QUASAT - A SPACE-BORNE ELEMENT FOR WORLD-WIDE VERY-LONG-BASELINE RADIO INTERFEROMETRY.

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Radio interferometry in astronomy has provided ever-increasing angular resolution as techniques advanced from early two-element cable-linked interferometers, through multi-element radio-linked interferometers, to Very-Long-Baseline Interferometry (VLBI) for which no real-time connections between the elements are required. For VLBI, the resolution is limited by the size of the Earth which limits the separation of the radio telescopes forming the elements of the array. That VLBI is successful at all demonstrates that there is no fundamental technical barrier to extending interferometer baselines into space.

In late 1982, the first concrete steps were taken in Europe and in the USA to study the feasibility of a space-borne radio telescope working in conjunction with ground-based arrays of telescopes to form an interferometer whose combined angular resolution and image quality is unprecedented, indeed, unattainable, on Earth. This concept which has come to be known as QUASAT (QUAsar SATellite) has been the subject of coordinated Assessment Studies in the European Space Agency (ESA) and in the US National Aeronautics and Space Administration (NASA) with a view to a joint mission in the early 1990's.

The basic mission concept is a free-flying spacecraft carrying a 15 m, or larger, diameter radio frequency antenna in an elliptical orbit around the Earth with a perigee altitude of about 6000 km and an apogee altitude of about 13000 km and with the orbital plane inclined at 63° to the equator. The resulting period is 5.33 hours.

The space-borne antenna will be capable of observing in both hands of circular polarisation simultaneously at any two of the wavelength complement of 1.35, 6 or 18 cm, or simultaneously at two frequencies with one polarisation, and will relay the received signals via a wide-band (32 MHz) link directly to telemetry stations on the ground. A clock reference for the antenna in space, stable to about 1×10^{-14}, will be based on hydrogen maser oscillators on the ground and relayed directly to the satellite from the telemetry stations in turn. All communication with the space element will be through one or more telemetry stations in the network.

After transmission to the ground, the signal will be recorded in digital form on conventional VLBI equipment, and transported to a central data processing facility for correlation, at a later date, with similar tapes from the ground VLBI arrays. Radio telescopes anywhere on the globe could contribute usefully to the mission and thus QUASAT has the potential to be a truly world-wide astronomical endeavour.

Two distinct flight systems have been derived by NASA and ESA although there are a number of elements in common, for example, the radio astronomy feeds and receivers. The most important element of the flight system is the radio astronomy antenna since this drives decisions on the location and construction of other elements of the system. The European concept for the antenna is based on an inflatable, space-rigidised structure, while the US concept relies on a wrap-rib, mesh, deployable reflector.

Another important driver is the launch system adopted since this determines the dimensions of the undeployed system. Both antenna concepts are compatible with either a Shuttle or Ariane launch.

The NASA flight system is based on existing technologies for space deployable antennas in US industry. The gold-plated Molybdenum wire mesh surface of the 15 m antenna is held in place by 72 radial ribs of graphite epoxy which slowly deploy from an aluminium cylindrical cannister until the mesh is taut (Figure 1). The cannister, which becomes the antenna hub after deployment, contains the antenna during launch. The deployment takes only a few hours. The final rms accuracy of the surface is expected to be 0.8 mm. The f/D ratio of the antenna is 0.4, leading to a focal length of 6 m.

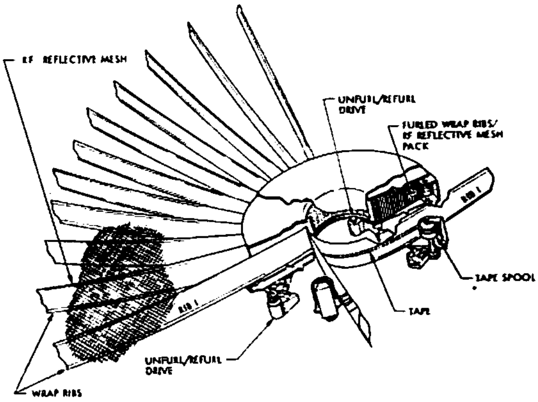

Figure 1. NASA wrap-rib antenna deployment scheme.

The radio astronomy feeds and receivers are housed in a forward module at prime focus. Several options for the feed support tower have been investigated, including a rigid tripod structure, a roll-up boom, a telescoping boom, folding links, a telescoping mast, and folded elastic joint members. Although the absolute feed alignment properties of these options are good, a focussing mechanism is probably required for any option involving a deployable feed support, in order to reduce de-focussing losses.

Following amplification, the received signal is transmitted to the ground on a digital or analogue link using small articulated medium gain (18 dB) directional horn antennas. There are two of these antennas, one located on the forward module and the other on the spacecraft bus to ensure continuous communication with the ground whatever the orientation of the main antenna.

The ESA flight system proposal is based on a new antenna development, a Rigidised Inflatable Structure and advantage has been taken of the potential of this technique to study a 20 m diameter dish (Figure 2).

During launch the antenna is stowed in a folded configuration; after final orbit acquisition the antenna is inflated to reach the required shape which then becomes rigid through thermal curing by the sun, and by injection of a special chemical agent into the antenna cavity during inflation. This concept has been made possible by the development of a special pre-impregnated Kevlar fabric with the appropriate properties, and techniques for cutting and bonding the material during antenna fabrication. The final rms accuracy is also expected to about 0.8 mm.

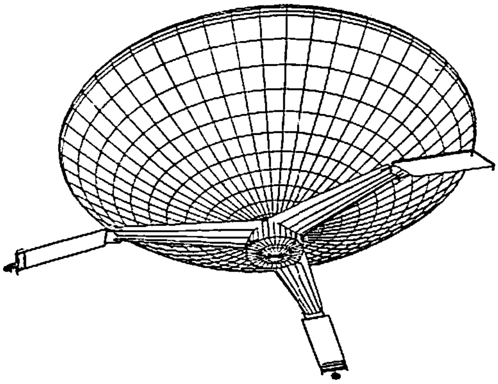

Figure 2. ESA Rigidised Inflatable Structure.

In the configuration, special emphasis has been placed on alignment stability when deployed and structural stiffness during launch, which can be either by Ariane or horizontally configured in the Shuttle.

To obtain a continuous up- and down-link signal to and from the ground, two medium gain pointed dishes of 50 cm diameter are employed mounted on booms at 120° to the solar array boom. This arrangement leads to a structural configuration in which the main load paths are divided into three which correspond to the boom anchorages. The inner section of the booms also serves as primary support during launch for the forward capsule which contains the feeds, pre-amps and mixers together with the star trackers. The forward module will be supported in orbit by the carbon-fibre quadrupod structure. No deployment of this structure is foreseen. The f/d ratio will also be 0.4.

A decision on which antenna concept to select will be made before the project enters phase A.

The feeds at the three frequencies are planned to be in a coaxial configuration at prime focus. The feed system will accommodate simultaneous dual-circular polarisation reception in all three wavelength bands. Good polarisation characteristics are mandatory at the 6 and 18 cm for astrophysical reasons; at 1.35 cm the requirements are not so stringent since source polarisation levels are expected to be below the sensitivity limit. The instrumental cross-polar terms are expected to be -30 dB on axis; this leads to rms errors in polarisation at 1.35 cm of 0.3 to 0.8% at the centre of the field of view, for absolute pointing errors ranging from 10 arcsec to 1 arcmin. The rms errors at 6 and 18 cm will be substantially better. Calibration will be critically dependent on good short term pointing stability, adequate absolute pointing and a knowledge of the azimuthal position of the antenna to be able to remove elliptical instrumental polarisation terms.

The orbit considered for QUASAT provides interferometer baselines to ground-based telescopes of more than 24000 km, giving about three times higher angular resolution than for the ground-based arrays alone, or an order of magnitude smaller pixel area in the resulting image. At an observing wavelength of 1.35 cm, the resolution is about 100 microseconds of arc. Not only is the angular resolution substantially increased over that obtained on the ground, but the image quality is dramatically improved for sources at all declinations, because the aperture plane of the interferometer system is very well-filled. This is important in reducing the uncertainty in image restoration. This comes about because the relative motion of the orbiting element with respect to the Earth during successive orbits allows interferometers of many different lengths and orientation to be synthesized in combination with the ground radio telescopes, that is, many different spatial frequencies are generated in the aperture plane. A movie will be shown during the talk demonstrating this.

Study has also been carried out of the orbital elements of a second space-borne antenna which might occupy an orbit beyond that of QUASAT and ensure dense aperture plane coverage to even greater spatial frequencies. The properties of one such orbit are: altitude of periapsis 20000 km; altitude of apoapsis 30000 km, inclination 63° and period 15.4 hours. The angular resolution at 1.35 cm wavelength for a combination of the ground VLBI arrays with QUASAT and a second spacecraft is about 40 microseconds of arc.