TELLUS. A new electromagnetic strainmeter for the monitoring of ground-field deformations.

V. Sgrigna[a], L. Conti[b], D. Zilpimiani[c]

[a] Dipartimento di Fisica e Sezione INFN, Università Roma Tre, Rome, Italy.
[b] Sezione INFN di Perugia e Dipartimento di Fisica, Università Roma Tre, Rome, Italy.
[c] Institute of Geophysics, Georgian Academy of Sciences, Tbilisi, Georgia.

Abstract

During 2008 an original differential electromagnetic strainmeter has been made for wide base-length and high-resolution ground-based continuous measurements of deformation processes. The equipment consists of a couple of central and peripheral units located at a sight distance relatively to each other. Each unit includes an antenna, an electronic package, and the power supply system. The central Unit is linked to a computer through an analog-to-digital converter. The equipment has been designed, built, assembled and calibrated in the ESPERIA Laboratory of the Department of Physics of the Roma Tre University. It can process, transfer and store data to a mass memory unit.

1 The Tellus experiment

The activity carried out during 2008 by the TELLUS team has been the construction of an original new electromagnetic strainmeter (patent pending) for the monitoring of deformation processes. These events have great importance both in engineering and science applications, such as in structural deformation surveys and in geophysical applications, respectively. A schematic representation of the instrument is reported in figure 1. As it can be seen, it is a dual frequency strainmeter. Basically, the instrument is a differential interferometer working in the microwaves frequency range and consists of ”elementary” one-dimensional (1-D) modules through which it is possible to measure the change (Δl) of the distance (l) between two assigned points. By using several 1-D modules of such kind one may to determine all the strain tensor components ϵ_{ij}. In fact, in a material with a homogeneous strain field, the measured change of the distance gives directly the strain component

$$\epsilon = \frac{\Delta l}{l} \tag{1}$$

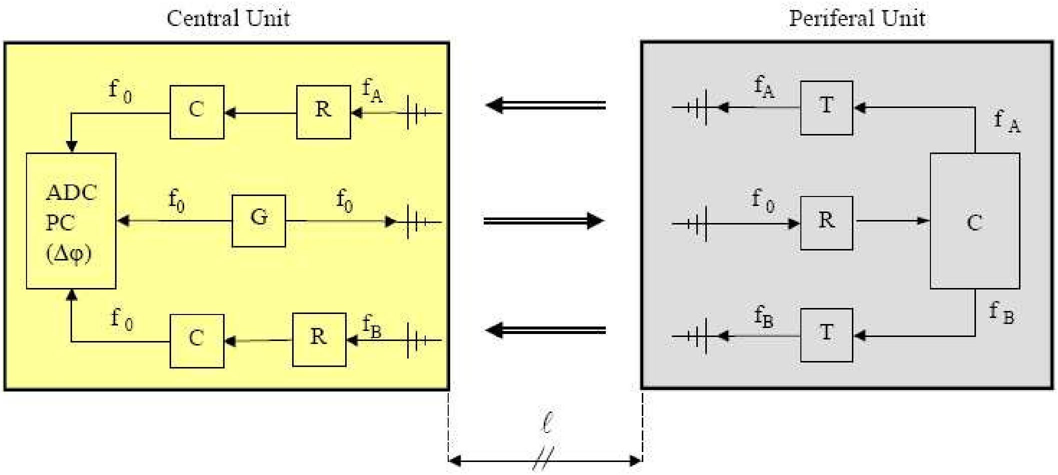

Figure 1: Schematic representation of the dual frequency electromagnetic strainmeter.

in the direction of the measurements. To determine the total strain tensor in a plane (two normal strains and one shearing), a minimum of three 1-D modules (that is a 3-D strainmeter) must be installed in three different directions.

2 Construction details

As shown in figure 1, each elementary module is constituted by a couple of central and peripheral units. These two units, are located at a sight distance l relatively to each other. Each unit includes an antenna, an electronic package, and the power supply system. The central unit is linked to a computer (PC) through an analog-to-digital converter (ADC). The electromagnetic signal of frequency $f_0 = 2$ GHz emitted by generator G is sent by the antenna of the central unit to the peripheral unit where it is divided (by dividers R) and converted (by mixers C) into two signals of frequency $f_A = 1.5$ GHz and $f_B = 2.5$ GHz. Two transmitters (T) send back signals f_A and f_B to the central unit where they are both converted again into waves of equal frequency f_0, so to be compared in phase with the reference wave which also has frequency f_0. The amplitude and frequency stability of signals is fundamental for the high-accuracy phase measurements requested by these kind of applications. The signal frequency stability is fixed by generator and selective filters specifications, while the amplitude stability is given by limiters. The reference signal is obtained by deriving towards the phase-detector the same EM-wave of frequency f_0 emitted by generator G of the central unit before it arrives at the antenna of the transmitters to be sent to the peripheral unit. The differential phase differences between the transmitted and returned signals allows to determine Δl changes without any effect due to possible fluctuations of atmospheric conditions (i.e., of refraction index of the medium).

3 Calibration

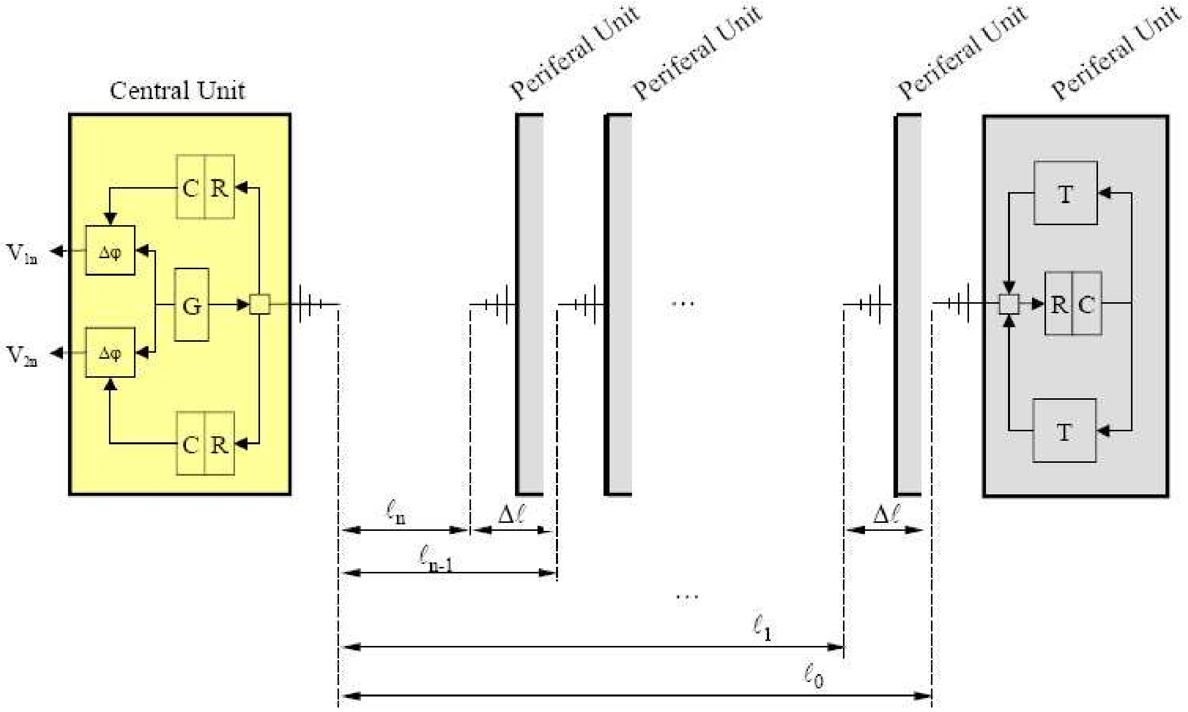

Figure 2: Schematic representation of the calibration procedures.

As shown in figure 2, the instrument has been calibrated in laboratory by changing step-by-step, of a fixed quantity Δl, the distance l between the antennas of the central and peripheral units and detecting the output potential differences V_{1n} and V_{2n} of the two phase detectors ($\Delta\phi$). At the beginning of calibration procedures the antennas of central unit (mounted on a fixing support) and peripheral unit (mounted on a sliding support) were positioned at the two opposite ends of a rectilinear guide at a relative distance l_0 = 600 mm. Then, the sliding support holding the antenna of the peripheral unit was moved along the guide by a numerical control machine. This allowed the antenna to reach 61 successive positions (e.g., 61 measurement data) $l_0, l_1, l_2, \ldots, l_{n-1}, l_n$ spaced by constant intervals Δl = 10mm, with a resolution of 0.01 mm. To construct calibration curves in correspondence to each position l, the output potential differences V_{1n}, V_{2n}, were detected and reported *vs* distance l. Results are shown in figures 3-4. V and l data in each calibration curve are reported with errors (1mV and 0.01mm, respectively). Such procedure has been repeated five times, so that each point of calibration curves reported in figures 3 and 4 is the average value of five repeated measurements. A best fitting carried out on the data exhibits a sinusoidal trend with correlation coefficient r = 0.99. Note that, as expected, the best fitting of calibration points is obtained with harmonic functions and data follow a sinusoidal trend with a change Δl of l_0 (baselength) corresponding to a phase shift $\Delta l = 2\pi$, according to the theory.

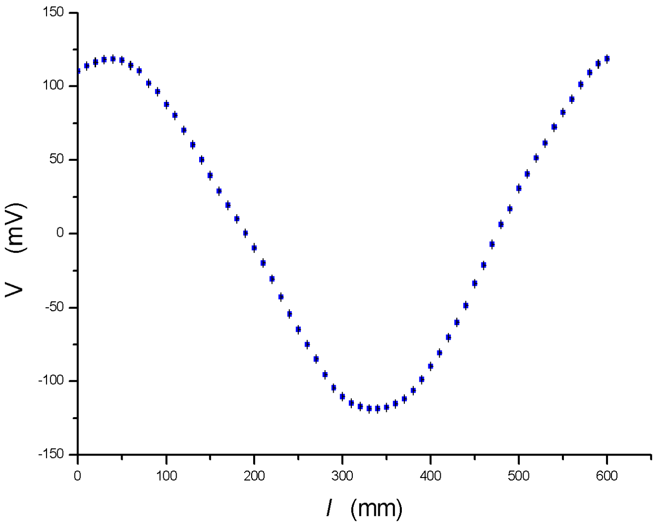

Figure 3: Calibration curve related to the return signal of frequency f_A.

4 Discussion and Conclusions.

A new and original strainmeter has been designed and constructed at the ESPERIA Laboratory of the Physics Department of the Roma Tre University. The methodological and technical solutions adopted for the instrument (mainly, the use of a two-frequency method and the possibility to keep constant in time the phase difference between input and output signals of the peripheral unit, even in presence of an amplification of output signals), demonstrate to be a good solution for simultaneously performing with a sole instrument: continuous measurements (monitoring) of Δl changes

- by detecting phase differences with a resolution of 0.1^o or less between direct and return em signals of frequency of the order of GHz
- in a wide baselength range (from hundreds meters to decades of kilometers)
- at high resolution (of the order of 10^{-1}mm) and dynamic range (about 80 dB)
- independently by possible fluctuations of the refraction index of the medium.

The prototype we have made can perform a strain monitoring with a resolution of about 10^{-9} in the strain interval of about $10^{-9} \div 10^{-6}$. At present no instrument is available with these characteristics for many applications such as geodetic surveys, geotechnical/structural measurements of local deformations, deformation events associated with earthquake and volcanic activities, geological and hydrogeological disarrangement, slope stability, movements of structures with respect to the foundation rocks, monitoring of dams and power plants structures as well as of horizontal and vertical movements of manufactures, etc. Also positive characteristics of the instrument are the use of high frequency ($\sim GHz$) and low-power ($\sim W$) penetrating waves, which also are stable both in amplitude and frequency. Normally, a 1GHz and 1W signal may reach distances of about 10km or more (for a double distance one should quadruplicate the power). The use of a so low-power signals implies a low-power consumption and that of solar panels and low-capacity batteries involves a large work autonomy of the strainmeter.

List of References including Publications during the year 2008

1. Sgrigna, V., A. Buzzi, L. Conti, P. Picozza, C. Stagni, D. Zilpimiani, 2008. The ESPERIA satellite project for detecting seismic-associated effects in the topside ionosphere. First instrumental tests in space, Earth Planets and Space, 60, 463-475.
2. Sgrigna, V., Buzzi, A., Conti, L., Stagni L., Zilpimiani, D., 2008. TELLUS. Ground deformations and their effects in the near-Earth space, Laboratori Nazionali del Gran sasso, INFN, Annual Report 2007, LNGS/EXP-01/08, May 2008, pp.187-190.
3. Massonnet, D., 1998. Radar Interferometry and its Application to Changes in the Earth's Surface, Review of Geophysics, 36, 441-500.
4. Maseroli, R., 1995. Il Sistema di Riferimento WGS84, Boll.Geodes. Sci. Aff., 54, 1619-1626.
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8. Sgrigna, V., A. Buzzi, L. Conti, P. Picozza, C. Stagni, D. Zilpimiani, 2008. The ESPERIA satellite project for detecting seismic-associated effects in the topside ionosphere. First instrumental tests in space, Earth Planets and Space, 60, 463-475.
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12. Massonnet, D., M., Rossi, C., Carmona, F., Adragna, G.,Peltzer, K., Feigi, and T., Rabaute, 1993. The Displacement Field of the Landers Earthquake Mapped by Radar Interferometry, Nature, 364, 138-142.

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14. Dubrov, M.N., V.A., Aleshin, and A.P., Iakovlev, 1989. Wideband Laser Strainmeters as a New Instrument for Geophysical Research, Gerland Beitraege zur Geophysik, 98, 292-300.

Patents

1. Sgrigna, V., Conti, L., Zilpimiani, D., 2008. "Variable Feedback Method for signal conditioning and related data acquisition, spectral analysis and digital management system " (patent RM2008A000688).

2. Sgrigna, V., Zilpimiani, D., 2000. "Method for detecting displacements, movements and deformations of ground and manufactures and related device" (patent RM2000A000392).

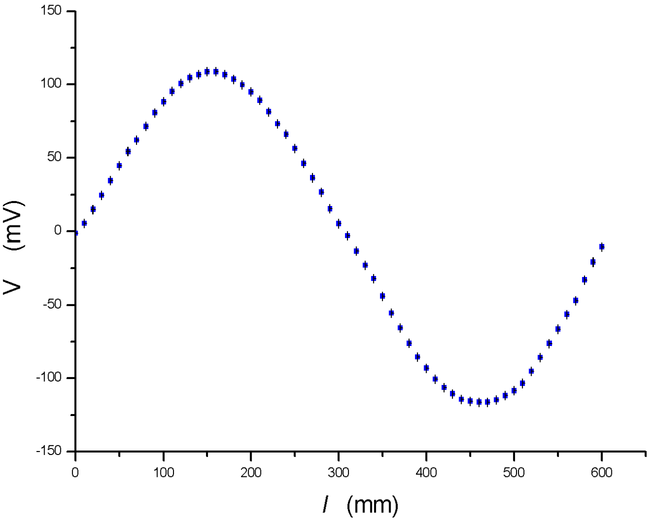

Figure 4: Calibration curve related to the return signal of frequency f_B.