A Conjugated-Phase Antenna/Transponder Array

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The current AMSAT satellites were almost all designed considering the launch and space environment constraints in the first place. The actual payload had to be fitted into an already defined space vehicle. Of course, the performance of any satellite can only be improved if the payload is considered first and then a suitable space vehicle is designed around the payload requirements.

Efficient communication satellites need efficient transponders and efficient antennas. Simple omnidirectional antennas can only be used in low Earth orbits. Higher orbits require directional antennas and suitable procedures to keep these antennas pointed towards the Earth. Either the satellite attitude has to be stabilized or the antenna beam has to be steered electronically.

There is no simple attitude stabilization procedure to keep the antennas oriented towards the Earth and the solar panels well illuminated at the same time in a low-inclination, high Earth orbit like a geostationary-transfer orbit (GTO), an ARSENE-like geodrifter or even a true geostationary orbit. On the other hand, a GTO is a very useful orbit for satellite communications and there are many launch opportunities that do not require any further propulsion on the satellite itself.

Future amateur communication satellites will probably require electronic antenna beam steering for many reasons, the most important being simple attitude stabilization and system redundancy offered by the large number of small and independent antennas, receivers and transmitters. On the other hand, a phased-array antenna requires additional signal processing (many phase shifters) and a control computer to steer them.

A rather simple solution for amateur satellites with global (hemispherical) coverage in a high Earth orbit is a retrodirective transponder. A retrodirective transponder uses similar antenna arrays for signal reception and transmission. The individual transponders are operated coherently with the same local oscillator and are connected to the antenna arrays so that the signal is transmitted back exactly in the same direction from where it came.

When the antenna beams have to be steered electronically over a very wide angle, like in the case of a spin-stabilized satellite, not all of the antennas actually see the groundstation at the same time. In this case, phase conjugation simplifies the design of a retrodirective transponder since the received signals are routed to transmitting antennas located approximately in the same position as shown on Figure 1.

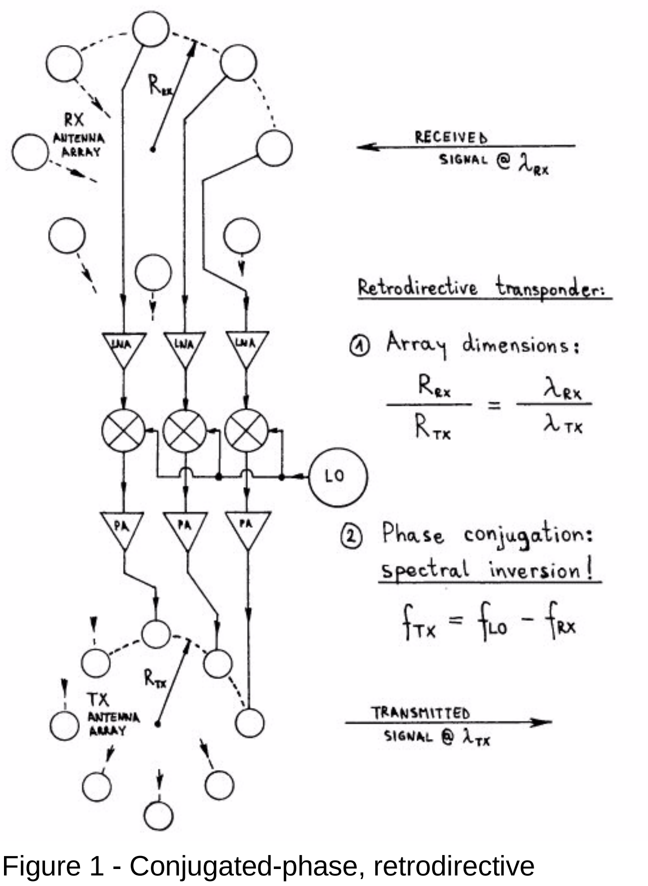

Figure 1 - Conjugated-phase, retrodirective transponder

Phase conjugation can be most easily achieved in the individual transponder modules using spectral inversion (inverting transponders). An additional but obvious requirement is that the transmitting antenna array is similar to the receiving antenna array and all dimensions, in particular the positions of the single antennas, are exactly scaled in frequency.

The design of a GTO or ARSENE-like orbit amateur communications satellite is shown on Figure 2. The satellite is spin stabilized with the spin axis parallel to the Earth rotation axis. Spin attitude stabilization also allows simple thermal management. Little if any manouvres are required since the spin axis needs not be reoriented during the satellite lifetime.

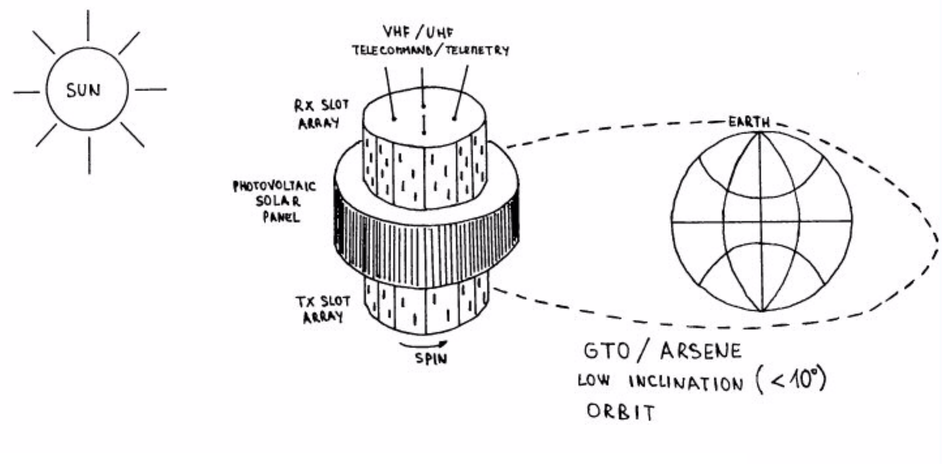

Figure 2 - Retrodirective-transponder satellite design

Due to the spin stabilization, the antenna beams need to be counterrotated to track the user groundstations. Therefore the antenna beam only needs to be steered in one dimension in the equatorial plane, while the single array elements can already provide a suitable radiation pattern in the north-south plane. Very suitable antenna elements are waveguide slot arrays.

Considering the antenna array dimensions and the amateur satellite power and mass budget, a S/C-band or a C/X-band transponder could probably be built. Besides the main antenna/transponder array, the satellite also carries VHF/UHF equipment for telecommand and telemetry with omnidirectional antennas. The latter could also provide a limited transponder service when the final orbit and attitude are reached. A high-resolution spin-scan camera with a line CCD sensor could serve as a precision navigation aid and provide high-quality pictures at the same time.

The actual satellite hardware developement should of course start with the developement and testing of the single antenna array elements and transponder modules. The proposed mechanical design is shown on Figure 3. The antenna element and transponder module make one single block. The antenna element is a waveguide slot array.

The electronics is installed directly on the backside of the waveguide. In this way, the waveguide acts at the same time as a mechanical support, as a heat sink for the power amplifier and as a radiation shield for the delicate electronic devices. Further, there are no transmission-line losses since the RF electronics is installed directly on the antenna.

The proposed waveguide slot array has a very broad radiation pattern in the equatorial plane approaching 180 degrees. In this way almost half of the antenna/transponder modules are in use at any given time. The design is inherently failure-proof since failures of the single transponder modules just decrease the overall radiated power. The only component that is not redundant is the local oscillator that must be common (coherent) for all of the modules.

The design of the single transponder modules is complicated by the fact that very accurate amplitude and phase tracking among the individual modules is also required. Therefore a very reliable, no-tune design is required. Fortunately, recent developements of the mobile phones made available many new and reliable microwave components.

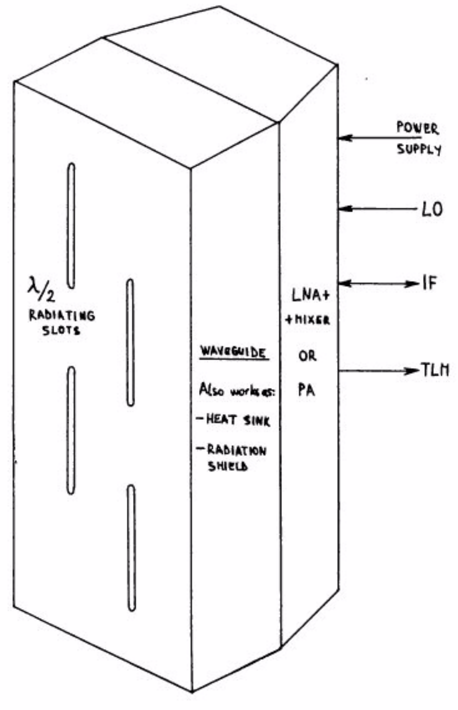

Figure 3 - Antenna/transponder module

The final question is the transponder power management both for the active transponders and for the inactive modules on the other side of the satellite. Of course, a linear design is highly desirable, possibly with a much reduced power consumption in the undriven state. On the other hand, due to the parallel operation of many modules in different conditions due to the different locations of the single antennas, the IMD of limiting transponders may be reduced to
tolerable levels.