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Notes on the Swarm SpaceBEE Satellites

In Sept 2020, I recorded an unknown emitter on 137.84 MHz. Each burst was about 50 kHz wide with a flat top. Similar bursts were also seen on 137.05 and 137.98 Mhz.

In 2021 there was a report of a similar signal on Scanner.ru blog site with the comment that it “looks like a LoRa signal”.

A bit of research showed that LoRa stood for Long Range and it was a new type of propriety RF modulation associated with two way communication for the “Internet of Things” using mainly the un-licenced IMS bands. More interestingly, one company (Swarm Technologies) were launching 150 1/4U cubesats for IoT data collection using LoRa on the 137-138 MHz Band for downlink and the 148-150 MHz Band for uplink.

Analysis of the SpaceBEE VHF downlink

Equipment

I initially used SDRangel software [1] with my existing VHF system to monitor the downlinks from the SpaceBEE constellation in the 137-138 MHz band. This software supports the Airspy SDR and has a built-in LoRa demodulator with adjustable Bandwidth, Spreading Factor and Coding Rate parameters. Three instances of the demodulator can be run simultaneously, one for each of the downlink frequencies, 137.050, 137.845 and 137.975 MHz.

The AirSpy SDR sample rate was 2.5 Msps with a decimation of 2 displaying a bandwidth 1.25 MHz centred on 137.5 MHz. After some experimentation, useful data was obtained and examined. The recovered data is displayed as 16 bytes per line of hex data plus the CRC with quality indicators for Header CRC, Header FEC, Payload FEC and CRC. The SDRangel LoRa decoder is based on reverse engineering the Simtech LoRa proprietary protocol hardware chip by others [2,3,4]. I found the program useful but error prone except on stronger signals.

The packets were of three lengths: 15 bytes, 87 bytes and infrequently longer packets with a similar structure. Typically, a 15-byte packet is transmitted every couple of seconds and a 87 byte packet about each minute.

I became aware that some Amateur Radio cubesats were using the LoRa communication protocol on 435 MHz and that they had developed a worldwide telemetry data collection system called TinyGS (Tiny Ground Station) based on cheap SX1276 chip based LoRa transceiver modules. I purchased a recommended module and installed the provided software. The module is command-line configurable, so it was easy to change the receiver frequency and other parameters to suit the SpaceBEE signal. The data quality was much improved, and it reliably decoded signals to -10 dB SNR. The LoRa module delivers only complete error free packets with the header and CRC removed. Any errored packets due to bad header or Data CRCs, short length etc are discarded.

Data

The initial recovered data revealed that the SpaceBEE satellite data packets are of variable length, implying the use of the LoRa Explicit Header mode. The Explicit Header is used to indicate to the receiver the packet length, packet code rate and an indication of a packet CRC being present.

Each data packet consists of a 6-byte header followed by a variable number of bytes.

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The Data Packet Header is made up of:

• a Message Number	3 byte, increments by one with each message		
• a Spacecraft Number	2 bytes, either 05XX or 06XX		See Table 1
• a Packet Type.	1 byte,	8C for a 15 byte packet	See Table 2
		CC for a 87 byte packet	See Table 3
		AC for all other packet lengths	See Table 4

The 8C packets could be acknowledgements of uplinked messages,
the CC packets could be system status, satellite state vectors and uplink time slots.
The AC Packets could be spacecraft telemetry to ground control stations, downlink messages or firmware updates to ground user devices, reportedly encrypted to the AES256-GCM standard.

There are a lot of unknows about this format. Analysis of the data continues.

References:

1. SDRangel https://github.com/f4exb/sdrangel
2. Revspace Decoding LoRa
3. Bastelle Research gr-lora
4. Rpp0 gr-lora
5. Swarm Technologies Inc Website - www.swarm.space
6. https://en.wikipedia.org/wiki/Swarm_Technologies
7. 2018 FCC Application for Mobile Satellite Service
   https://fcc.report/IBFS/SAT-LOA-20181221-00094
8. 2020 FCC Application to Modify the Authorization for the Swarm NGSO Satellite System
   https://fcc.report/IBFS/SAT-AMD-20200504-00041
9. https://en.wikipedia.org/wiki/Swarm_Technologies
10. https://space.skyrocket.de/doc_sdat/spacebee.htm
11. https://learn.sparkfun.com/tutorials/satellite-transceiver-breakout---swarm-m138---hookup-guide/all

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Table 1: SpaceBEE Hex SCID to SpaceBEE-nnn

nnn on 137.050 MHz, nnn on 137.845 MHz, **nnn** on 137.975 MHz.
"?" indicates SCID seen but not yet matched to SB-nnn. ~~nn~~ indicates decayed spacecraft

	050X	051X	052X	053X	054X	055X	056X	057X	058X	059X	05AX	05BX	05CX	05DX	05EX	05FX	060X	061X	062X	063X	064X	065X	066X	067x
0						~~30~~							~~91~~		111		133	146	121			?		?
1						104													**115**			?		?
2			152								148	100						153	123					?
3					110													154	116	?	?			
4						~~40~~										**130**	137		127					?
5											~~76~~		~~96~~			132	135		122		?			
6																	151		124		?			?
7										150			~~98~~			136	?		114					?
8								~~47~~			~~78~~		~~99~~			129	142		125		?			?
9														101			141		126					?
A				21										102		138			117		?			?
B														103		139	155		118		?			?
C										55				105		128	147		119		?			
D												~~88~~		106			145		120	?	?			
E											108			107		134	149		**112**		?			
F										63				109			140	113		?	?			

LoRa sync word 12 hex, Bandwidth 41667 Hz, Spreading Factor 8 for 137.05 MHz and 137.845 MHz, Spreading Factor 7 for 137.975 MHz

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Table 2: SpaceBEE packet descriptions

15 byte packet
d6b54d9f058c 2f1284 a71d03 2aa54d

	Parameter	**Hex, Little Endian**	**Type**	**Value**		**Interpretation**
Header 6 bytes	Message Number	d6b5 4d	Int16+int8	5092822		
	Spacecraft Identification	9f05	Int16	1439		SpaceBEE-63
	Packet Type	8c	Int8	104		15 byte packet
Data 9 bytes	?	**2f12** 84	Int16+int8			84 + Uplink device ID ?
	?	a71d 03	Int16+int8			03 + unknown
	?	2aa5 4d	Int16+Int8			Uplink device msg # ?

Notes:

See Table 1 for SCID to SpaceBEE-nnn
The Message Number least significant byte is incremented each packet.
The Message Number most significant byte seem to be incremented modulo 65536, approximately daily but is not synchronised to 000 UTC.
Acknowledgement packet of ground Device's "Request to Send" uplink message?
E.G. Uplink Device ID (**2f12**) appears in the next 87-byte packet's Device Acknowledgement field, two seconds later.

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Table 3: 87 byte Packet

d7b54d9f05cc 0000c0c 7744b0159db9b62 4ccecdc1dfdf2143a9260800 978a80 232a00 0c 28 e6fb10dc0a03000881de6b0b060800 2f120459db9b62 bc090455db9b62 c7090411db9b62 25120401db9b62 281204ffda9b62

	Parameter	Hex, Little Endian	Type	Values	Remarks
Header 6 bytes	Message Number	d7b54d	Int16+ Int8	5092823	
	Spacecraft Identification	9f05	Int16	1439	SpaceBEE-63
	Packet Type	cc	Int8	204	87 byte packet
Data 81 bytes	fixed field	0000c0	3x Int8		
	?	c774 4b 01	4x Int8		?
	UTC Time Stamp	59db9b62	Int32	Saturday, 4 June 2022 22:23:21	
	Satellite Subpoint Latitude	4ccecdc1	SPFP	-25.72573	(^{o}North +, ^{o}South -)
	Satellite Subpoint Longitude	dfdf2143	SPFP	161.8745	(^{o}East +, ^{o}west -)
	Satellite Subpoint Altitude	a9260800	Int32	534185	Metres
	?	978a 8023	2x Int16		?
	?	2a00 0c28	2x Int16		?
	Telemetry?	e6fb10dc0a03000881de6b0b060800	15x Int8		?
	Device Acknowledgement?	**2f12** 04 59db9b62	Int16 Int8 Int32	Saturday, 4 June 2022 22:23:21	04 + Uplink ID + TS
	Device Acknowledgement	bc09 04 55db9b62	Int16 Int8 Int32	Saturday, 4 June 2022 22:23:17	
	Device Acknowledgement	c709 04 11db9b62	Int16 Int8 Int32	Saturday, 4 June 2022 22:22:09	
	Device Acknowledgement	2512 04 01db9b62	Int16 Int8 Int32	Saturday, 4 June 2022 22:21:53	
	Device Acknowledgement	2812 04 ffda9b62	Int16 Int8 Int32	Saturday, 4 June 2022 22:21:51	

Notes:
Beacon Packet: indicates active spacecraft to ground device, contains spacecraft GPS orbital data (latitude, longitude, altitude), telemetry? and acknowledgment of the previous 5 successfully uplinked messages?

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Table 4: N byte Packet

70 Byte AC Packet Example
b15185 0806 ac f664b1 b28b3a 192385 6b15a4 0000b4 bea5**2e**
0600002aa6231b8ecb67f2be2710795d7950d0ccc47b02ac30b414dcdece3c54a8cf80a33bdd1e4432ac75ec911e

Parameter		Hex, little endian	Type	Value	Interpretation
Header 6 bytes	Message Number	b15185	3 x Int8		
	Spacecraft Identification	0806	Int16		SB-129
	Packet type	ac	Int8	172	N byte packet
AAD? 24 bytes		f664b1	3 x Int8		
		b28b3a	3 x Int8		
		192385	3 x Int8		Uplinked msg no?
		6b15a4	3 x Int8		
		0000b4	3 x Int8		
		bea5**2e**	3 x Int8		
AES? 46 bytes		0600002aa6231b8ecb67f2be2710795d 7950d0ccc47b02ac30b414dcdece3c54 a8cf80a33bdd1e4432ac75ec911e	46 x Int8		

Notes:
N-byte packets, where N varies from 70 to 244 byte encrypted message to ground devices.
Value of Byte 24 (**2e** hex, 46 decimal) = Number of bytes (46) in AES section following.
AES 256 with Galois/Counter Mode (AES-GCM) provides both authenticated encryption (confidentiality and authentication) and the ability to check the integrity and authentication of additional authenticated data (ADD) that is sent in the clear. AES-GCM is specified in NIST Special Publication 800-38D.
https://www.cryptosys.net/pki/manpki/pki_aesgcmauthencryption.html

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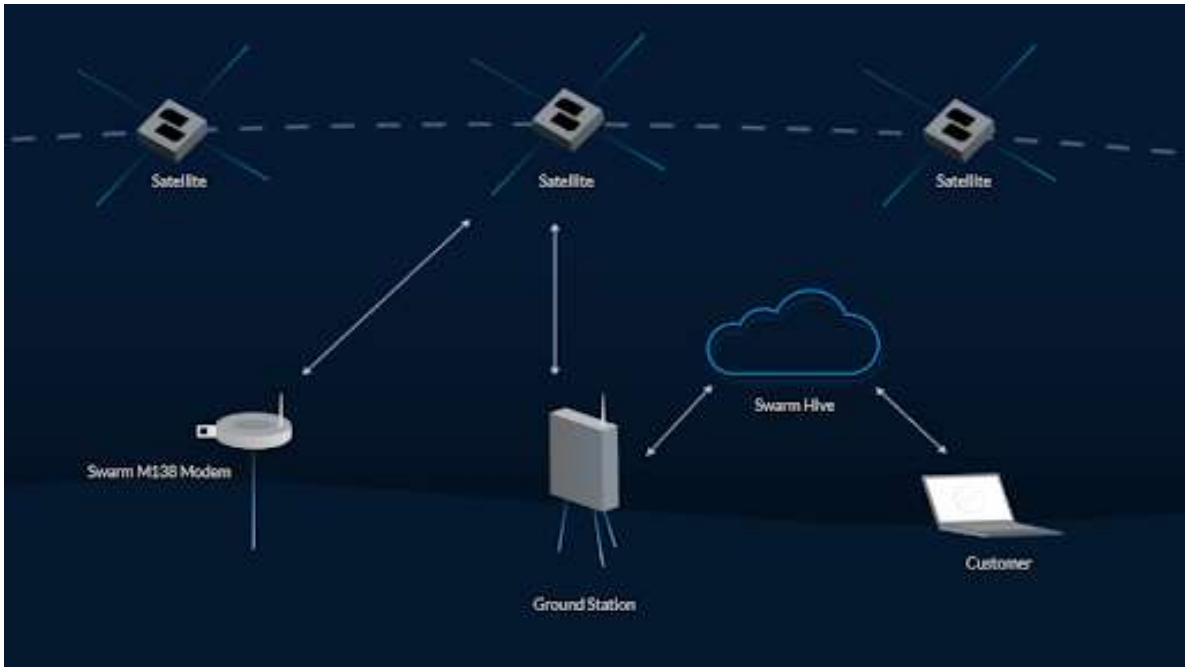

Swarm SpaceBEE Network

When an active SpaceBEE satellite passes over a location, it is transmitting an 87-byte beacon packet per minute to Swarm ground modems that are in their receiver-ready state. Once a modem receives this satellite beacon, it will attempt to transmit any queued message packets to the satellite. Message packets that are successfully received by the satellite will be acknowledged by the satellite back to the modem by a 15-byte packet.

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SpaceBEE launches

Date	#	Spacecraft	Orbital Plane
12/1/2018	4	SB-1 to 4	98^{o}
3/12/2018	3	SB-5 to 7	98^{o}
29/6/2019	2	SB-8 to 9	45^{o}
3/9/2020	12	SB-10 to 21	98^{o}
20/11/2020	18	SB-22 to 39 and NZ-1 to 6	94^{o}
24/1/2021	36	SB-40 to 75	98^{o}
28/2/2021	12	SB-76 to 87	98^{o}
30/6/2021	24	SB-88 to 111 and NZ-7 to 10	98^{o}
15/3/2022	16	SB-112 to 127 and NZ-11 to 14	98^{o}
1/4/2022	12	SB-128 to 139	98^{o}
2/5/2022	16	SB-140 to 155 and NZ-15 to 22	98^{o}
3/1/2023	12	SB-156 to 167	98^{o}

Totals	167		

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SpaceBEE launches and decays to 3 June 2023

12/1/2018	3/12/2018	29/6/2019	3/9/2020	21/11/2020	24/1/2021	28/2/2021	3/6/2021	15/3/2022	1/4/2022	2/5/2022	31/1/2023				
1	5	8	10	22	40	76	88	112	128	140	156				
2	6	9	11	23	41	77	89	113	129	141	157				
3	7		12	24	42	78	90	114	130	142	158				
4			13	25	43	79	91	115	131	143	159				
			14	26	44	80	92	116	132	144	160				
			15	27	45	81	93	117	133	145	161				
			16	28	46	82	94	118	134	146	162				
			17	29	47	83	95	119	135	147	163				
			18	30	48	84	96	120	136	148	164				
			19	31	49	85	97	121	137	149	165				
			20	32	50	86	98	122	138	150	166				
			21	33	51	87	99	123	139	151	167				
				34	52		100	124		152					
				35	53		101	125		153					
				36	54		102	126		154					
				37	55		103	127		155					
				38	56		104								
				39	57		105								
					58		106								
					59		107								
					60		108								
					61		109								
					62		110								
					63		111								
					64										
					65										
					66										
					67										
					68										
					69										
					70										
					71										
					72										
					73										
					74										
					75										
4	3	2	12	18	36	12	24	16	12	16	12				
4	0	2	10	18	29	12	12	0	0	0	0				

Source: Space-Track.org Satellite Catalog, SATCAT

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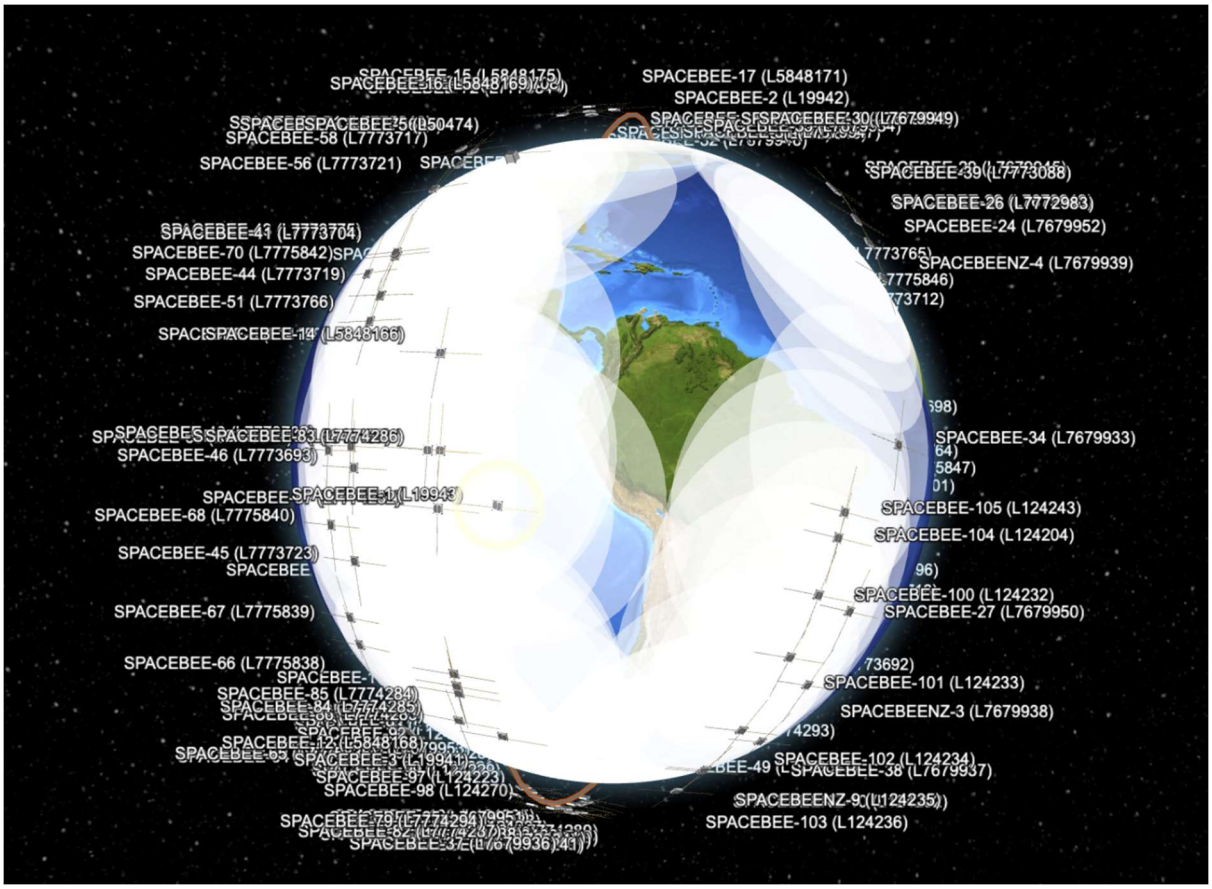

The Lxxxxx labels are LeoLab Tracking Service designations. Rollout

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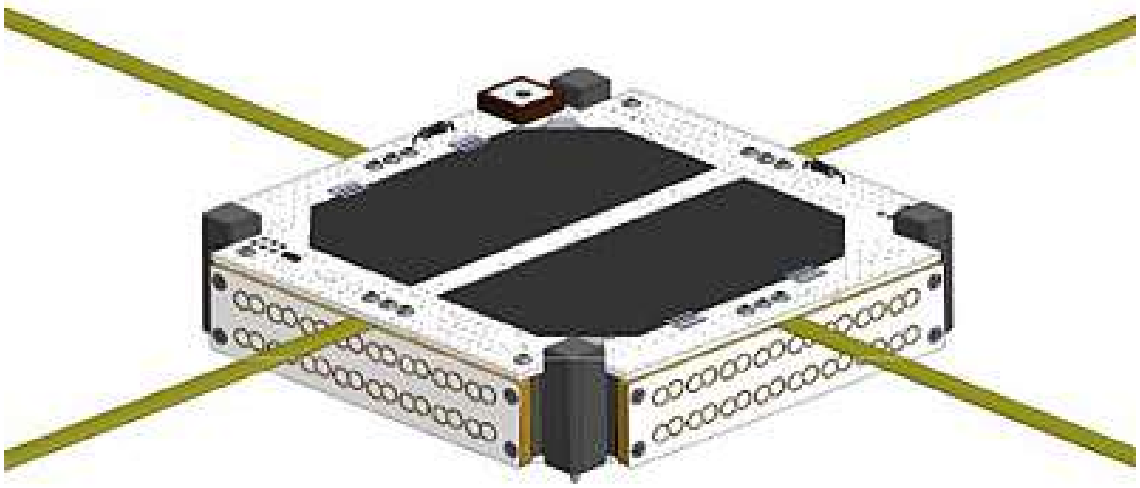
SpaceBEE Satellites



A CAD rendering of the Swarm satellite (antennas are cropped in this rendering).

BEE is an acronym for Basic Electronic Element. There is little to no technical information published about the SpaceBEEs. The following is gleamed from FCC documents cited.

1/4U CubeSat format (110 x 110 x 28 mm), approximately 400 grams

Flight Computer
- Onboard processor
- Memory

Attitude Determination and Control
- Passive stabilisation
- Active Magnetorquer system,
- L1 1575.42 ± 12 MHz GPS receiver and patch antenna
- 9 Degrees of freedom DOF Inertia Management Unit IMU eg. (Comparison)
- 3 axis magnetometer
- 4 passive Ku-band radar Van Atta retro-reflectors, 100 x 25 mm

Power
- 12.5 WHr Li-ion 18650B cell, 3.7V, 3400 mAHr
- 4 solar panels, 80 x 40 mm
- Temperature, voltage and current sensors
- Power control and Distribution

Communications
- VHF Band communications: 137-138 MHZ downlink, 148-149.9 MHz uplink
- Deployable metal tape circularly polarised turnstile antenna.

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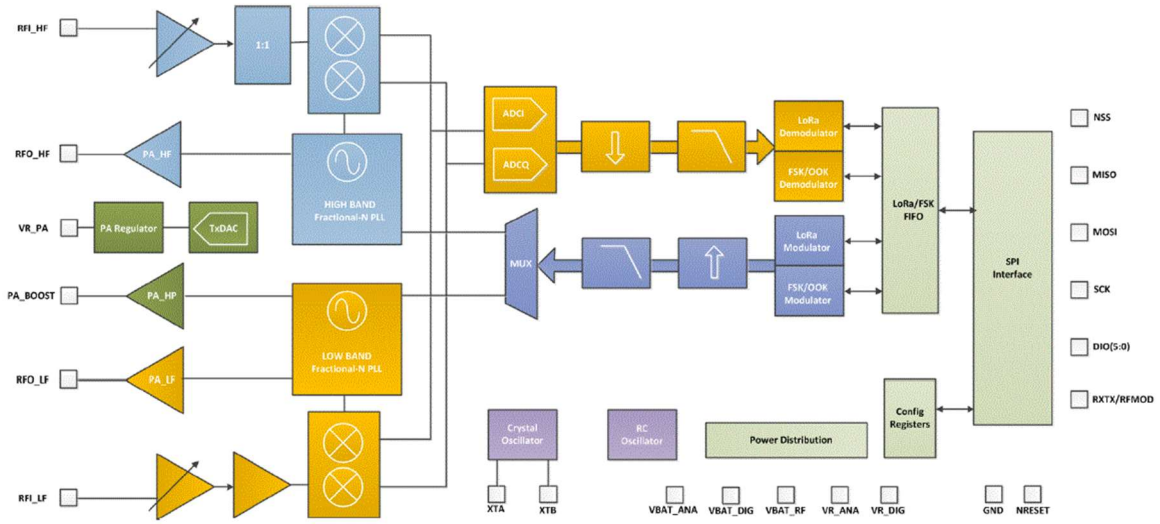
Nylon monofilament ‘melt wires’ release the antennas 45 minutes after on-orbit deployment.
LoRa modulation, Proprietary protocol.
Radio: originally Swarm Tile01 Modem, upgraded to Swarm M138 Modem in October 2021

The LoRo transceiver chip is made by Semtech. See AN1200.18 and AN1200.22



https://www.semtech.com/products/wireless-rf/lora-core/sx1276

Press Release -Semtech and Swarm Deliver Satellite Communications With LoRa®

Collaboration integrates LoRa® devices with Swarm’s satellite communications network

CAMARILLO, Calif., Jan. 27, 2021 – Semtech Corporation (Nasdaq: SMTC), a leading supplier of high performance analog and mixed-signal semiconductors and advanced algorithms, announced that Swarm Technologies, a global satellite communications network developer, has integrated Semtech’s LoRa® devices into its connectivity solution that enables two-way communications to and from its satellites in Low Earth Orbit (LEO).
<snip>

https://www.semtech.com/company/press/semtech-and-swarm-deliver-satellite-communications-with-lora

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SpaceBEENZ spacecraft

These spacecrafts are similar to SpaceBEE but operate in another band, maybe 400 MHz.

Photo shows 6 out of 12 spacecraft with a shorter antenna arrangement, GPS patch antennas not fitted and Ku-band retro-reflector panels not fitted.

Photo of the 20/11/2020 launch of 6 SpaceBEE and 6 SpaceBEENZ spacecraft before being loaded into 3U Maxwell dispenser.