Re: The Cost of Relativity

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From: Tom Potter (*tdp_at_earthlink.net*)
Date: 07/14/04

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Date: Thu, 15 Jul 2004 00:00:11 +0800
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"Dirk Van de moortel" <dirkvandemoortel@ThankS−NO−SperM.hotmail.com> wrote
in message news:40f53cf9@usenet01.boi.hp.com...
\>
\> *"Tom Potter" <tdp@earthlink.net> wrote in message*
news:2lkrd5Fe33p1U2@uni−berlin.de...
\> >
\> > *"Gregory L. Hansen" <glhansen@steel.ucs.indiana.edu> wrote in message*
\> > *news:cd1advgof2@hood.uits.indiana.edu...*
\>
\> *[snip]*
\>
\> > > *A bunch of satellites updated once per day from ground stations.*
Without
\> > > *the relativistic consideration, the error would drift by about a*
\> > > *kilometer per day between corrections.*
\> >
\> > *As I explained in a lengthy, explicit post*
\> > *on the GPS system several months ago,*
\>
\> *http://users.pandora.be/vdmoortel/dirk/Physics/Fumbles/FullHoles.html*

As my pappy used to say,
"You get better information from the horses mouth,
than from a horses ass."

An old post of mine about the GPS system follows.
Straight from the horses mouth.

For more of my articles on the GPS system,
do a Google search on "tom potter" and GPS.

Of course, if you prefer getting stuff from a horses ass,
by all means, visit Dork's web site.

1. Light travels at a constant speed
of 299 792.458 meters per second
in the absence of matter,

and in media with sparse matter,
such as the Earth's atmosphere.

2. Time interval measurements of E−M waves in air, and space,
are equivalent to distance measurements.

distance = time interval * C

3. Synchronized clocks can be used to
quantize the distance between the points
by measuring the time it takes light/radio waves
to travel from one point to another.

Clock(A) sends a message that it is time(X).
Clock(B) notes that it is time(X) + I1 on its' clock.

The distance between the clocks is
I1 * C

In other words, systems of synchronized clocks
can quantize the distances between the clocks,
by transmitting the time at each clock's location.

Any clock can determine the distances
between it and other clocks,
by simply determining time(I) for all of the other clocks.

For example,
if one measures a time delay of "I1" of a radio wave
from New York, they must be somewhere on
the surface of a sphere, with a distance radius of I1 * C,
centered about New York

If they also measure a time delay of "I2" of a radio wave
from San Francisco, they must be somewhere on
the surface of a sphere, with a distance radius of I2 * C,
centered about San Francisco.

If they measure both,
they must be on a circle represented by the
intersection of the two spheres.

As can be seen, the measurement of a third point,
would be the intersection of the circle with
another sphere, and would let tell the observer that
they are on one of two points.

A fourth measurement would resolve the situation,
and tell them at which of the two points they are
located.

4. As the GPS satellites are moving,
whereas New York and San Francisco are located
at fixed points (With respect to Earth bound observers.),
it is necessary that GPS receivers know where
the satellites were when they transmitted the time.

This is handled, by having each satellite
transmit its' position in space, along with
the time data.

Each satellite not only transmits where it is ("ephemeris data"),
it transmits its' orbital data ("almanac data"),
along with its' time.

The "ephemeris data"
serves the same purpose to the GPS receiver,
as the Sun does is to a sailor with a sextant.

5. Ground stations continuously monitor
the satellites' orbits and transmissions,
and when changes exceed certain amounts,
signals are sent to the offending satellites,
updating their "almanac data", their "ephemeris data",
their time settings, and drift in their clocks
with respect to the master clock on Earth.

In other words, the ground station monitors the data
transmitted by the satellites and when necessary
sends them signals that tells them, that their
clock is x nano−seconds fast, their orbit has changed to
such and such (Perhaps because of dust drag, etc.),
that their "ephemeris data" should be xxx, etc.

The GPS clocks are set,
to some reference time,
just as your digital watch is,
the only difference being that
the ticks are far more stable, and much finer,
nanoseconds, rather than tenths of seconds.

Drifts in oscillators are corrected by
inserting "ticks", and by adjusting
divider circuits to divide by the desired count.

6. As portable GPS receivers do not have
extremely stable oscillators, they must
derive precision times from the satellites.

As the satellites are at an altitude of about 11,000 miles,
and radio waves travel 186,000 miles in one second,
it takes about .006 seconds for the

time, ephemeris, and almanac data
to reach a sea level receiver.

This means that in a typical transmission,
the GPS receiver must subtract about .006 seconds
from its' clock, in order to set its' clock.
GPS receivers receive and average the times
from several satellites, and recursively
home in on the master time, and make an adjustment
for recursively computed position of the satellite.

In other words, at the reception of the first data,
the GPS receiver knows the master time to about .006 seconds
higher than the first time it receives,
and as it picks up signals from other satellites,
and recursively computes the distances to the
satellites, and averages out multi−path signal variations,
its' own clock homes in on the master clock time.

As the satellites take about 12 hours
(43200 seconds) to orbit the Earth,
and the ephemeris data takes about .006 seconds
to reach the receiver, this means that
the GPS receiver knows where the
satellite is to an accuracy of about one part in
43000 / .006 = 71600000 parts,
even without clock and ephemeris corrections.

Considering that the Earth is about
24,000 miles or 126,000,000 feet in circumference,
this amounts to a sphere of uncertainty of about
1.76 feet at sea level.

7. The clocks used in the GPS system are extremely stable.
They have a long term and short term stability
of about 1 part in 10^14 over one day and even months.

As there are about 3 x 10^13 MICROseconds in a year,
this means that the GPS clocks can maintain microsecond
agreement for over a year, even if no corrections are made.

But of course, adjustments ARE made to the clocks
on a regular basis by a ground clock,
to which all of the GPS clocks are referenced to.

8. As the satellites have a life expectancy of about 10 years,
their orbits are very stable.
In other words, when ground stations get a fix on a satellite's orbit,
we know pretty much where the satellite will be for a long time, and
GPS receivers on the ground have an extremely dependable target to sight on

9. There is some variation in the time it takes the
signal to reach the receiver due to multi paths
taken by the radio wave to the GPS receiver,
so GPS receivers are programmed to compute out the
multi−path variations, and to compute the time,
using the most reliable data it gets from
several satellites.

10. The GPS satellites broadcast on two carrier frequencies:
L1 at 1575.42 MHz and L2 at 1227.6 MHz.
They transmit a "coarse acquisition code" at 1.0 bits per nanosecond and
a "precision code" at a bit rate of 10.230 bits per nanosecond.

As light travels at about 300,000,000 meters per second,
or 300 meters in one micro−second,
a one nano second error would result in an error sphere of about .3 meters
(One foot), and a 10 nanosecond error would
result in an error of about 3 meters or ten feet.

By averaging data from multiple satellites,
a receiver can reduce the timing uncertainty
due to multipaths, and can reduce the error sphere
by only averaging where the error spheres
of several satellites overlap.

The single largest contributor to time transfer uncertainty is path delay,
the delay introduced as the signal travels from the satellite
to the receiver.

In order to measure the time interval most accurately,
a quasi−random code is used. The GPS receiver performs
an auto−correlation on the quasi−random signal
in order to eliminate the jitter in the leading edge
of the transmitted signal, caused by transmitter noise,
receiver noise, environmental noise, multipath signal combining,
jamming, etc.

In other words, a segment of the quasi−random signal is
incrementally delayed, and multiplied by the signal stream.
If two string of random numbers are multiplied,
a maximum occur when and if the strings match,
otherwise the product tends toward zero.

The Military can play games with the GPS signals by
juggling the "precision code" signals,
and thus messing up the accuracy
to which a GPS receiver can the time interval.

In summary, the largest contributor
to time transfer uncertainty is caused by
variations path delay, due to signals reflected

off mountains, buildings, etc., and as note,
much of the path delay errors can be averaged out,
because the satellites are moving, and signals
are received from several satellites.

The best GPS receivers can,
by using the methods addressed above,
reduce the uncertainty in time to about one nanosecond,
which amounts to a sphere of uncertainty of about one foot.

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