DETECTION OF WATER LEAKS IN SUPPLY PIPES WITH ACTIVE MICROWAVE GPR SENSORS AND ELECTROMAGNETIC MODELLING

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Abstract: Accurate and timely detection of leaks in water supply pipes is a significant environmental issue. Development of efficient non-invasive methods would lead into significant water saving and prevention of health hazards introduced by water leakage. Implementing electromagnetic detection techniques is an innovative approach in locating leaks in water supply pipes, since until now mainly acoustic detection techniques are utilised. In the framework of the EU funded “LEAKING” project (Growth Programme 2001), passive (radiometric) and active ground penetrating radar technologies are developed to improve the detection capability of leaks in water supply pipes. In the present article active methods used to detect leaks and a relevant electromagnetic modelling method to enhance detection capability are presented.

INTRODUCTION

Driven by the requirements to detect accurately and effectively leaks in water supply pipes, active radar techniques are considered. Two specific active techniques using wide-band frequency modulation-continuous wave (FM-CW) and Continuous Wave (CW) are utilised. In case of FM-CW the operation frequency is between 4.3 – 5.3 GHz with a 1000MHz linear frequency sweep, while the CW radar operates at 2.45 GHz frequency. Both sensors are able to operate simultaneously as shown in Figure 1.

DESCRIPTION OF RADAR UNITS

The FM-CW radar operates with a linear up-down sweeping transmitter output while the receiver operates as a homodyne receiver with zero intermediate frequency output. The system characteristics of the FM-CW radar are:
- Frequency (centre): 4.8 GHz sweeping 1000 MHz linearly
- Power Output: 500 mW
- Independent Transmit/Receive Antenna: Horn type antennas, with 12 dBi gain
- Receiver Sensitivity: -90 dBm
- Processing: Analog-to-Digital Conversion at 2KHz sampling rate, 4096-point FFT

The CW radar sensor basic characteristics are:
- Frequency: 2.45GHz
- Power Output: 5W
- Independent Transmit/Receive Antenna: Microstrip Cavity Radiator with 14dBi gain

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• Receiver Sensitivity: -100 dBm
• Processing: Analog-to-Digital Conversion at 75Hz sampling rate, 4096-point FFT in a Pentium Processor

The reason of combining FM-CW and CW is to achieve both detection of spatial inhomogeneities inside the ground medium because of the presence of water caused by the leak and also detection of small Doppler shift because of the flow of water which is of the order of few Hz. In addition to the two radar modalities, in the framework of the “LEAKING” project a passive microwave radiometer is also used to detect independently the presence of water leaks in supply pipes. The three independent modalities being supplementary are expected to provide better detection performance in diverse environmental conditions (high detection probability and lower false alarm rates).

MEASUREMENT RESULTS

Testing measurements have been carried out in experimental sites and several features of leak detection were evaluated. The aim of the field tests was to locate water leaks in underlying supply pipes by detecting the slow leaking water movement and the voids caused by water concentrations. It has been shown that the use of FM-CW in conjunction with CW radars provides promising results. The following figures provide several measurements taken from both sensors after A/D Conversion and FFT processing with the aid of the National Instruments LabView® program.

The CW measurements prove that this active sensor can detect even the very slow movement of water created by the leaks. The effect of this movement on the returned signal (Figure 2) is evident, compared to the weak and noisy signal of Figure 3.

The FM/CW measurements (Figure 4) exhibit the capability to spot inhomogeneities in the ground medium. The frequency domain can be mapped to the spatial domain linearly, thus providing information about the structural defects and alterations caused by the presence of ample amounts of leaking water. Indeed, the information obtained by the linear FM on the vertical axis can be used as a test bed for obtaining results from the EM modelling algorithm presented in the following section.

![Figure 2: CW radar measurements on leak point: 2V p-p signal (sec – V) and spectrum (Hz – dB)](image)

![Figure 3: CW radar measurements away from leak: 0,1V p-p signal (sec – V) and spectrum (Hz – dB)](image)
ELECTROMAGNETIC MODELLING

The two layered ground medium shown in Figure 1 was analysed by applying the Sommerfeld technique [1,2]. A dipole source inside the earth medium is assumed and then the field in the air medium is determined. The obtained result has the form of Sommerfeld integrals which cannot be computed analytically [1,4]. Taking into account the fact that near-field regime is valid, the electric field induced by a dipole source inside the earth is computed by using a Taylor expansion of the integral terms [3]. By considering all possible dipole orientations, a Green’s function of the structure is obtained. The result can be written in the following convenient form:

\[
\mathcal{G}(x', y', z') = \sum_{i=1}^{I} \sum_{j=1}^{J} x'' y'' \mathcal{G}_{ij}(z')
\]

where \((x', y')\) is the source point inside the earth, while the observation point is on the origin of the coordinate system on the surface of the earth. The \(a_{nm}\) coefficients are computed numerically and are readily available if they are computed once. In order to develop an imaging algorithm the inhomogeneities caused by water leak are computed by minimizing the error function:

\[
\varepsilon = \sum_{n=1}^{N} \sum_{m=1}^{M} \left| V(x_n, y_m) - \sum_{ij} \mathcal{G}(x_n', y_m', z_i') \Delta x_{ij} \right|^2
\]

where \(V(x_n, y_m)\) is the measured voltage at the observation point \(x_n, y_m\), and \(\Delta x_{ij}\) is the dielectric permittivity function described by a cubical basis function inside the earth.

CONCLUSIONS

The present work analyses a novel approach in leak detection techniques, based upon ground penetrating radar technology. The method proposed here combines a microwave subsurface imaging technique with an underground movement detector, in order to obtain a more accurate and robust leak detection system. The measurements have shown the efficiency of the CW radar in detecting the very small Doppler shift of the moving water, while the FM/CW sensor provides a suitable device for applying the subsurface imaging algorithm shown here. Future work plans include the development of an expert subsystem that translates radar measurements to simple indications about the probability of water leak existence, a task requiring extensive field tests in diverse environmental conditions.

REFERENCES


Figure 4: FM-CW radar FFT magnitude (Hz – dB): away from leak (left) and on the leak (right)