CONCEPTUAL DESIGN OF CPR PROPOSED TO MDS-3 MISSION

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1. INTRODUCTION

Clouds play an important role in the hydrological cycles and energy balance of our climate. However, there are no sufficiently accurate models of clouds so far because of lack of the global three-dimensional distribution data of clouds. Accurate modeling of clouds is necessary to understand the earth's energy budget and to achieve the precise prediction of the global warming which is urgent issue for human beings. For this reason, satellite programs dedicated to the global measurement of clouds have been studied and proposed by various science committees.

Cloud Profiling Radar (CPR) and LIDAR are recognized in common to be most suitable instruments onboard a satellite to make this global measurement of clouds although there are technical subjects to be solved. Under these circumstances, NASA has already started ClouldSat project carrying a CPR as a satellite program aiming to the launch in 2003. ESA has intensively conducted phase-A study of ERM carrying both a CPR and a LIDAR. Similarly to these activities, Japanese science team organized by Earth Science and Technology Organization (ESTO) has studied a satellite program called ATMOS-A1 carrying both a CPR and a LIDAR. In parallel with ATMOS-A1, a science team (PI: Prof. Nakajima of University of Tokyo) has conducted a feasibility study of a satellite project carrying a CPR under the Mission Demonstration Satellite (MDS) program of National Space Development Agency of Japan (NASDA) since October 1998.

In October 1999, an AO (announcement of opportunity) for MDS-3 satellite mission was issued by NASDA. The above science team involved in the CPR onboard MDS has applied to this AO with a mission proposal for studying effects of cloud system to the global change using a CPR and an imager. In this article, we describe the outline of the CPR (hereafter MDS/CPR) proposed in this mission proposal.

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2. MISSION REQIREMENTS

Mission requirements of MDS/CPR are not only to produce data set of the vertical distribution of clouds in the global scale for cloud modeling but also to provide data set for the process study on radiation effects of clouds and interactions among cloud, aerozol and rain.

For these purposes, MDS/CPR is designed to have unique functions, - beam switching function for studying the meso-scale structure model of clouds and Doppler function for identifying drizzle particles in clouds. Figure 1 shows observation concept of MDS/CPR.

Five antenna beams, whose number is determined from a compromise with the technical feasibility and requirement of sensitivity, can be switched every 1.43 degrees step. Swath width of 40km can be achieved by this multi-beam switching function every 10 km distance when the altitude of the satellite is 400 km.

Doppler function is implemented at the nadir beam is to identify drizzle particles in clouds. To realize the Doppler measurement, so-called polarization diversity pulse-pair technique (Pazmany et al.1999) will be used taking its antenna size and moving speed into consideration.

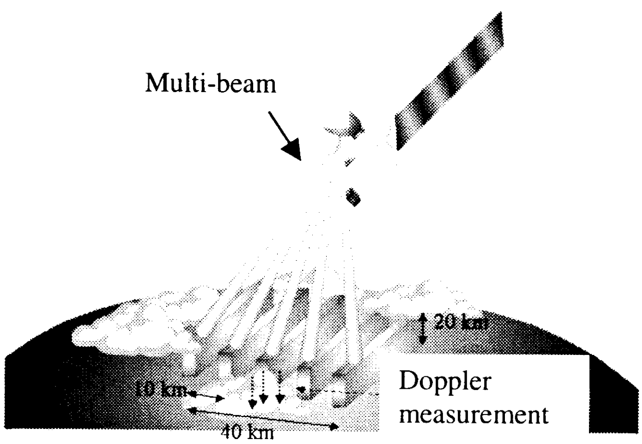

Figure 1. Observation Concept by MDS/CPR

3. DESIGN SPECIFICATIONS

Table 1 and Figure 2 are MDS/CPR design specifications and schematic block diagram, respectively.

Table 1. Major design specifications of MDS/CPR. Satellite altitude of 400 km and PRF of 4500Hz are supposed in this Table, but they are not fixed ones.

Parameter	Full option	Descope option
Frequency	94.05 GHz	94.05 GHz
Antenna size	3.1 m × 2.3 m	2.3 m (diameter)
Antenna gain	64 dB	65 dB
Swath (number of beam)	40 km(5)	Nadir only (1)
Vertical resolution(pulse width)	500 m (3.33 μs)	500 m (3.33 μs)
Footprint	800 m (-3 dB one way)	800 m (-3 dB one way)
Horizontal resolution	5 km	5 km
Noise equivalent dBZ per pulse @10 km alt. ( ) : nadir	-17.8 (-18.2) dBZ	-21.0 dBZ
Minimum dBZ @10 km alt. ( ) : nadir	-30.7 (-32.6) dBZ	-37.8 dBZ
Pulse repetition frequency	4500 Hz (×2)	4500 Hz (×2)
Duty ratio of transmitter tube	<3 %	< 3 %
Receiver NF	5 dB	5 dB
Satellite altitude	400 km	400 km
Weight	250 kg	194 kg
Power consumption	350 W	328 W

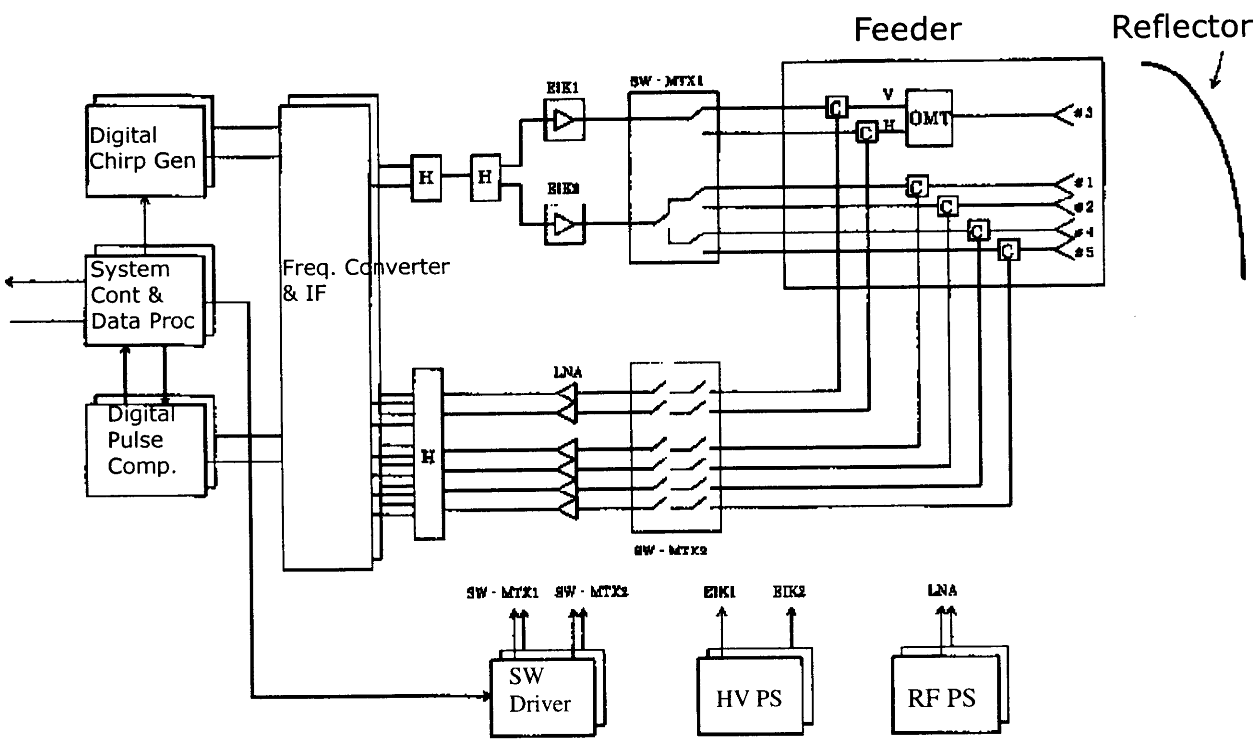

Figure 2. Schematic block diagram of MDS/CPR

3.1 Antenna

The antenna of MDS/CPR consists of a reflector and five primary horns. Because adoption of the mechanical switching and phased array for the beam switching of MDS/CPR are not practical, method to switch five primary horns is used for the beam switching at MDS/CPR. Reflector size should be as much as large within a fairing capacity to achieve necessary sensitivities for all beams. As a result of trade-off study, it has been confirmed that a torus type antenna with a aperture of about 2.3 m (parabola at along-track) × 3.1 m (arc in cross-track) and a focal length of 4 m satisfies gain and sidelobe characteristics for all beams and so suitable as a reflector. It is estimated that the antenna gain is more than 64 dBi and side lobe is less than –45 dB. Figure 3 shows the antenna pattern of the nadir beam.

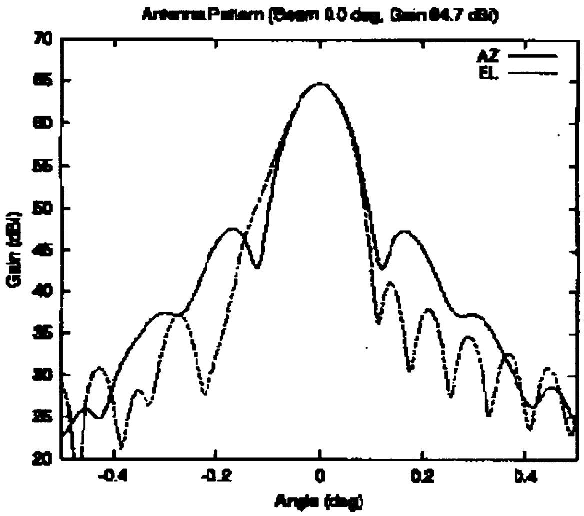

Figure 3. Estimated antenna pattern (Nadir)

3.2 Feeder

In order to realize both the multi-beam and Doppler, the beam switching should be done every transmit pulse. As the switching time should be very short (about less than 1 micro second), switching performance is very important in MDS/CPR as well as feeder loss characteristics. Although a quasi-optical switch, which is used as a T/R switch at CloudSat and ERM CPRs, has a good loss performance, waveguide ferrite switches is adopted at MDS/CPR from switching performance point of view.

The feeder system consists of ferrite switches, directional couplers, and waveguides as shown in Figure 2. (Directional couplers are indicated as "C" in Figure 2) In the beam number 3 (#3;nadir), an OMT is installed to make Doppler measurement using two orthogonal polarization (V and H) signals. Two transmitters (EIK1 and EIK2) are installed as shown in Figure 2. This is to reduce the feeder loss and then get high sensitivity by operating these two transmitters simultaneously. Figure 4 shows an outlook of the feeder system.

The total losses caused at the transmit and receive feeder are estimated to be 4 dB at beam #3 and 4.3 dB at the other beams. T/R isolation is expected to be more than 65 dB. In order to verify performances of the switching function and the feeder loss, we plan to develop a Bread Board Model of the feed system.

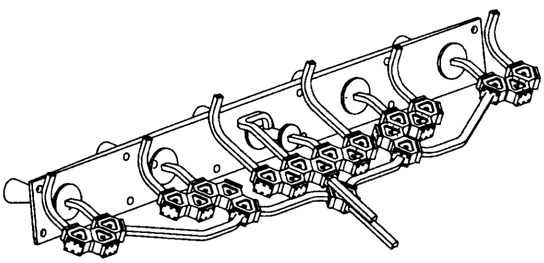

Figure 4. Outlook of feeder system

3.3 Transmitter

EIK (Extended Interaction Klystron) produced by CPI (Communications and Power Industry) in Canada is now widely used as a transmitter of the grand-based W band CPR. And based upon the grand-based EIK, a space qualified EIK is being developed by JPL and CPI in order to use it at CouldSat CPR. In this development of EIK, CRL made a sort of contribution to JPL at the development of EIK-EM1 (mechanically space qualified EIK) which was successfully completed in 1999.

From above mentioned and requirements of minimum 1.5 KW transmit peak power and maximum 3 % duty ratio, we plan to use EIK as a transmitter of MDS/CPR. In addition, two EIKs will be used for reduction of the switching loss.

3.4 Receiver

A Low Noise Amplifier (LNA) is used for each primary horn in order to reduce the switching loss. Expected noise figure of LNA is 5 dB.

3.5 Data processing

(1) Transmit pulse sequence

Figure 5 shows one example of the transmit pulse sequence. The pulse width is 3.33 microsecond and interval of the pulse pair is about 10 microsecond.

During PR11, H and V polarization pulses with frequency f3 are transmitted from EIK1 to beam

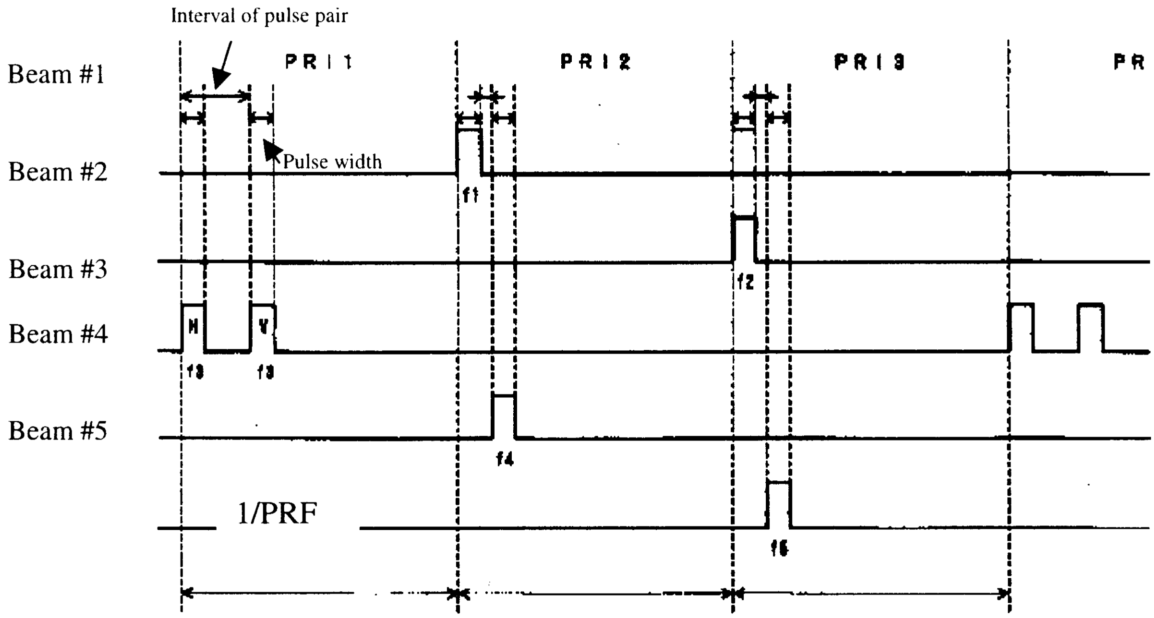

Figure 5. Example of the transmit pulse sequence

#3 (nadir beam) for Doppler measurement. During PR12, one pulse with frequency f1 is transmitted from EIK2 to beam #1 and the other pulse with frequency f4 is transmitted from EIK2 to beam #4. During PR13, one pulse with frequency f2 is transmitted from EIK2 to beam #2 and the other pulse with frequency f5 is transmitted from EIK2 to beam #5. Use of different frequencies for each beam is to prevent signal echoes from interference such as ground clutters.

Above is the fundamental sequence of the transmit pulse. The other pulse sequence will be used according to the different observation mode, such as pulse compression mode. We are going to investigate further what pulse sequence should be employed.

(2) Sample rate and incoherent integration

Each received signal corresponding to five beams is in parallel A/D sampled after a log-amplifier detection and integrated incoherently. Range resolution given by the pulse width is 500 m and so the normal sample rate is 300 KHz. However, sampling rate of 600 KHz will be employed in order to obtain 250 m range resolution. Incoherent integration is done over the 5 km resolution in along-track direction.

(3) Doppler processing

The polarization diversity pulse-pair technique will be employed for the Doppler processing. At first correlation between the pulse pair at the nadir beam (V and H polarization pulses) is calculated. Then Doppler frequency is derived from the phase difference between successive correlation functions. Although this method is established in ground base observations, there are no applications of it to a spaceborne CPR. By using a CPR of CRL (SPIDER), we are going to evaluate followings before the design of MDS/CPR will be fixed.

- time interval between the pulse pairs appropriate to the correlation ?
- number of integration required to obtain the precision of 1 m/s
- influence of cross-polarization
- effects of the antenna beam expansion

The target of Doppler measurement is to measure the speed of the cloud or rain particles within ±10 m/s with a precision of 1 m/s.

(4) Pulse compression

Pulse compression technique using chirp modulation will be implemented for MDS/CPR in order to measure very week echoes from cirrus clouds which have radar reflectivity of about –36 dBZ.

Length of the chirp pulse is set to be ten times as that of the short pulse. PRF is also set to be 10 times to keep constant duty ratio. Although the integration number is decreased by 1/10, the sensitivity is increased by 5 dB by using this pulse compression technique. Because the range sidelobes due to ground echoes should be prevented, pulse compression will be employed above 5 km height.

(5) Protection of radio astronomy observation

In order to prevent the interference from CPR to radio astronomical observatories, a GPS receiver is installed at MDS/CPR to stop the W band radiation over the designated radio astronomical observatories automatically.

4. MAJOR MISSION PARAMETERS

(1) Spacecraft configuration

Figure 6 shows a concept of the spacecraft configuration carrying CPR. The upper figure is the originally proposed configuration. But, this has been changed to the lower configuration where the antenna tower is removed from the thermal and mechanical points of view.

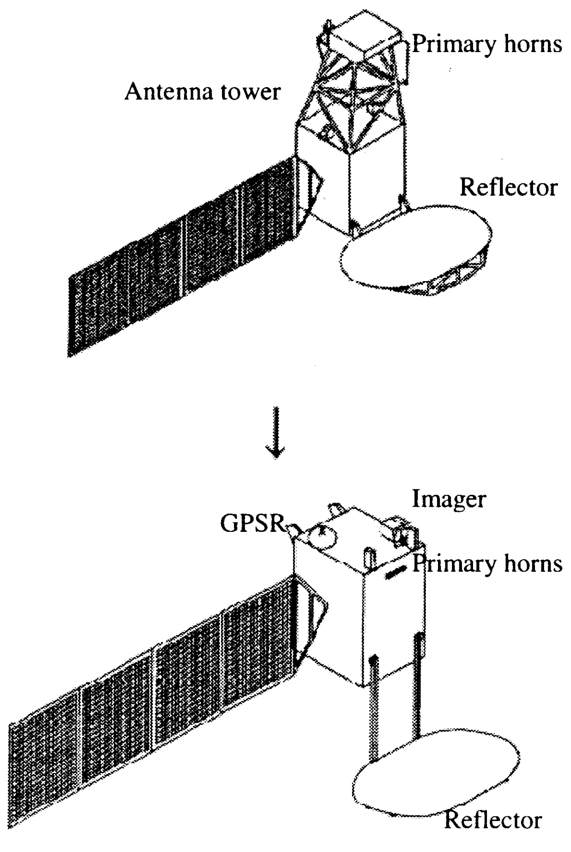

Figure 6. Concept of spacecraft configuration (The upper configuration has been changed to the lower one. TX/RX of CPR is contained in the spacecraft box.)

(2) Major mission parameters

- mission life: two years
- orbit: sun-synchronous / polar orbit
- altitude: 450 km (changed from 400 km)
- CPR sensitivity >-32 dBZ (nadir, short pulse)
- Data transmission : X band direct transmission

5. MAJOR ISSUES AND SCHEDULE

(1) Development of space qualified EIK and HV

EIK and HV PS for space use are now being developed by JPL. This development is expected to finish until the year of 2003. At the moment, we plan to use those EIK and HV PS for MDS/CPR.

(2) Development of feed system

We plan to develop BBM of the feed system in FY 2000. Feeder loss and switching speed of the feed system will be evaluated using this BBM.

(3) Doppler capability

CRL airborne CPR called SPIDER has an ability to make Doppler measurements using the polarization diversity pulse pair technique. By using this ability, technical subjects described in section 3.5 (3) will be tested and evaluated.

(4) Development of data processing algorithm

Experiments by CRL airborne CPR (SPIDER) will be conducted more than once a year to gather observation data. We plan to develop data processing algorithm such as propagation attenuation correction algorithm, cloud water/ice retrieval algorithm, etc., by using these data.

In addition, we will investigate to apply data processing algorithms developed for TRMM Precipitation Radar to MDS/CPR.

(5) Investigation of in-orbit calibration

Besides an internal calibration, external calibrations using natural targets (sea surface, snow/ice surface, tropical forest, etc.) are considered to be effective for the overall calibration. For this reason, we plan to gather precise scatter coefficient data by experiments using CRL airborne CPR (SPIDER).

The proposal of MDS/CPR is under NASDA's review. Despite the result of the selection of the proposal, CRL will continue the development algorithms and start the research and development of a spaceborne CPR from FY 2000. Figure 7 shows a development schedule of MDS/CPR although it is still tentative.

REFERENCE

Andrew L. Pazmany et al; "Polarization Diversity Pulse-Pair Technique for Millimeter-Wave Doppler Radar Measurements of Severe Storm Features", J. Atmos. Oceanic Technol., **16,** pp1900-1911, 1999

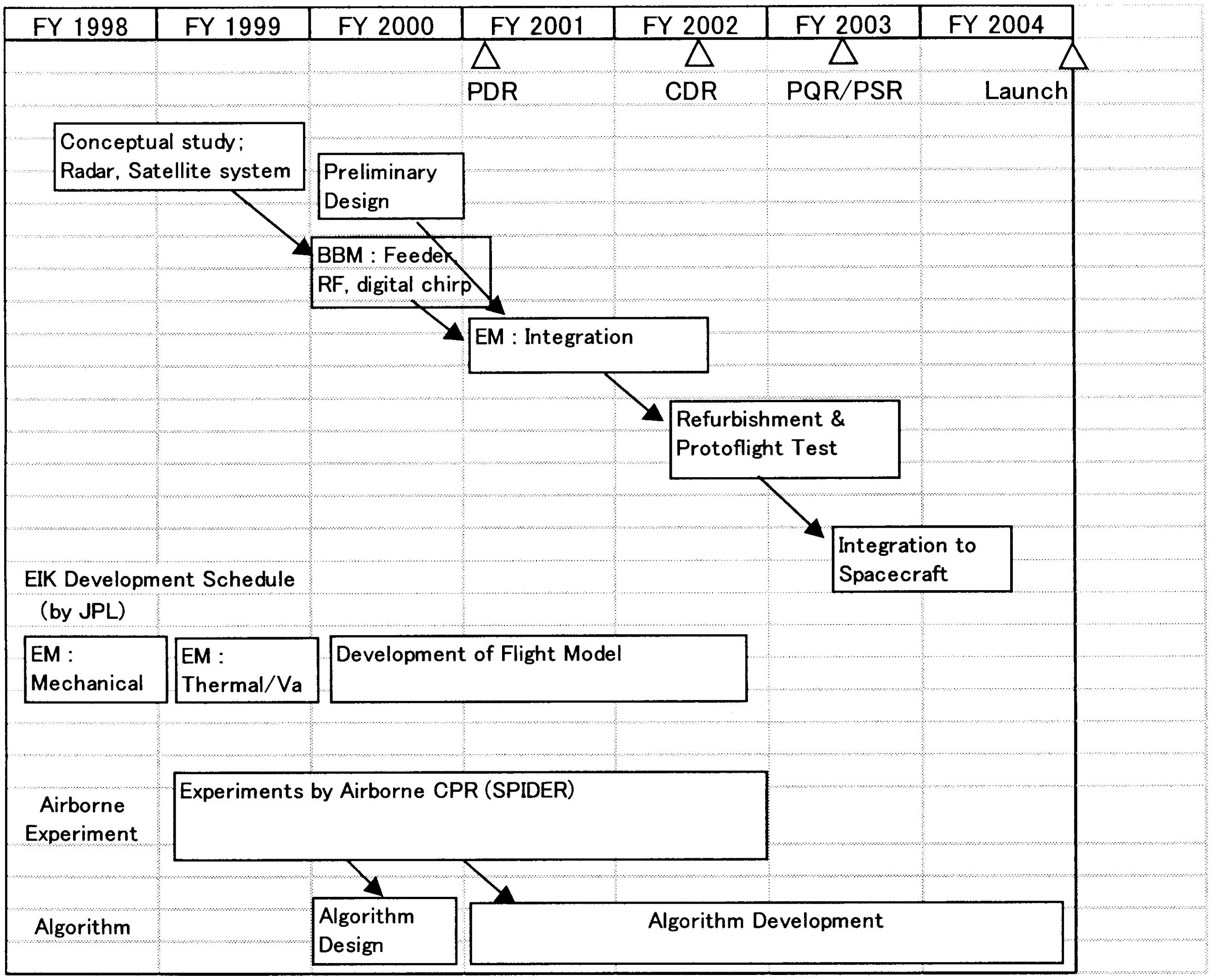

Figure 7. Development schedule of MDS/CPR (Tentative)