3-4 Onboard Ka-band Feeder Link Communications Equipment

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Onboard Ka-band Feeder Link Communications Equipment (FLCE) is one of the mobile satellite communications payloads carried by the Engineering Test Satellite VIII (ETS-VIII) and communicates signals with a ground feeder link station. NASDA has developed and installed the Ka-band feeder link communications equipments for inter-satellite communications on the ETS-VI, COMETS and DRTS, and developed the FLCE based on their technologies. This paper describes the function and performance of the FLCE and summarizes its development.

Keywords
Feeder link communications equipment, Ka-band, Mobile satellite communications, ETS-VIII

1 Introduction

The Engineering Test Satellite VIII (ETS-VIII) performs various experiments in mobile satellite communications using overall link it establishes between ground mobile stations and ground feeder-link stations via the ETS-VIII. The service link is established between the ground mobile station and the Mobile Communications and Broadcasting experimental equipment (MCB) on the satellite using the S-band (2.6/2.5 GHz). The satellite also establishes a feeder link between the ground feeder-link station and the Feeder-Link Communications Equipment (FLCE) on the satellite, using the Ka-band (31/21 GHz band). The FLCE receives the forward link signals transmitted from the ground feeder-link station in the 30 GHz band, converts them into IF frequencies in the 140 MHz band, and inputs these signals into the MCB. The satellite also converts the return link signals output from the MCB in the 140 MHz band into the 20 GHz band and transmits these to the ground feeder-link station. The main functions of the FLCE are as follows:

(1) The FLCE receives the uplink signals of the feeder link from the ground feeder-link station and sends the signals to the S-band converter (SCNE), the on-board processor (OBP), and the packet switching (PKT) of the MCB.

(2) The FLCE amplifies the signals from the ground mobile station after relay and switching is performed by the SCNE, the OBP, and the PKT, and then transmits the signals to the ground feeder-link station as downlink signals of the feeder link.

(3) The FLCE continuously transmits the Ka-band beacon signals to the ground feeder-link station for Automatic Frequency Control (AFC) at the ground feeder-link station.

2 Configuration of the FLCE

Table 1 shows the system configuration of the FLCE. Fig.1 shows a functional system diagram and the interface point of the FLCE.

Table 1 *FLCE system configuration*

Component		Number	Mass [kg]	Power Consumption [W]	Heritage
Name	Acronym		Measured Value	Max. Value	
Antenna Subsystem	FL-ANT	1	9.560	–	DRTS, COMETS
Repeater Subsystem	FL-RPT				
Input Sub-assembly	FL-INS	1	0.298	0.5	DRTS, COMETS
LNA-A	FL-LNA-A	1	0.548	2.1	DRTS, COMETS
LNA-B	FL-LNA-B	1	0.545	0.2	DRTS, COMETS
30 GHz Hybrid	FL-30GHYB	1	0.036	–	DRTS
Down Converter-A	FL-DNC-A	1	2.920	5.8	DRTS, COMETS
Down Converter-B	FL-DNC-B	1	2.900	5.8	DRTS, COMETS
Local Oscillator-A	FL-LO-A	1	1.420	9.5	DRTS, COMETS, ETS-VI
Local Oscillator-B	FL-LO-B	1	1.447	0.2	DRTS, COMETS, ETS-VI
Local Hybrid	FL-LOHYB	1	0.229	–	DRTS, COMETS
Up Converter-A	FL-UPC-A	1	2.708	4.9	DRTS, COMETS
Up Converter-B	FL-UPC-B	1	2.732	4.9	DRTS, COMETS
20 GHz Hybrid	FL-20GHYB	1	0.047	–	DRTS
TWTA-A	FL-TWTA-A	1	3.120	84.5	DRTS, COMETS
TWTA-B	FL-TWTA-B	1	3.238	0.2	DRTS, COMETS
Output Sub-assembly	FL-OUTS	1	0.813	0.9	DRTS, COMETS
Wave Guides	FL-WG	1 set	0.694	–	
Cables	FL-CBL	1 set	1.127	–	
Connector					
	FL-WG3	1	0.119	–	
	FL-WG16	1	0.093	–	
合計			34.594	119.5	

Remarks: Power consumption shows maximum value in nominal operating configuration.

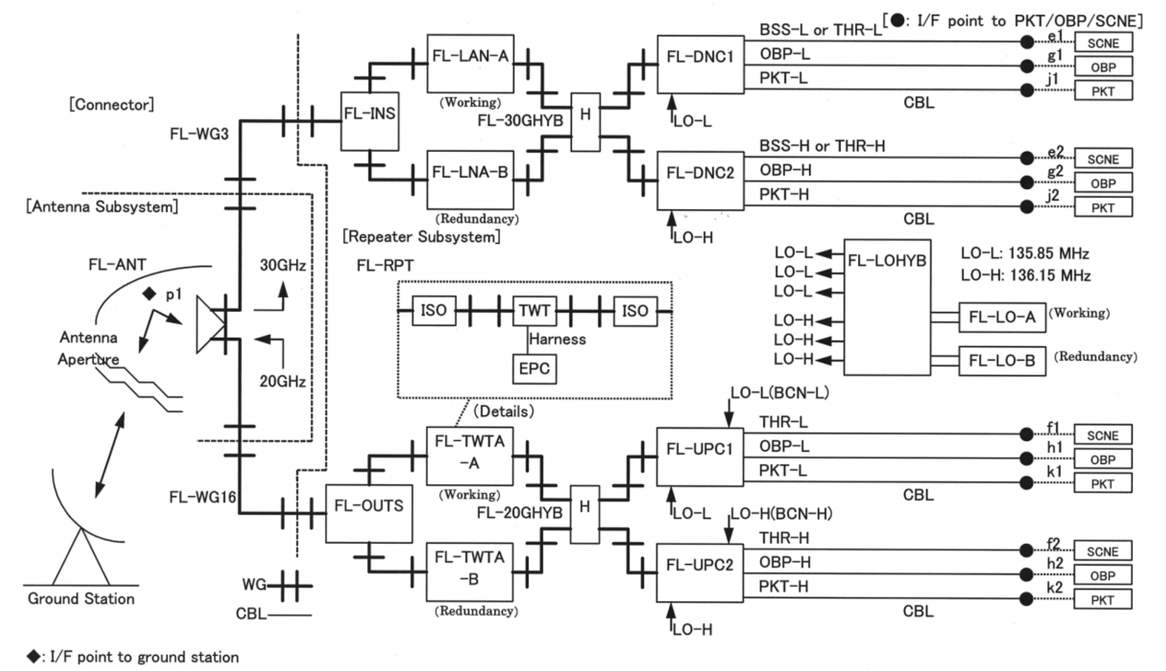


Fig. 1 *FLCE system block diagram and interface point*

The FLCE consists of a feeder-link antenna (FL-ANT), a feeder-link repeater (FL-RPT), and a connector between the two. The FL-RPT consists of an input sub-assembly (FL-INS), low-noise amplifiers (FL-LNA), a 30 GHz hybrid (FL-30GHYB), down-converters (FL-DNC), local oscillators (FL-LO), a local hybrid (FL-LOHYB), up-converters (FL-UPC), a 20 GHz hybrid (FL-20GHYB), traveling wave tube amplifiers (FL-TWTA), and an output sub-assemblys (FL-OUTS).

Fig.2 shows the appearance of the FL-ANT, and Fig.3 shows the appearance of the FL-RPT.

3 Features of the FLCE

The FLCE succeeds to technologies of feeder-link communications equipments for inter-satellite communications continuously

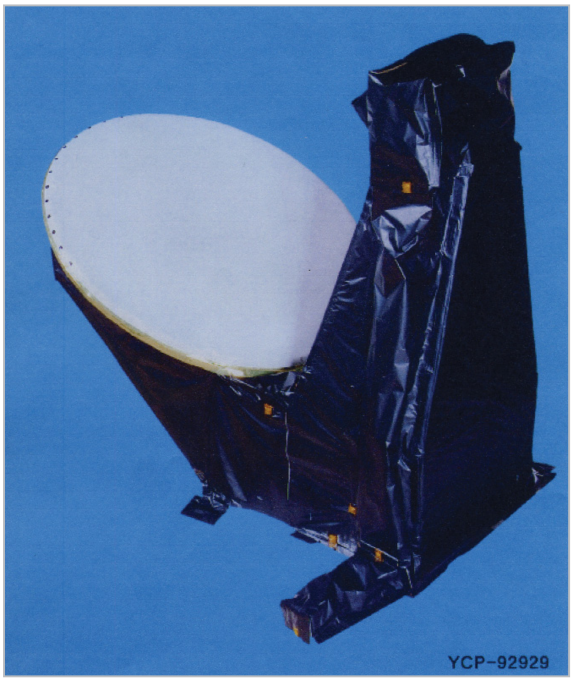


Fig.2 Feeder-link antenna (FL-ANT)

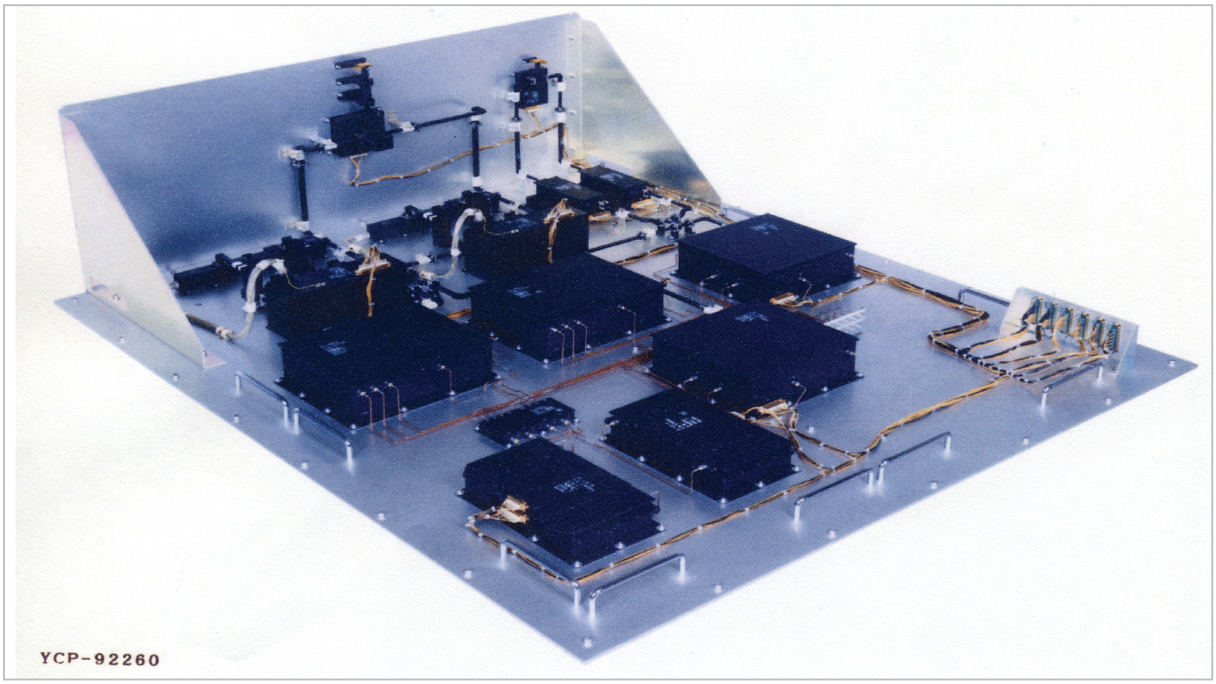


Fig.3 Feeder-link repeater (FL-RPT)

developed by the National Space Development Agency of Japan (NASDA) for the Engineering Test Satellite VI (ETS-VI), the Communications and Broadcasting Engineering Test Satellites (COMETS), and the Data Relay Test Satellite (DRTS). In particular, development costs have been significantly reduced through application of the results of the DRTS program. This eliminated the need to produce the engineering model required under conventional EM-PFM system design, permitting to progress directly to prototype flight-model production in an engineering test phase.

However, although the ETS-VIII FLCE has been developed based on the results of the DRTS program, the ETS-VIII mission requirements demand modifications to the design of some items of equipment, such as the 100 V primary power supply bus interface. Specific modifications include changes to the antenna, the redundant configuration, the local oscillator, and the allocation of signal frequencies, as described in detail below.

3.1 Antenna

Although conventional feeder-link antennas are deployable antennas, the FL-ANT is a fixed offset parabolic antenna. As the mission requirements do not demand high data rate signal transmission, the link is ensured with an antenna diameter of approximately 0.8 m. The small aperture leads to wide beam width, eliminating the need for antenna pointing control. Further, due to its small diameter, the fixed antenna can be installed on the satellite without folding at launch. Eliminating the need for a deployment mechanism simplifies antenna hardware, enhances reliability, and reduced overall mass. These are the main advantages to the selection of a fixed antenna.

The COMETS ground station at the Communications Research Laboratory (CRL), Kashima, is to be used in experimentation; thus, antenna frequency and polarization are determined in accordance with the specifications of this station: a 30.622 GHz right-hand circular polarization for uplink and a 20.811 GHz left-hand circular polarization for downlink. The design of the antenna feeder is based on techniques developed for the COMETS and DRTS programs.

3.2 Redundant configuration

The FLCE is redundantly equipped in all elements of the repeater system, except for the antenna. However, for some components, redundancy is maintained using components with slightly different frequency bands. This method differs from the traditional practice of installing redundant components featuring the same functions and performance as the primary components. The slight difference in frequency bands among these components allows for simultaneous operation of the two frequency bands. The FL-DNC and FL-UPC components feature this type of configuration. Simultaneous operation doubles the frequency bands that can be used simultaneously (useful in verifying OBP capacity, for example) and secures a path for reference signals in antenna-pattern measurement.

3.3 Local oscillator

Conventional feeder-link communications equipment uses a pilot synchronizing oscillator to generate reference frequencies. On the other hand, the ETS-VIII uses an oven-controlled crystal oscillator (OCXO) as a local oscillator, providing highly stable reference frequencies to the FL-DNC and to the FL-UPC. This method was selected principally for the following reasons:

* The pilot synchronizing oscillator requires the pilot signals transmit from a ground feeder-link station.
* Frequency correction is possible at the ground feeder-link station.

The reference frequencies can be fine-tuned via command to correct any variation of frequency over time (AFC). As this type of frequency correction requires monitoring of the satellite oscillator frequency at the ground feeder-link station, the FLCE transmits beacon signals to the ground feeder-link station at a frequency synchronized to the reference frequency of the oscillator. For this reason, the output frequency of the local oscillator is selected in the 136 MHz band, close to the 140 MHz IF frequency used for the communications signals.

3.4 Signal frequency configuration

The FLCE relays one of the following four types of signals in operation:

(1) Voice communication signals (OBP)
(2) Packet data signals (PKT)
(3) Multicasting signals (BSS)
(4) Through repeater signals (THR)

In addition to these signals, the FLCE continuously generates and transmits beacon signals (BCN) in the 20 GHz band for AFC operation in the ground station.

Fig.4 shows the signal frequency allocation of these signals in the FLCE. The uplink frequency is in the 30 GHz band, and the downlink frequency is in the 20 GHz band. These bands are selected for the following reasons:

* Applying the DRTS technologies to the hardware of the FLCE, frequencies can be selected that are close to those of the DRTS.
* In terms of the interface with the ground feeder-link station, selection of a frequency close to that of the COMETS will allow use of the COMETS ground station at the CRL's Kashima facility.

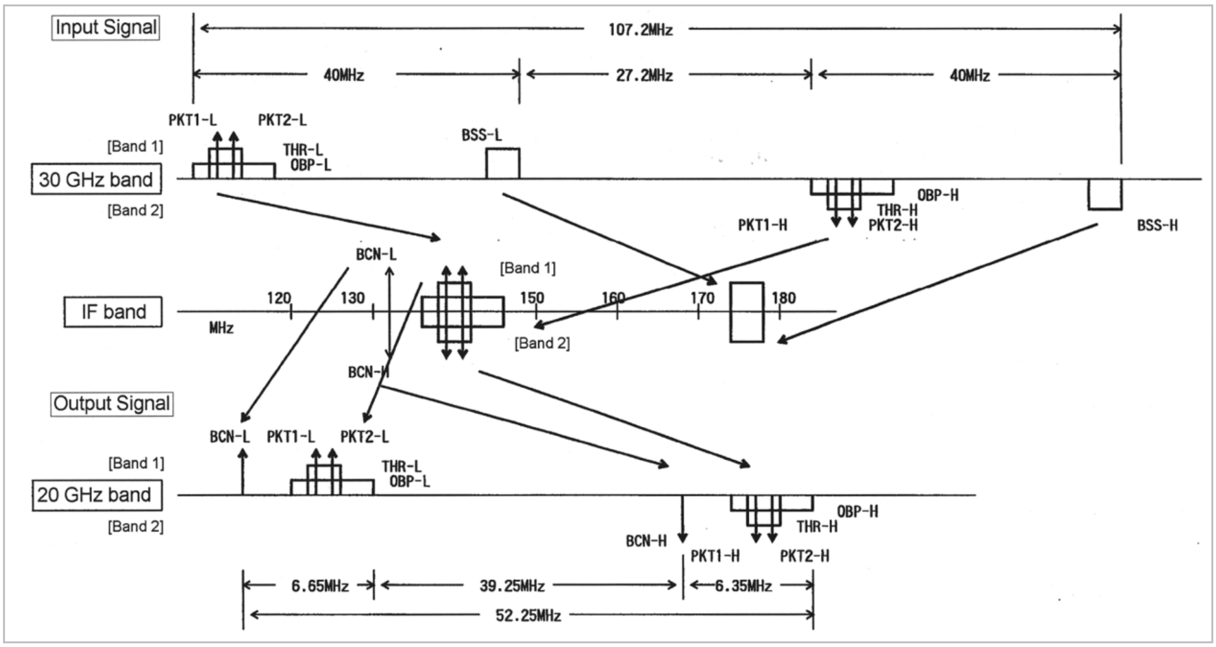


Fig.4 FLCE signal frequency allocation

The IF frequency is in the 140/176 MHz bands. The IF frequency in the 140 MHz band is in principle used for the three subsystems in the MCB (SCNE, OBP, and PKT) that interface with the FLCE. However, for interfacing with the SCNE, the 176 MHz IF frequency (for BSS signals) is used, in addition to the 140 MHz band (for THR signals).

As shown in Fig.1, the FL-DNC and the FL-UPC consist of two sets of components, each with different operating frequency bands. This is due to the requirement that simultaneous operations of the two frequency bands must be available for OBP and THR signals. PKT signals operate in two channels (PKT1 and PKT2) in the same frequency band and are not subject to the requirement of simultaneous operations with two frequency bands. The BSS signals also use only one frequency band and do not require simultaneous operations. The IF frequency is the same for the two frequency bands in simultaneous operation; thus, the local oscillator frequencies of the two frequency bands are varied slightly, to distinguish the two frequency bands for both the uplink and downlink frequencies. Table 2 illustrates the frequencies of each band in detail.

Table 2 Frequencies of the FLCE system in detail

Forward Link	Ka-band total frequency: 30.622 GHz±60 MHz (nominal)				
Signal Mode / Route		MC-TDM signal OBP mode / F-a	PKT signal PKT mode / F-b	BSS signal BSS/THR mode / F-c	Through Repeater signal BSS/THR mode / F-c
Ka-band Uplink Point p1	Band 1	30.5704 GHz±2.5 MHz (OBP-L)	30.5689 GHz±0.5 MHz (PKT1-L) 30.5704 GHz±0.5 MHz (PKT2-L)	30.60665 GHz±1.25 MHz (BSS-L)	30.56965 GHz±1.25 MHz (THR-L)
	Band 2	30.6376 GHz±2.5 MHz (OBP-H)	30.6361 GHz±0.5 MHz(PKT1-H) 30.6376 GHz±0.5 MHz(PKT2-H)	30.67385 GHz±1.25 MHz (BSS-H)	30.63685 GHz±1.25 MHz (THR-H)
IF-band output	Band 1	140±2.5 MHz (OBP-L)	138.5±0.5 MHz (PKT1-L) 140.0±0.5 MHz (PKT2-L)	176.25±1.25 MHz (BSS-L)	139.25±1.25 MHz (THR-L)
	Band 2	140±2.5 MHz (OBP-H)	138.5±0.5 MHz (PKT1-H) 140.0±0.5 MHz (PKT2-H)	176.25±1.25 MHz (BSS-H)	139.25±1.25 MHz (THR-H)
Return Link	Ka-band total frequency: 20.811 GHz±30 MHz (nominal)				
Signal Mode / Route		MC-TDM signal OBP mode / R-a	PKT signal PKT mode / R-b	Through Repeater signal BSS/THR mode / R-c	Beacon signal
IF-band input	Band 1	140±2.5 MHz (OBP-L)	138.5±0.5 MHz (PKT1-L) 140.0±0.5 MHz (PKT2-L)	139.25±1.25 MHz (THR-L)	N/A
	Band 2	140±2.5 MHz (OBP-H)	138.5±0.5 MHz (PKT1-H) 140.0±0.5 MHz (PKT2-H)	139.25±1.25 MHz (THR-H)	N/A
Ka-band downlink Point p1	Band 1	20.7892 GHz±2.5 MHz (OBP-L)	20.7877 GHz±0.5 MHz (PKT1-L) 20.7892 GHz±0.5 MHz (PKT2-L)	20.78845 GHz±1.25 MHz (THR-L)	20.78505 GHz (BCN-L)
	Band 2	20.8348 GHz±2.5 MHz (OBP-H)	20.8333 GHz±0.5 MHz (PKT1-H) 20.8348 GHz±0.5 MHz (PKT2-H)	20.83405 GHz±1.25 MHz (THR-H)	20.83095 GHz (BCN-H)

4 Main functions of the FLCE

4.1 Forward link receiving function

The forward link receiving function permits reception of 30 GHz band communications signals from the ground feeder-link station using the FL-ANT. After low-noise amplification and conversion of the signals into the 140 MHz band in the FLCE receiver, this receiver outputs signals to the MCB as IF-frequency signals. The details of this function are as follows:

(1) Outputs the two bands (OBP-L or OBP-H) of voice communication signals (MC-TDM signals) to the OBP. These bands have no special band-limiting filter.
(2) Outputs the four channels for the two bands (PKT1-L and PKT2-L or PKT1-H and PKT2-H) of packet data signals to the PKT. These bands have no special band-limiting filter.
(3) Outputs the two bands (BSS-L or BSS-H) of multicasting signals (e.g., OFDM signals) to the SCNE through a band-limiting filter.
(4) Outputs the two bands (THR-L or THR-H) of applied communications signals to the SCNE through a band-limiting filter.
(5) Features (1) to (4) above operate alternately and not simultaneously. There is no on/off switching function for each band, and all bands are subject to continuous operation.
(6) The output signal levels of features (1) to (4) above can be varied (all bands have the same variable amplification gain). However, potential instantaneous signal interruption occurs when switching gain.
(7) The two down-converters (FL-DNC1 and FL-DNC2) can be switched on or off independently.

4.2 Return link function

The return link function performs frequency conversion and high-power amplification of the 140 MHz IF frequency signals from the MCB in the 20 GHz FLCE transmitter. This transmitter also transmits the processed signals to the ground feeder-link station via the FL-ANT. The details of this function are as listed below. No special band-limiting filter is used in any of the following signals.

(1) Transmits the two bands (OBP-L and OBP-H) of voice communication signals from the OBP to the ground feeder-link station.
(2) Transmits the four channels for the two bands (PKT1-L and PKT2-L or PKT1-H and PKT2-H) of packet data signals from the PKT to the ground feeder-link station.
(3) Transmits the two bands of applied communications signals (THR-L and THR-H) from the SCNE to the ground feeder-link station.
(4) Features (1) to (3) above operate alternately, not simultaneously. There is no on/off switching function for each band. All systems are subject to continuous operation.
(5) The frequencies of the local oscillator in the 30 GHz receiver and those in the 20 GHz transmitter should be synchronized. The return link function transmits the two bands (BCN-L and BCN-H) of beacon signals, synchronizing the local oscillator to the ground feeder-link station.
(6) The local oscillator frequency can be fine-tuned via command.
(7) Output signal levels can be varied for functions (1) to (3) above (all systems have the same variable amplification gain). However, potential instantaneous signal interruption occurs when switching gain.
(8) The aggregate Ka-band signals output level of the transmitter can be monitored as telemetry signals.
(9) The two up-converters (FL-UPC1 and FL-UPC2) can be switched on or off independently.

5 FLCE performance and results of development

Primary components of the FL-RPT and the FL-ANT were developed for satellite system electrical test in the system development phase. This test confirmed that the FLCE system satisfies the required functions and performances, and that it also satisfies system requirements when combined with the MCB. Next, the remaining redundant components were developed and proto-flight test (PFT) in a full FLCE configuration was performed. All requirements were satisfied for all test items. Table 3 shows the results of PFT of the FLCE with reference to the required performance specifications. Fig.5 shows the measured antenna gain contour. Table 8 shows the PFT results of the FL-ANT.

Table 3 *FLCE Proto-flight test results*

Item	Specification	Test result
G/T	+10 dB/K min.	11.5～15.6 dB/K Details are shown in table 4.
EIRP	+73 dBm min. (NPR>20 dB, C/3IM>25 dB)	77.6～80.2 dBm (NPR>20 dB) Details are shown in table 5. 79.8～81.8 dBm (C/3IM>25 dB)
Local frequency stability		
Temperature stability	±0.2 ppm / 20℃	+0.17/-0.13 ppm / 20℃
Long term drift	±0.8 ppm (3 years after launch)	+0.16/-0.01 ppm / 3 years
Adjustable step	0.1 ppm / step (nominal)	0.08～0.10 ppm / step
Overall gain		
Forward link		
Gain	115 dB (nominal)	Details are shown in table 6.
Variable range	+10 dB～-10 dB min.	+15.67/-16.00 dB (DNC1) +15.34/-15.73 dB (DNC2)
Return link		
Gain	88 dB (nominal)	Details are shown in table 7.
Variable range	+10 dB～-10 dB min.	+15.77/-15.47 dB (UPC1) +15.62/-15.68 dB (UPC2)
Amplitude-frequency characteristics		
Forward link	1.0 dBp-p max. (THR)	0.43 dBp-p max.
Return link	0.75 dBp-p max. (THR)	0.19 dBp-p max.
3 dB bandwidth		
Forward link	4 MHz nom. (THR)	4.0 MHz
Return link	N/A	
Group delay		
Forward link	200 nsp-p max. (THR)	Same as in the left
Return link	50 nsp-p max. (THR)	Same as in the left
Spurious D/U		
IF-band output		
In-band	35 dB min. 30 dB min. (C/3IM)	53 dB min. 52 dB min. (C/3IM)
Out-band	50 dB min. 30 dB min. (Harmonics, C/3IM)	33 dB min. (Harmonics) 52 dB min. (C/3IM)
20GHz-band output		
In-band	35 dB min. 25 dB min. (C/3IM)	43 dB min. 33 dB min. (C/3IM)
Out-band	50 dB min. 25 dB min. (C/3IM)	57 dB min. 33 dB min. (C/3IM)
Phase Noise	［-35-10logf］ dBc/Hz max.	Same as in the left
Out-band spurious		
Forward link	D/U 50 dB min. D/U 30 dB min. (Harmonics)	D/U 52dB min. D/U 33dB min. (Harmonics)
Return link	D/U 50 dB min.	D/U 57dB min.

Table 4 FLCE G/T

	G/T [dBK]		Remarks
	MSS	BSS	
Max.	15.6	15.5	LNA-A
	15.5	15.7	LNA-B
Nom.	14.9	14.8	LNA-A
	14.8	15.1	LNA-B
Min.	12.5	12.4	LNA-A
	12.4	12.5	LNA-B
Specification	10.0	10.0	T=290K

Remarks: Antenna gain is defined toward Kashima.

Table 5 FLCE EIRP

	EIRP [dBm]			Remarks
	MSS	BCN-L	BCN-H	
Max	80.1	62.2	62.2	TWTA-A
	80.2	63.0	62.9	TWTA-B
Nom.	79.7	61.8	61.8	TWTA-A
	79.8	62.6	62.5	TWTA-B
Min.	77.6	59.7	59.7	TWTA-A
	78.2	60.3	60.3	TWTA-B
Specification	73.0	56.0	56.0	NPR≧20dB

Remarks: Antenna gain is defined toward Kashima.

Table 6 Total gain of FLCE forward link

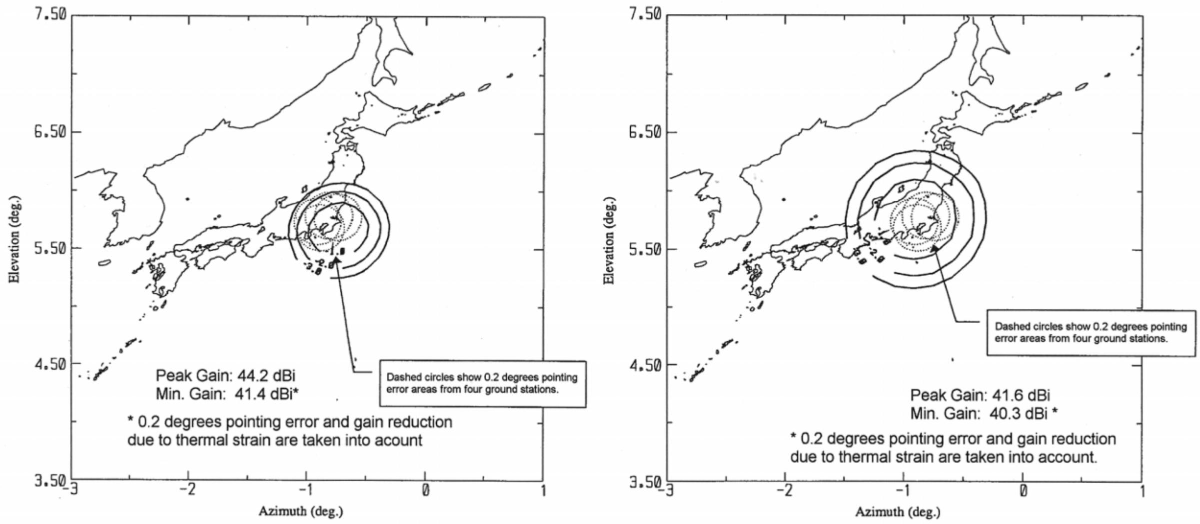
	Total gain of FLCE forward link [dB]				Remarks
	LNA-A／DNC1	LNA-B／DNC1	LNA-A／DNC2	LNA-B／DNC2	
Max.	119.5	120.6	120.2	121.0	THR signal
	120.3	121.2	121.0	121.8	OBP signal
	120.6	121.4	120.9	121.7	PKT signal
	118.7	120.0	122.0	122.7	BSS signal
Nom.	117.1	118.0	117.7	118.7	THR signal
	118.8	119.7	119.3	120.1	OBP signal
	118.9	119.9	119.2	120.1	PKT signal
	116.7	117.6	119.1	120.1	BSS signal
Min.	111.9	113.7	113.7	115.0	THR signal
	113.4	115.5	115.4	116.8	OBP signal
	113.8	115.8	115.3	116.6	PKT signal
	112.3	112.9	114.3	115.5	BSS signal
Specification	115	115	115	115	FL-DNC nominal gain (GAIN STS 16)

Remarks: Antenna gain is defined toward Kashima.

Table 7 Total gain of FLCE return link

	Total gain of FLCE return link				Remarks
	UPC1／TWTA-A	UPC1／TWTA-B	UPC2／TWTA-A	UPC2／TWTA-B	
Max.	90.7	91.0	90.8	90.8	THR signal
	90.8	91.1	90.7	90.6	OBP signal
	90.7	91.2	90.9	90.8	PKT signal
Nom.	90.3	90.6	90.4	90.4	THR signal
	90.4	90.7	90.3	90.2	OBP signal
	90.3	90.6	90.5	90.4	PKT signal
Min.	88.0	88.1	88.2	88.1	THR signal
	88.1	88.2	88.1	88.0	OBP signal
	88.0	88.2	88.3	88.0	PKT signal
Specification	88	88	88	88	FL-UPC nominal gain (GAIN STS 16)

Remarks: Antenna gain is defined toward Kashima.



Receiving antenna gain contour (30.622 GHz)　　Transmitting antenna gain contour (20.811 GHz)

Fig.5 Measured antenna gain contour of FL-ANT (Orbital position : 146 E)

Table 8 *FL-ANT proto-flight test results*

Item			Specification	Test result			Remarks
				Nom.	Max.	Min	
Gain	Uplink (30.622 GHz)	Kashima	40.4 dBi min.	43.9	44.2	42.3	*1
		Tsukuba		43.8	44.2	41.9	
		Koganei		43.6	44.2	41.4	
		Yokosuka		43.8	44.2	42.0	
	Downlink (20.811 GHz)	Kashima	38.4 dBi min	41.2	41.6	40.3	*1
		Tsukuba		41.4	41.6	40.7	
		Koganei		41.5	41.6	41.0	
		Yokosuka		41.4	41.6	40.7	
Polarization	Uplink		RHCP	RHCP			
	Downlink		LHCP	LHCP			
Axial ratio	Uplink		3.0 dB max.	2.2 dB max.			*2
	Downlink		3.0 dB max.	1.3 dB max.			*2

*1: Nominal gain values exclude pointing error, however maximum and minimum gain values include 0.2 degrees pointing error. Moreover, gain reduction due to thermal strain is taken into account in minimum gain value.

*2: Pointing error is taken into account.

*3: Location of Earth stations are 35.95N, 140.67E (Kashima), 35.72N, 139.48E (Koganei), 35.25N, 139.67E (Yokosuka) and 36.07N, 140.12E (Tsukuba).

6 Conclusions

The FLCE is one subsystem of an ETS-VIII mobile satellite communications experimental equipment. This subsystem was developed based on past inter-satellite feeder-link communications technologies, including those applied in the DRTS program. FLCE subsystem tests have been completed, confirming superior functions and performance. The FLCE is to be combined with the MCB in a satellite system, and after functional and performance testing of the mobile satellite communications experimental equipment, the H-IIA launch vehicle will launch the entire ETS-VIII satellite system into orbit. Once there, expectations are high that FLCE will perform according to plan in the mobile satellite communications experiments—key mission of the ETS-VIII.

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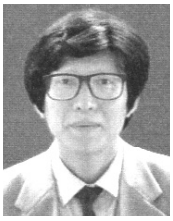
Satellite Development



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