NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, West Virginia

May 10, 1993

MEMORANDUM

To: R. Hall
J. Lockman

From: R. Norrod

Subject: **GBT Phase Stability and Equipment Locations**

Since discussions of GBT control room needs and locations have been reopened, I wanted to present some technical issues which should be considered when making the final decisions. These deal with phase or delay stability, which can be important for certain types of observations, including interferometry, pulsars, and polarimetry. Detailed design of the maser reference distribution system should not proceed much further until locations of the backends and masers are settled, or at least a couple of likely arrangements are agreed on.

Figure 1 shows a simplified block diagram of the GBT receiving system design which has evolved over the past couple of years. With the exception of a few things in the IF/LO approaches, it is quite like any radiotelescope design. The three dotted boxes represent three areas where equipment is located. The Receiver Room is located at the focal point of the antenna. The maser area and backend area are located off the antenna but, since there has been talk of putting the maser in a separate building, not necessarily near each other. Mainly, I will discuss here how the length and temperature sensitivity of the three cables connecting these areas effect the recorded signal phase stability.

For simplicity, only two "qualities" of cable will be considered, one with a temperature coefficient of 10 ppm/°C, and one with a coefficient of 0.5 ppm/°C. The first is achievable with standard loose-tube single-mode optical fiber, or certain coaxial cables (e.g. Andrews Corporation's Heliax). The second is achievable, at a high dollar cost, with Sumitomo's Low-T_c optical fiber. Expressing these coefficients as delay (or electrical phase per GHz) per km per °C, for the 10ppm cable:

$$\delta\tau_1 = 50 \text{ ps/km/°C}$$

$$\delta\phi_1 = 18 \text{ °/GHz/km/°C}$$

and for the 0.5ppm cable:

$$\delta\tau_2 = 2.5 \text{ ps/km/°C}$$

$$\delta\phi_2 = 0.9 \text{ °/GHz/km/°C}$$

Delay changes in the path from the maser to the LO synthesizers are critical because phase changes in a LO reference signal gets multiplied up to the synthesizer output frequency. For example, if the 10 MHz reference is used to lock a synthesizer producing a 10 GHz signal, a 1° change in the 10 MHz causes a 1000° change in the 10 GHz output. When the 10 GHz is mixed with an observed signal, the IF output changes in phase by 1000°, and is indistinguishable from a change in the observed signal. Experience has shown that delay changes in the LO Reference cable dominate the reference phase stability, and the cable change is dominated by cable temperature changes. On many telescopes (e.g. the VLBA and 85-3) the LO Reference cable delay is actively measured by electronics in the LO system, and this data is used to correct the recorded phase.

In order to estimate how temperature will effect the cable delay, we need to know how the air and subsoil temperatures behave. Experience on the 85-3 round-trip phase measurement system has shown (EDTN 168) that the air temperature is highly indicative of aerial cable delay, and I assume that soil temperature is indicative of buried cable delay. We have been logging air and soil temperatures at several depths for a few months, and Figure 2 shows one week's data. (Note that the air temperature scale is on the left; buried sensor scales are on the right.) The air temperature will often change by 20 °C in a few hours, while soil temperature at 2-3 feet depths typically change by less than 0.2 °C during the same time periods. These temperature deltas have been used in the following as representative of what will be experienced.

Figure 3 illustrates what performance might be expected for the LO Reference cable. The top part of the diagram is based on an estimated 200 meter length for the portion of the aerial cable from the Receiver Room to the Pintle Room, and gives the delay and phase deltas for both 10ppm and 0.5ppm cables experiencing a 20 °C temperature change. The phase deltas expressed in °/GHz should be multiplied by the LO frequency used in the observation, to obtain the resulting electrical phase change. The lower portion of the figure illustrates delay and phase deltas for three lengths of buried 10ppm cable, experience a 0.2 °C temperature change.

The numbers shown in Figure 3 can also be used to estimate the IF cable performance, except the IF frequency should be used to obtain the phase delta. The GBT will be more sensitive to the IF cable than a typical telescope because of the broadband, high-frequency IF running up to 8 GHz. The coefficients of the buried cable can also be used for the Backend Reference cable, assuming that the backends and maser are either in the same building or connected by buried cable.

Figure 4 serves to illustrate how each portion of the cable runs effect the resultant phase stability. Assume observations at 22 GHz, for which the first LO is set at 18.5 GHz, giving a first IF at 3.5 GHz. This IF is transmitted to the backend area, where it is converted to baseband for recording. (Because I wish to concentrate on the cable effects, I ignore phase effects in the electronics, such as phase drift or phase noise in the oscillators. They will have to be taken into account in the detailed design though.) Assume we have low-T_c cable for the aerial runs, 10ppm cable for the buried runs, the backend area is 500 meters from the pintle room, and the maser area is 2.3 km away. Then, the IF phase change would be:

$$\begin{aligned}\delta\phi = \; & (\text{LO Ref Aerial °/GHz} + \text{LO Ref Buried °/GHz}) * \text{LO1} \\ & + (\text{IF Aerial °/GHz} + \text{IF Buried °/GHz}) * \text{IF} \\ & + (\text{Backend Ref °/GHz}) * \text{LO2} \\ & + (\text{Backend Ref °/GHz}) * \text{LO3}\end{aligned}$$

$$\begin{aligned}= \; & (3.6\ \text{°/GHz} + 8.3\ \text{°/GHz}) * 18.5\ \text{GHz} \\ & + (3.6\ \text{°/GHz} + 1.8\ \text{°/GHz}) * 3.5\ \text{GHz} \\ & + (6.5\ \text{°/GHz}) * 2.5\ \text{GHz} \\ & + (6.5\ \text{°/GHz}) * 1\ \text{GHz}\end{aligned}$$

$$= 220° + 19° + 16° + 7° = 262°$$

Note that if we use the less expensive 10ppm cable for the aerial runs, their contributions increase by a factor of 20. Since the phase should be stable to about half a radian for reasonable correlations, it is obvious that during periods of rapid air temperature changes, some means of measuring and correcting the instrumental phase changes will be needed for phase sensitive observations, at other than the lowest frequencies. We will need a round-trip phase measurement system on the LO reference cable. The Pulse Phase Cal Generator may be used to measure the signal path phase, and it might be necessary to provide a round-trip measurement system on the Backend Reference cable, depending on the length of the cable between the maser and backends. Since the round-trip measurement equipment can be quite expensive ($15K-$20 K), it is desirable that the maser and backends are near each other with a highly stable cable connecting.

copy:		
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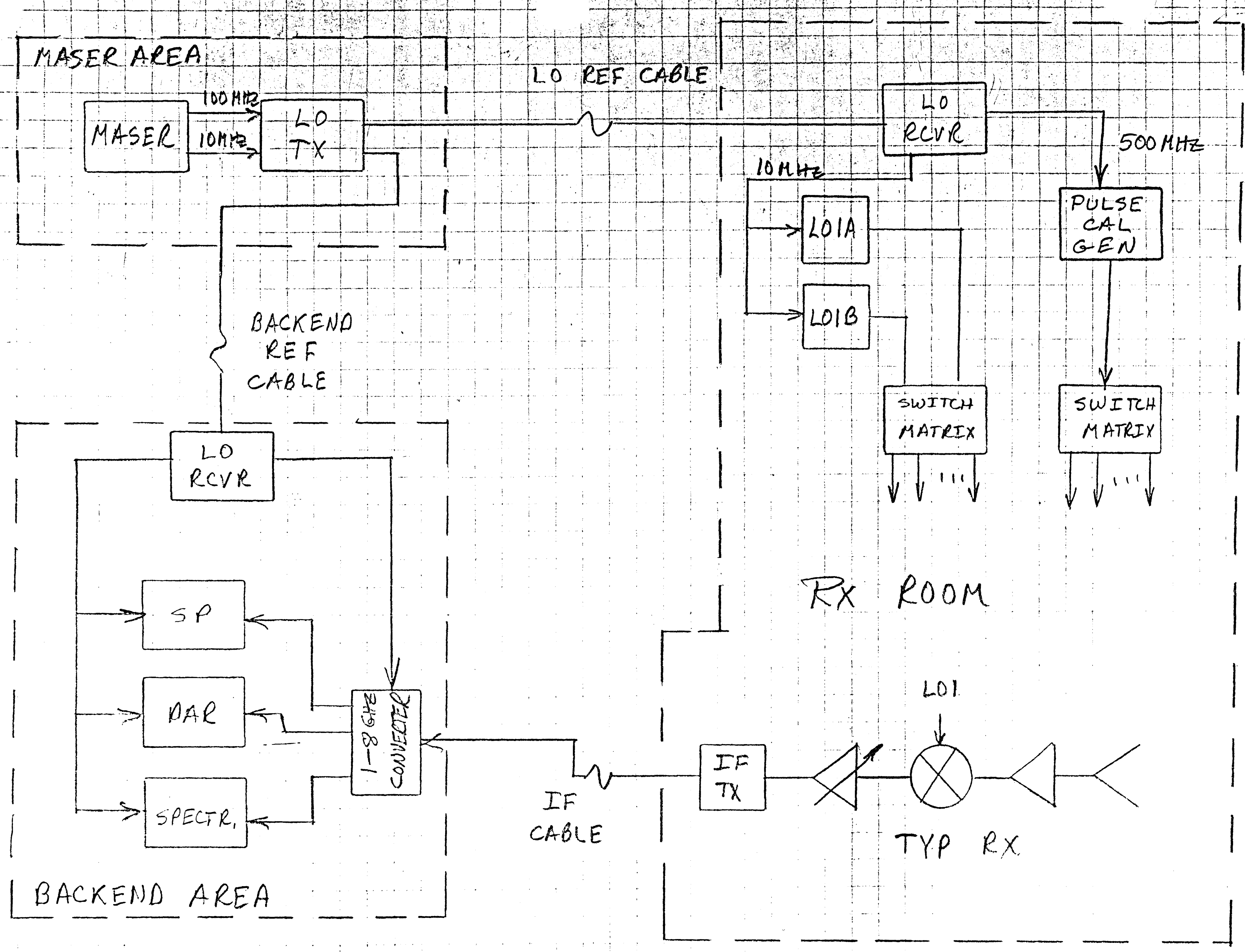

MASER AREA
MASER
100 MHz
10 MHz
LO TX
LO REF CABLE
LO RCVR
500 MHz
10 MHz
LO1A
LO1B
PULSE CAL GEN
SWITCH MATRIX
SWITCH MATRIX
BACKEND REF CABLE
LO RCVR
SP
DAR
SPECTR.
1-8 GHz CONVERTER
BACKEND AREA
IF CABLE
IF TX
LO1
RX ROOM
TYP RX

FIG 1

SUBSOIL TEMPS FEB 5, 1993-FEB 11, 1993

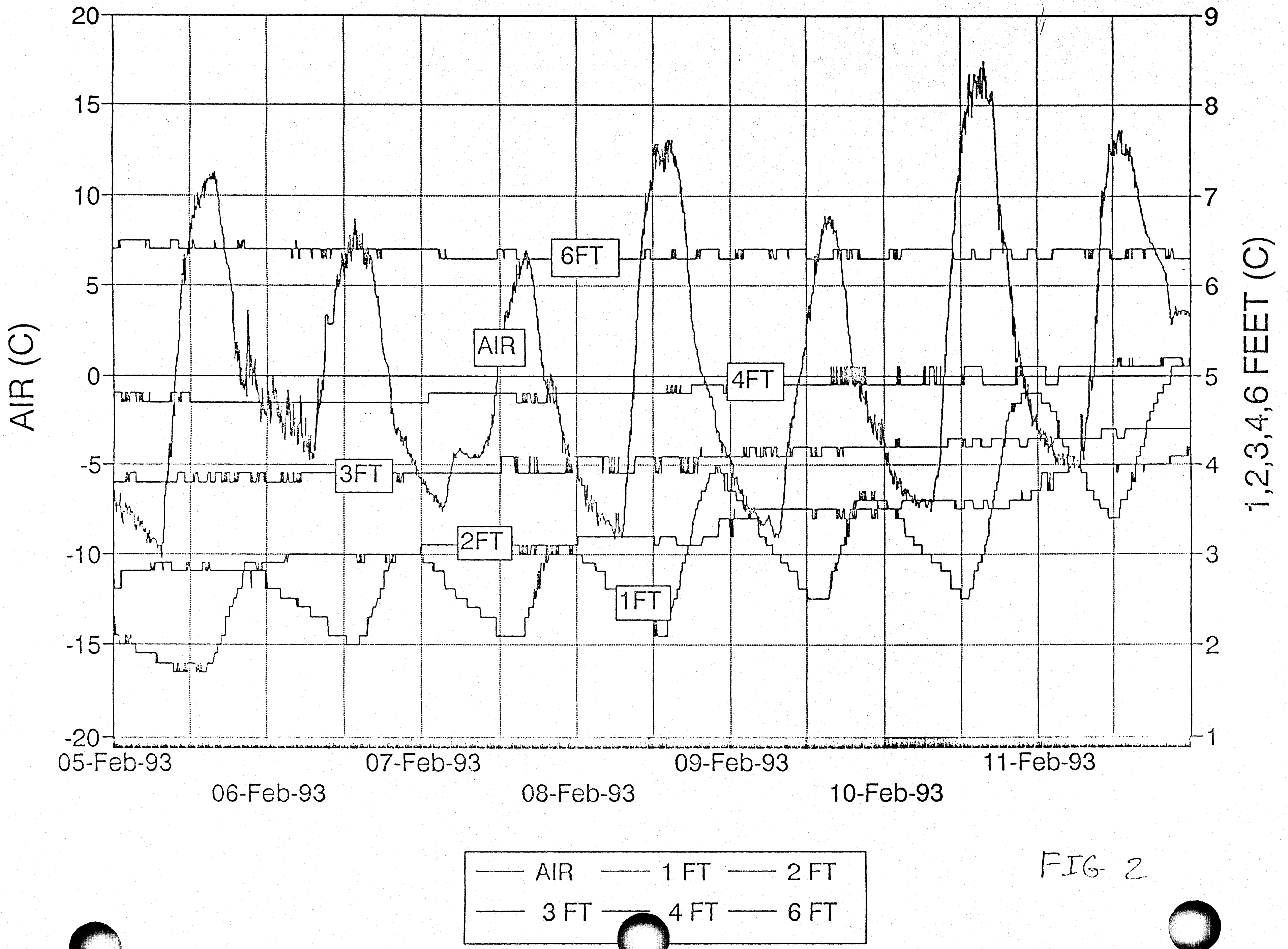
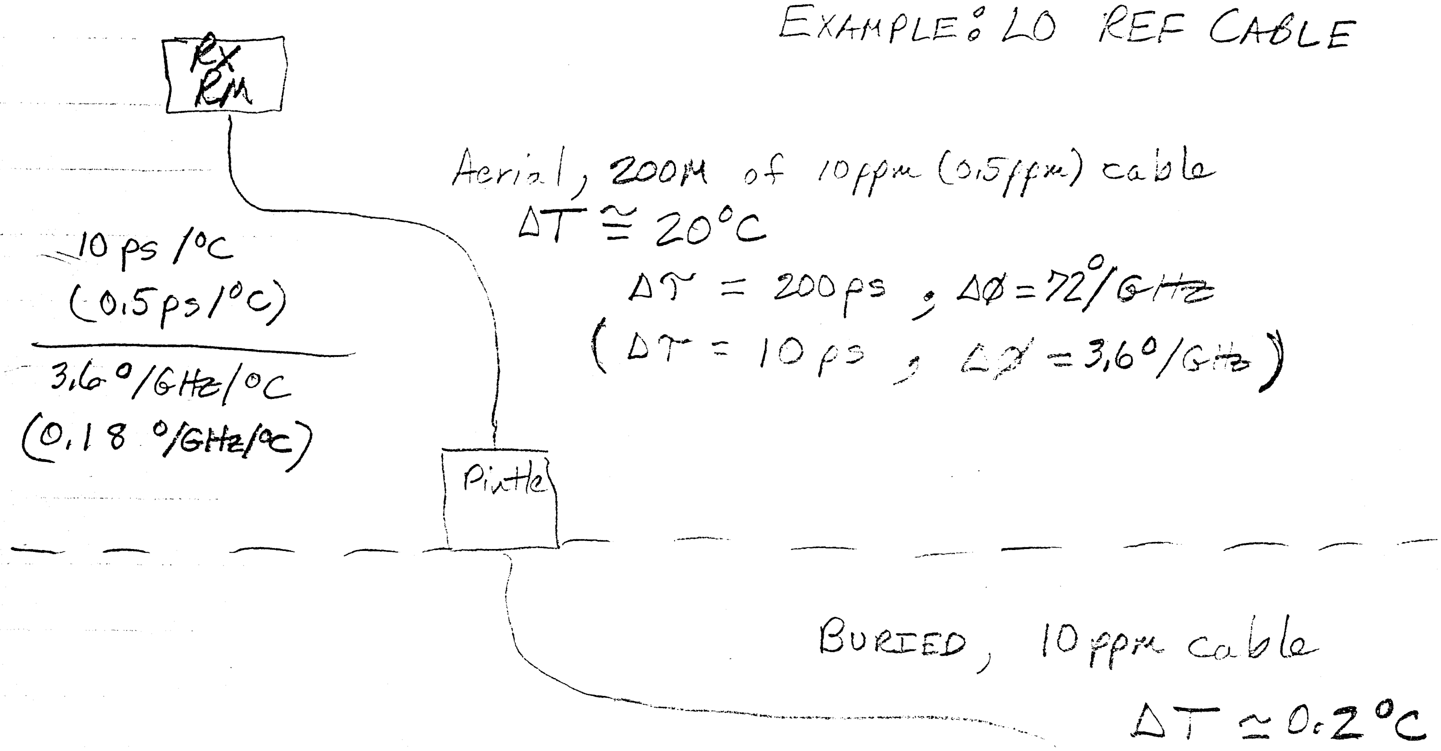


FIG 2

FIG 3

EXAMPLE: LO REF CABLE



LENGTH	$\frac{\Delta\tau}{\Delta T}$	$\frac{\Delta\phi}{\Delta T}$	$\Delta\tau$	$\Delta\phi$
100 M	5ps/°C	1.8°/GHz/°C	1 ps	0.4°/GHz
500 M	25ps/°C	9°/GHz/°C	5 ps	1.8°/GHz
2.5 KM	125ps/°C	45°/GHz/°C	25 ps	9°/GHz

Figure 4 a
Example
Cable Runs

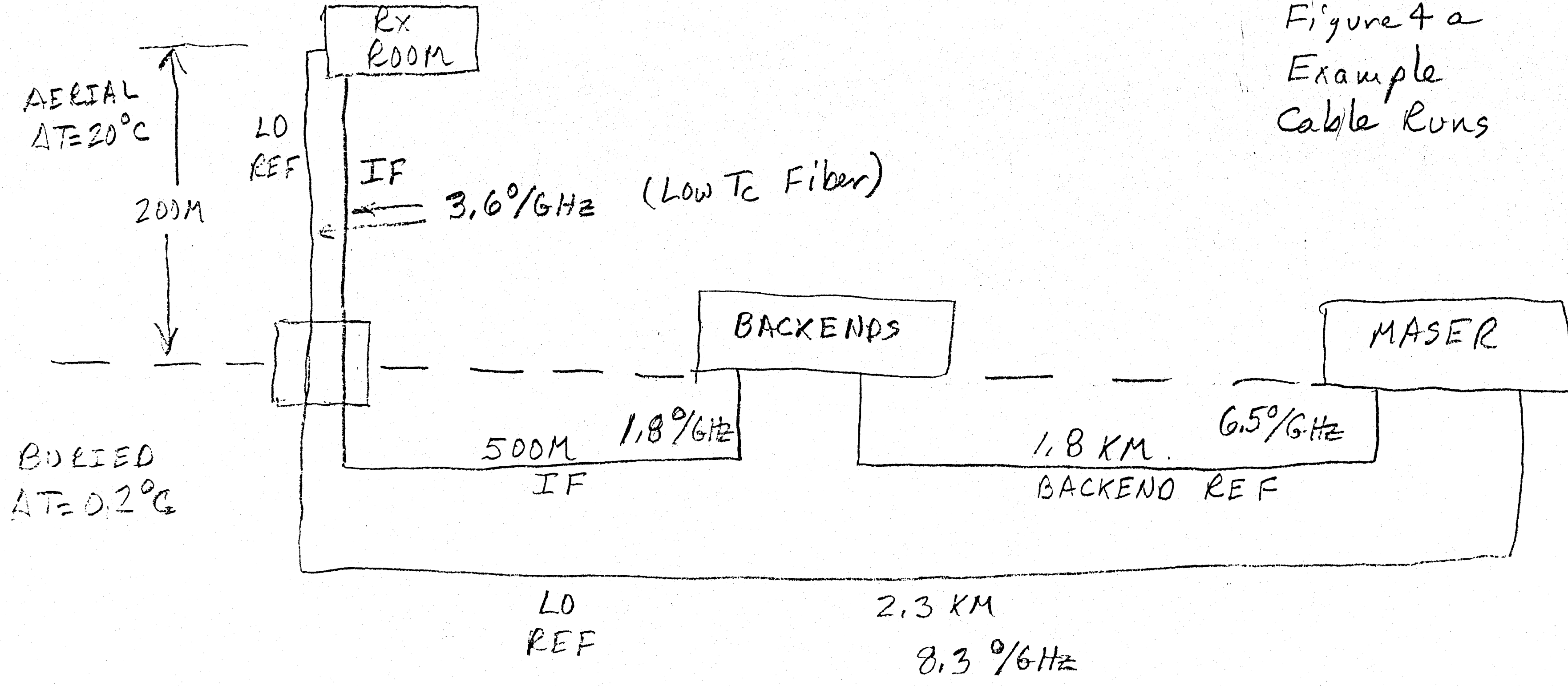


Figure 4b
Example
Chain