CULTURAL HISTORY
Arthur C. Clarke 1917-2008

By Neal McLain

Sir Arthur C. Clarke, CBE, at his home in Colombo, Sri Lanka, March 2005
Photo: Mamyjomarash <http://en.wikipedia.org/wiki/Image:Clarke_sm.jpg>

Arthur C. Clarke died on March 19, 2008 at his home in Sri Lanka at age 90. Numerous articles and news reports published after his death described his dual career as science-fiction writer and scientist.

As a scientist, he wrote extensively on various technical subjects. Perhaps his most significant publication was an article that appeared in the October, 1945 issue of *Wireless World*, a British technical journal. In this article, Clarke proposed the concept of "stationary satellites" capable of distributing television signals to earth. In his original conception, three stationary satellites, spaced 120 degrees apart above the equator, would provide television service to the majority of the world's population.

Clarke believed that it would be economically impossible to provide adequate television service to entire nations with conventional ground-based transmitters. He believed that only satellites, transmitting signals directly to consumers, could provide television service at a reasonable cost. But he believed that it would be fifty years before such an idea would be realized.

By the early 1970s, Clarke's grand vision was already becoming a reality. The feasibility of distributing television programming by satellite had been proven, and governments around the world began launching satellites for domestic television distribution. Numerous satellites were launched for the purpose; the number quickly grew beyond the three that Clarke had originally suggested. By the end 1975, Clarke himself, from his home in Sri Lanka, was able to watch educational programming provided by the government of India—just 30 years after his famous *Wireless World* article, not "half a century" later, as he had originally predicted.

Here in the United States, the cable television industry led the way. In 1975, Time, Inc., then the owner of a fledgling television service called *Home Box Office* (HBO), began transmitting its program signal by satellite to cable TV companies nationwide. Within a year, two other industry leaders followed suit: Ted Turner began transmitting the signal of his Atlanta television station WTCG (now *TBS Superstation*), and Pat Robertson added *Christian Broadcasting Network* (now *ABC Family*). Clarke was indeed correct: satellites would be able to deliver television programming at far lower cost than ground-based transmitters. The enormous proliferation of television programming since 1975 speaks to that fact.

Geostationary Satellites

So what is so special about the "stationary satellites" that Clarke proposed?

Clarke proposed placing the satellites in a unique earth orbit where they would appear to remain stationary with respect to a point on the earth's surface. Today we call this orbit the *geostationary orbit*, although it's also known as the *Clarke Belt* in honor of Clarke.

Of course geostationary satellites aren't actually stationary; in fact, they move quite rapidly—about 11,145 Km per hour. They move around the earth at the same rate that the earth rotates on its axis, so they appear to be fixed in the sky. This fact makes it possible to use fixed antennas at receiving stations on the earth's surface. Once an antenna is aimed at the satellite, it can be permanently locked in place. This greatly reduces manufacturing and construction costs. Fixed satellite antennas are now commonplace throughout the world.

Fixed Satellite Antennas for Direct Broadcast Service
Photo: Neal McLain

Later Life

Clarke spent his final years in his adopted country of Sri Lanka, where he had spent many years as a youth. He shared his home with a family of pet monkeys and a fixed satellite antenna donated and constructed by friends.

In 1989, on the occasion of Queen's Birthday Honours, Clarke was appointed Commander of the Order of the British Empire (CBE) "for services to British cultural interests in Sri Lanka."

Clarke's technical writings, including the *Wireless World* article, have been re-published in *Ascent to Orbit: A Scientific Autobiography* (New York: John Wiley & Sons, 1984). This volume contains all of Clarke's original technical writings, together with historical annotations in Clarke's own words.

As a result of these publications, Clarke is recognized as the originator of the concept of the geostationary communications satellite. Among other honors, he was the 1988 recipient of the Marconi International Fellowship "for first specifying in detail the potentialities and technical requirements for the use of geostationary satellites for global communications ..."

Yet Clarke never claimed that the geostationary orbit was an original concept. Indeed, in *Ascent to Orbit*, he goes to some length to disclaim credit: "I have sometimes been credited with the discovery of the stationary orbit itself, which of course is ridiculous. No one could have 'discovered' this, since its existence was perfectly obvious from the time of Newton (indeed, of Kepler!) ..."

Kepler's Laws of Planetary Motion

And this brings us to a discussion of Kepler's Laws. Between 1609 and 1618, the German mathematician and astronomer Johannes Kepler (1571-1630) published three mathematical laws that define the motion of the planets around the sun:

- ***Kepler's First Law:*** Every planetary orbit is an *ellipse* with the sun at one *focus*.
- ***Kepler's Second Law:*** The radius vector from the sun to a planet sweeps out equal areas in equal times. Stated non-mathematically, this law simply says that the farther a planet is from the sun, the slower it moves.
- ***Kepler's Third Law:*** The relationship R^3/T^2 is the same for all planets, where R = average orbit radius and T = average orbit period.

Although Kepler defined these laws in terms of the planets, they apply equally to the motion of satellites around the earth. The characteristics of the geostationary orbit can be specified in terms of Kepler's Laws.

To be geostationary, a satellite in earth orbit must meet three requirements**:**

Requirement #1. The orbit must be a circle.

The *First Law* tells us that the orbit is an ellipse with the earth at one focus. The *Second Law* tells us that the velocity of the satellite varies as a function of its distance from the earth.

But, of course, to remain at a fixed point in the sky, the satellite must move at constant velocity. Therefore, the orbit must be a circle, a special case of the ellipse in which the eccentricity of the orbit equals zero and both foci merge at a single point at the Earth's Center of Gravity.

Requirement #2. The orbit must be *geosynchronous*.

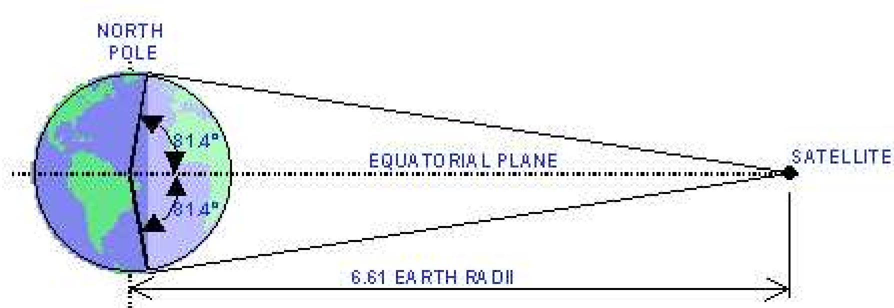
This requirement means that the satellite must move about the earth at the same rate at which the earth rotates on its axis. To meet this requirement, the orbital period T_{sat} must equal one *sidereal day* (23 hours 57 minutes 4.09 seconds, or 0.99727 mean solar days).

From this starting point, we can calculate the average radius of the geosynchronous orbit R_{sat}. The *Third Law* tells us that the relationship R^3/T^2 is the same for all satellites in earth orbit. From the study of the moon's orbit, we know that R_{moon} = 384,403 km and T_{moon} = 27.32153 mean solar days. From this, we can calculate**:**

$$R^3/T^2 = 7.6093 \times 10^{13}$$

for any earth satellite.

Plugging the known value of T_{sat} (0.99727 mean solar days) into the above equation yields R_{sat} = 42,453 Km., or about 6.61 earth radii.



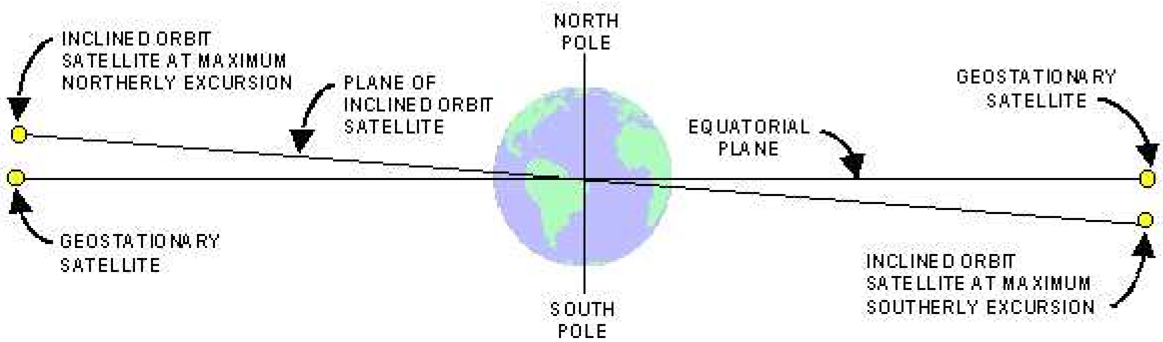
Further calculations can provide other information about the orbit:

PARAMETER	METRIC UNITS	U.S. UNITS
Height Above Equator	36,082 Km	22420 Miles
Average Orbit Radius	42,453 Km	26379 Miles
Orbit Circumference	266,740 Km	165744 Miles
Arc Length per Degree	741 Km	460 Miles
Orbital Velocity	11,145 Km/Hr	6925 Miles/Hr

Requirement #3. The orbit must lie in the earth's equatorial plane.

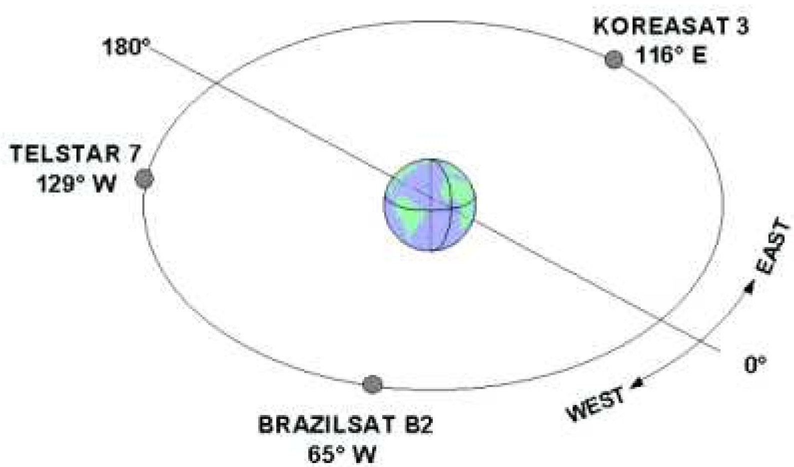
If the orbit does not lie in the equatorial plane, the satellite appears to oscillate north-and-south at a rate of one cycle per sidereal day. The following figure illustrates:

Note that during the course of one orbit around the earth (one sidereal day):



- The satellite in the geostationary orbit remains at the same altitude angle with respect to any point on the earth's surface.
- The satellite in the inclined orbit moves from MAXIMUM NORTHERLY EXCURSION (left side of the illustration) to MAXIMUM SOUTHERLY EXCURSION (right side) then back to MAXIMUM NORTHERLY EXCURSION. Thus, the altitude angle to the satellite with respect to any point on the earth's surface varies.

The following figure illustrates examples of three satellites in the geostationary orbit:



Note that specific satellite positions in the orbit are identified by longitude (or, more precisely, by the longitude of the point on the equator directly beneath the satellite).

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