Frequency Dependency of Phase Stability of RF Cables

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***Abstract*— During qualification tests of phase stable cables for the ACES ("Atomic Clock Ensemble in Space") flight segment, an unexpected frequency dependency of thermally induced phase drift of RF cables has been discovered. These observations led to a thorough test campaign involving high performance RF cables from a variety of manufactures. Tests have been performed at frequencies ranging from 5 MHz up to 10 GHz using dual- or single-mixer type phase detectors.**

Recent measurements show a general trend of reduced thermal sensitivity when the cables are operated at higher signal frequencies. In general, thermal sensitivities measured at 5 and 10 MHz are significantly higher compared to those found at 100 MHz or even at 1 GHz. Furthermore, thermal sensitivity data measured at low frequency appear to exceed manufacture's data significantly.

This paper gives a presentation of the test results and a critical analysis of the measurement setups.

I. Introduction

Today's high performance clocks like Active Hydrogen Masers or fountain-type Clocks require careful selection and layout of interconnection cables. Thermal variations in the distribution system may lead to a degradation of mid- and long-term stability, especially if the signals have to be distributed over a larger distance (i.e. longer than 20m) or if the cables are run in a thermally less stable environment.

The phase stability of a microwave cable is measured in terms of the electrical length (units ppm), which is beside its name a dimensionless quantity and is defined by

$$\left(\frac{\Delta\varphi}{360 f_0}\right)\frac{c_m 10^6}{L} \qquad (1)$$

where $\Delta\varphi$ is the signal phase in degrees, f_0 is the signal frequency in Hz, c_m is the speed of light in the dielectric medium (typically 80% of the vacuum speed of light), L is the physical length of the cable. The temperature coefficient is the change of the electrical length for a given temperature change (units ppm/K).

II. Selection of Cables for the ACES Mission

Space-qualified RF cables for the ACES mission had to be integrated into the Columbus module of the ISS. Two cables have been selected:

- PhaseTrack PT210
- Times Microwave TF4FLEX

A test campaign was started to measure the phase stability of these two cables. The measurements were performed at 3 sites:

- SYRTE in Paris (Single Mixer, 0.1-1GHz)
- TIMETECH in Stuttgart (Dual-Mixer Phase Comparator, 5-100MHz)

Figure 1. Phase Comparator for 5, 10 and 100MHz

- ASTRIUM in Friedrichshafen (Network Analyzer, 10GHz)

The signal from the ACES clocks (PHARAO, SHM) is distributed to the Microwave Link, which manages the comparison with the ground clocks [2]. The impact of these cables on the performance of the ACES clocks at the MWL input is shown in Figure 2. for several cables with a temperature coefficient between 1.5ppm/K and 30ppm/K. The maximum peak occurs at 3000s (half of the ISS orbit). This is a critical time scale for the ACES mission, because the Long-Term Servo Loop, which compensates the

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frequency drift of the Maser, is acting also there [3].

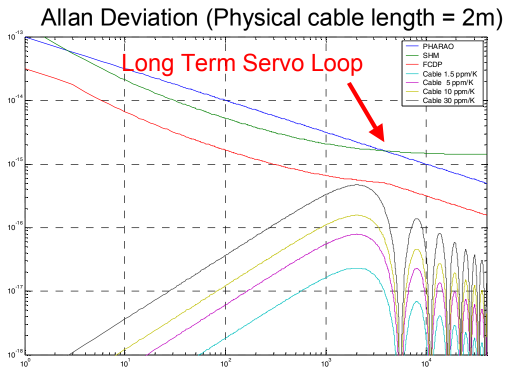

Figure 2. Impact of cables on the ACES clock signal

The results of the phase stability measurement of the TF4FLEX cable are shown in the next figures. The first figure shows that the temperature coefficient of this cable depends on the frequency (9fs/m/K at 1.2GHz, 26fs/m/K at 100MHz). The measurement at 100MHz was confirmed independently and showed a good agreement.

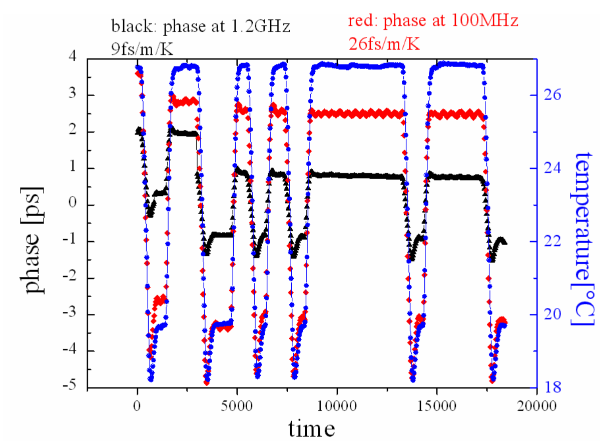

Figure 3. TF4FLEX phase stability at 0.1 and 1.2GHz (SYRTE)

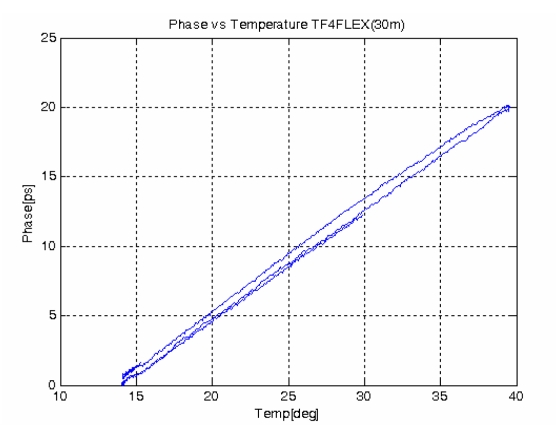

Figure 4. TF4FLEX phase stability at 100MHz (TIM)

III. Time and Frequency Distribution for Kourou Ground Station

A major challenge for the Kourou installation was the distance between the masers and the antenna site of approx. 200 m. Even high quality cables would exhibit prohibitively large temperature coefficients. The distribution frequency is 5MHz, therefore phase stability measurements at 5 and 100MHz were performed. The results are summarized in the next table.

Cable Type	TK [ppm/K] 5MHz	TK [ppm/K] 100MHz
Andrew FSJ-4 Standard 20m	10.0	1.3
Andrew FSJ-4 phase stable 20m	15.0	4.0
Andrew FSJ-1 Standard 12m	25.0	7.1

Based on these tests, the Andrew cable type FSJ4, UMTS grade, not thermally compensated, was selected together with an active delay compensation as shown in the next figure. The delay compensation uses a bi-directional link with symmetric paths and compensation elements.

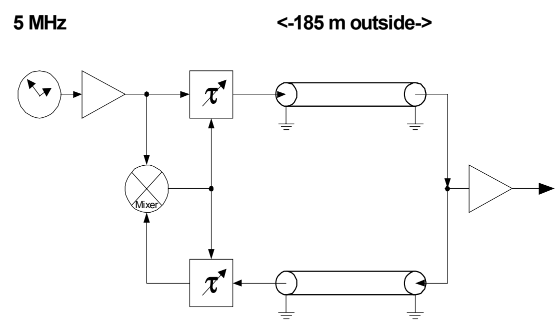

Figure 5. 5 MHz delay compensation for Kourou station [1]

The thermally compensated variant of the FSJ-4 cable type ironically showed slightly worse result for the relevant temperature range. Again, a frequency dependent temperature coefficient was observed.

IV. Cable Measurement Campaign

To investigate the frequency effect more deeply, a test campaign was started to measure the temperature coefficient of various cables with different test setups to exclude instrumental effects.

In addition to the phase comparator, which was already used for the measurements before, a special down-converter was developed for the frequency range 5-500MHz and 500MHz-20GHz. Together with the Vector Analyser HP89410A and two synthesizers HP8642B, the system can cover a wide range of frequencies and allows frequency stability measurements of 2.10^{-16} at 10GHz [4].

Figure 6. Down-Converter 500MHz - 20GHz

The test setup is shown in Figure 7. The phase comparator and the signal sources are in a temperature-controlled environment. The signals are routed to the thermal chamber room over 5 FSJ-1 cables of equal length. One cable distributes the signal to the thermal chamber room, where it is connected to a distribution amplifier. One signal goes directly back and is used as a reference, while the other 3 signals are connected to test cables inside the thermal chamber. A PT-100 temperature sensor is used to monitor the cable temperature.

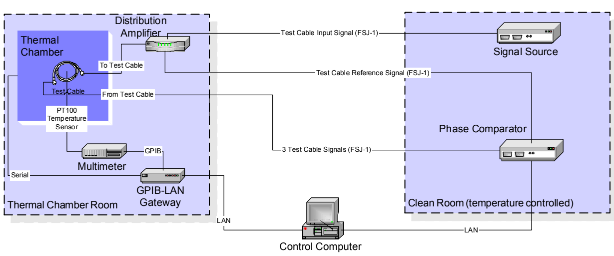

Figure 7. Cable Test Setup

The temperature range was chosen to be 20 to 50 degrees having a 2 hour stabilization phase to reach thermal equilibrium at the start and end temperature.

The typical cable length was around 10m. For comparison of the test instruments the LMR-240 cable was chosen because of its linear phase-temperature profile. The total delay for a temperature variation of 30 degrees is shown in the next table.

Frequency [MHz]	Delay [ps]	Instruments
5	+20	PCO, Vector Analyser
10	-4	PCO
100	-30	PCO, Vector Analyser
1000	-37	Vector Analyser
2000	-32	Vector Analyser

Measurements with the Vector Analyser using the FSJ-4 cable were made to check if the temperature coefficient gets even better for frequencies > 100MHz. The measurements showed that between 500MHz and 2GHz the temperature coefficient is between –3ppm/K and –5ppm/K, which is slightly worse than the value at 100MHz.

A summary of measured cables is shown in the next table

Cable	TK at 5 MHz	TK at 10 MHz	TK at 100 MHz
Huber-Suhner Multiflex 141 10m	51.3ppm/K	-6.0ppm/K	-25.2ppm/K
RG-223 10m	-141.2ppm/K	-131.9ppm/K	-125.9ppm/K
Semiflex Cable 8.18m	6.6ppm/K	-11.5ppm/K	-28.6ppm/K
Huber-Suhner 10m	-6.9ppm/K	-8.6ppm/K	-11.1ppm/K
Times Microwave LMR-240 10m	17.1ppm/K	-3.4ppm/K	-24.0ppm/K
Times Microwave SFT-205 10m	15.4ppm/K	7.7ppm/K	-4.3ppm/K
Meggitt 2T693 SiO_2 7m		30.6ppm/K	4.3ppm/K
Andrew FSJ-1 12m	25.0ppm/K		7.1ppm/K
Andrew FSJ-4 20m	10.0ppm/K		1.3ppm/K
Andrew LDF-1P-50-42 10.6m	15.1ppm/K	2.8ppm/K	-10.4ppm/K
Andrew LDF4-50A 10.6m	7.2ppm/K	4.7ppm/K	0.6ppm/K
Times Microwave TF4FLEX 30m			6.4ppm/K
Phasetrack PT210 6m			2.0ppm/K

Note: Also for cables with a non-linear phase-temperature profile, the temperature coefficient was calculated using the total delay divided by the temperature range.

V. Summary and Conclusions

A frequency-dependency of the temperature coefficient of RF cables has been observed. The effect was present in almost all cables measured so far. No systematics has been found, which attribute the effect to a specific cable construction or dielectric material. Different measurement equipment was used to exclude instrumental effects. The size of the effect is very different from cable to cable.

Although tests have been conducted carefully, together with cross-checks, further work is necessary to exclude other factors (mismatch, load variation etc), which may have impact on the phase stability.

Ideally, a cable has to be measured prior to its use in a specific application, where phase stability is crucial.

References

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