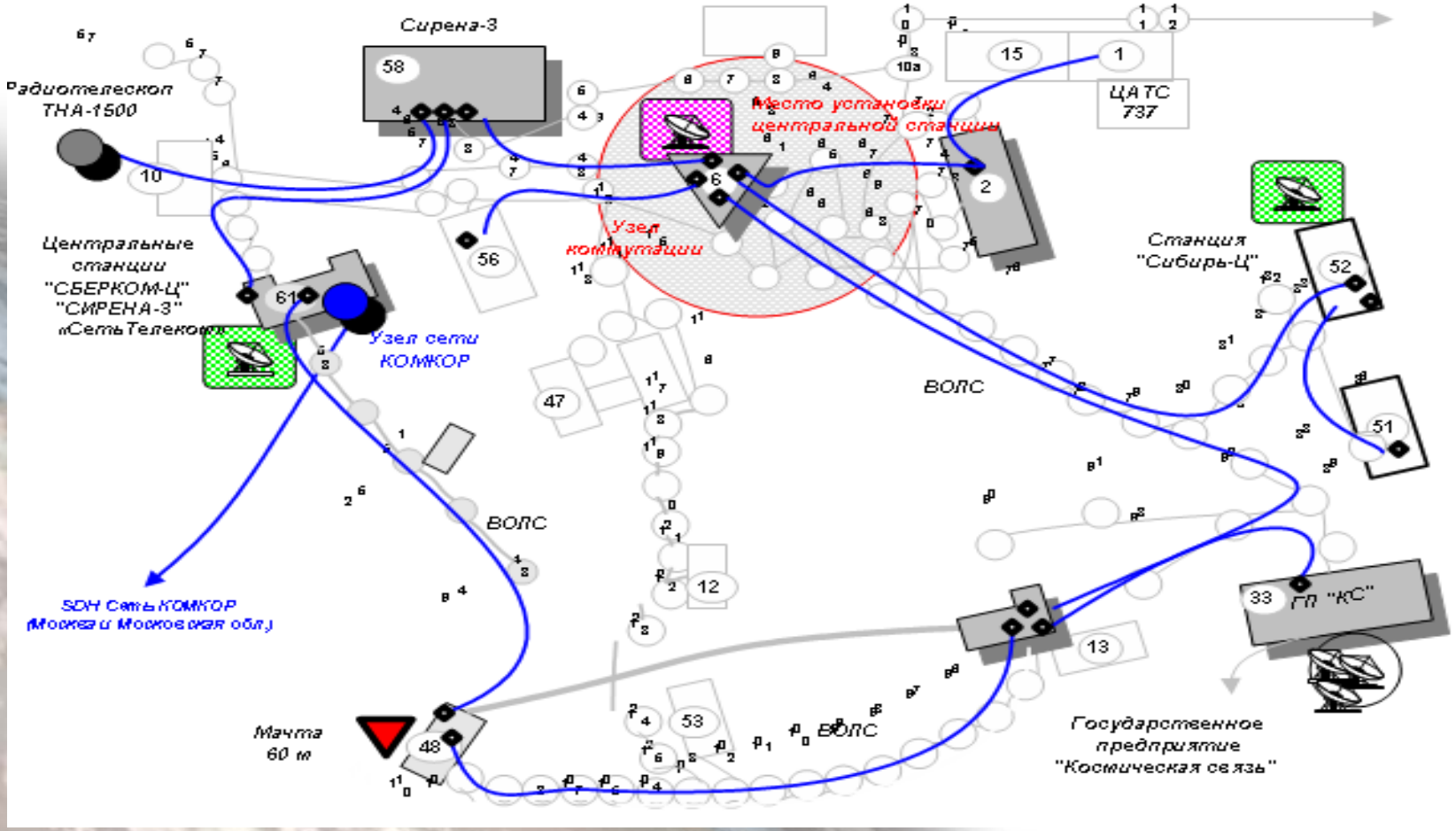
Полноповоротная антенна ТНА-57 диаметром 12 метров.



Полноповоротная антенна Диметром 9 метров для приема данных со спутников дистанционного зондирования Земли.

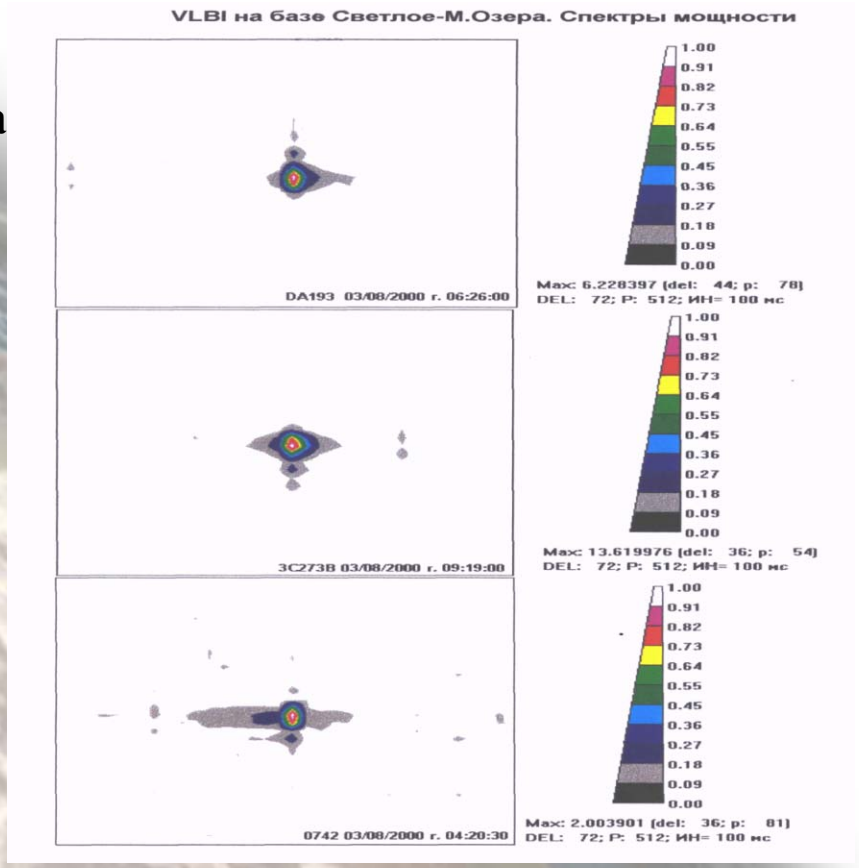
Полноповоротная антенна диаметром 4,7 метра C, Ku диапазоны.

Local Array in Bear Lakes



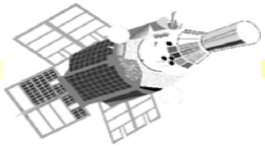
VLBI-observations

п. «Медвежьи озера



п. «Калязин»

Three-way Dopler of Phobos Soil Mission



КА Фобос Грунт

Режим «Самоход»

Режим «Когерент»

п. «Медвежьи Озера» РТ-64

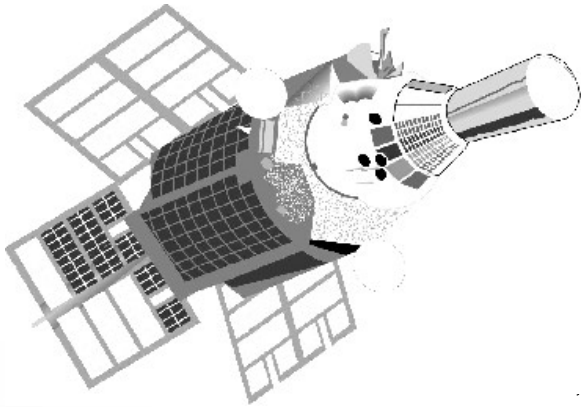
п. «Калязин» РТ-64

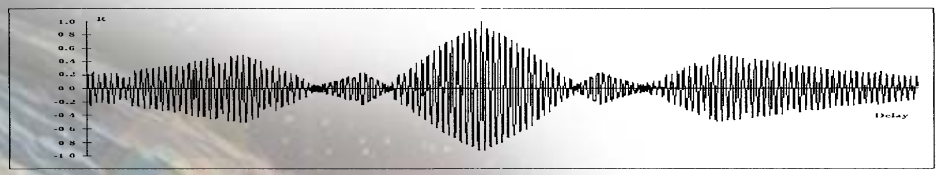
ЦУП БЦ

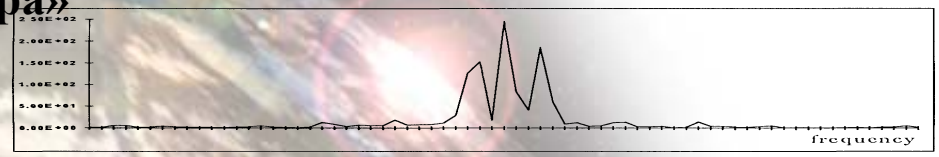
Комплекс П-2500 в Уссурийске

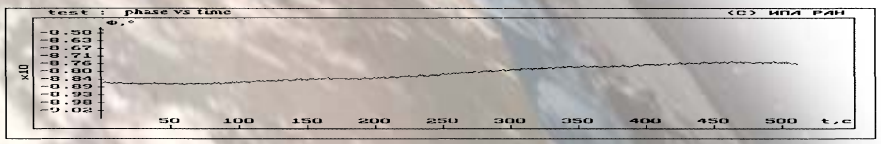
Уссурийск РТ-70

VLBI-observation of Space Craft GRANAT





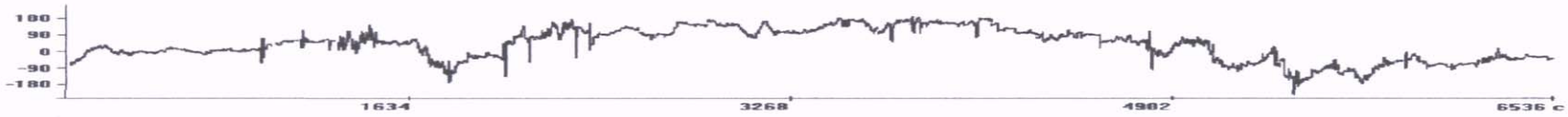




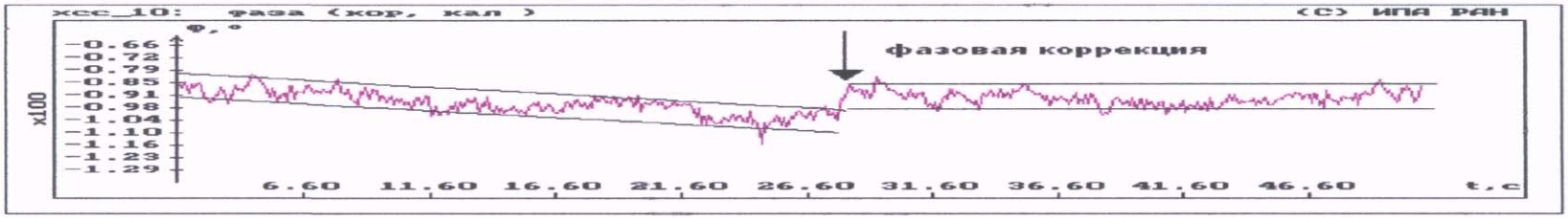
п. «Медвежьи озера»

п. «Калязин»

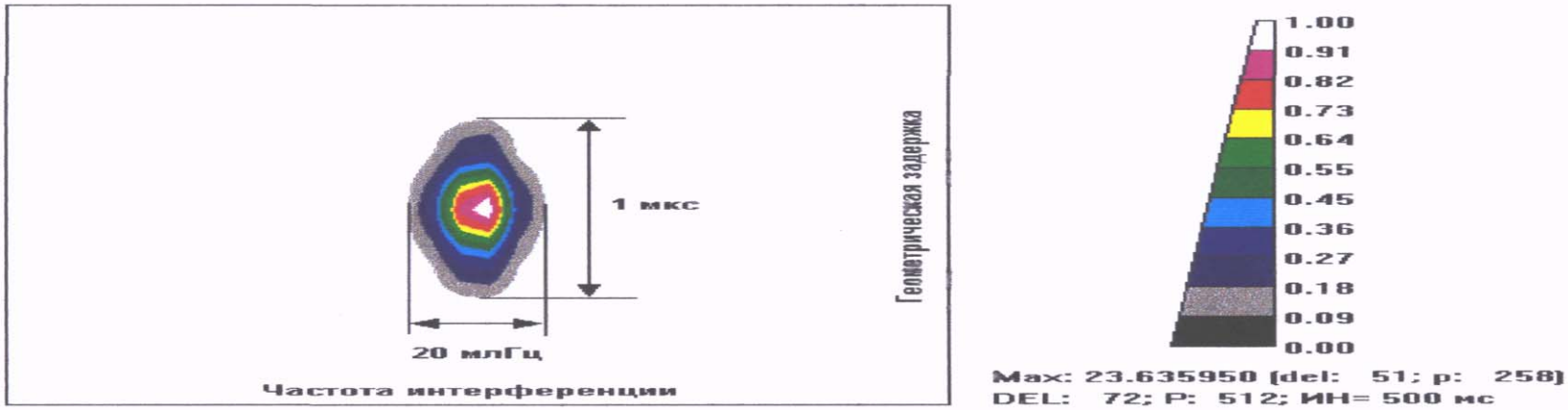
VLBI-observations of GLONASS



Фаза кореляции GLON15
20/09/2000 г. 14:10:00 — 17:30:00 ИН = 500 мс, 1312 точек, 72 задержки

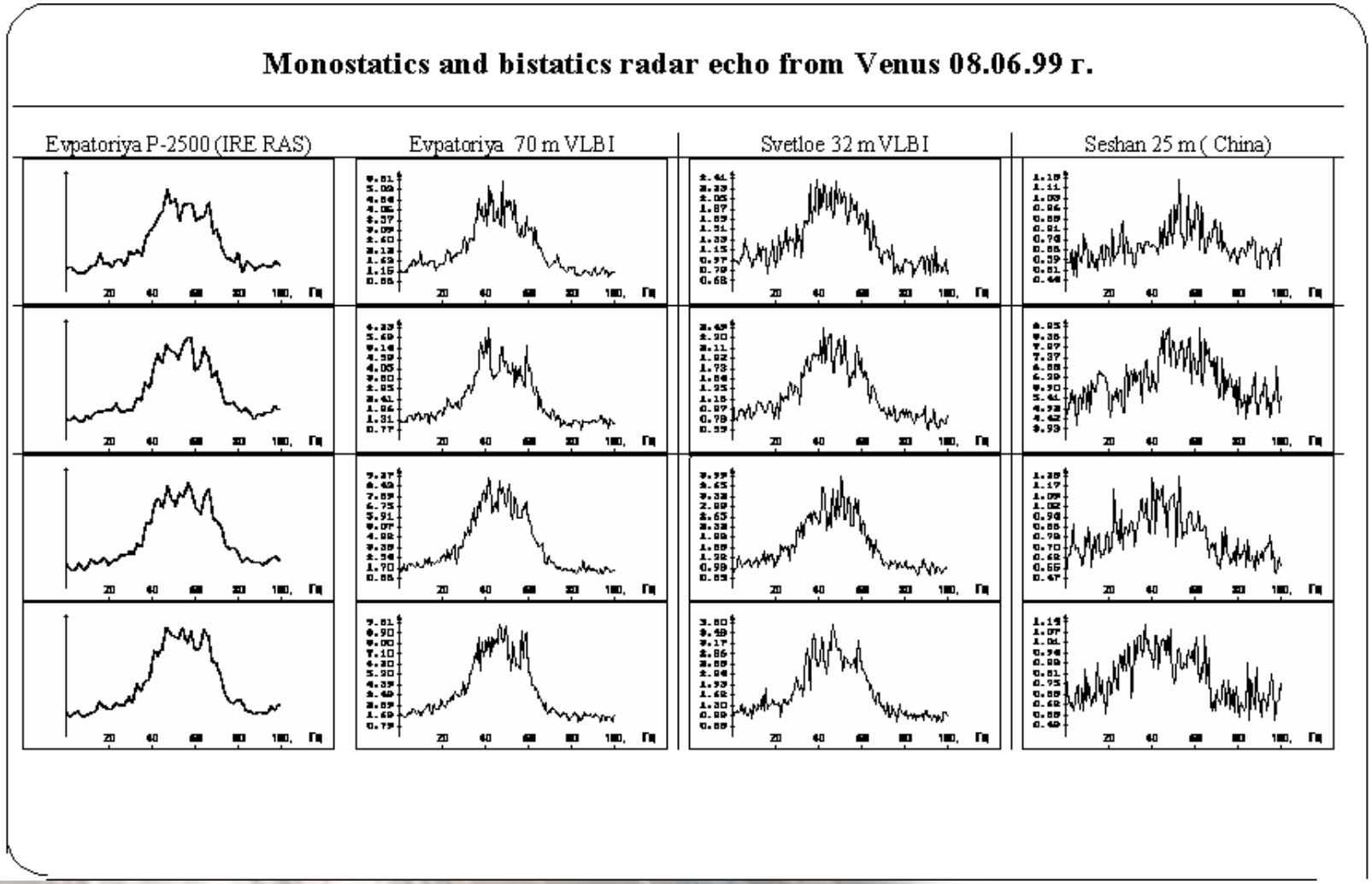


Фаза кореляции GLON15
20/09/2000 г. 14:11:30 $\delta\varphi$ = 2,5 ° при τ= 0,1 с

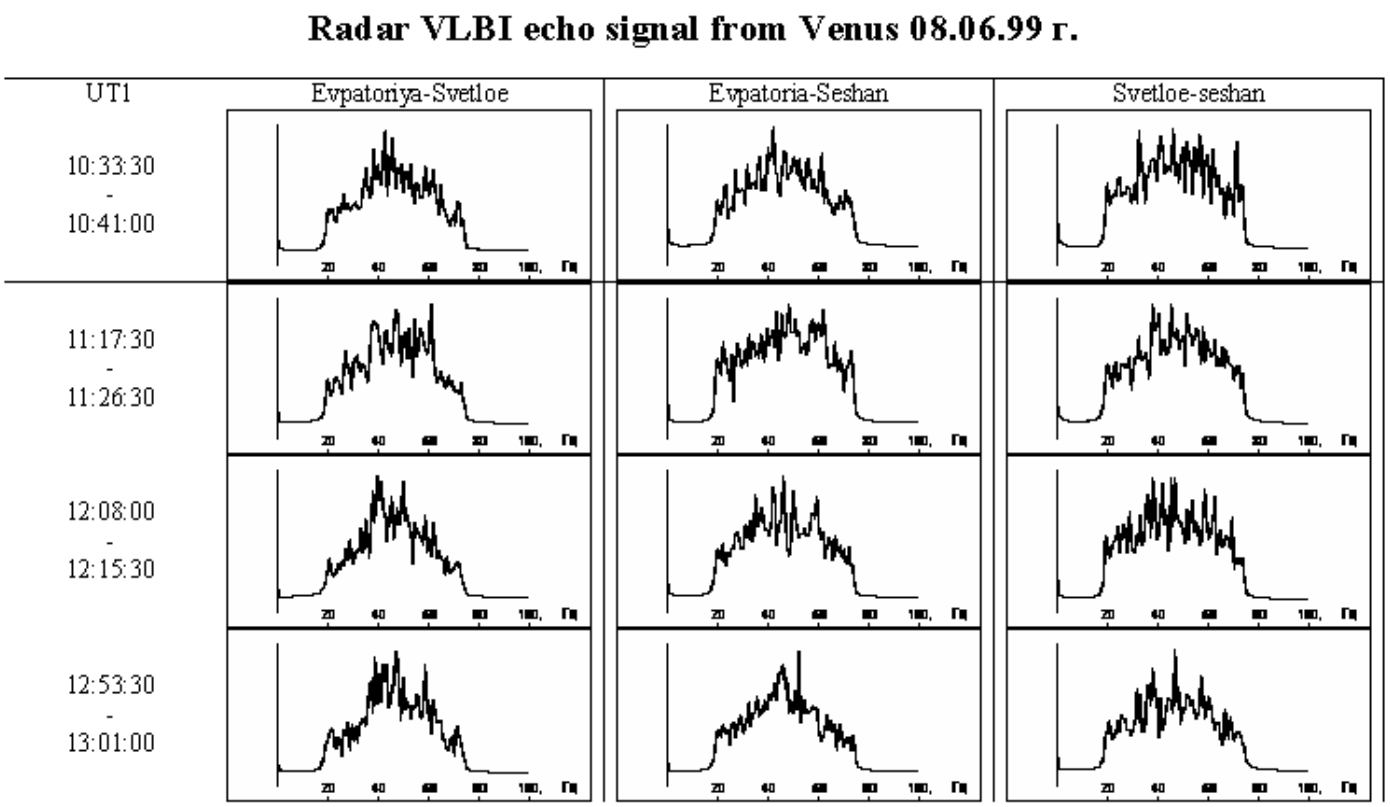


Максимум спектра мощности GLON15

Monostatic and bistatic radar echo from Venus 08.06.99 г.



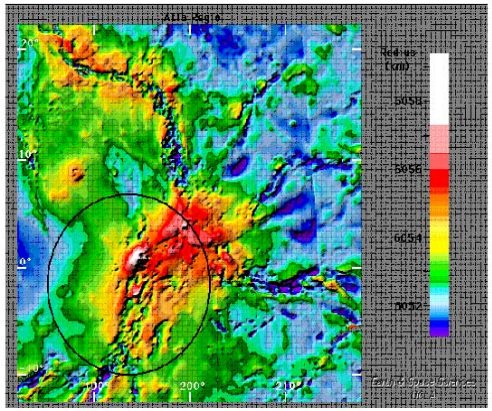
Radar VLBI echo signal from Venus 08.06.99

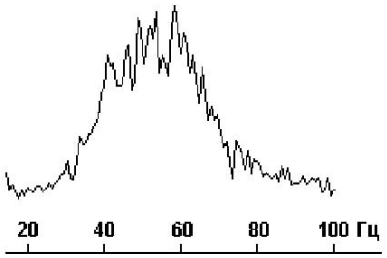


Speckle diagram «delay rate –Doppler shift» .

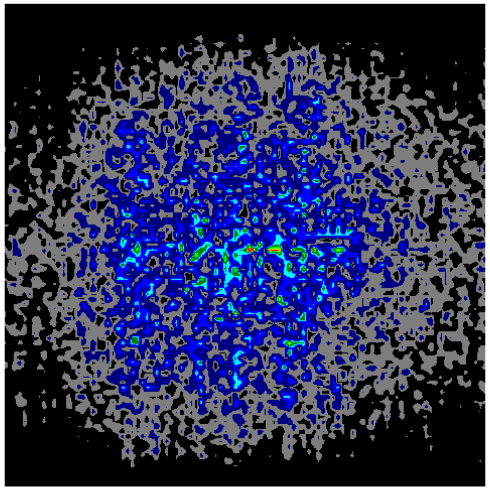
Evpatoriya-Svetloe VLBI baseline . Venus

Monostatics radar \echo: ATLA REGIO (-2.38, 193.52)
8 august 1999 ., 12:08 – 12:15 (UTC).

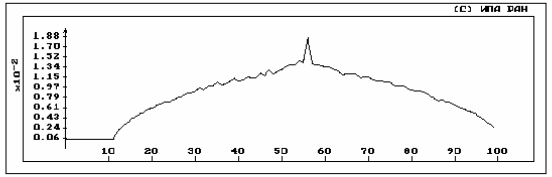




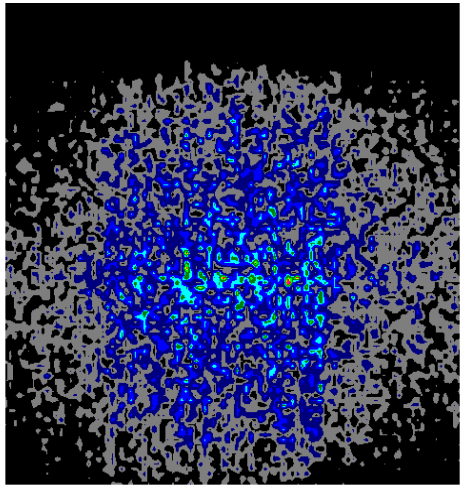
Specl giagram «delay rate –Dopplershift» .
Evpatoriya-Svetloe VLBI baseline . Venus, V32 (12:14:00, Tint=81,92 s)



Evpatoriya-Svetloe VLBI baseline . Venus, V32 (11:08:00, Tint=491,52 s)



Specl giagram «delay rate –Dopplershift» .
Evpatoriya-Svetloe VLBI baseline . Venus, V32 (12:12:30, Tint=81,92 s)



UPGRADE AND RECONSTRUCTION

Bear Lakes new subreflector contol system and feed horn

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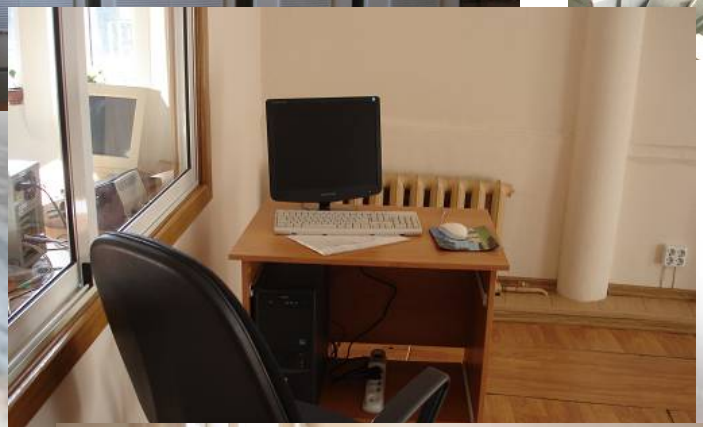

Reconstructed of antenna control and moving system «Siemens»

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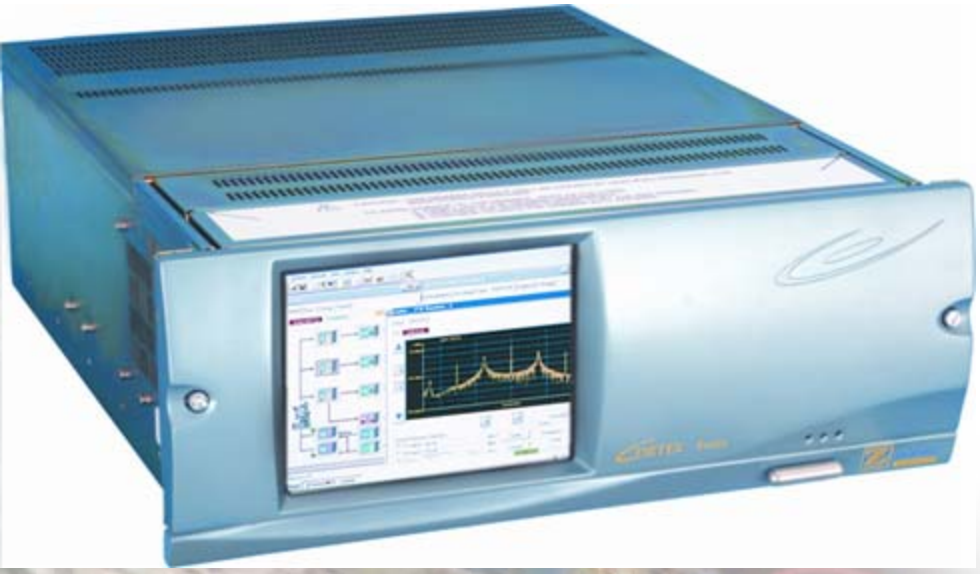
-Reconstructed power system for fast antenna moving

-Reconstructed precise optical sensors for azimuth and elevation

- Provided geodetic tuning of main reflector THA-1500, RMS – 0,9 mm

-Installed new control and monitor software system

TT&C процессор CORTEX CRT-DS for Mars missions



Большой интерес представляет примененный в терминале TT&C процессор CORTEX CRT DS, разработанный специально для работы с аппаратами дальнего космоса.

Это самый совершенный в настоящее время прибор для приема телеметрических сигналов, передачи команд, измерений дальности и радиальной скорости. Прибор полностью совместим с рекомендациями CCSDS.

Active Hydrogen mazer CH1-75A

GCS DSM Array Background

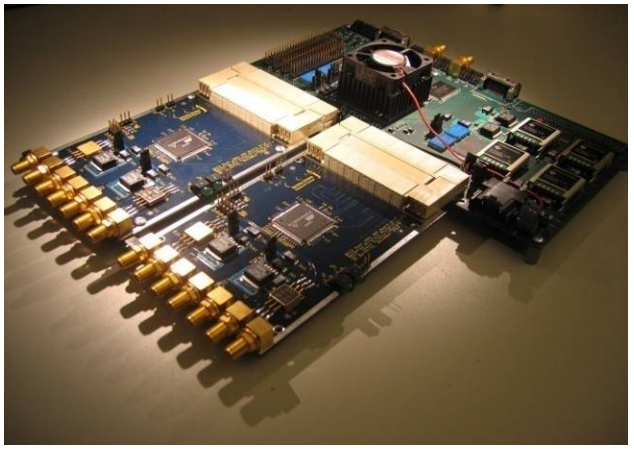
Array Overview

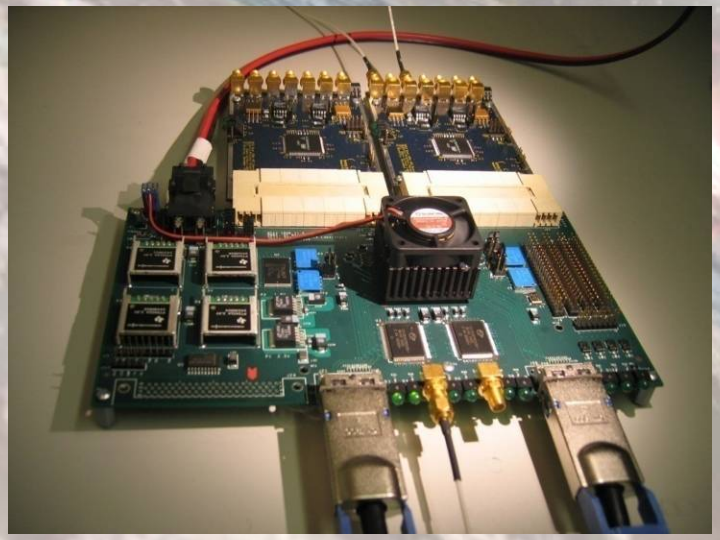
- The GCS DCM is currently evaluating the use of a Array to provide high sensitivity and resolution of current 12 , 64 and 70 meter antennas and correlating-phased array «RITM-M».
- Will mainly be used to support telemetry of deep space missions but will also support navigation and some science requirements.
- The current Array design calls for
  - Three Complexes (Bear Lakes, Kaliyazin, Ussuriysk), each with:
    - Uplink and downlink antennas nominally sized at 64/70 each.
    - Remotely conduct all real-time monitor and control for the network

Proposed Signal Processing Req.

- Number of Antennas in a cluster scaleable up to 16.
  - Design needs to accommodate growth but is not infinitely scalable
- Number of IF inputs per antenna ~4.
  - RCP & LCP for X and Ka
- IF signal bandwidth ~500 MHz 1dB
- Signals of interest can come from anywhere in input passband
- Provide up to 16 simultaneous phased array outputs
- Provide a wideband correlator (~500 MHz) which can process a significant number of the antenna signals
  - Required to support the array for phase and antenna position calibration and searching for lost spacecraft

Prototypes of GCS DSM correlator





Possibilities of the utilization of "Cobalt RLS" multifunctional radar system for studies of Near Earth Space

Enterprise " Special Design Bureau of Moscow Energy Institute" of Russian Space Agency

Тел. (095) 362-5652. Fax (095) 362-5576 info@okbmei.ru

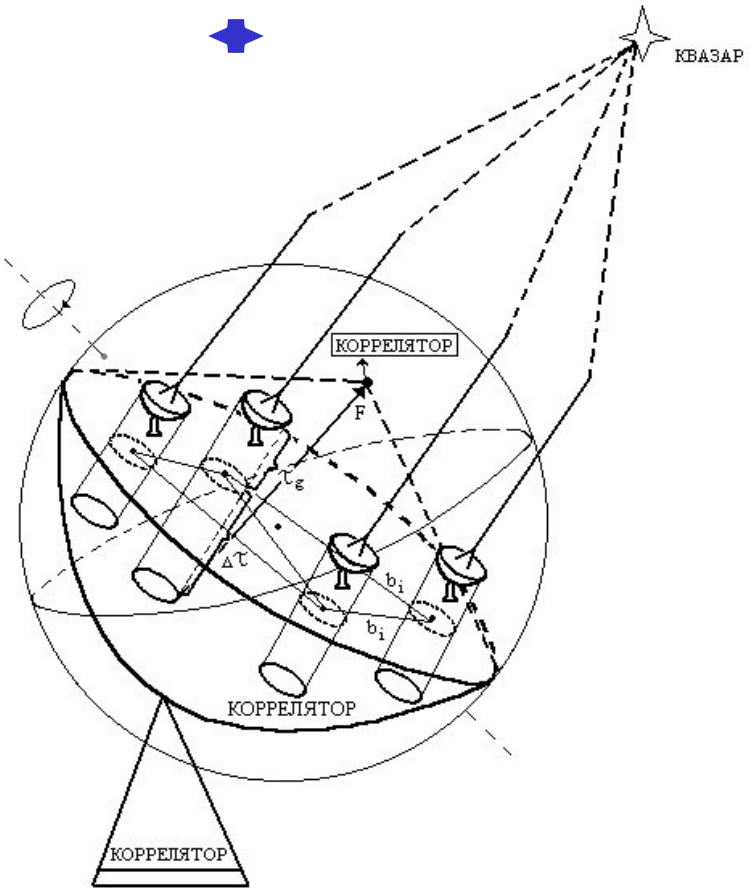
Goals

- The "Cobalt RLS" radar system on the base of TNA-1500 64-meter antenna of "Bear Lake" space control and monitor center of the Russian Deep Space Network is a multifunctional system for complex studies in the field of astrometry, celestial mechanics and physics on the base of the motion parameter, the forms and reflecting characteristics measurements of near and deep space objects by
- monostatic,
- bistatic and
- differential radar technics on the base of the VLBI.

Main purpose of "Cobalt RLS"

- 1. The Determination of relation between reference and dynamic coordinate systems
- 2. The forecast motion revision of potentially dangerous asteroids approaching the Earth.
- 3. The synthesis of the three-dimensional image of the objects approaching the Earth.
- 4. The Study of the physical features surfaces of the objects approaching the Earth.
- 5. Development of the methods and technology of near Earth space monitor on base of the global overview-measuring systems.

GLOBAL RADIO TELESCOPE
(real-time VLBI-network)



Launch Service Providers and potential users of «Cobalt RLS»

U.S. Launch Service Providers

- **Lockheed Martin (Atlas)**
- **Boeing Launch Services (Delta)**

International Launch Vehicle Market

- **Sea Launch (Zenit)**
- **ILS (Atlas/Proton)**
- **Arianespace (Ariane)**
- **India (PSLV)**
- **Russian (Proton)**
- **China (LongMarch)**
- **Japan (H2A)**

«COBALT-RLS» RADAR Purposes

- Searching and discovering of the space objects, spacecrafts and satellites on the task orbit or geosynchronous orbit;

- Determination of the discovered object orbit position,

- Determination of the space debris on the task orbit or orbit segment

-Monitoring of useful and start spacecraft blocks separation

- Determination of the initial movement parameters of useful blocks

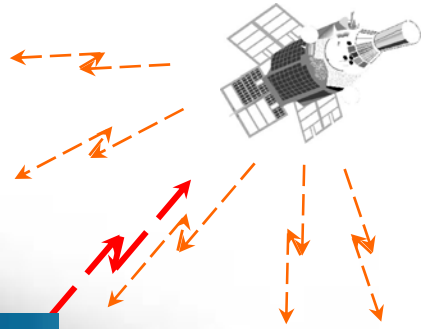
- Monitoring of the space satellite on the geosynchronous orbit and etc.

«COBALT-RLS» RADAR
Technical Specification

- antenna diameter	- 64 m,
- beam width	- 1,8 arc min.,
- transmit power	- 20 kW,
- frequency	- 7,2 GHz,
- pulse length	- (1,5 – 200) ms,
- modulation mode	- LFM,
- frequency deviation:	
- “rough" mode	- 1 MHz,
- “fine tuning“ mode	- 10 MHz,
- receiving system noise temperature	- 50K,
- efficient range of angles:	
- on azimuth	- (0 ± 280) deg.;
- on elevation	- (1 - 89) deg.;
- angle speed range:	
- on azimuth	- 1,5 deg/s;
- on elevation	- 1 deg /s;
- angle accelerations	- 0,2 deg/s^2.
Position measurement errors (RMS):	
- on angle	- < 0.4 arc min,
- on distance:	
- «rough» mode	- < 40 m,
- «fine» mode	- < 7 m,
- radial velocity -	- (0,1 - 0,5) m/s.

SNR for the object having EDS = 0,001 sq km for the distance of 1000 км - 27 дБ.

CALCULATIVE CHARACTERISTICS of the «COBALT-RLS» SYSTEM



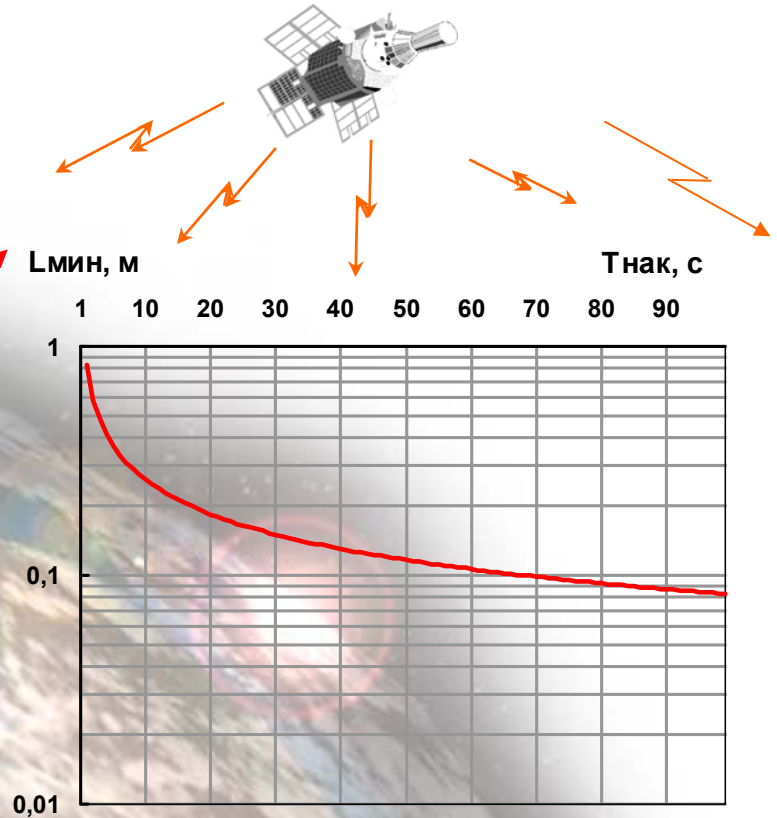
«Bear Lakes» Radar

Monostatic mode $(SNR)_{pulse}$ = 10 дБ	
Orbit height, км	Minimum size, sm
300-2000	0,4 – 2,0
2000 – 8000	2 – 10
18000 – 20000	20
HEO	30

CALCULATIVE CHARACTERISTICS of the «COBALT-RS» SYSTEM

Bistatic mode (SNR = 10 дБ, GEO)

«Bear Lakes» station

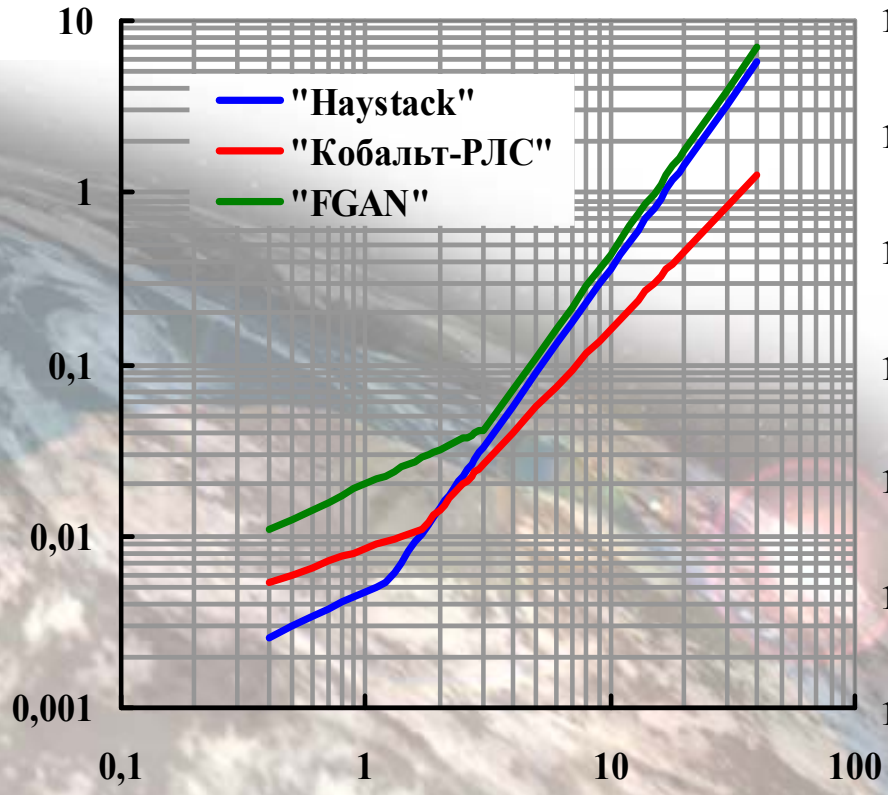


Зависимость минимального размера обнаруживаемого объекта от времени накопления

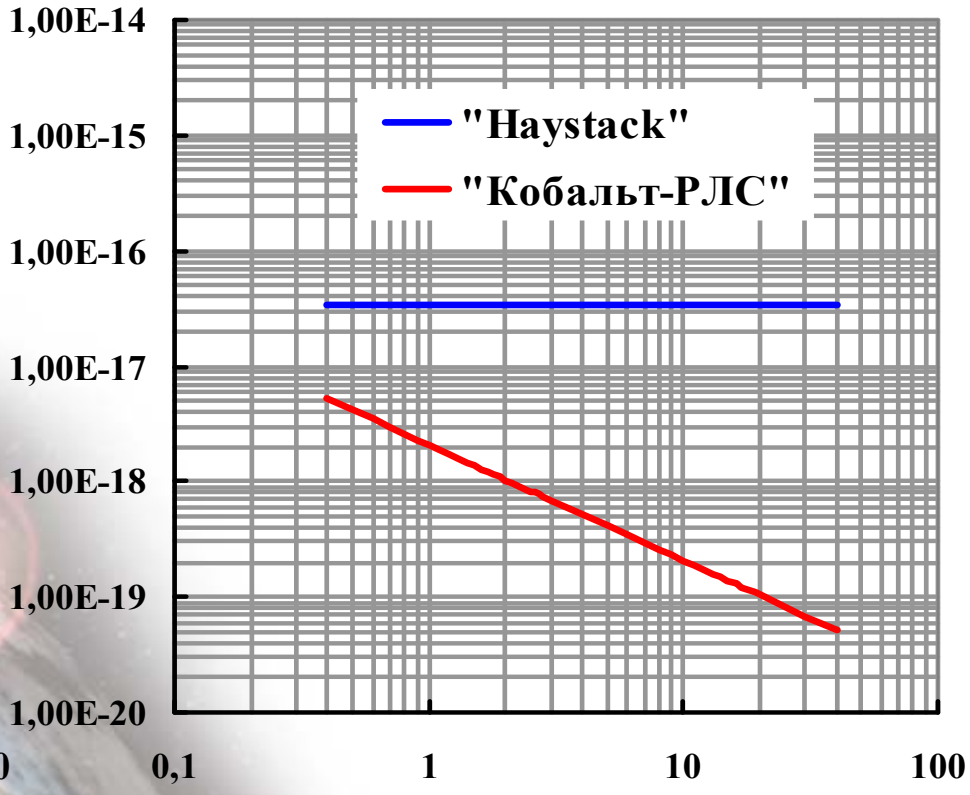
«Kalyazin» station

Comparison of CALCULATIVE CHARACTERISTICS of the «COBALT-RS» SYSTEM

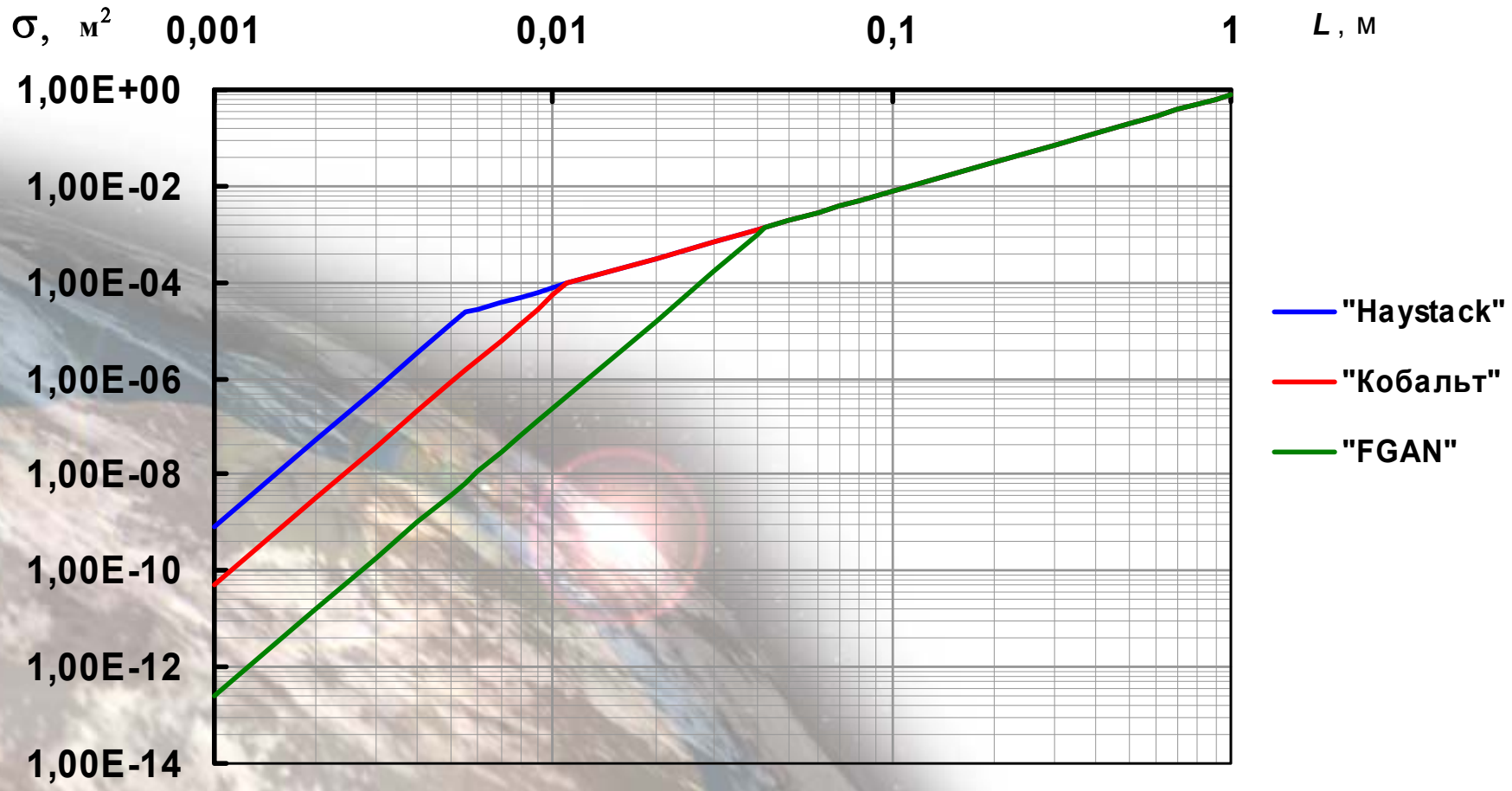
Минимальный размер обнаруживаемого объекта



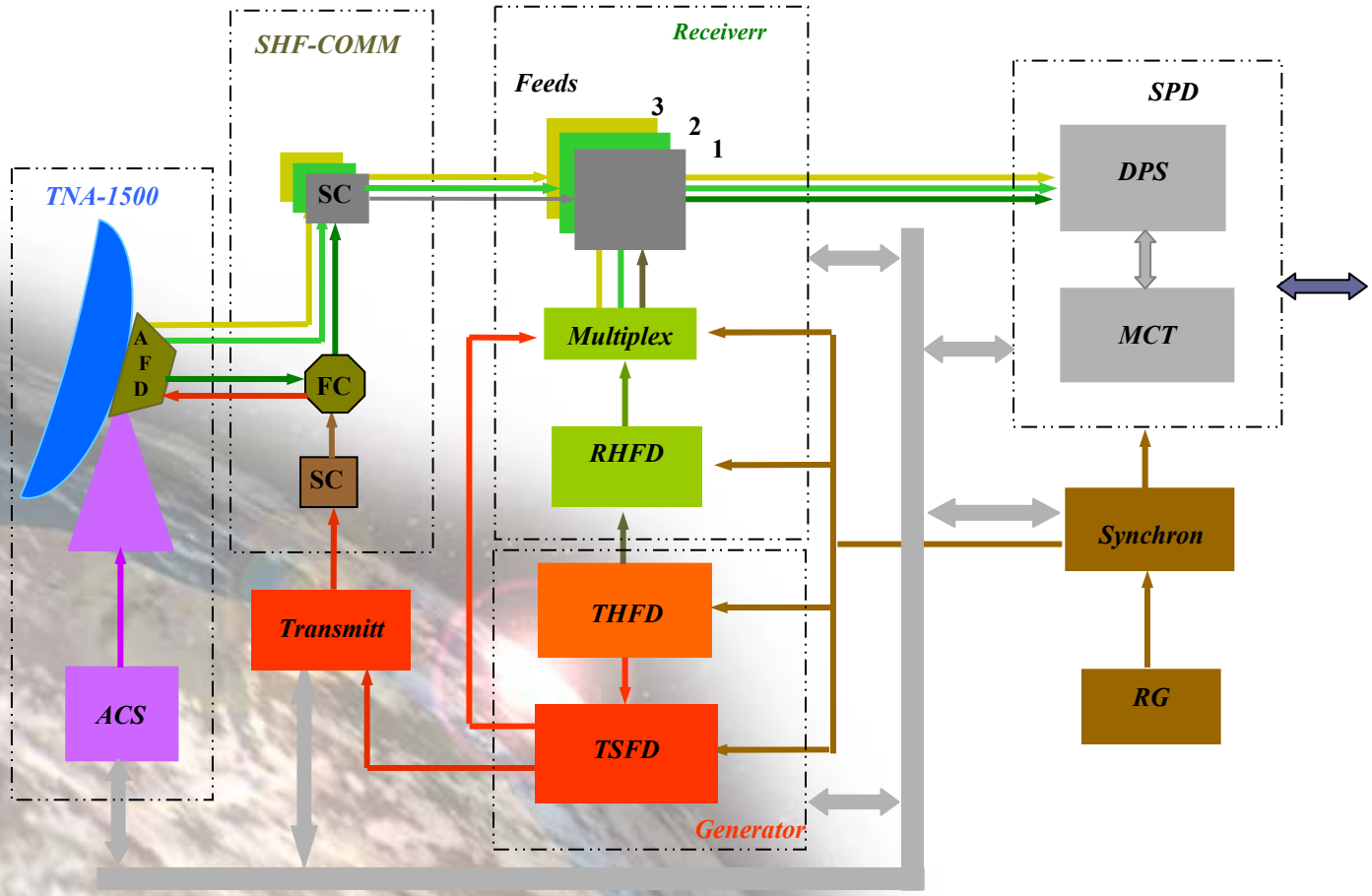
Мощность отраженного сигнала при $L = L_{мин}$



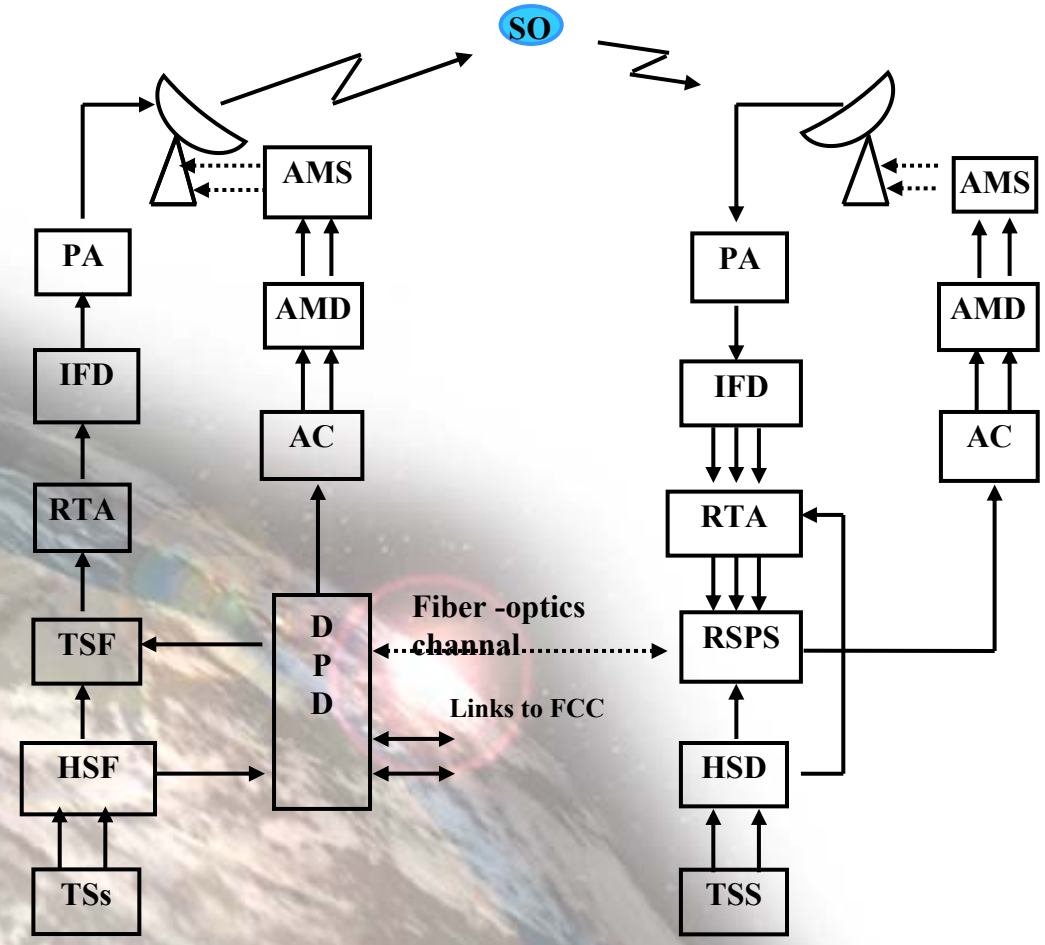
Effective dispersion surface dependence from the object size



«COBALT-RLS» RADAR BLOCK DIAGRAM



Block diagram of the «Cobalt-RLS» receiver-transmitter system for bistatic mode



Prototype radar VLBI Correlator

- **We have developed the prototype. PCI-bus correlator board has the following features:**
  - standard office PC board format,
  - single board supports 2 cross-correlation 64 lags channels for one baseline,
  - input data rate up to 64 Msamples/sec/channel, 1 or 2 bit sampling,
  - integrated input data rate to 512 Mbit/s,
  - the board can be connected directly to Canadian S2-RT or S2-PT.

The features of the radar VLBI correlators

• Data input format	VSI
• Number of channels	16
• Number of lags	64
• Processing rate/ch	64 Mbps
• Sample bit	1 or 2 bit
• Phase resolution in fringe rotation	32 bit
• Phase cal detect	1 Hz - 4 MHz
• Accumulation counter	30 bit
• Parameter period	50ms - 50s
• Pulsar gate	Yes
• Main logic	FPGA
• Data transfer	Mark 5B/C
• Baselines	6

Prototype PCI-bus correlator board.

Conclusion

- 1. «Cobalt-RLS» combines technologies as follows
  monostatic,
  bistatic
  and differential radar VLBI.
  2. «Cobalt-RLS» general technical specification will be compatible with Mark4 international VLBI standard.
  3. «Cobalt-RLS» will cooperates with optics and other compatible radar system