

UWB enhanced Microwave Fire Detection

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1 Abstract

Microwave Fire Detection is a passive detection technique and relies on the increased radiation of hot spots due to PLANK's law. However, the received microwave power depends both on the objects temperature and the material, namely its surface emissivity. Conducting materials like metallic objects or foils e.g. might hide a hot spot due to blocking of its radiation.

In this respect Ultra-Wide Band (UWB) radar measurements might help in some aspects. This active measurement technique could help in detecting areas with metallic objects thus identifying areas being uncovered by passive microwave fire detection. In addition, UWB measurements could lead to a rough characterisation of the objects material with respect to its electrical properties.

The paper gives an overview on UWB radar technology and its possible application in the detection and localisation of a fire and shows results from recent experiments of UWB radar measurements of test fires. Unfortunately, UWB radar measurements are influenced by the incidence angle at the point of contact of waves and object in addition to the surface roughness. The paper describes concepts how to treat such influences.

2 Introduction

The detection of hot spots using the measurement of microwave power for the frequency band 2 GHz to 40 GHz is subject of current investigations. Using this technique PLANK's law is practised for microwave fire detection in the form of a passive detection principle [1]. First results are promising. They show a temperature resolution of some degrees for sufficiently large hot objects in relation to the microwave antennas opening angle.

One problem of microwave fire detection is that a hot spot could be hidden by metallic objects, even by metallic foils. But also other materials could impact the radiation. If some information about the material would be known, the received microwave power to some extent could be adjusted for with respect to different emissivities. A method of obtaining additional information about the electrical properties of objects is UWB Radar. It is an active method which relies on microwave backscattering. This happens at material boundaries essentially due to different dielectric and magnetic properties.

Backscattering always takes place if electromagnetic waves pass through media with different wave resistance values. The value for free space is:

$$Z_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} = 377\Omega \quad (1)$$

Essentially the wave resistance is a function of the relative dielectric constant ϵ_r with $\epsilon = \epsilon_r \epsilon_0$ for materials which are not ferro- or ferrimagnetic. For non-magnetic materials the relative permeability μ_r with $\mu = \mu_r \mu_0$ is close to 1. If waves propagate through air and hit an object, the different wave resistance values, i.e. when different from 377Ω , lead for perpendicular incidence to a reflection at the material boundary according to the reflection coefficient p with

$$p = \frac{Z_w - Z_0}{Z_w + Z_0} \quad \text{and} \quad Z_w = \sqrt{\frac{\mu_0}{\epsilon_0}} = Z_0 \sqrt{\frac{\mu_r}{\epsilon_r}} \quad (2)$$

Thus, the wave transition from air to an arbitrary non-magnetic material is always connected with a negative p -value. Metals cause a full reflection with $p = -1$.

If the waves pass through the object (and if still the boundary material-air is given) once more a reflection takes place, this time with a changed sign of p but with the same amount.

For other materials than air, the wave resistance is determined by the fraction ϵ_r/μ_r . Figure 1 show this relation for fractional values in the range of 1 to 60.

The property of classifying materials on the basis of microwave reflections is used in a number of applications like Ground Penetration Radar (GPR) and related Imaging Radar techniques. The application cover very different areas such as:

- Mining (locating of coal) [2]
- Road maintenance (non-destructive inspection of weak layers in the ground) [3]
- Archaeological investigations (determining hidden or inhomogeneous structures in historical buildings and monuments) [4]
- Agriculture (determination of soil humidity) [5]
- and several other applications (e.g. anti personnel mine removal, localisation of hidden persons, localisation of metallic bars in concrete, rain radar)

The UWB radar technology is described in the following chapter.

3 UWB Principle for Radar Sensing

Signals with an ultra-wide spectrum can be produced based on different approaches. Using a classical carrier modulation a suitable (stepped or continuous) frequency modulation can be applied. Another method is to emit short impulses of adequate energy. Both approaches suffer from disadvantages. A third method combines advantages of the first two onsets without suffering from major drawbacks. Due to the availability of digital circuits with clock rates above 1 GHz, UWB signals for radar applications can be cost effectively realised. These are periodic signals exhibiting a power spectral density (PSD) with dominant values spread in an ultra-wide band.

Such a UWB signal is then transmitted to the objects to be analysed.

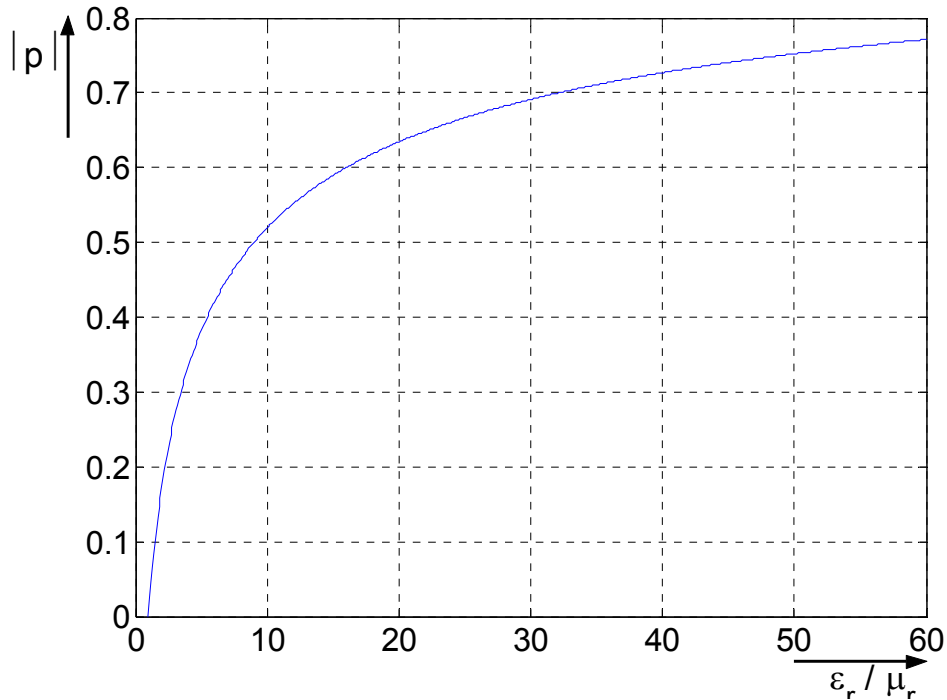


Fig. 1. Plot of $|p|$ over ϵ_r / μ_r .

The path from the transmission antenna to the receiving antenna across the object to be analysed can be thought of as an LTI system. Its properties are fully determined by its impulse response $h(t)$.

It is a well known approach to exploit a so called M-Sequence for estimating $h(t)$. Certain sequences with a sufficiently high order n give an auto-correlation function of the antenna signals used which comes close to a Dirac impulse sequence. A direct and preferred way of producing sequences is to use feedback shift-register circuits.

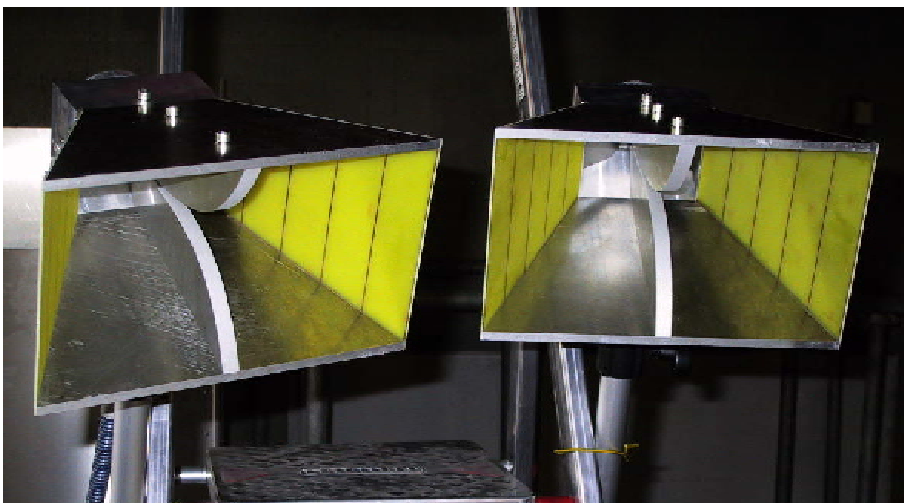


Fig. 2. UWB antennas for the range 1 – 18GHz.

For certain feedback combinations the Maximum Length Binary Sequence (or short M-sequence) results. Figure 3 shows an example of an M-sequence with the order of $n = 4$ in the time and frequency domain.

The M-sequence is produced on the basis of a highly stable clock and an n -stage shift register. Without additional modulation or signal processing the binary output signal of the shift register is then fed to an UWB antenna. Another antenna of the same kind then receives the back-scattered signals [6]. Here, the LTI-system is denoted with device under test (DUT). In this case, the device under test covers the antennas and the scenario to be monitored.

It should be mentioned that according to the Nyquist criteria, the sampling of the back-scattered signal would normally be performed at the clock frequency f_c . Fulfilling the demand according to the Nyquist criteria leads to a sampling rate in the GHz frequency range with all associated problems.

If the objects analysed does not (or only to a sufficiently low extent) change properties over time the impulse response can be gained by distinct undersampling. According to figure 4 this is realised by an m -stage divider giving an undersampling factor of $2m$. In the present realisation of the UWB radar sensor the clock rate is set to 9 GHz and 512-times undersampling is performed. Due to direct coupling of the sampling control signal with the system clock the usual jitter and drift problems are reduced. The highly reduced sampling rate has also a positive impact for all following signal processing components. Thus, normal DSP chips or a more convenient PC can be used for the subsequent analysis.

4 Concepts for UWB enhanced microwave detection of hot spots

The objective of improving microwave fire detection by UWB radar measurements is to help detecting metals or other conducting materials which might prevent electromagnetic waves from reaching the sensor.

A second objective is to obtain information about an object which is a potential hot spot due to previous radiometric measurements showing an increased electromagnetic radiation. The aim is here to determine very roughly the class of the material in order to compensate for to some extent different surface emissivities of the objects. This would contribute to improved measurement results especially in those cases where a limited range of materials is expected.

For such an application UWB sensors are very well suited. If frequency bands match, the UWB antennas could be used for the radiometric measurements too. UWB and radiometric measurements could even share many other components. The transmit antenna needs to be switched off and just a different processing of antenna signals needs to be performed.

There is also another aspect where UWB radar measurements might improve the capabilities of microwave fire detection sensors. This improvement is related to the advantages of UWB technologies for the localisation of the fire. With UWB devices objects or other UWB devices can be precisely localised.

It has to be taken into account that in a typical situation a classical fire detection system will hardly benefit from UWB radar sensors. The additional information provided by the UWB sensor on the existence of metallic objects influencing microwave fire detection will hardly lead to moving away the corresponding object or to find a new improved position for the microwave sensor.

This situation would be different for special application areas. Such an application is the area of fire detection based on mobile sensors, e.g. on robots. In such a situation the robot could move to another position which gives a clearer “view” on possible hot spots.

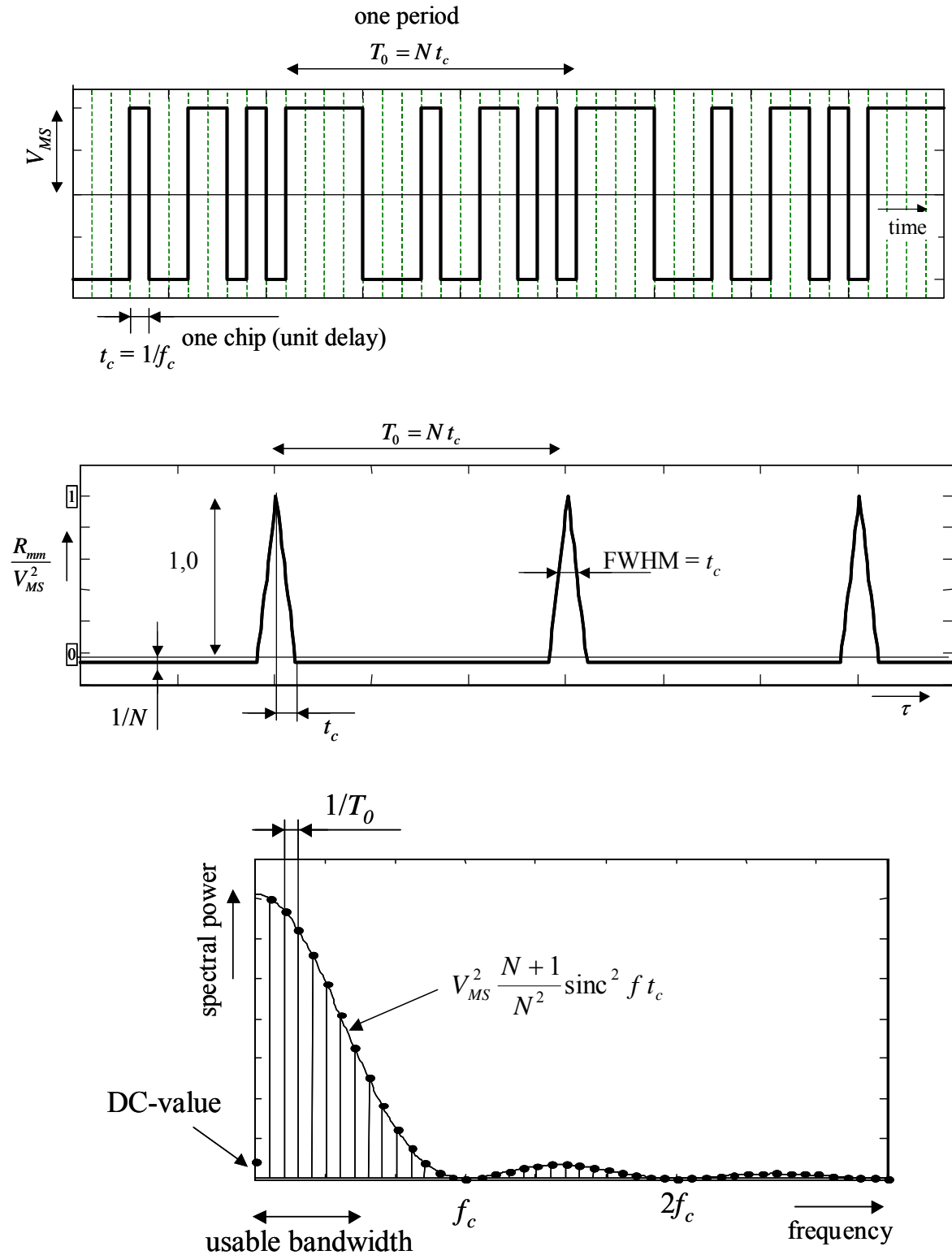


Fig. 3. M-Sequence signal, its shape, auto-correlation function and spectrum

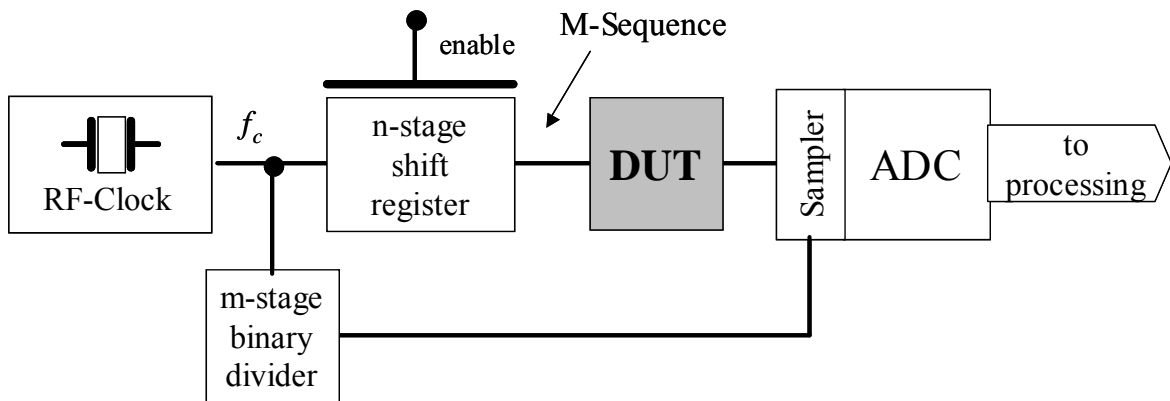


Fig. 4. Basic structure of an M-Sequence radar system.

The ability to move the sensor position is also extremely useful for taking into account different incidence angles. Smooth surfaces (in terms of the microwave wavelength) only lead to reflections in the direction of the receiver antennas with suitable incidence angles. So a robot could perform measurements at optimised angles. If on the other hand, rough surfaces are analysed, microwaves are scattered in a wide angle and a certain reflectivity pattern does exist. The idea is here to use again the robots motion for measurements at difference incidence angles and thus to estimate the material class of the object.

Finally also the size of objects matter. Here the use of antennas with a small opening angle could be used to reduce the dependency of backscattering on objects size.

5 Conclusion and outlook

UWB sensors might enhance the detection of hot spots in terms of determining possibly uncovered areas and in terms of roughly classifying the materials scanned. UWB radar technology is a supplement for microwave fire detection insofar as a common set of components can be used. UWB radar technology most probably will not penetrate the market for classical fire detectors. The advantages of UWB radar sensing can be better exploited in a scenario with new mobile sensors.

UWB radar technology in such an application has to take into account different kinds of influences on measurements. So a lot of work needs to be done on methods for compensating as far as possible various effects due to different object size, inclination angle and surface roughness. Concepts of such methods have been described for the application area of mobile sensors.

Recent experiments in the fire lab have indicated the potential of UWB radar technology for precise resolution concerning the localisation of objects. In the (of course) artificial environment of a fire detection lab, burnt from unburnt pieces of TF2 material could be clearly distinguished.

Improved results in terms of spatial resolution (with reduced backscattered signal width) can be expected if the impulse response of the antenna is taken into account by means of deconvolution. Thus the data of scattered signals would indicate dielectric boundaries of even thinner components than those used in the tests.

6 References

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