PACKET RADIO WITH RUDAK II ON THE RUSSIAN RADIO-Ml MISSION

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INTRODUCTION

Let's face it ! RUDAK, the digital regenerative transponder on-board OSCAR 13 was a grievous loss. No need to say that this was a very big disappointment not only for the RUDAK group of AMSAT-DL but also for many satellite packeteers in the world.

Early 1989 the AMSAT-U-ORBITA group, represented by Leonid Labutin, UA3CR, of the USSR offered AMSAT-DL another opportunity to fly a second generation of the RUDAK experiment commencing an up to that point unprecedented Russian/West German cooperation in amateur radio satellite activities. It was during the annual AMSAT-UK colloquium in Surrey 1989 when representatives of both organizations met to sign a memorandum of understanding. Subject of this MoU was to design, manufacture and launch a joint transponder mission on-board the Russian scientific satellite GEOS. The satellite is to be launched by a Russian launcher in fall 1990.

This paper will report on the mission objectives and the sofar achieved results. The transponder has been named RADIO-Ml by AMSAT-U-ORBITA. A "one" because it is our first joint project and "M" because the involved AMSAT groups are located in Molodechno near Minsk (ORBITA), Moscow and Munich (RUDAK). Once the satellite is in orbit it will probably become RS 14 (Radio Sputnik).

The main part of the RADIO-Ml transponder is dedicated to packet radio operations as it has become normal practise also by the other packet radio satellites such as FUJI OSCAR and MICROSATs. The RUDAK operational software is ready for a long time. It has been field tested with the engineering model of the transponder from top of the water-tower in Ismaning near Munich in South Germany over several years and proven to be operational.

The other part serves as a high-speed, multi purpose computer facility good for a number of different communication experiments including digital signal processing (DSP).

SYSTEM OBJECTIVES

The RUDAK I system was ideally suited for the particular advantages of highly inclined elliptical orbits (HEO) of the AMSAT Phase 3 satellites. One of the main advantages of these

HEO orbits is that, at least in the Northern Hemisphere, the satellite is visible for many hours daily. Therefore, RUDAK I has primarily been designed to feature “real-time” packet radio communications (digipeating) and, in addition to that, provide minimum mailbox functions in the so-called “ROBOT” mode.

The ROBOT mode allows direct connects to the RUDAK processor by using “RUDAK” as a callsign with the extender (SSID O-15) standing for a few standard messages. Those messages include e.g. latest orbit information (Keplerians), transponder schedules, selected telemetry parameters, uplink statistics, mheard list and so on. These messages are transmitted in response to a connect request under full control of the AX.25 protocol, i.e. error corrected. It will download the information to the connected user terminal followed by an automatic disconnect initiated by the satellite as soon as the message transfer is completed.

Different from the Phase 3 satellites on elliptical orbits will GEOS travel along a circular earth orbit at an altitude of 1000 km almost over the poles (83° inclination). Consequently we have similar conditions in terms of visibility, doppler and so forth as we already know from the FUJI satellites. The RUDAK system itself demonstrated excellent performance for more than two years from top of the water-tower in Ismaning near Munich, FR Germany.

When the RUDAK group had their first system meeting on RUDAK 11 in August 1989 (!) it became very soon clear that due to the extremely short project time of not more than six months it would be better to stick with the A013 design and simply to repeat it. RUDAK I can shortly be described by a general purpose computer with special protocol interface devices (Z80 SIO) to run the AX.25 protocol. At least, to be more precise, this would have been the most logical conclusion. However, in the course of further discussions on the system performance and the actual state-of-the-art in processor technology it became very quickly obvious, that a simple re-built of the equipment appeared not very attractive to us.

First, because RADIO-Ml will be flying at a low altitude of 1000km. It has been said before that from this orbit you get many visibility periods a day but only at relatively short intervalls of about 10 to 20 minutes. Therefore, the digipeat mode, which would be very desirable from an elliptical orbit is much less interesting from an low earth orbit (LEO). In LEO preferably operating modes such as file transfer (ROBOT/ Mailbox) and store-and-forward are much better suited.The second and probably more important reason for not only re-building the former RUDAK was the missing challenge.

Eventually, after thorough investigation of several options we concluded in the following mission objectives

1 demonstrate full RUDAK 1 operation
2 provide a user friendly communications transponder, compatible with present amateur packet radio satellites (FUJI, Microsats, UoSat)
3 introduce additional experimental modes with higher bitrates, different modulation schemes etc. to provide a flying testbed for demonstration of new communication methods and software. (multiple access, store-and-forward, signal processing etc.)
4 to fly advanced technology (processors and VLSI circuits) to study their behaviour under real application conditions gaining experience for future satellite projects (Phase 3D etc.)

Admittedly, the objectives became quite ambitious in the end and the resulting payload architecture grew slightly more complex.

PAYLOAD ARCHITECTURE

Figure 1 shows a blockdiagram illustrating the key features of the RADIO-M 1 system. The system consists mainly of two sections, an RF receiver/transmitter and a digital processor section. Both are interconnected by a baseband signal switch and hard-command decoder. The hard command decoder processes the PN sequences to enable a secure command access to the transponder without use of on-board computer resources.

In OSCAR 13 this service was provided by the main computer (Integrated Housekeeping Unit). The RF section has been designed and jointly built by AMSAT-U-ORBITA and AMSAT-DL. It comprises four independent receiver channels (uplinks) in the 70cm band and a single multi-mode transmitter (downlink) on 2m. Reference is made to Table 1 for exact frequency information. The RF front-end, two linear downconverter and the power amplifier were built by AMSAT-U.

The digital section comprises two independent computers of which one is the exact replica of the OSCAR 13 processor and the second is a very fast digital signal processing (DSP) computer with a so-called reduced instruction set (RISC) architecture.

RECEIVER AND TRANSMITTER SECTION

Digital uplink signals received on 7Ocm are delivered on a 10.7 MHz intermediate frequency as a 400 kHz wide signal. Selectivity is provided in four receivers respectively each operating on a different frequency in the IF range. Each of the four receivers has its own attraction providing special flavour to the RUDAK experiment.

The first receiver (RX-l) is equipped with an FM discriminator followed by a bit clock regeneration circuit to achieve a clean (regenerated) data and clock signal at a bitrate of 1200 bit/s. As shown in Figure 1, the FM demodulated baseband signal is further connected via an A/D converter to the digital signal processor.

This receive path will mainly be used for normal packet uplinking since bitrate, modulation scheme and coding is fully compatible with FUJI OSCARs and the other AMSAT packet radio satellites. Except for the mode U configuration, i.e. 70cm up and 2m down, which is reversed to FUJI operation, the same ground user terminal equipment can therefore be utilized for RADIO-Ml operation as well. During certain periods of time, which will be announced through appropriate bulletins, experiments may utilize this link for other purpose, e.g. voice processing from an FM voice uplink etc..

The second receiver (RX-2) is indeed mostly a re-built of the former A01 3 receiver. It demodulates 2400 bit/s in digital phase modulation (BPSK). The receiver scans around its nominal center frequency for ± 10 kHz at a scan rate of 120 msec. Therefore, doppler shift and other contributions to uplink frequency ambiguity are to a great extend compensated by the satellite receiver. So, nominally the user may set his transmitter to the nominal center frequency provided in Table 1 and the satellite receiver will quite probaly track your uplink signal. Both receiver, RX-1 and RX-2, are considered the main receivers for normal packet operation. They will normally be connected to the R1 processor.

The third receiver (RX-3) is connected to two demodulators operating a.t bitrates of 4800 and 9600 bit/s respectively. This system operates in both bitrates with a new type of modulation, named Rectangular Spectrum Modulation (RSM). This highly efficient modulation scheme was invented some years ago by Dr. Karl Meinzer, DJ4ZC. RSM is applied through optimum filtering and preshaping of the transmitted binary signals and a matched filter on the receive side. RSM provides optimum bandwidth performance under minimum inter symbol interference. Further information on RSM is available on request from AMSAT-DL. RX-3 is also a frequency scanning type of receiver scanning ± 10kHz around nominal frequency.

Finally, last but not least, the most sophisticated part of the experiment is the receiver RX-4 consisting of only minimum hardware to provide baseband signals as an analog inphase (I) and quadrature phase (Q) signal to the RISC computer. With this configuration the actual demodulation and decoding process is left with the DSP, in other words with software. The characteristic and performance of the receive path is only limited by its RF-bandwidth of 30 kHz maximum and the maximum speed and capability of the application software. This link should allow bitrates of up to the order of 20 . . 25 kbit/s at any vector modulation be it BPSK, QPSK, 16-QAM or what have you. It is probably redundant to emphasize that this part of the experiment is an Eldorado for communication and software enthusiasts.

The transmitter is an entirely new design. It has multi mode operation capabilities. It can operate at any bitrate up to 9600 bit/s since the actual bitrate, its coding and even the type of modulation is under control of the processor, thus software. Table 1 gives an impression on the various modes of operation. The nominal output power on 2m is 3W.

PROCESSOR SECTION

The processor section comprises two independent computers. The first is actually a clone of the A013 RUDAK processor. The CPU is a 65SC02 CMOS 8-bit processor with 56 kByte of SRAM. The operating system is IPS, which is a derivate of FORTH ® but with very powerful add-ons, e.g. enabling multi processing. IPS has proved its viability in OSCARs 10 and 13 and has also been adopted for the RUDAK system.

The computer is booted from a ROM based loader. The ROM device is a so-called fusible link PROM of 2 kByte capacity. It contains actually a minimum operating system, the ROM operating system (ROS). ROS provides a number of useful utilities beside initializing the computer and preparing it for uploading of the operational software. The RUDAK system on GEOS will permanently be connected to the main power bus of the spacecraft.

It is for the time beeing not yet shure, if the system will be launched with its operational software already resident or not. Presumably it will be not resident. In this case the ROS system will transmit telemetry information at a 400 bit/s bitrate in a format compatible with the OSCAR 13 telemetry. But except for certain engineering tests later, this mode is only used for a short time during initial performance checks.

Two input channel into the computer can be used for communication through a sophisticated SIO device (Z80 SIO). This device supports significantly the AX.25 protocol calculations unloading the computer from excessive number crunching and counting, thus leaving more computer power for the higher level tasks. The two input channels are configured in a way that one channel is permanently set to 1200 bit/s operation while the second can be connected to any of the receivers RX-1 to 3 and operated at variable bitrates. The switching is performed by the baseband switch under software or hard telecommand control.

A 1 MByte RAM has been added as a universal mass storage device. It is addressed in a similar manner as a floppy disk drive in a normal computer system, i.e.through an I/O device. Therefore it is called RAM-Disk. The RAM-Disk will mainly be used for the mailbox but it may also store experimental software which is to be invoked by either of the two computer for special communication tests.

A bi-directional 8-Bit interface interconnects both computer and the RAM-Disk. Through this interface one computer can support the operation of the other. For instance, one computer can take care of all AX.25 protocol aspects while the second searches the mailbox for special files at a very fast speed. This double-computer architecture is also advantageous if a problem with one processor occurs. The redundancy will in this case be used to maintain normal packet operation.

The real challenge of the RUDAK 11 system is no doubt in the second computer. It is basically a reduced instruction set computer which runs at the very high processing speed of about 10 MHz (CPU: RTX 2000) providing 100 ns processor cycles. The CPU may be operated with or without wait states in error correcting or non-correcting mode. Error detection and correction of single failures is incorporated by means of a special VLSI-device (EDAC: 39C60). This configuration leaves greatest flexibility in the operation of the equipment under outer space conditions which are mainly characterized by various types of cosmic radiations. Fast memory with 35 nsec typical access time (we measured actually 15 nsec with the real devices!) at a quantity of 128 kByte (plus 64 kByte for error correction) opens a wide field of signal processing possibilites, in other words application software.

In this context it is interesting to note, that the main reason for selecting the RTX 2000 CPU was its internal FORTH@ oriented hardware structure. This structure actually comprises IPS definitions in hardware. That, together with the high speed operation of the hardware leaves plenty of room for ambitious expectations.

Different from the R1 processor, the RTX has a direct memory access @MA) logic to allow secure uploading of loader software. This hopefully will avoid a similar lock-up condition which occured on OSCAR 13 RUDAK with the initialization process.

BASEBAND SWITCH

The baseband switch serves two purposes. First, it flexibly can interconnect all receiver outputs with the communications processor R1 while the RTX computer is permanently connected to all receivers. In return, the transmit signal generated by either of the two processors can be switched onto the downlink. For ranging or checking of the uplinks any of the receivers can alternatively be connected to the downlink.

The second major task of this unit is the generation of a complex PN binary sequence to decode commands from ground command stations. To this end two pairs of receivers, actually bitrates, can be routed to the processors alternatively. Either of the receive channel can be used to upload software or commands to perform engineering tests requiring access to the operating system.

POWER SECTION

The amateur payload RADIO-Ml of the host satellite GEOS will remain permanently connected to the main power supply bus. Four independent DC/DC-converter are provided to power up the various functional groups independently. One for the RF section, another two for each of the processors and finally one for the RAM-Disk. This provides a relatively high degree of independence from any failure condition.

RADIO-M1/ RUDAK II - TECHNICAL DATA SHEET

LAUNCH:	Fall 1990 from Plesetsk, USSR with Russian launcher
SATELLITE:	"Subtenant" to GEOS, Russian geological research satellite
ORBIT:	circular at 1000km altitude; 83° inclination; orbital period 105 min
PAYLOAD:	linear and regenerative transponder for analoge and digital (AX.25) communications
TRANSPONDER 1:	Uplink: 435.102 - 435.022 MHz (80 kHz bandwidth) Downl.: 145.852 - 145.932 MHz inverted Power: 10 W max. Beacon: CW telemetry (8 parameter) 145.822 MHz ; 2OOmW digital PSK (30 parameter) 145.952 MHz; 400mW 1100 bit/s scrambled
TRANSPONDER 2:	Uplink: 435.123 - 435.043 MHz (80 kHz bandwidth) Downl.: 145.866 - 145.946 MHz inverted Power: 10 W max. Beacon: CW telemetry (8 parameter) 145.948 MHz ; 200mW digital PSK (30 parameter) 145.838 MHz; 400mW dto. on 145.800 MHz; 2W (1 100bit/s scrambled)
RUDAK II:	two on-board computers with IPS operating system for packet radio (AX.25) and digital signal processing (DSP).
HARDWARE:	65C02 CPU with 56 kByte RAM (RUDAK I primary computer) RTX 2000 CPU (RISC 10 . . 15 MIPS) with 128 kByte + 64 k for EDAC at 35ns access time. 1 MByte RAM DISK for Mailbox and data storage Hard command decoder (PN) and baseband switch 4 RX, 1 TX, Modems and 4 DC/DC converter

SOFIWARE: Multiconnect Mailbox (1 MByte RAM), ROBOT mode and Digipeating
IPS Operating System

UPLINK	RX-1	RX-2	RX-3a	RX-3b	RX-4	unit
Frequency	435.016	435.155	435.193	435.193	435.041	MHz
Baudrate	1200	2400	4800	9600	DSP	bit/s
Modulation	FSK	BPSK	RSM	RSM	any	
Coding	NRZIC Bi-0-M	Bi-0-S	NRZIC Bi-0-M	NRZI NRZ-S + scrambler	I + Q	

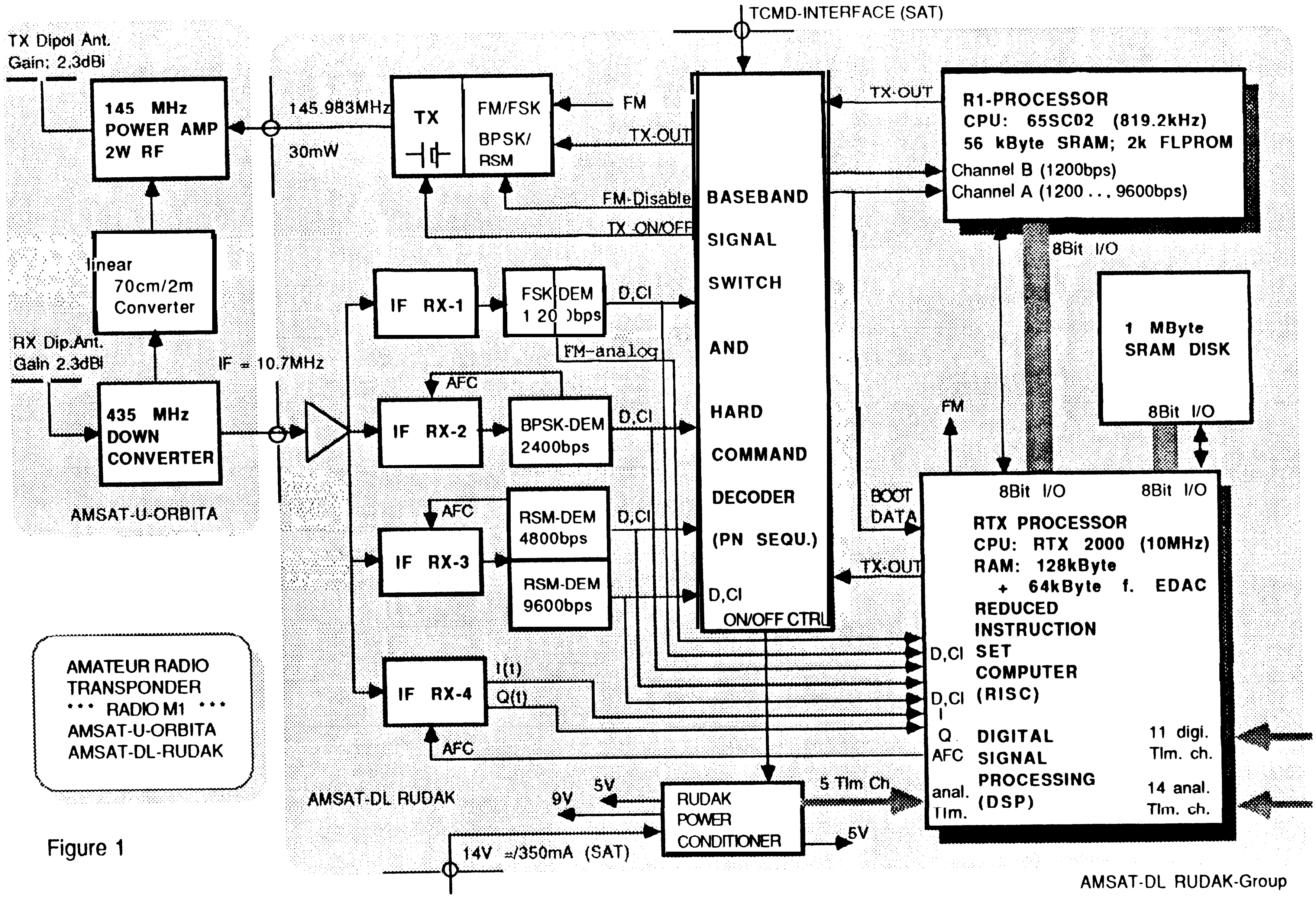
DOWNLINK 145.983 MHz with 3W typical (10W optional)

Mode 1: 1200 bit/s; BPSK, NRZI (NRZ-S) (like FO 20)
Mode 2: 400 bit/s; BPSK, Bi-0-S (like OSCAR 13 beacon)
Mode 3: 2400 bit/s BPSK, Bi-0-S (planned for OSCAR 13)
Mode 4: 4800 bit/s RSM, NRZIC, (Bi-Ø-M) (like 4800 bit/s Uplink)
Mode 5: 9600 bit/s, RSM NRZI (NRZ-S) + scrambler (like 9600bit/s Uplink)
Mode 6: CW keying (for special events)
Mode 7: FSK (F1 or F2B) e.g. RTTY, SSTV, FAX etc. (for special events)
Mode 8: FM by D/A converted signals from the DSP-RISC processor (e.g.speech)

TABLE I: Main system parameters

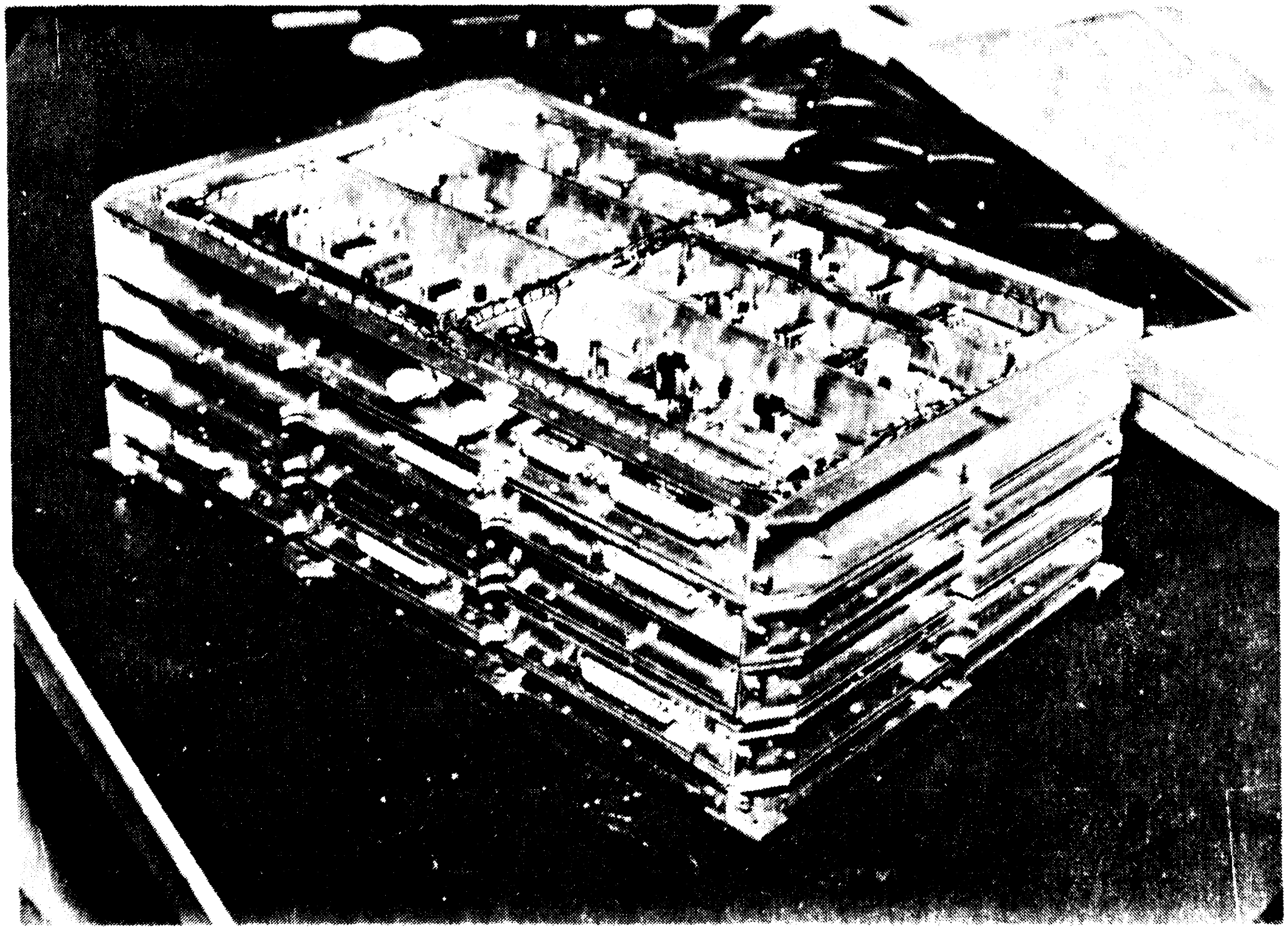
ACKNOWLEDGEMENTS

It must really be stressed that the work reported here has been performed by a highly motivated and highly skilled team in less than six months (6.89 - 1.90) starting from paper to flight hardware in “leisure” (hi) time after work. Special thanks to the Marburg based AMSAT group headed by Dr. K. Meinzer, DJ4ZC and W. Haas, DJ5KQ and the RUDAK group DL2MDL, DG2CV, DK8CI, DF8CA, DF2IR and DB2OS.



TCMD-INTERFACE (SAT)
TX Dipol Ant.
Gain: 2.3dBi
145 MHz
POWER AMP
2W RF
145.983MHz
30mW
TX
FM/FSK
BPSK/
RSM
FM
TX-OUT
FM-Disable
TX-ON/OFF
linear
70cm/2m
Converter
RX Dip.Ant.
Gain 2.3dBi
435 MHz
DOWN
CONVERTER
AMSAT-U-ORBITA
IF = 10.7MHz
IF RX-1
FSK DEM
1 200bps
D,CI
FM-analog
AFC
IF RX-2
BPSK-DEM
2400bps
IF RX-3
RSM-DEM
4800bps
RSM-DEM
9600bps
IF RX-4
I(1)
Q(1)
BASEBAND
SIGNAL
SWITCH
AND
HARD
COMMAND
DECODER
(PN SEQU.)
D,CI
ON/OFF CTRL
R1-PROCESSOR
CPU: 65SC02 (819.2kHz)
56 kByte SRAM; 2k FLPROM
Channel B (1200bps)
Channel A (1200 . . . 9600bps)
8Bit I/O
1 MByte
SRAM DISK
8Bit I/O
FM
BOOT
DATA
TX-OUT
8Bit I/O
8Bit I/O
RTX PROCESSOR
CPU: RTX 2000 (10MHz)
RAM: 128kByte
+ 64kByte f. EDAC
REDUCED
INSTRUCTION
SET
COMPUTER
(RISC)
DIGITAL
SIGNAL
PROCESSING
(DSP)
D,CI
D,CI
I
Q
AFC
anal.
Tlm.
11 digi.
Tlm. ch.
14 anal.
Tlm. ch.
AMATEUR RADIO
TRANSPONDER
*** RADIO M1 ***
AMSAT-U-ORBITA
AMSAT-DL-RUDAK
AMSAT-DL RUDAK
9V
5V
RUDAK
POWER
CONDITIONER
5 Tlm Ch.
5V
14V =/350mA (SAT)
AMSAT-DL RUDAK-Group

Figure 1



Rudak II Flight Unit