Future HTS Satellite Output Section Design

AsiaSat Engineering Department – White Paper

HU Hai, Senior Communications Systems Engineer, AsiaSat

September 2017

Comparison of configurations that practically improve future HTS throughput and flexibility

Executive Summary

The recently launched multi-spot beam high throughput satellite (HTS) systems are capable of delivering several tens to more than 100 Gbps throughput, showing the users as well as the satellite operators an opportunity to significantly lower the cost of the satellite data service which was dominated by the wide beam Fixed Satellite Service (FSS) satellites. To accommodate even higher data-intensive services in the future and compete even with the ground broadband providers in some under-served markets, a much more competitive and advanced HTS system that can support at least one magnitude higher throughput and is fully flexible in relocating the payload re-sources should be envisaged. In the roadmap to the future HTS, one of the most critical part lies in the out-put section design. Since it handles the high power microwave signals, the output performance is directly related to the spacecraft sizing, spectrum efficiency and hence the total throughput that can be harvested. This paper describes and compares the feasible output section technologies and implementation configurations that can practically improve the future HTS' throughput and flexibilities.

Technologies for the Future HTS Output Section

An HTS repeater system consists of the input section and the output section. The input section is mainly the low power payload of the HTS, which handles the received uplink signal from the gateway forward beams and the user return beams. It picks up the RF carriers from the receiving (Rx) antenna, amplifies them, frequency converts and routes them to the output section. The output section is mainly the high power payload of the HTS, which power amplifies the signals routed from the input section, and then feeds them to the designated downlink beams by the transmitting (Tx) antenna. The HTS antenna system receives the input signal and transmits the output signal of the same beam simultaneously from the same cluster feed.

A future Tbps-class HTS that covers East Asia is illustrated in Figure 1. To make such high throughput possible, the number of beams as well as the beam capacity of the HTS must be significantly increased. Since the beginning of HTS, most of the industry’s efforts was endeavored to feed cluster integration and RF pay-load performance improvement. On the input section, the noise figure is reduced to as low as possible, while on the output section, the RF output power is augmented to as high as possible, resulting in a high overall link carrier-to-noise ratio, so that the capacity of each beam and the whole satellite can be enhanced. Unfortunately, the more challenging problem faced now is that not all designed capacity would be consumed. With more HTS joining the competition, simply increase the throughput for a future HTS design may not be enough.

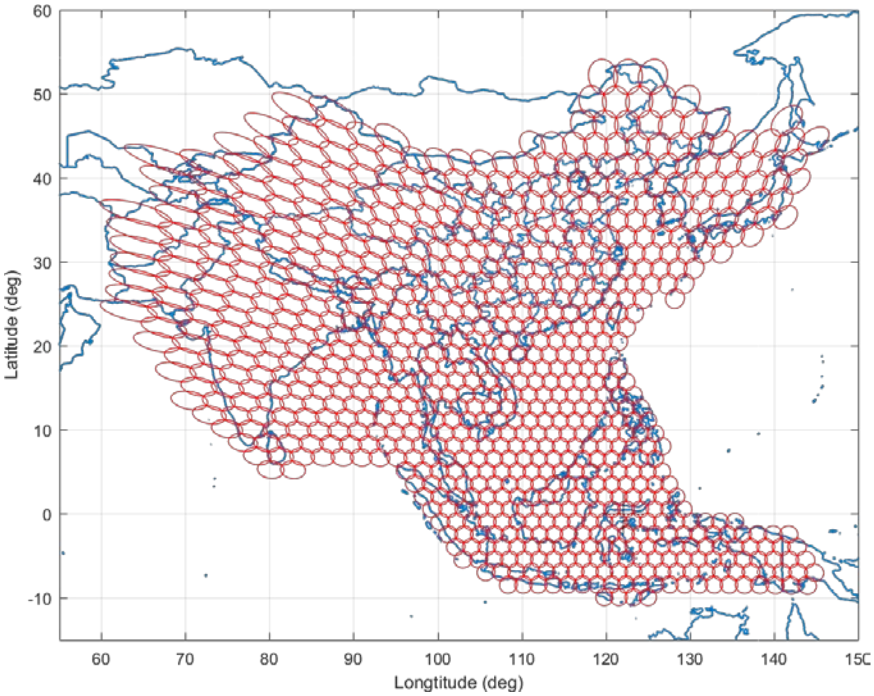
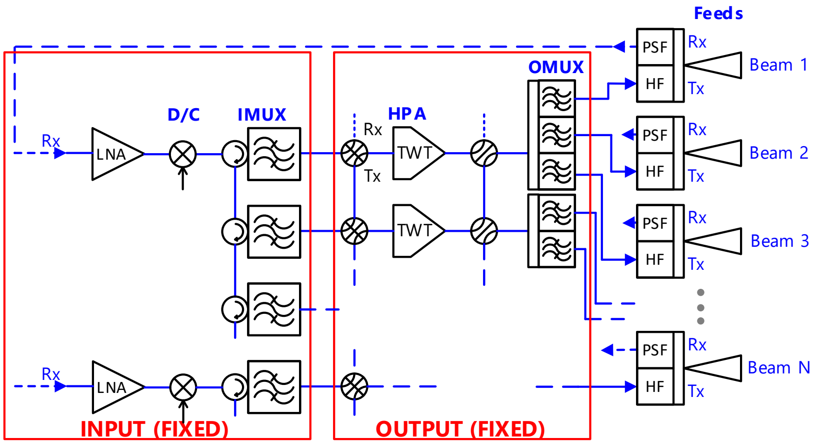


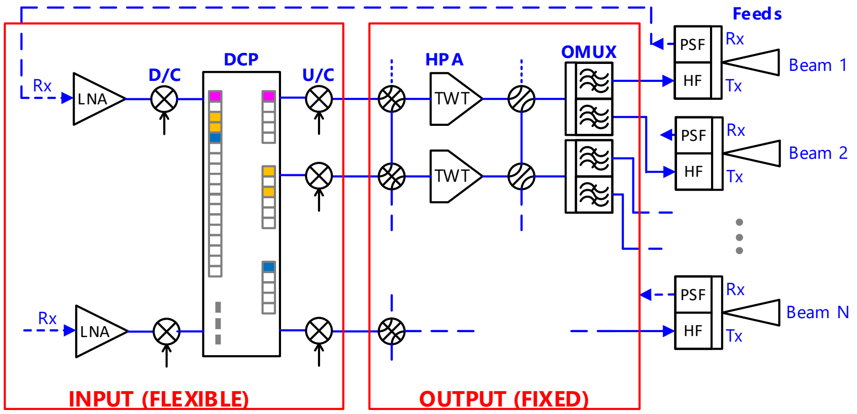
Figure 1. A future multi-beam HTS layout over East Asia for > 1Tbps throughput

What the HTS operators craved for is full flexibility in order to readily reassign the payload resource during the lifetime of the satellite. On the input section, the flexibility can be realized by a digital channelizing processor (DCP). A typical onboard DCP is capable of signal carriers' digitization, segmentation, routing, reassembling and multi-casting in between different beams, easily achieving the star, mesh and loopback net-work topologies as required. Many useful functions such as on-board carrier spectrum analysis, anti-uplink jamming, and gateway deployment ramp up can also be achieved by DCP, bringing solid flexibility to the HTS operators. Currently, the DCP begins to be more popular and is adopted by more and more HTS pay-load designs, and its technology is still fast evolving towards the future specifications of ultra-wide processing bandwidth (BW), lower DC power consumption and even higher processing speed. The only limitation is, with DCP alone, the beam throughput flexibility cannot be truly fulfilled without the design change on the output section.

(a)



(b)



(c)

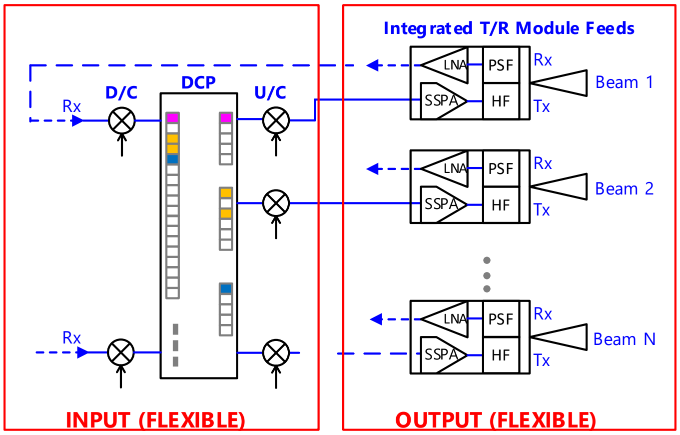


Figure 2. HTS payload evolution illustration: a). conventional fixed input/output sections, b). flexible input section with DCP, and c) flexible input/output sections with DCP and integrated T/R module cluster feeds antenna.

A desirable “future-proof” HTS must possess the true throughput flexibilities, including 1) beam BW adjust-ability, 2) beam power adjustability, and 3) beam shape adjustability. With the use of DCP, the input BW adjustability can be achieved by the control of carrier BW, sharpness and regrowth levels. The band-limiting input multiplexer (IMUX)’s function can be taken by the digital processor, as is illustrated in Figure 2(a) and (b). However, the beam absolute BW is still limited by the channel BW of the output multiplexer / de-multiplexer (OMUX). Nowadays, most commercial HTS still adopt OMUX design (Figure 2(a), (b)). This is because conventional traveling-wave tube amplifier (TWTA) is still widely used for the microwave high power amplification. The merits of a TWTA are the high output power, high power-added efficiency (PAE), high operating frequency and wide operating bandwidth, but its heavy mass, bulky profile and high DC power consumption features also virtually prevent the configuration of single beam per TWTA for an HTS with hundreds of spot beams. When multiple beams per TWTA has to be configured, carefully-designed OMUXs tailing to the TWTA output ports must be used to channelize and route the amplified microwave signals to the designated downlink beams. Once the OMUXs are manufactured and installed, the output beam BW adjustability is then constrained. The corresponding beam power adjustability would also be limited due to the multi-beam per TWTA configuration. Even though the recently-proposed tunable output filters may help the beam BW flexibility, their complex tuning mechanisms cannot guarantee the reliability offered by the conventional fixed OMUXs.

To realize the full flexibility of the output section, Monolithic Microwave Integrated Circuit (MMIC) based transmit/receive (T/R) modules have to be used and integrated with the HTS antenna feeds. Each module contains the MMIC low noise amplifier (LNA) and the MMIC solid-state power amplifier (SSPA) with significantly reduced profile, mass and DC power consumptions compared to their conventional discrete counterparts in the input and output sections. As shown in Figure 2(c), the LNA and the SSPA in the T/R module immediately connect to the Rx and Tx ports of each feed, introducing much lowered cable loss and cable mass than those in a traditional HTS. With the one T/R module per beam design, no fixed narrow-band channelizing devices are needed throughout the signal path.

The frequency selectivity is solely driven by the DCP at the input, implying that each beam can occupy the whole available downlink spectrum without fixed multi-color scheme used in a conventional HTS design. The beam traffic and inter-beam interferences can be optimized by the carrier frequency and BW allocations managed by the ground system with the aid of the onboard DCP, and thus the beam capacity and BW flexibility can be greatly improved.

The MMIC-based active T/R module antenna feed is also a cost-effective output-end solution to the future HTS, where extremely narrow spot beams of high frequencies (e.g. in Ka-band) are massively deployed. Thanks to the high antenna gain of the narrow spot beam, the downlink output power requirement on the onboard SSPA can be relaxed, which in turn reduces the cost of the MMIC module. Traditionally, such active T/R antenna feeds are more common in the low frequency (e.g. L and S-band) satellite payloads where Gallium Arsenide (GaAs) semiconductors are well competent with. However, with many years' research and development in the industry, the Gallium-Nitride (GaN) based MMICs have been gradually adopted in the Ku and Ka band satellite communication payloads as well. The GaN-based LNA boasts of high robustness and higher linearity performance. The wider bandgap, higher operable junction temperature and higher electron mobility properties of GaN semiconductor make it more appropriate for the high frequency space-borne power amplifier than those by GaAs. Moreover, the relatively higher output impedance of GaN amplifiers eases the matching network's design, while the high drain voltage simplifies the DC/DC power supply net-work's design, which all favor the integration and packaging of the MMIC for the HTS application. The use of GaN MMIC also facilitates the miniaturization and integration of the active and the passive components, e.g. gain blocks, phase shifters, attenuators, mixers, oscillators and even switches and isolators that a repeater system requires, onto the same microwave chip.

With the help of specialized software and hardware module in the DCP, the MMIC-based active T/R array-feed antenna system can be easily configured to realize digital beamforming (DBF). The DBF function is the prerequisite of the advanced beam flexibilities, such as electrical beam-steering and beam shape adjustment, which are beneficial to the future HTS business when high resolution conformal coverage contours are required.

The MMIC-based active T/R module configuration simplifies the feed network design. Not to mention the mass saving by the T/R module itself, the complex waveguide feed networks existing in a traditional HTS can now be replaced by a straightforward design with much lighter cables. The corresponding path loss saving is translated into a much better noise figure at the input section and a higher downlink power at the output section. The redundancy design is also made straightforward thanks to the simplified network and the smaller beams used. If DBF function is equipped, any single beam failure can be compensated by beam-forming and would only bring graceful degradation on the coverage instead of leaving a black hole as in a traditional HTS system.

Output Section Performance Comparison

To show the effect of MMIC-based HTS output design, this section compares its performance with the conventional TWTA-based HTS design. Assuming a fixed coverage area, e.g. China, illuminated by the beam layouts of different beam sizes, the corresponding number of beams and the downlink spot beam gains are shown in the first two rows of Table 1. The downlink EIRP of the spot beams with 5 W, 7 W, 10 W SSPAs as well as 150 W TWTA cases are also shown in Table 1. The SSPA operation assumes 2 dB OBO and adopts 1 beam per amplifier configuration, while the TWTA operation assumes 3 dB OBO and adopts 2 beams per amplifier configuration. It can be observed the beam antenna gain makes the greater portion of the EIRP when spot beam size decreases. Even the TWTA case always gives a higher downlink EIRP than the SSPA cases, it has to be reminded that the overall link performance would not be limited only by the beam EIRPs, the other factors like the inter-beam interference, inter-modulation interference, adjacent satellite interference, uplink carrier to noise ratio, etc., can also become the bottleneck of the link performance when the beam size shrinks, leaving the high downlink EIRP of marginal help to the throughput.

With the narrower spot beams employed in the future HTS, the beam uplink G/T will also increase, which benefits the uplink performance and thus the total throughput of the HTS. The typical Ka-band beam peak G/T values of different beam sizes are listed in Table 2 for the reference.

The HTS throughputs and the estimated DC power consumptions are compared in Figure 3 using the number of beams and beam sizes shown in Table 1, and the BW per user beam is assumed to be 250 MHz on the forward link. It can be easily found when the beam size is larger than 0.5 deg, the TWTA-based solution provides more throughputs with the realizable HPA DC power levels (<20 kW). However, when the beam size keeps reducing, the TWTA DC power consumption would be too high to be acceptable on a GEO satellite platform. On the other hand, the MMIC-SSPA based solution provides the comparable throughput with a much lowered DC power consumption, even when the total throughput reaches 400 Gbps (399 x 0.3 deg spot beams). In this paper, Figure 3 compares only the DC power with the throughputs, but other key physical parameters of a satellite, such as the payload mass, HPA thermal dissipation, etc., can also be com-pared, only with the same conclusion reached that the MMIC-based technology would be more competitive and cost-effective in the output section design of a future HTS. If taking 60 dBW EIRP as the line of demarcation of a good downlink design, then the best trades between HTS beam size and SSPA power level are: 5 W for 0.3 deg, 7 W for 0.35 deg and 10 W for 0.4 deg.

Beam Size (deg)	1.50	1.00	0.60	0.50	0.40	0.35	0.30
# of beams required	16	36	100	144	224	293	399
DL spot beam peak gain (dB)	42	45	50	51	53	54	56
1 beam per **5W** SSPA, DL EIRP (dBW)	46	49	54	55	57	58	60
1 beam per **7W** SSPA, DL EIRP (dBW)	47	51	55	57	59	60	61
1 beam per **10W** SSPA, DL EIRP (dBW)	49	52	57	58	60	61	63
2 beams per **150W** TWTA, DL EIRP (dBW)	54	58	62	64	66	67	68

Table 1 HTS spot beam downlink EIRP trade with beam sizes and HPAs of different output power levels.

Beam Size (deg)	1.50	1.00	0.60	0.50	0.40	0.35	0.30
UL spot beam peak gain (dB)	44	47	52	53	55	57	58
UL beam G/T (dB/K)	13	17	21	23	25	26	27

Table 2 HTS spot beam uplink G/T change with beam sizes.

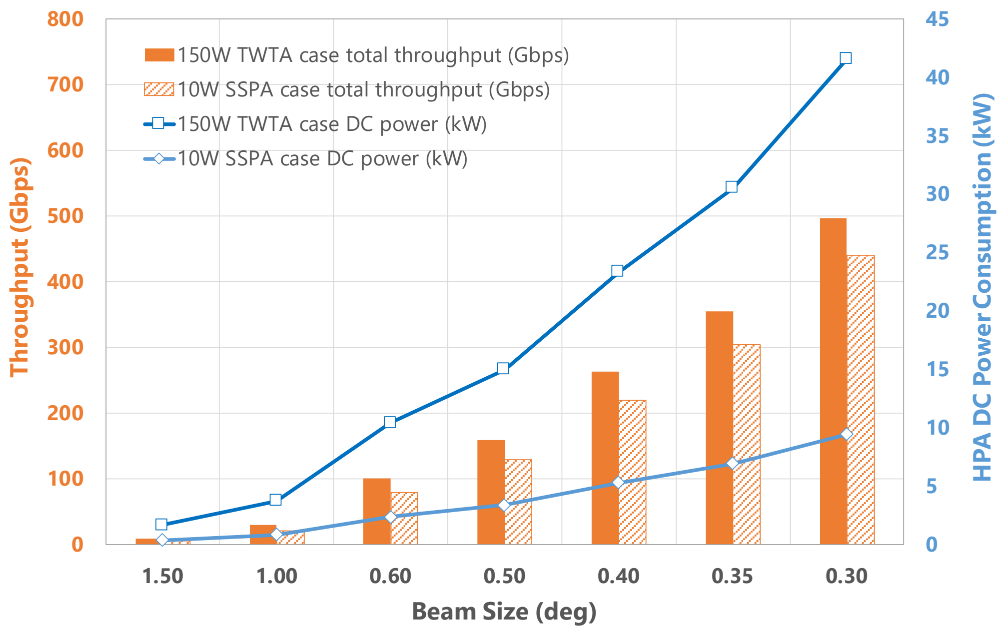


Figure 3 Throughput and DC power consumption trend for a HTS covering the same area with different beam sizes and HPA types.