OVLBI-ES MEMO NO. 32

PRELIMINARY IDEAS ON A MASTER REFERENCE SIGNAL DISTRIBUTION SYSTEM FOR GREEN BANK

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There are are least five geographically separated facilities at Green Bank that will have a need for maser-stability timing reference signals in the GBT era. These include: the GBT, the OBLBI Earth Station, the new USNO VLBI station, the 140-ft telescope, and the Interferometer. It is possible that the need for such signals at the latter two places will be less critical in the future than it is now, depending on how (and whether) they are used in the long term, but they are included for completeness. Besides, these are the places where H masers are installed already; this makes them desirable for inclusion in any distribution network that might be built soon.

There is also a need for stable signals at the Jansky Lab, but I suppose that this is less critical than at the telescopes. Also, I expect that the central sources will be close to the lab, so short coax cables can distribute any needed signals to sufficient accuracy. Therefore, I neglect the lab needs in this discussion.

ASSUMPTIONS

1. In the long run, we want a single, central source of precision timing signals that can be accurately distributed to all users at Green Bank. This is because of (a) the high cost of installing and maintaining separate sources, and (b) the desirability for some experiments of having signals at the separated facilities which remain coherent over long time periods.

2. The USNO will build a central timing signal source that is much better than we could afford on our own.

3. Single-mode optical fiber is the best technology for the transmission of stable timing signals around Green Bank. (This should really be established by exhaustive study of alternatives, but for now I'll just assume it.) It is very low loss, immune to interference, and quite cheap.

4. Long-term timing stability at each facility should be no worse than a few ps on time scales of 24h or more. This allows good coherence up to around 100 GHz. It is acceptable to use some post-facto corrections in order to achieve this.

5. The reference frequencies provided should allow each facility to synthesize any frequency with any desired resolution and with no ambiguity of phase. That is, if power to the facility's synthesizer (but not to the central source) is interrupted and then restored, the output phase will be the same as it would have been without an interruption.

REMARKS

Assumption 4 implies that the reference signal distributed should include a component at the highest possible frequency. But assumption 5 requires it to contain a component no higher than the finest *resolution* to be synthesized. Together, these imply the need for a multi-frequency reference signal. I am sure that 1 Hz is low enough for the low frequency reference; to obtain resolution less than

1 Hz, lower frequency reference information can be sent by periodic messages between computers, using links separate from those discussed here.

OPTICAL FIBER

Readily available single-mode fiber has a typical loss of 0.4 dB/km and a typical temperature coefficient of delay of 7ppm/C at 1300nm wavelength. Lower TC fiber is available at high prices, but may not be available in flexible cables suitable for use in antenna wraps.

For distribution around Green Bank, the longest run should be less than 10 km, in which case the loss is completely negligible.

If the fiber is buried at least 2 m in the ground, the temperature variation should be <10 C annually and <0.1 C diurnally. Thus, a 10 km run will show <70 mm annual variation in effective length and <0.77 mm diurnally. Assuming a velocity factor of 0.33, this is <700 ps and <7 ps, respectively. For a run up an antenna that is subject to the ambient temperature variation, assume 50 C annual and 15 C diurnal range and a 100 m length, yielding 35 ps annual and 11 ps diurnal variation. These numbers imply that the stability goal cannot easily be achieved without correction for variation of the delay or use of the special low-TC fiber. If the buried cable's temperature is very stable, say .01 C diurnally, then if the antenna run is kept short and well insulated, perhaps an uncorrected system using common fiber will be good enough in some applications.

The delay variation can be corrected by two-way phase measurement. But this prevents use of a multi-drop fiber to the several facilities (unless some form of signal multiplexing is employed). Since the fiber is fairly cheap (with the buried installation expected to cost more than the fiber itself), and since it typically comes in multi-fiber cables, it is quite feasible to use a separate fiber to each facility and to include several spares.

A STRAW MAN DESIGN

Some ideas for a system design are shown in Figure 1. It should be emphasized that this is a preliminary proposal and represents only one of several possible approaches. Nevertheless, it seems worthwhile to see how some of the details work out.

At the central source, we use whatever frequencies are available from our most stable oscillator (e.g., an H maser producing 5 MHz and 100 MHz) to synthesize several frequencies for possible distribution. I propose that we produce 1000 MHz, 500 MHz, 10 MHz, 5 MHz, 1 MHz, and 1 Hz. The oscillator and all these synthesizers should be on uninterruptable power so as to prevent glitches in their relative phases, and they should be located as close as possible to the stable source. Any frequencies lower than those brought out of the oscillator's PLL (including at least the 1 Hz) must be derived by division, so their phases are ambiguous. They can be occaisionally synchronized to an external signal (like GPS), but this should be done very rarely and such resettings should be carefully logged.

We distribute 1 Hz to all stations via a single multi-drop fiber. This distribution needs to be accurate only to about 50 ns, since another reference with period at least 100 ns (10 MHz) will also be distributed.

For each station, we have a separate fiber on which two other

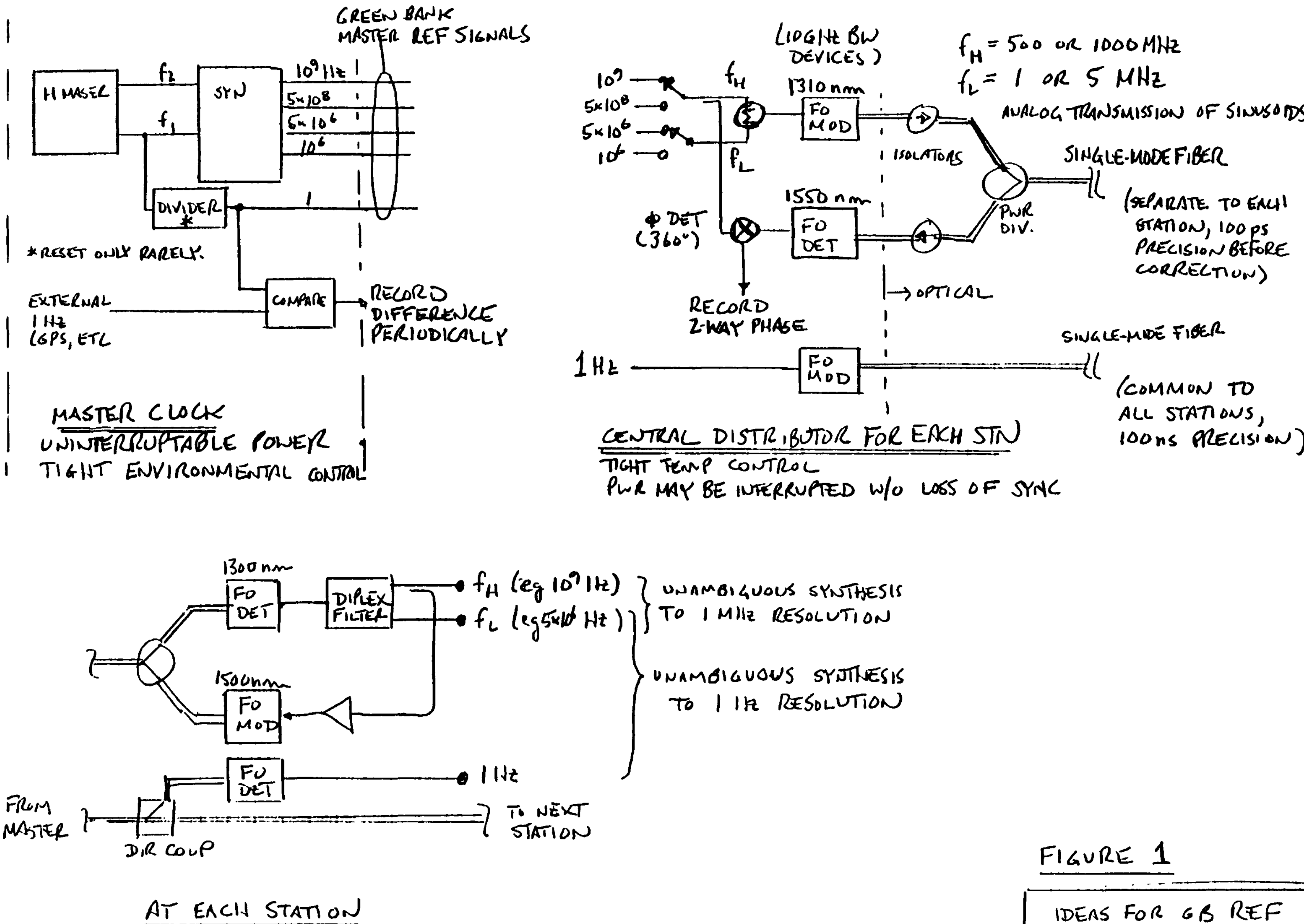

FIGURE 1

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references are transmitted, typically 1000 MHz and 5 MHz. The 1000 MHz high frequency reference is low enough so that much less than 1 cycle of fiber length change will occur in a day, so a two-way phase measurement will be unambiguous. If these two frequencies are used, then they allow the unambiguous synthesis at the station of any frequency from 5 MHz to 100 GHz with multiplication factors no larger than 100 and with a resolution of 5 MHz. For finer resolution, the 1 Hz reference can be used; no loss of phase accuracy occurs if the timing of the 1 Hz is accurate to less than 1 cycle of the 5 MHz. It is my proposal that all newly designed LO systems use exactly these reference frequencies. However, to accomodate existing equipment, the central source should allow for the selection of 500 MHz as the high frequency reference and either 1 MHz or 10 MHz for the low frequency reference for any station requiring these. Fiber optic modulators and demodulators are very broad-band, with units covering d.c. to 10 GHz being readily available; so all the optical components are the same regardless of the reference frequencies used.

At the station, the detected high-frequency reference is used to modulate another optical carrier for transmission back to the center over the same fiber. The two directions can be separated by wavelength multiplexing: say, 1310 nm out and 1550 nm back. The outgoing and returned signals are compared in a phase detector at the center. If a particular station's requirements are not so stringent as I have supposed, then for that station the return-direction components can be deleted to achieve a cost saving.

Since all of our applications involve large antennas, it is best if the reference signal fiber is carried through the cable wraps of the antenna to a point as close as possible to where it's really needed, rather than terminated in a "downstairs" building.

It would be possible to install sufficient new fiber to support all of the mentioned facilities by running a new buried conduit as follows: from the master clock near the Jansky lab to manholes near (in this order) (1) the OVLBI Earth station; (2) the new USNO antenna; (3) the 140-ft telescope; (4) the GBT; and (5) the Interferometer control building. In the conduit, we should place two 8-fiber cables, one of which is a spare. The main cable will include one common fiber for 1 Hz, 5 separate fibers for the separate stations, and 2 spares. At each station, the arrangement is as shown in Figure 2. The 1 Hz fiber and that station's dedicated fiber are broken out in the manhole and both ends are fusion-spliced to other fibers running up to that station. The upper ends of the two 1 Hz fibers are looped through a directional coupler. One of the two RF fibers, depending on from which direction the reference frequency comes, goes (via the antenna wraps) to its fiber optic tranceiver; the other is unused.

The last point may need some explanation. Ultimately, we expect the reference signals to come from the new master clock, in which case the fiber dedicated to a given station is unused beyond that station. However, the reference signals could just as well originate on the other end of the cable (at the Interferometer building), in which case the used and unused portions of each dedicated fiber are reversed. This allows the entire distribution system to be built and installed long before the new clock system becomes operational, with an easy move of some hardware from one end to the other afterwards.

ALTERNATIVES

There are several alternatives which ought to be investigated before a system like that described above is adopted. First, it should be established that the continuous two-way path monitor is really needed by seeing whether passive measures like temperature control of the above-ground portions of cables and careful design of wraps for minimum stress might not be adequate. Second, other approaches to two-way monitoring should be evaluated for performance and cost tradeoffs. These include use of separate fibers in the two directions and use of time division multiplexing rather than wavelength division.

The use of underground conduit needs to be compared against direct burial of properly armored cable. Although this memo considers only the timing reference signals, there are other signals to be communicated around Green Bank, using both optical fiber and copper wire. It may be cost effective if some of these share the conduit or burial operation with the timing references. Some may even share the same cable by expanding the number of fibers.

ACKNOWLEDGEMENTS

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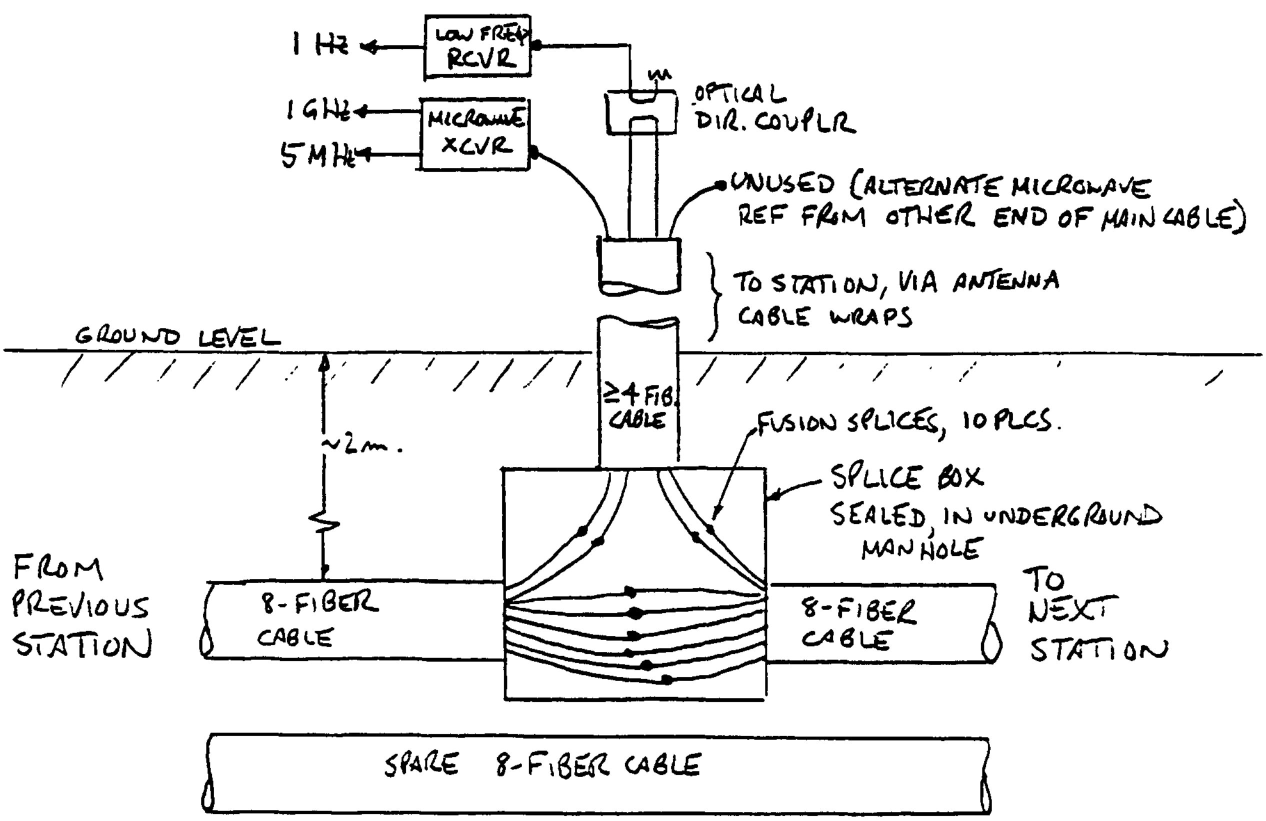

FIGURE 2: OPTICAL FIBER ARRANGEMENT AT EACH STATION.