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Modulation and Coding Detection of Energy Absorption
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ABSTRACT

This report discusses the theory of modulation and coding detection schemes. Applications of these techniques in active radiation dosimetry measurements would appear to be particularly promising. Modern integrated circuits provide ready made modulation and coding detection electronics so that the circuit design problems for such systems are already worked out and the circuits available as off the shelf devices. We describe in particular the applications to real time measurement of fast neutrons in a hostile environment of high gamma ray background using either a gaseous or solid state ionization chamber.

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Modulation and Coding Detection
of Energy Absorption

P. R. Moran

1. Preface. This report is a disclosure for possible patent considerations and describes a method for sensitive energy absorption measurements. Actually it is not a specific method, but a group of concepts which can be combined and practically applied to a whole class of different methods. Before discussing these methods further, some background regarding the ideas is appropriate.

In research activities at our laboratories, we have been studying a number of areas and coping with several experimental problems. Although none of these bear directly on the methods to be described, all have played their part in formulating some basic ideas. To recount them all at this stage does not seem important.

The general methods to be described combine techniques which are all quite simple and well-known. It is difficult to believe that they have never been successfully combined for many of the applications discussed here. Nevertheless, to my best knowledge, they never have. Perhaps the ideas have just never come together, or perhaps they have been attempted without success and therefore received little publication.

2. Introduction. It is well known that one never makes a dc measurement if it can possibly be avoided. The reason is that dc measurements suffer large noise problems. This is caused by a rising noise power spectrum as one approaches lower and lower frequencies. Often this is referred to as the "(1/f) noise" problem. The standard solution is somehow to modulate the

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desired signal to a a.c. signal, thus move it to a frequency away from the d.c. noise, and use a.c. amplification and detection techniques.

There are two ways to accomplish this. First, one can modulate the detector as in a chopper amplifier. Second, one can modulate the source as in the magnetic field modulation used for sensitive magnetic resonance detection. In the specific case of magnetic resonance measurements, we once researched these techniques and showed the end results of detector and source modulation were exactly the same. (M, 1969).

The modulation method also has its limitation. The desired signal is modulated to and detected at a modulation frequency, ω_M . Invariably the physical process by which the modulation is accomplished introduces some spurious modulation pickup also at frequency ω_M . This gives a non-zero background signal against which the desired signal must be measured. Time dependent fluctuations in the modulation pickup introduce noise into the a.c. measurement. Of course, this may be several orders of magnitude improvement over the d.c. measurement, but it usually provides the limitation on the a.c. method.

The same kinds of problems arise in transmission situations. Many schemes are developed for transmitting information accurately and keeping pieces of it separated from one another. A particularly widely used one is multiplexing. A good example is the transmission of two stereo channels or a single f.m. transmission carrier. The scheme used is to modulate the carrier directly with channel one, then double modulate the carrier with a multiplex frequency (at about 40 kHz) together with channel two. One winds up with a triply modulated system and the information electronically coded in a way so that it can be separated out by the detection system. The ideas to

be presented later involve multiply modulated, or multiplexed, measurement systems.

3. Modulation and Mixing. 'Mixing' processes result when an output signal is proportional to the produce of two physical quantities, both of which can be modulated. A simple example is the voltage across a resistor,

$$V = IR. \quad (3.1)$$

Suppose we wish to measure the current, I , by detecting the output voltage V . To get out from under the d.c. noise we might modulate I into an a.c. current at frequency ω ,

$$I = I_0 \cos(\omega t). \quad (3.2)$$

This would give an a.c. output voltage

$$V = I_0 R \cos \omega t; \quad (3.3)$$

but, suppose we also have a way to modulate R . For example,

$$R = R_0 \{1 + \cos \Omega t\}. \quad (3.4)$$

Then the output voltage, $V(t)$, is doubly modulated,

$$V(t) = I_0 R_0 \{ \cos \omega t + \cos(\omega t) \cos(\Omega t) \}. \quad (3.5)$$

We can use the trigonometric relation for the produce of cosines to write Eq. (3.5) as

$$V(t) = I_0 R_0 \cos(\omega t) + \frac{1}{2} I_0 R_0 \cos(\Omega - \omega)t + \frac{1}{2} I_0 R_0 \cos(\Omega + \omega)t. \quad (3.6)$$

The significant thing about Eq. (3.6) is that the doubly modulated output

occurs not just at modulation frequency ω or Ω , but has components at the sum and difference frequency $(\Omega+\omega)$ and $(\Omega-\omega)$. By detecting at these mixing frequencies, spurious modulation pickup at Ω or ω is avoided.

Now, it is important to understand that the sinusoidal modulations in Eq. (3.2) and Eq. (3.4) are convenient, but not necessary, forms. Any modulation shape will work. Another important point, which is not an obvious one, is that even a self-modulated signal can be employed by a simple extension of the methods outlined here. At this point we wish only to state the following example: if we wish to measure the "self-modulated" pulsatile blood flow to someone's finger, and if we simultaneously record a correlated signal such as the EKG output, then we can later form the exact modulation equivalent of a sinusoidally modulated blood flow. In practice the methods of direct modulation and extracting the effective modulation from an intrinsically modulated effect may constitute different techniques. Because they are the same from an information theory viewpoint, however, one can discuss them as the same method.

4. The photo-acoustic effect. This just serves as an example of applications. The photo-acoustic effect has been studied for about 90 years. If you have a substance that absorbs light, it absorbs energy and heats up. It will expand thermally, or transmit heat energy to its gaseous surroundings which expand thermally. If the light source is chopped (modulated) the cyclic thermal expansion generates an acoustic wave which can be detected. Roentgen discovered this in 1881 using a stethoscope as a detector on a glass bottle. Twenty years later, he apparently detected x-rays with it as well as with film.

Lately, with lasers and very sensitive electret microphones, photo-

acoustic detection has received renewed attention. It has many surprising advantages.

The modulation and coding methods suggested in this report go beyond the simple modulation of chopping the light, which is only the first step,

(I) Modulate the light intensity at frequency ω . This gives a pressure wave which is proportional to the energy absorbed, $E(\lambda)$, in the sample at optical wavelength λ .

$$\delta p = kE(\lambda) \cos \omega t \quad (4.1)$$

(II) The pressure modulates the capacitance, C , of the microphone element,

$$(\delta C = k' \delta p = k'' E(\lambda) \cos \omega t.) \quad (4.2)$$

To doubly modulate, we first realize that the microphone charge is

$$Q = CV, \quad (4.3)$$

so we apply a modulated bias-voltage, $V_0 \cos \Omega t$, to it (we have modulated both the source and the detector, but at different frequencies)

$$\begin{aligned} \delta Q &= k'' E(\lambda) (\cos \omega t) \cos \Omega t \\ &= \frac{k'' E(\lambda)}{2} \{ \cos(\omega + \Omega)t \\ &\quad + \cos(\omega - \Omega)t \}. \end{aligned} \quad (4.4)$$

Basically, the microphone outputs a signal proportional to δQ , so the output frequencies at $(\omega + \Omega)$ and $(\omega - \Omega)$ do not have the modulation pickups at ω or Ω to fight against.

(III) The idea can be extended even further. If we wish to measure optical spectra, then we also modulate the light source wavelength λ at frequency f . This gives us a spectrally sensitive energy absorption modulation

$$\delta E = \epsilon(\lambda_0) \cos ft. \quad (4.5)$$

Now the triply modulated microphone charge output corresponding to Eq. (4.4) is

$$\begin{aligned} \delta Q \propto \frac{\epsilon(\lambda_0)}{4} \{ & \cos(\omega + \Omega + f)t \\ & + \cos(\omega + \Omega - f)t + \cos(\omega - \Omega + f)t \\ & + \cos(\omega - \Omega - f)t \}. \end{aligned} \quad (4.6)$$

(IV) Phase sensitive detection. Once we've got a signal at, say, $\omega + \Omega + f$, what do we do with it? The smart thing is to use phase-sensitive detection. This means we first derive a reference signal at $(\omega + \Omega + f)$, which is accomplished by mixing together the physical driving voltages originally used to modulate V , $I(\text{optical})$, and λ . Then electronically we finally heterodyne, or mix, back to d.c. (after large amplification of the signal detected) by taking the product output of $V_{\text{ref}}(t) \times V_{\text{sig}}(t)$.

5. Ionizing Radiation Measurements. Another example that seems especially important is the real-time measurement of fast neutrons in a hostile environment such as high γ -ray background. Here we use as a detector either a gaseous or solid state ionization chamber.

(1) The front of the detector would incorporate a collimator and a chopping shutter; the entire radiation input would be modulated at frequency ω_0 .

(2) At the other end of the collimator, within the gas of a gas ionization

chamber, one would spin a sectored disc of graphite-polyethylene alternating sectors. The γ -rays pass through both sectors equally, but the neutrons produce recoil protons from the polyethylene and nothing from the carbon. This modulates neutron ionizing radiation at ω_N .

(3) One could go on spinning a series of discs which do not modulate part of the gamma beam. Thus one could build up a whole coding of the different radiations according to their different modulation frequencies. We'll not go thru these further useful complexities now.

(4) Finally, we build a balanced dual ionization chamber so that when one-half is exposed to the proton recoils, the other half is not. We pick off the difference signal and drive the electrodes at frequency Ω

Schematic
Diagram of
Multiple Modulation
Fast Neutron Detection

MAIN SHUTTER
and HOUSING

7.1

Neutron Modulation Detector

7.2

These methods of multiple modulation techniques for energy absorption, can be applied to acoustic detectors, ionization chamber detectors, temperature detectors, etc. The purpose of this preliminary report is to secure some degree of protection and documentation of our ideas while we pursue research efforts along these lines.