More Fundamental Instabilities in Oscillators?

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Abstract—**This is a speculative paper. It introduces some as yet untested ideas based on some new observations of electromagnetic (EM) waves in three areas. It postulates that multiple EM surface wave layers and multiple lattice paths in waveguides should have counterparts in acoustic and dielectric resonators and delay lines. Because the paths are partially coupled, energy can exchange between them in a way that may become chaotic. The 'non-linearity' required for chaos to occur is the 'finite energy' constraint. Does the 'finite energy' constraint actually cause instabilities in oscillators? Can this be a chaotic process? Does it only occur when there are multiple paths? Bulk and surface acoustic waves have many of the attributes and features of electromagnetic waves. Perhaps these effects do exist, but normally are of too low level to be of concern? SPICE simulations can illustrate some of the speculative effects.**

I. Introduction

New layered surface wave effects have been detected in electromagnetic (EM) waves. Perhaps controversially they require extensions to Maxwell's equations. Maxwell's equations were actually derived by the three 'Maxwellians', FitzGerald, Lodge and Heaviside, [1] from Maxwell's original nineteen or so equations [2], [3]. Can we be sure that these are actually what Maxwell intended? Have unnecessary constraints or incorrect assumptions been applied?

The new effects are experimental observations. If repeatable they cannot be challenged theoretically. Any theory that appears to challenge them must itself be revised until it agrees with the observations. Maxwell's equations are no exception. The approach taken in this paper is that experiments take priority over and dictate the theory and mathematics.

We observe that in sometimes discrete layers of preferred propagation *can* be seen for EM waves. Each layer can be considered as a separate transmission line resonator that is partially coupled to the other layers. In waveguides that are several wavelengths in lateral dimensions there is a 'lattice' of preferred paths. The paths are partially coupled and energy can exchange between them in potentially chaotic way. The 'non-linearity' required for chaos to occur is the 'finite energy' constraint. The sum of the energies in all the paths is constant.

Three sets of evidence for layered EM waves are presented. In this context "The Millington Effect" and "Wave pockets" were originally noted in [4]. The 77 GHz radar measurements showing layers are from [5].

The first speculative question is whether the multiple partially coupled paths can or do exist in acoustic, dielectric, optical or electromagnetic cavity resonators?

The second question is whether the 'finite energy constraint' can cause instabilities in oscillators? The positive feedback in an oscillator applies a finite energy constraint. Such a constraint causes the instabilities seen in injection locked oscillators [4] and in multimode delay line oscillators [5]. It can be the cause of random phase or frequency jumps in oscillators [6].

The third question is whether instabilities causes by a finite energy constraint are chaotic or not?

An underlying question is whether there are sufficient similarities between electromagnetic waves and bulk and surface acoustic waves, so that partially coupled acoustic multimode effects will also exist? Perhaps these effects do exist, but normally are of too low level to be of concern?

SPICE simulations can illustrate some of the speculative effects.

II. Simplifying and Extending Maxwell's Equations

Maxwell's equations can be simplified and extended by partitioning into (a) transmission line (TL) equations in the direction of travel, and (b) orthogonal Transverse Evanescent (TEv) wave equations.

To represent the near field physics of an antenna we find we need four pairs of separate partially coupled TL and TEv wave equations for the four fields E, D, B, and H.

Electric and magnetic displacements, and displacement currents, with associated (vector) potentials can usefully substitute for the four fields. These are closely analogous to the real currents and voltages on a real transmission line. This is an alternative representation.

A. *Maxwell's Equations in the Wave Direction*

We derive a one dimensional equation for a traveling wave along the x axis, at right angles to the direction z of polarisation of the Ez field, and y of the of the Hy field. We use the local values of ε and μ.

Then Maxwell's equations simplify to:

$$\partial E_z / \partial x = - \mu \ \partial H_y / \partial t \qquad (1)$$

$$\partial H_y / \partial x = - \varepsilon \, \partial E_z / \partial t \qquad (2)$$

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A single frequency solution is $X = |X|e^{-jkx\ -j\omega t}$. Thus we put $\partial/\partial x = -jkx$ and $\partial/\partial t = -j\omega$ in (1) and (2) to give:

$$jkz\ E_z = j\omega\mu\ H_y = 0 \quad \text{or} \quad kz\ E_z + \omega\mu\ H_y = 0 \tag{3}$$

$$-jkz\ H_y = j\omega\varepsilon\ E_z = 0 \quad \text{or} \quad kz\ H_y + \omega\varepsilon\ E_z = 0 \tag{4}$$

These equations are transmission line equations if

$$E_z \equiv V,\quad H_y \equiv I,\quad \varepsilon \equiv C \text{ and } \mu \equiv L. \tag{5}$$

The wave nature is confirmed by further differentiation to give traditional wave equations of the form:

$$\partial^2 X/\partial x^2 = \varepsilon\mu\, \partial^2 X/\partial t^2 \tag{6}$$

where $X = E_z$ or H_y

The velocity is $v_p = 1/\sqrt{(\varepsilon\mu)}$. The propagation constant $k = 2\pi/\lambda = \omega/v_p$. The spatial impedance is $Z_c = E/H = \sqrt{(\varepsilon/\mu)}$.

B. *The Transverse Evanescent (TEv) Wave Equations*

The four evanescent Wave equations for E, D, B, and H all are radial profiles of stored energy. The equations have an origin at a source or a sink.

The seven main processes in the formation of evanescent waves are: (i) the spreading function, (ii) the self-coupling function, (iii) (radial) standing wave function, (iv) time variation of phase of stored energy components, (v) Root Sum of the Squares (RSS) combination of the four coupled equations giving dominance to the strongest field, (vi) dissipation, radiation or absorption of energy, (vii) exchange of energy between multiple coupled evanescent modes.

Evanescent wave equations can represent surface wave propagation in layers or the lattice waves in waveguides.

C. *Evanescent Waves for Antennas*

For antennas the radial evanescent equations are one dimensional and represent the energy stored in dr at a distance r from a line sources on the antenna. The energy profile also depends on the geometry of the sources and their spreading functions.

Energy is the total source field charge times the in-phase potential that this 'material' sits in. The *field charge* is the modulus of the field amplitude. This is a new definition. *Field substance* is an alternative term for *field charge*. (This latter definition draws attention to the fact that fields can have energy and energy is matter.) A quadrature phase component means that energy is being radiated or received.

The potential is created by the source charge by a self-coupling process. This process dominates near the source. Thereafter the expected spreading function dominates. An RSS process governs the changeover from one to the other.

The change-over distance r_{co} (the *Goubau distance*) is given by: $r_{co} = \sqrt{(f/f_0)}$, where from measurements f_0 = 20MHz (± 20%)

D. *The General Evanescent Wave Equation*

The general evanescent equation is derived as:

$$X_1 = |X_{01}|\ \{(Sin\ kr)/kr\}\ \sqrt{(1+k^2r^2)/(1+r^2f/f_0)n}\ e^{-j\omega t} \tag{7}$$

Vertically above a (conducting) surface the field charge density is approximated by $n = 1$, above a wire by $n = 2$, and away from a point source by n=3. In all the above cases the potential is approximated by $n = 1$.

$$X_1 = |X_{01}|\ \{(Sin\ kr)/kr\}\sqrt{\{(1+k^2r^2)/(1+r^2f/f_0)n\}}\ e^{-j\omega t} \tag{8}$$

$$X_2 = j|X_{02}|\ \{(Cos\ kr)/kr\}\sqrt{\{(1+k^2r^2)/(1+r^2f/f_0)n\}}\ e^{-j\omega t} \tag{9}$$

The second part is dependent on, the first part. The two parts represent two independent types of radiation sources/sinks and they are in phase quadrature.

As for any standing wave the phase is constant over each half-wave section. Successive half-wave sections for each part alternate in phase.

The exponential phase factor is an analytic signal where

$$e^{-j\omega t} = Cos\ \omega t - j\ Sin\ \omega t. \tag{10}$$

Figs 1 to 4 respectively show *X1* and *X2* radial plots well above and below the change-over frequency of about 20MHz.

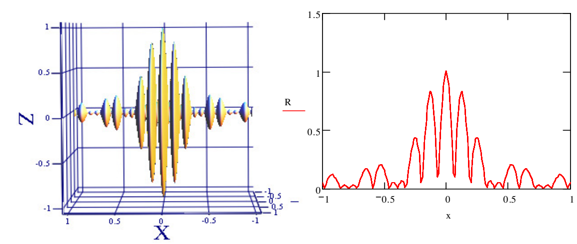

Figure 1. Primary Evanescent Wave amplitude distribution at 1GHz.

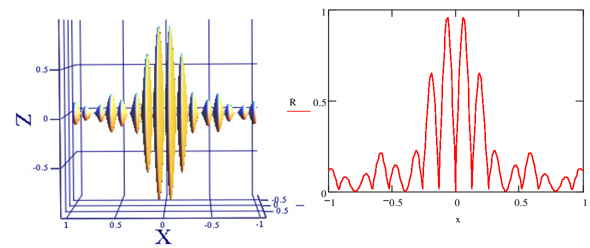

Figure 2. Secondary Evanescent Wave amplitude distribution at 1GHz

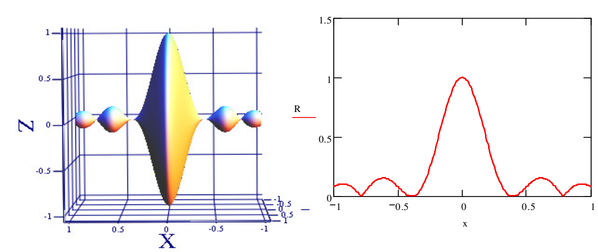

Figure 3. Primary Evanescent Wave amplitude distribution at 1MHz

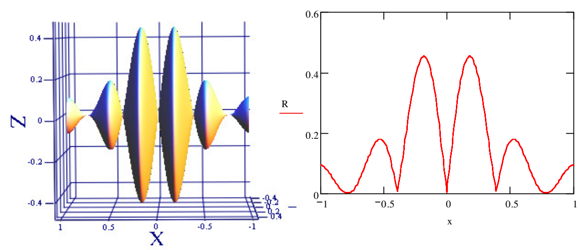

Figure 4. Secondary Evanescent Wave amplitude distribution at 1MHz

Note that there are two layer forming processes. The envelope is the ‘Goubau process’ that dominates at low frequencies. At high frequencies there are many layers within the Goubau distance envelope.

III. Evidence for Multiple EM Layers

The case for multiple EM surface wave layers, predicted by the evanescent wave equations, derives from the following three sets of observations:

A. The Millington Effect

The ‘Millington Effect’ of propagation over a land-sea boundary implies energy exchange between layers of different heights. There is either a 20dB increase (counter-intuitive) as the ground-wave signal passes from land to sea or a 20dB decrease as the signal passes from sea to land.

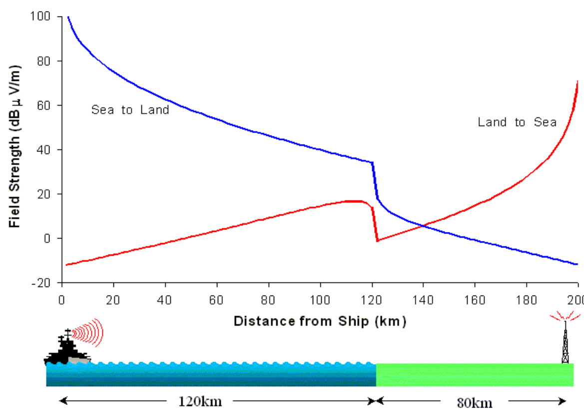

Figure 5. The Millington Effect

Fig. 5 was taken (on 16-03-03) from the QinetiQ website http://www.cpar.qinetiq.com/grapple.html. Could this be exchange of energy between two horizontal propagation layers at different heights?

B. Wave Pockets for Tall MF Antennas

F. M. Kabbary’s ‘Wave Pockets’ for tall MF antenna propagation over desert sand implies energy exchange between two coupled layers having slightly different velocities.

Fig. 6 shows F. M. Kabbary’s ground wave results from a broadcast CFA (Crossed-Field Antenna) in Egypt.

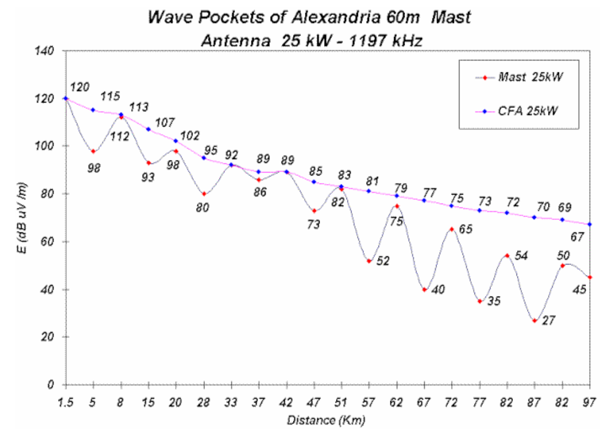

Figure 6. Measured ‘Wave Pockets’ of MW broadcast antennas with distance from antenna

The conventional antenna generates an interference pattern as if the ground wave travels about 2.6 % slower than the ‘space-wave’ over the ground. Fig. 7 is a SPICE ‘Wave Pocket’ model showing an interchange of energy with distance. The model is two over-coupled tuned circuits. Time is the analogue of distance and the distance decay is exponential.

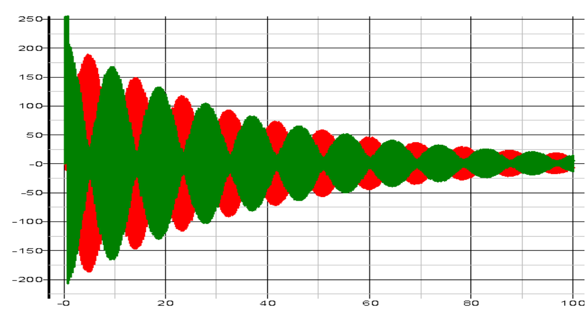

Figure 7. SPICE model of Wave Pockets

When there are three layers (or more) the energy interchange with distance can start to look chaotic. as shown in the Fig. 8 SPICE results for three layers.

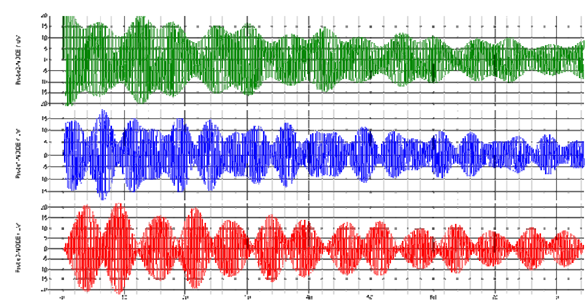

Figure 8. SPICE model of interchange of energy between three EM layers with distance (beginning to appear chaotic?)

C. 77GHz Radar Returns from Spinning Cylinders

Fig. 8 shows the 77GHz coherent FMCW radar on the left. The dual antenna is shown in more detail on the right.

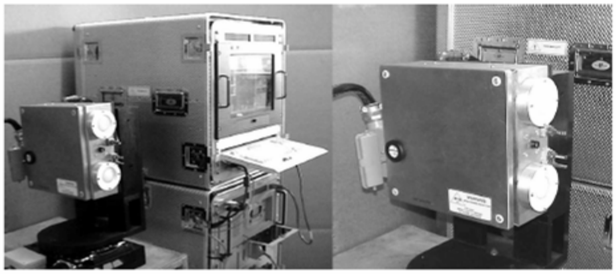

Figure 9. Phase coded Doppler and continuous wave 77MHz radar. Dual antenna enlarged on right

The 77GHz coherent radar (Fig. 9) returns from a 10cm diameter smooth vertical spinning cylinder are shown in Figs 10 to12. These imply over twenty multiple EM layers experiencing 'ether dragging'.

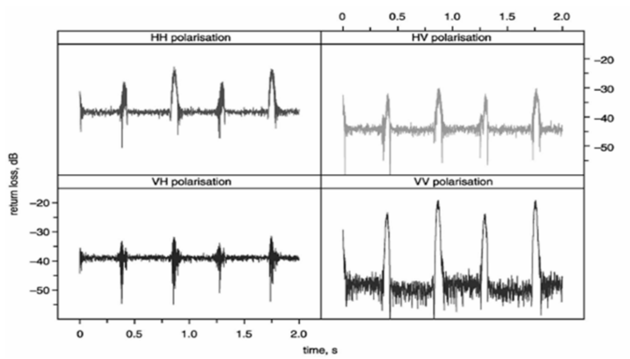

Figure 10. Temporal returns for different antenna polarisations

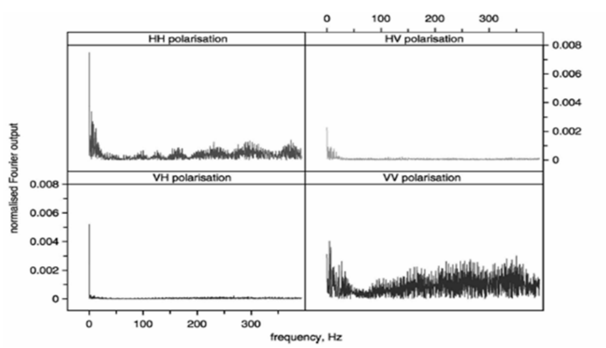

Figure 11. Doppler sieband returns for different antenna polarisations

D. *Interpretation of returns from spinning cylinder*

The 77GHz wavelength is 3.9mm. The cylinder is 100mm diameter. The circumference is 80.6 wavelengths. The cylinder surface velocity at 60rpm (1Hz) is 0.157m/s.

We postulate that layer resonances exist if a layer circumference is an integer number of wavelengths. Then the resonant layers are $3.9/\pi = 1.24$ mm apart in radial distance. But we observe that there are discrete spin frequency spaced sidebands. This is still a mystery!

Maximum Doppler shift is thus 80.6Hz. This should be the maximum frequency of the Doppler spectrum. In one case this is exceeded and in another it is less. Why?

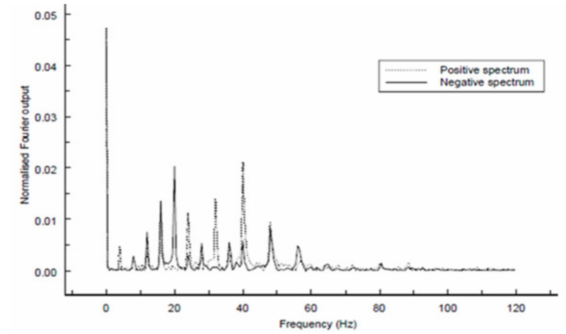

Figure 12. Overlaid upper and lower Doppler siebands

We postulate that ether dragging occurs out to the 'Goubau distance' of about 10 to 20 wavelengths. Then the outer layers have progressively diminished velocity and Doppler shift, but nonetheless appear as discrete sidebands.

Note in Fig 10 the short pulsed flashes that occur at the spin frequency. Is this like the pulses of pulsars? What sets the timing point of these on a very smooth cylinder?

IV. CONCLUSIONS

Multiple EM surface wave layers have been shown to exist. By analogy the same may be true for acoustic waves.

Multiple energy paths in resonators can cause oscillator instabilities, or chaotically random but occasional phase or frequency jumps. Multiple paths for energy may thus be additional instability mechanisms in some oscillators?

The spinning cylinder observed with a 77GHz radar displays multiple EM paths. Short pulses are generated – like pulsars? Pulsars have very stable repetition frequencies that occasionally jump chaotically.

Do these effects make a case for "More Fundamental Instabilities in Oscillators?"

REFERENCES

[1] Bruce J. Hunt. *The Maxwellians*, Cornell University Press 1991, ISBN 0-8014-8234-8

[2] J. Clerk Maxwell, *A Treatise on Electricity and Magnetism*, *3rd ed.,, Vol. I,* Dover reprint, ISBN 0-486-60636-8.

[3] J. Clerk Maxwell, *A Treatise on Electricity and Magnetism, 3rd ed., Vol. II*, OUP reprint, ISBN 0-19-850374-1. .

[4] M. J. Underhill, "Fundamental limitations of oscillator performance", *IEE Conf. Pub. 303, Frequency control and synthesis, 1989*, pp 18-31.

[5] M..J.. Underhill, "The estimation and measurement of the efficiency and effectiveness of small antennas in an environment", *IEE Conf. Pub. 493, 9th IEE Intl Conf on HF Radio Systems and Techniques,* June 2003, pp: 203-209.

[6] M. J. Underhill, N. Siripon, and N. Christophorou, "Determinationof the capture range and locking range of injection locked oscillators", *15th EFTF,* Neuchatel, Switzerland, March 2001, pp 232-236.

[7] M. J. Underhill, "Fundamental phase jumps in oscillators?", *20th EFTF,* Braunschweig, March 2006, pp 125-132.

[8] J. K. Christensen and M. J. Underhill, "Phase coded pulse Doppler and continuous wave 77 GHz radar measurement and analysis facility", Radar, Sonar and Navigation, IEE Proceedings, vol. 151, no.6, pp 365-374,. vol. 151, no.6, pp 365-374.