Principles of Operation of Electronic Neural Loop Technology

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Abstract

An Electronic Neural Loop (ENL) is a high frequency, fundamental electronic component, capable of identifying ENL characteristic Fourier components in analog signals. The process is near instantaneous and continuous. The theory and technology is described, with associated precedents supporting the functionality and uses. *This is a work in progress*

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1 How the ENL works

A burning question even amongst some of Variance Dynamical Corporation's very own science team, is how (and why) the ENL works. In what follows, I will attempt a clear description of the ENL's operation from first principles.

The motivation for the inventions of Dr. Goodwin followed from investigations of the biological nervous system. Although interesting and instructive, this area of research falls under current research into cognitive computing and machine intelligence, and will not be covered in the current document. Instead focus will be given to the electronic component applications of the device.

2 Short Description of ENL Operation

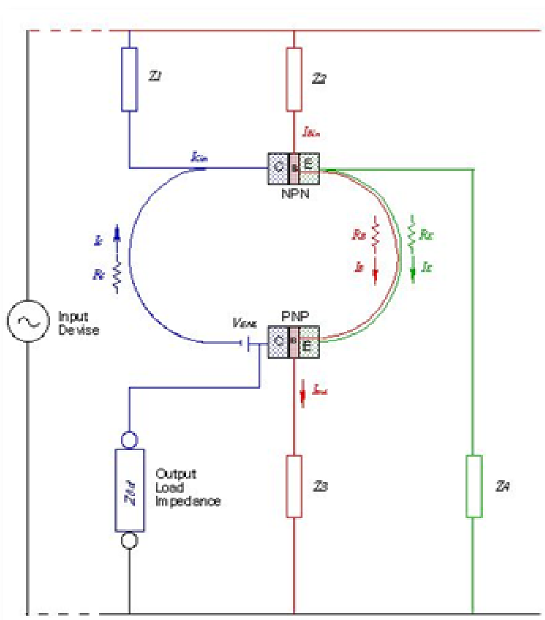

Figure 1. ENL circuit

Variance technology is based on the creation of standing waves between two transistors in an electronic circuit. The transistors act as nodes, between which standing waves which have an integral number of half wavelengths will develop resonances. The physical length of the transmission lines between transistors define the preferred wavelengths.

An analog signal containing the characteristic ENL frequency will produce a resonance by which identification is made. By this method, ENLs can be used to perform continuous Fourier component spectrum decompositions.

Thus an ENL does not frame the data or calculate Fourier components, but identifies their presence in analog signals. It is this property of our technology which makes it both extremely fast and continuous.

Sequentially channeling an input signal through cascading ENLs of various lengths, results in the full set of Fourier components, thus Variance's patented Automatic Fourier Analyzer (AFA) application.

3 Waves

Let us first examine the general properties of a wave, from which we will build higher concepts. The graphical representation of a simple wave, shown in Figure 2, contains everything we need for a visual inspection.

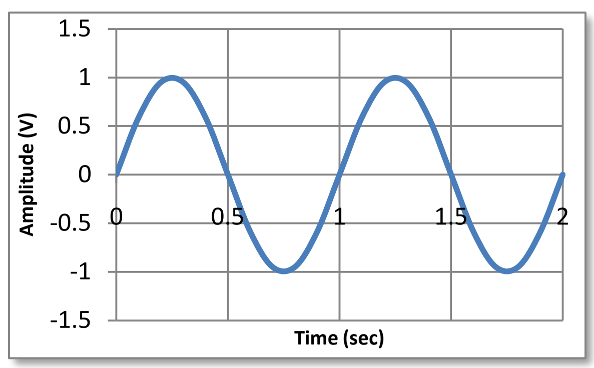

Figure 2. A simple wave

The amplitude **V** is the maximum height of a wave. In the case of a wave on the surface of a body of water, this amplitude represents the physical height of the wave and is measured in meters. When we speak of analog electronic signals, the amplitude represents the maximum value of the alternating voltage, which described the analog signal.

The time needed for a wave to complete a cycle is called the period **T** measured in seconds. The length of this wave is called the wavelength **λ**, measured in meters. The wavelength is often quoted as the distance between consecutive peaks. To summarize,

- Amplitude, A (Volt)
- Period, T (Seconds)
- Wavelength, λ (Meters)

The wavelength of a signal also defines the scale size of its interactions with matter. For instance, radio waves can transmit signals by interacting with large antennae, but produce no acoustic effect on humans. Glass windows often resonate from acoustic tones produced from trucks passing by.

An appreciation of such analogies is necessary to understand the principles of ENL operation. When a standing wave develops along the transmission lines of an ENL, the wavelength of the "confined" frequency is exactly equal to the physical length of the line. We will discuss this more in the following chapters.

The frequency of the wave is the number of wave cycles repeated per second, also determined by the inverse of the period and is measured in Hertz,

$$f = \frac{cycles}{sec} = \frac{1}{T} \qquad (1)$$

So if you have a 100 MHz cable this means that the cable can transfer 100,000,000 wave cycles of voltage in one second.

3.1 Wave Propagation Speed

Having defined the anatomy of a wave, we can now move to elementary descriptions of wave mechanics. All mechanics start with a definition of the speed and so will we.

The speed of transmission of all waves in nature, are proportional to the wavelength and the frequency of a wave,

$$v = \lambda f \qquad (2)$$

In the case of electromagnetic radiation, the speed of light, $c = 2.998 \cdot 10^8\ m/s$. Here we are interested in the wave propagation speed of an electrical voltage, which is often taken to be half of the speed of light, $c_e = 0.5c$. Let's take a moment to elaborate on what the transmission speed of an electronic signal is.

The discussion we have led so far addresses all types of waves, as they all share the same overall behavioral properties. Optical signals for instance, carried by photons travel at the speed of light through vacuum. The speed with which an optical wavefront in general, travels through a transmission medium depends on the refractive index of that medium, defined as,

$$n = \frac{c}{v} \qquad (3)$$

which is to say, the index of refraction is defined as the ratio of the speed of light in vacuum to the speed of light in the medium.

Photons are comprised of electric and magnetic fields, as shown in Figure 3, which tend to displace the electrons which are present in the transmission medium. The movement of these electrons in turn produce varying electromagnetic radiation, which is dispersed through the material. Thus the initial wave speed is decreased in the process, as energy must always be conserved. As waves propagate through various materials, their wavelength and velocity change, while frequency remains, according to equation (2).

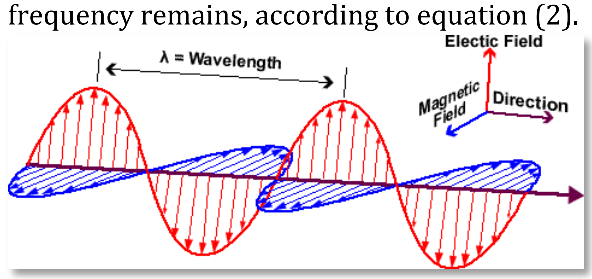

Figure 3. Electromagnetic radiation

The refractive index is also frequency dependent, which means different wavelengths of light will experience different losses in speed through a material. As a consequence, they will also refract differently at the boundary of a medium. This is exactly how rainbows are produced.

For a yellow photon, for instance with wavelength 590 nm, the refractive index of water is n_{water} = 1.3330. Therefore the speed of a yellow photon in water is,

$$v = \frac{c}{n_{water}} = \frac{c}{1.3330} = 0.75c \qquad (4)$$

To extend these equations to the speed of wave transmission through a conductor, we follow the same line of thinking. The transmission will travel through a conductor displacing the electrons found in the surrounding insulation.

Now, the speed of light in vacuum can be derived from Maxwell's equations to be (Appendix A),

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \qquad (5)$$

where $\boldsymbol{\varepsilon_0}$ is the permittivity and $\boldsymbol{\mu_0}$ is the magnetic permeability of free space. In a dielectric medium, the speed of propagation is,

$$v = \frac{1}{\sqrt{\varepsilon_0 \mu_0 \varepsilon \mu}} = \frac{c}{\sqrt{\varepsilon \mu}} \qquad (6)$$

where ε and μ are the relative permittivity and permeability of the dielectric which forms the insulator. These together are called the "relative dielectric constant", $\boldsymbol{\kappa = \varepsilon\mu}$. We can rewrite this equation as,

$$\sqrt{\kappa} = \frac{c}{v} \qquad (7)$$

Comparing this with equation (4) we find,

$$n = \sqrt{\kappa} \qquad (8)$$

We have now made a connection between optical electromagnetic waves and electronic transmissions through a conductor, and we can clearly state the speed of transmission of an electronic wave as,

$$v = \frac{c}{\sqrt{\kappa}} \qquad (9)$$

Let's consider some examples now. For most materials $\mu \approx 1$, so we can let $\kappa \approx \varepsilon$. A common material used for printed circuit boards (PCBs) is a laminated reinforced glass epoxy, with grade designation FR-4, having permittivity $\varepsilon_{FR4} = 4.8$. A signal travels through its channels with speed,

$$v_{FR4} = \frac{1}{\sqrt{4.8}} c \cong 0.45c \qquad (10)$$

If we were to suspend a copper wire, or wire of any conducting material in water at 0 ^{0}C, where $\varepsilon_{water} = 88$, the signal speed would be,

$$v_{water} = \frac{1}{\sqrt{88}} c \cong 0.10c \qquad (11)$$

As we can see, the speed is unrelated to the material of the conductor. The physical characteristics of the medium around the wire are those which define the wave propagation speed.

In ENL research and prototype development, the transmission speed is taken to be 0.5c, in close accordance to expected values implied by equation (11).

+[*Dielectric Spectroscopy* and PSF/2011 Patents]

3.2 The Wave Equation

Consider a homogeneous string with one-dimensional wave equation [3],

$$\frac{\partial^2 u}{\partial x^2} = \frac{1}{c^2} \frac{\partial^2 u}{\partial t^2} \qquad (12)$$

where,

- $c = T/\rho$ is the transverse speed of wave,
- T, is the tension on the string,
- ρ, is the linear mass density of the string,
- *u(x,t)*, is a measure of deformation.

Physical problems impose certain conditions on the solution *u(x,t)*. For instance, a typical stretched-string problem implies that the string, of length L, is fixed at its ends. The general form of these *boundary conditions* is,

$$\lim_{x \to 0,L} u(x,t) = 0$$
$$\lim_{x \to 0,L} \frac{\partial u(x,t)}{\partial y} = 0 \qquad (13)$$

The first condition tells us the amplitude of the wave goes to zero at the boundaries. This is how we establish the nodes at the endpoints, which must be stationary.

The second assures us there is no motion perpendicular to the propagation direction, so there is no "slipping up and down", if we were to think of a rope tied to two posts. This condition becomes more important when we consider the full waveguide problem, where *u(x,y,z,t)*.

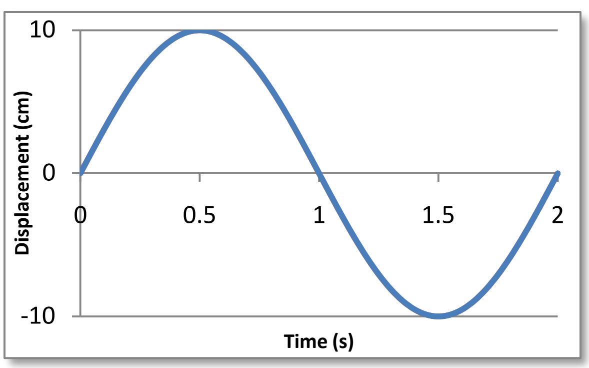

Figure 4. A stretched-string problem.

Moreover, the physical problem begins at a certain instant of time, usually selected to be *t=0*, and with a specified state. These *initial conditions*, are functions of the variable *x* and can be expressed as,

$$u(x,0) = u_0(x) \qquad (14)$$

$$\frac{\partial u(x,0)}{\partial t} = v_0(x) \qquad (15)$$

These conditions together specify the initial shape and distribution of initial velocities of the string. They can be thought of as describing the energy content of the system, without which we would be looking at static solutions only.

To solve this problem we use the method of separation of variables, where we seek solutions to the partial differential equation (13), of the form,

$$u(x,t) = X(x)T(t) \qquad (16)$$

where *X(x)* is designed to address the boundary conditions, which are functions of position and *T(t)* the initial conditions.

Differentiating we form the left and right hand sides of equation (13),

$$\frac{\partial^2 u(x,t)}{\partial x^2} = \frac{d^2 X(x)}{dx^2} T(t) \qquad (17)$$

$$\frac{\partial^2 u(x,t)}{\partial t^2} = X(x) \frac{d^2 T(t)}{dt^2} \qquad (18)$$

Substituting equations (17) and (18) into (13),

$$\frac{d^2 X}{dx^2} T = \frac{1}{c^2} X \frac{d^2 T}{dt^2} \qquad (19)$$

Dividing both sides by *X(x)T(t)*, we get,

$$\frac{1}{X}\frac{d^2 X}{dx^2} = \frac{1}{c^2}\frac{1}{T}\frac{d^2 T}{dt^2} \qquad (20)$$

In the equation above, the left-hand side depends only on *x* and the right-hand side only on *t*. It follows that they must both be constant,

$$\frac{1}{X}\frac{d^2 X}{dx^2} = \lambda \qquad (21)$$

$$\frac{1}{c^2}\frac{1}{T}\frac{d^2T}{dt^2} = \lambda \qquad (22)$$

By the method of separation of variables we have transformed a partial differential equation into two ordinary differential equations, with known solutions.

The equation for *X(x)*, can be written as,

$$\frac{d^2X}{dx^2} = \lambda X \qquad (23)$$

and leads to exponential functions for $\lambda > 0$, trigonometric functions if $\lambda < 0$ and to a linear function if $\lambda = 0$,

$$\begin{array}{cc} A_1 e^{x\sqrt{\lambda}} + B_1 e^{-x\sqrt{\lambda}} & \lambda > 0 \\ A_2\cos\left(x\sqrt{-\lambda}\right) + B_2\sin\left(x\sqrt{-\lambda}\right) & \lambda < 0 \\ A_3 x + B_3 & \lambda = 0 \end{array} \qquad (24)$$

Imposing our boundary conditions, we find valid solutions for $\lambda < 0$, $A_2 = 0$ and

$$\sqrt{-\lambda} = \frac{n\pi}{L} \quad (n = 1,2,3,\dots) \qquad (25)$$

The allowed values of the separation constant, or *eigenvalues*, are,

$$\lambda_n = -\frac{n^2\pi^2}{L^2} \quad (n = 1,2,3,\dots) \qquad (26)$$

The corresponding eigenfunctions comprise an infinite set,

$$X_n(x) = B_n \sin\left(\frac{n\pi x}{L}\right) \quad (n = 1,2,3,\dots) \qquad (27)$$

where B_n are arbitrary nonzero constants. Now recall the solutions in equation (22), to which the separation constant (26) is also a solution,

$$\frac{1}{c^2}\frac{1}{T_n}\frac{d^2T_n}{dt^2} = -\frac{n^2\pi^2}{L^2} \qquad (28)$$

Imposing our boundary conditions again for $\lambda < 0$,

$$T_n(t) = C_n\cos\left(\frac{n\pi ct}{L}\right) + D_n\sin\left(\frac{n\pi ct}{L}\right) \qquad (29)$$

We can now summarize our solution of equation (18),

$$u_n(x,t) = \sin\left(\frac{n\pi x}{L}\right) \times \left(A_n\cos\left(\frac{n\pi ct}{L}\right) + B_n\sin\left(\frac{n\pi ct}{L}\right)\right) \qquad (30)$$

where we have recast the arbitrary constants for simplicity ($A_n{}' = B_nC_n, B_n{}' = B_nD_n$).

This function $u_n(x,t)$ represents all possible motions of the stretched string and are known as the *characteristic modes* or *natural modes,* of the vibrating string. Each one represents a harmonic motion with *characteristic frequency* or *eigenfrequency,*

$$\omega_n = \frac{n\pi c}{L} \qquad (31)$$

Substituting equations (31) into equations (16) and taking the necessary derivatives, we find that $u_n(x,t)$ satisfies initial conditions of the form,

$$\begin{aligned} u_0(x) &= A_n\sin\frac{n\pi x}{L} \\ v_0(x) &= B_n\frac{n\pi c}{L}\sin\frac{n\pi x}{L} \end{aligned} \qquad (32)$$

We now need to extract the solutions which satisfy our desired initial conditions. To find all possible solutions to our problem, we take advantage of the *principle of superposition*, which tells us that any linear combination of solutions is also a solution, therefore,

$$f(x,t) = C_1u_1(x,t) + C_2u_2(x,t) + \cdots \qquad (33)$$

is also a solution to the wave equation. By extrapolation, an infinite series of such linearly combined solutions, is also a solution,

$$y(x,t) = \sum_{n=1}^{\infty} \sin\left(\frac{n\pi x}{L}\right) \times \left(A_n \cos\left(\frac{n\pi ct}{L}\right) + B_n \sin\left(\frac{n\pi ct}{L}\right)\right) \tag{34}$$

provided the series converges, or represents a distribution. The function $y(x,t)$ is a Fourier sine series in x (and in t, which is of less importance).

Consequently, we have constructed a solution to our problem in the form of a series, which satisfies all our boundary conditions and initial conditions.

3.3 Standing Waves

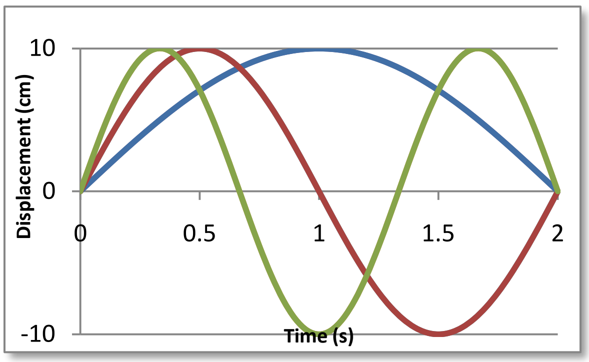

Figure 5. Standing Waves

Having presented the analytical solutions to the wave equation, we can now take a step back and visualize some standing wave phenomena.

Figure 5 depicts a string of length $L = 2\ m$ and the first three orders of standing wave solutions. The amplitude scale is arbitrary.

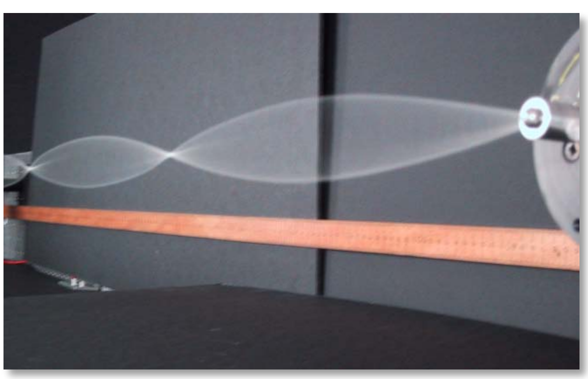

Figure 6. Standing Waves on a String

In general any integral number of half wavelengths will equal the total length of the string and represents a standing wave solution,

$$L = \frac{n}{2}\lambda \tag{35}$$

We can rewrite equation (3) as,

$$\lambda = \frac{\nu}{f} \tag{36}$$

and so,

$$f_n = \frac{n}{2}\frac{\nu}{L} \tag{37}$$

is the range of frequencies which can be found travelling along this length of string.

For instance, if we assume the three waves shown in the figure are sound waves, they have frequencies ($v_{sound} = 340\ m/s$),

$$\begin{aligned} f_1 &= 85\ Hz \\ f_2 &= 170\ Hz \\ f_3 &= 255\ Hz \end{aligned} \tag{38}$$

These frequencies are unique solutions.

4 Fourier Transform

From these examples one can see how dealing with a large number of frequencies is cumbersome. The problem in all transient systems is finding a representation that is independent of time.

When dealing with frequencies, it is convenient to plot the power or energy of the wave against its frequency, in what is called a Fourier Spectrum. Namely, a Fourier Transform (FT) transforms a signal representation from the time domain, to the frequency domain.

The Fourier Transform of a function f(x) is given by [3],

$$F(k) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{+\infty} f(x)e^{ikx}\,dx \tag{39}$$

with the inverse transform, from frequency space back to time space being,

$$f(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{+\infty} F(k) e^{-ikx} \, dx \qquad (40)$$

where $k = 2\pi/\lambda$, is the wavenumber.

4.1 Fourier Series

The power of Fourier transforms becomes evident when we recall a fundamental algebraic theorem which states [4],

"Any function can be written as the sum of an even and an odd function."

Even functions are symmetric about the y-axis and can be defined as,

$$E(x) = E(-x) \qquad (41)$$

Similarly, odd functions are antisymmetric about the y-axis and can be written as,

$$O(x) = -O(-x) \qquad (42)$$

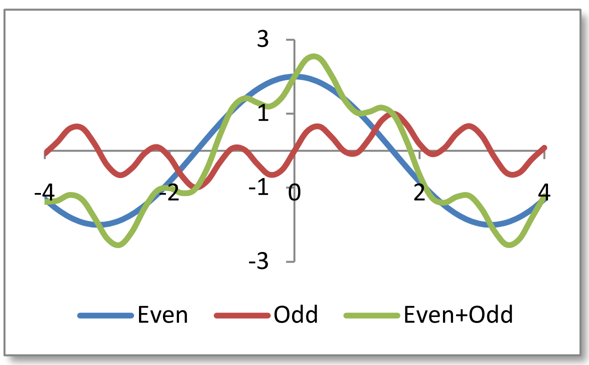

Figure 7. The sum of even and odd functions

Figure 6, graphically describes how any function $f(x)$ can be described as the sum of an even and odd function,

$$f(x) = E(x) + O(x) \qquad (43)$$

The Fourier Cosine Series can now be defined from $\cos(mt)$ which is an even function for all m. Therefore, we can write any even function as,

$$f(t) = \frac{1}{\pi} \sum_{m=0}^{\infty} F_m \cos(mt) \qquad (44)$$

where F_m are a set of coefficients that define the series and we are only interested in $f(t)$ over the interval $(-\pi, \pi)$. Similarly, the Fourier Sine Series is always odd for all n,

$$f(t) = \frac{1}{\pi} \sum_{m=0}^{\infty} F_n \sin(nt) \qquad (45)$$

where F_n are coefficients which define the sine series. We can calculate these coefficients by multiplying both sides of the equation by $\sin(n^{'} t)$ and integrating,

$$\begin{aligned} &\int_{-\pi}^{\pi} f(t) \sin(n^{'} t) \, dt \\ &= \frac{1}{\pi} \sum_{m=0}^{\infty} \int_{-\pi}^{\pi} F_n \sin(nt) \sin(n't) dt \end{aligned} \qquad (46)$$

The coefficient F_n is independent of time, so the integral reduces significantly to,

$$\int_{-\pi}^{\pi} \sin(nt)\sin(n't)dt = \pi\delta_{mm'} \qquad (47)$$

where we have taken advantage of the properties of the Kronecker delta function property,

$$\delta_{mm'} = \begin{cases} \pi, & \text{if } m = m' \\ 0, & \text{if } m \neq m' \end{cases} \qquad (48)$$

to arrive at,

$$F_n = \int_{-\pi}^{\pi} f(t) \sin(nt) dt \qquad (49)$$

which gives us the Fourier Sine coefficients for any f(t). A similar expression holds for the Cosine coefficients.

Now that we have arrived at closed form expressions for the Fourier Cosine and Sine Series, we can define a Fourier Series by the equation,

$$f(t) = \frac{1}{\pi}\sum_{m=0}^{\infty} F_m \cos(mt) + \frac{1}{\pi}\sum_{m=0}^{\infty} F_n \sin(nt) \tag{50}$$

which by extension can be used to describe any function, because as we stated at the beginning of this section, ANY function can be written as the sum of an odd and an even function.

This remarkable result tells us that every motion, behavior and function in nature can be modeled by a series of simple trigonometric components. Since Variance technology takes advantage of this fact directly, while staying in the analog regime, it has the potential to be a most powerful analysis technique.

In Figure 7, we see how a square wave can be approximated by the sum of three sine functions. Adding more orders to the sine function, improves the accuracy of the approximation, which in terms of Variance technology, this translates to more ENLs within the specific AFA device.

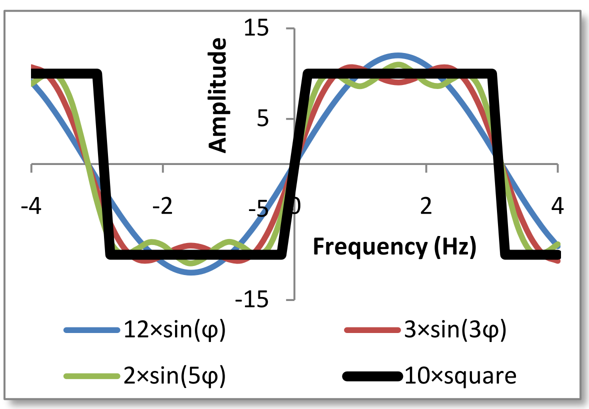

Figure 8. A square wave simulated by three orders of sine waves.

4.2 Fourier Spectrum

A Fourier Series approximation of a wave, allows us to extract any indigenous frequencies present. The resulting range of frequency and amplitude pairs can be plotted on a graph, which concisely represents the wave. The signals Figure 8 can be described very simply by the Fourier spectrum shown in Figure 9.

This graph shows a wave of frequency 1 Hz and amplitude 12 m, a 3 Hz wave of amplitude 3 m and a 5 Hz wave of amplitude 2 m.

On the vertical axis the power of the wave is often plotted in what is known as a power spectrum, which is especially useful when the signal to noise ratio is sought.

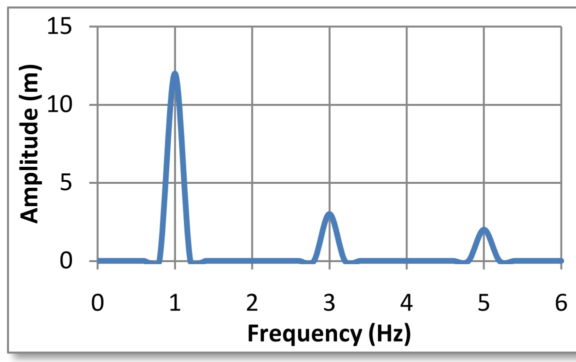

Figure 9. Fourier spectrum of the square pulse partial decomposition.

A Fourier spectrum is undeniably a powerful diagnostic and analytical tool. Fourier analysis is in fact a ubiquitous calculation in modern technology. In telecommunications, voice data is recorded and compressed by eliminating redundant Fourier components. The common radio tunes its transmission to a specific carrier wave, by creating a resonance at the radio station's frequency. Medical instrumentation such as nuclear magnetic resonance imagers (NMRIs) use powerful magnetic fields and radio frequency fields to align hydrogen atoms. The internet itself is an enormous network of encoded signal transmissions.

5 The Casimir Effect

In the 1950s a physicist by the name of Hendrik Casimir, was trying to calculate the var der Waals forces between polarizable molecules. He proposed that two conducting plates would only permit certain frequencies to exist between the two, those satisfying the appropriate standing wave conditions. A surplus of external wavelengths would develop a characteristic pressure gradient.

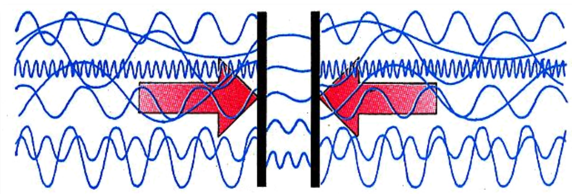

Figure 10. The Casimir effect: an imbalance in the quantum fluctuations of empty space can push two metal plates together.

This phenomenon has subsequency been proven to exist by several groups and has far reaching consequences to the fields of Quantum Mechanics as well as Cosmology.

The theory surrounding the operation of the Casimir force is reminiscent of ENL principles. The differences are that the Casimir effect excludes zero point field frequencies, whereas the in Variance technology, traditional electronic signals are being excluded. This provides us with yet another piece of evidence pointing to frequency filtering in nature, by promoting the development of standing waves.

6 Wave Phenomena in Electronics

Resonance phenomena are familiar to all of us in our day to day life. Most commonly, we are witness to resonances in our homes when a heavy vehicle passes by and we hear our windows vibrating. This however does not happen when all vehicles come by and it also does not happen for every window, even if they are exactly the same make and design. We directly conclude from this observation that every object has a characteristic sound frequency, which is capable of producing large mechanical oscillations.

The same is true for electronic circuits. Whereas variations in resonance frequencies between physical objects depend on the material and its environment (brace, supporting structure, etc), in electronics the physical characteristics can be analyzed in terms of the resistance (R), inductance (L) and capacitance (C) of a circuit. All of these present a measure of opposition to alternating currents.

6.1 Resonance Frequency

Now let us examine how resonance phenomena manifest. During a resonance phenomenon in general, a characteristic quantity of the system experiences a drastic amplification in its nominal value. In macroscopic phenomena this would depend on its mass, modulus of elasticity and moment of inertia to make but a few. In electrical circuits this depends on R, L and C, namely the impedance of the circuit, which describes the total opposition to the alternating circuit,

$$Z = \sqrt{R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2} \qquad (51)$$

Where we have assumed a series RLC circuit and $\omega = 2\pi f$ is angular frequency. The current through the circuit is given by Ohm's law,

$$I = \frac{V}{Z} \qquad (52)$$

The impedance is always positive and can be minimized by eliminating the terms in the parenthesis, which happens when the inductive equals the capacitive reactance. This happens at the resonance frequency,

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \qquad (53)$$

Then the impedance equals the physical resistance of the circuit and the current becomes maximum,

$$I_0 = \frac{V}{R} \tag{54}$$

This type of resonance produces a characteristic curve which is sharper for decreasing resistance.

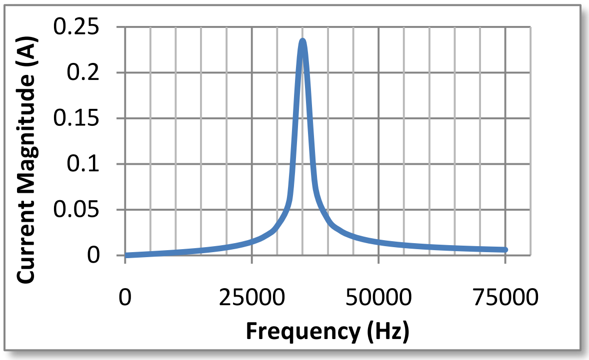

Figure 11. RLC Current Resonance

6.2 Signal Reflections

Reflections occur as a result of discontinuities, such as an imperfection in an otherwise uniform transmission line, or when a transmission line is terminated with other than its characteristic impedance. The reflection coefficient Γ is defined thus,

$$\Gamma = \frac{V_r}{V_f} \tag{55}$$

Γ is a complex number that describes both the magnitude and the phase shift of the reflection.

These signal reflections in electronics imply the mechanics of boundary layers which satisfy certain conditions which set up standing waves. Therefore, the most basic for idea that the ENL can setup a standing wave within a transmission line is supported.

6.3 Standing Wave Ratio

A useful measure of the amplitude of a signal in a uniform transmission line is the standing wave ratio (SWR). The voltage component of a standing wave in a uniform transmission line consists of the forward wave (with amplitude V_f) superimposed on the reflected wave (with amplitude V_r).

For the calculation of voltage SWR (VSWR), only the magnitude of Γ, denoted by ρ, is of interest. Therefore, we define,

$$\rho = |\Gamma| \tag{56}$$

At some points along the line the two waves interfere constructively, and the resulting amplitude V_{max} is the sum of their amplitudes,

$$V_{max} = V_f + V_r = V_f + \rho V_f = V_f(1+\rho) \tag{57}$$

At other points, the waves interfere destructively, and the resulting amplitude V_{min} is the difference between their amplitudes,

$$V_{min} = V_f - V_r = V_f - \rho V_f = V_f(1-\rho) \tag{58}$$

The voltage standing wave ratio is then equal to,

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{1+\rho}{1-\rho} \tag{59}$$

Since $\rho \in [0,1]$, then $VSWR \geq 1$, where a value close to 1 is most desirable, corresponding to a low reflection coefficient.

To understand this better, we can perform a time dependant calculation, using the wave equation form of the forward

$$V_f(x,t) = A\sin(\omega t - kx) \tag{60}$$

and reflected voltages,

$$V_r(x,t) = \rho A \sin(\omega t + kx) \tag{61}$$

Using the principle of superposition we arrive at the total voltage at any given time,

$$V_t(x,t) = V_f(x,t) + V_r(x,t) \tag{62}$$

After some processing we arrive at,

$$V_t(x,t) = A\sqrt{4\rho\cos^2 kx + (1-\rho)^2} \times \cos(\omega t + \phi) \quad (63)$$

This brief study, provides us with president for the mechanics and processing of standing waves in electronic circuits - the basic principle applied to ENL operation.

Usually SWR studies are used in transmitter/antenna impedance matching, where a low SWR are desirable. In our case however, the standing wave is set up between the transistors and propagated around the closed neural loop, purposefully. In addition to some reflections from the transistor terminals, we also take into account the transistors amplification ratio.

Current resonances are setup between the ENL legs by virtue of the operation of the transistor. Each time the signal comes around it is cleaner and cleaner, having rejected more and more uncommon modes and the amplification becomes more efficient. With every cycle the Q of the ENL increases. The required ENL fidelity for each application will define how much of this signal we need to 'burn off' on each transmission line termination.

Eventually we say the ENL fires, signifying detection of its characteristic frequency. Specifically, "ENL firing" signifies the sufficient isolation of a signal within the ENL, so as to allow for its detection above any background noise. This has been taken to be 5σ in theoretical calculations. An accurate Q-value calculation will be part of the prototype benchmarking planned for the near future.

+[Variance Custom ENL/SWR Model]

7 Transistor Operation

There are certain rules that govern the operation of any bipolar transistor. These rules of operation can be stated as follows [6, 7, 8].

For an NPN transistor, the voltage at the collector V_C should be greater than the voltage at the emitter V_E ($V_C>V_E$) by at least a few tenths of a volt. On the other hand, for a PNP transistor, the emitter voltage should be greater than the collector voltage ($V_E>V_C$) by a similar amount. In either case the voltage differences establishes an electric field that serves as the impetus for the direction of current flow.

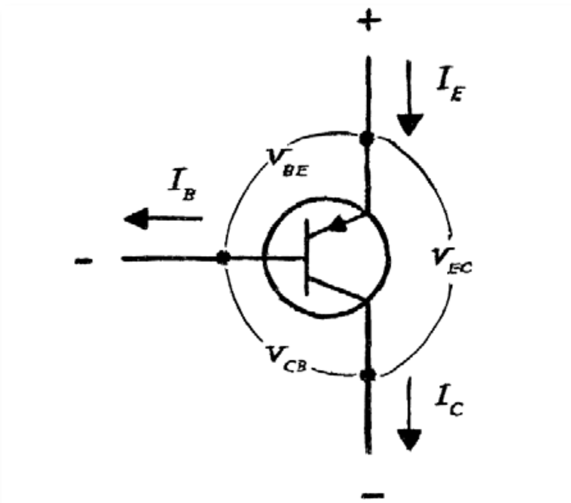

Figure 12. A schematic of a PNP transistor.

For an NPN transistor there is a voltage drop from the base to the emitter of about 0.6 volts. For a PNP transistor, in contrast, there is a voltage rise of about 0.6 volts from the base to the emitter.

Transistors can amplify base current. For a base current of 0.2 mA when V_{CE} or $V_{EC} \simeq 12$ V, for example, the transistor amplifies the base current to about 7.5 mA on the collector. This is an amplification factor of about 37.5. This can be expressed by saying that $I_C=\beta I_B$ where I_C is the collector current, I_B is the base current and where β is the current gain. So, in the foregoing example, $\beta=37.5$.

The above characteristics and rules may be mathematically summarized as follows,

$$I_C = \beta I_B \quad (64)$$

$$I_E = I_C + I_B \quad (65)$$

Combining these equations gives us an equation that relates emitter and base currents, which is the counterpart of the first gain equation,

$$I_E = \beta I_B + I_B = (\beta + 1)I_B \qquad (66)$$

From the discussion above regarding the about 0.6 V changes,

$$\text{NPN:} \quad V_{BE} = V_B - V_E = 0.6\,V \qquad (67)$$

$$\text{PNP:} \quad V_{BE} = V_B - V_E = -0.6\,V \qquad (68)$$

Finally, the internal, inherently present resistance of a bipolar transistor is called the transresistance, r_{tr}, and is suitably expressed as,

$$r_{tr}(t) = k + \frac{k}{2\pi^2} \sum_{n=odd}^{\infty} \frac{1}{n^2} \cos(n\omega t) \qquad (69)$$

In most circuits, transresistance is negligible. However, because the ENL is designed in a somewhat non-ordinary way we make note of it here.

+[AC Transistor Response Profiling]
+[Semiconductor node formation promoting SW]

8 ENL Operation

Having touched on all of the theoretical and practical foundations of Variance technology, we can now focus on ENL operation.

8.1 ENL Transmission Line Calibration

The current prototype manufactured by SemQuest, focused on designing gigahertz ENLs, which allowed them to be small enough to be printed on an integrated circuit. This decision comes with all the design benefits that modern electronic foundries offer such as, high signal to noise ratio, low parasitic impedance, inductance and capacitance.

The decision to make the ENLs operate at the relatively high frequency of 10 GHz makes the size of the ENL legs of the order of 1 cm, which is the appropriate scale size of an integrated circuit. The length of the ENL legs, which allow a standing wave with fundamental frequency f to develop, is

$$L_{ENL} = \frac{nc}{2f} \qquad (70)$$

Where, we note that only integral numbers of half wavelengths forms standing waves,

$$L_{ENL} = n\frac{\lambda}{2} \qquad (71)$$

If we assume that the speed of transmission of an electronic signal is half of the speed of light, as discussed, then for a sinusoidal signal with frequency $f = 10\,GHz$, the ENL must have legs,

$$L_{ENL} = \frac{c_e}{2f} = \frac{1.5 \cdot 10^8}{2 \cdot 10 \cdot 10^9} = 0.0075\,m = 0.75\,cm \qquad (72)$$

And for a signal at the lowest end of the ENL spectrum where $f = 100\,MHz$,

$$L_{ENL} = \frac{c_e}{2f} = \frac{1.5 \cdot 10^8}{2 \cdot 100 \cdot 10^6} = 0.75\,m \qquad (73)$$

When designing an ENL, the transmission line length is determined by the simple analysis described above. The circuit design is also very simple compared to the design and analysis of other frequency and Fourier analysis electronics. This is one of the most attractive features of Variance signal analysis technology.

8.2 ENL Circuit Analysis

Figure 13 is a schematic diagram of the first exemplary embodiment of an ENL. In this diagram, arbitrary values for voltages on the transistors (voltage is proportional to energy) have been selected for discussion purposes.

These voltages are in accord with the transistor rules discussed above.

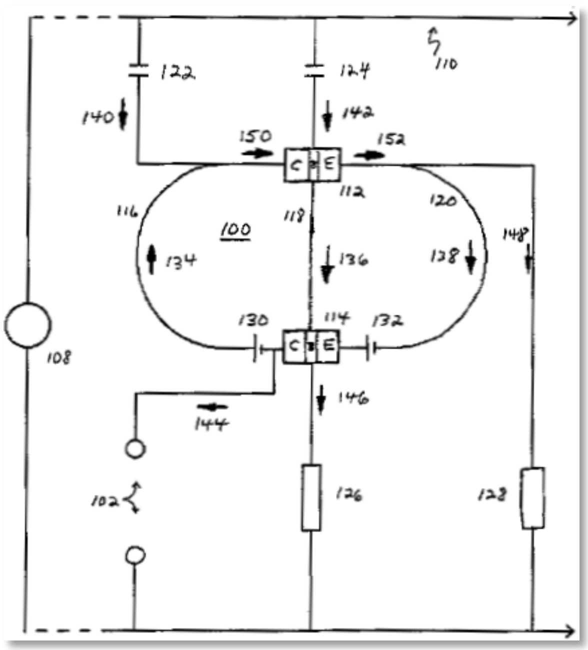

Figure 13. Exemplary ENL Circuit.

As shown, the collector of NPN transistor **112** is charged at +12 V. In other words, V_{Cnpn}=12 V. A transistor behaves like an open switch unless there is a base current. That base current can be assured by also setting V_{Bnpn}=12 V. As discussed above, in an NPN transistor there will be about a 0.6 V drop (caused by the depletion zone). That means that V_{Enpn}=11.4 V. Thus, an electric field (the pathway and impetus for current flow) from the collector, through the base, and on to the emitter exists. The main NPN circuit is completed through element **128**, which is used to set $V_{Enpn.}$

Connector **120**, coupled to the emitters of NPN transistor **112** and PNP transistor **114**, comprises at least some resistance. For this example, the resistance is such that V_{Enpn}=11.4 V is dropped to V_{Epnp}=11.3 V. In that eventuality, current flow is assured from the emitter of NPN transistor **112** to the emitter of PNP transistor **114**. The 0.6 V drop discussed above results in V_{Bpnp}=10.7 V. Because connector **118** joins the two bases, and the base of NPN transistor **112** is already set at 12 V, the resistance of connector **118** should be such that the voltage drop across connector **118** is equal to 1.3 V. In turn, to assure an electric field through to the PNP collector, the collector voltage is set to V_{Cpnp}=10.6 V. This last PNP circuit is completed through output node **102**, although another route can easily be provided if one wished.

We note that although the circuit is drawn so that current flows from the collector of PNP transistor **114** to the collector of NPN transistor **112** (with the current arrow drawn in that direction), the voltages described above would be inappropriate for that purpose. This issue may be addressed by the addition of, for example, a DC power supply ("DCPS"). In Figure 13, the DCPS is shown as elements **130** and **132** using the circuit symbol for a battery. Thus, for example, the voltage across element **130** may be 0.6 V and the voltage across element **132** may also be 0.6 V. These two voltage sources are used to increase voltage while not increasing current. Note that either of these voltage sources could be more or less than 0.6 V, depending on the particular circuit design used. Also note that they represent another path length on the ENL circuit. The current path with the additional DCPS path length should remain an integer wavelength.

This addition of the DCPS boosts the voltage, thus assuring the current flows as depicted. The DCPS may be replaced, for example, by a voltage amplification circuit or other means for providing the needed voltage.

The rest of the circuit elements are chosen to "tune" the ENL to a desired frequency. This is done using the following analysis. In Figure 13, elements **122** and **124** are capacitors such that element **122** comprises high capacitance and element **124** comprises low capacitance. In combination with element **128**, the effect is to charge the NPN transistor in such a way that no actual current flows. If the capacitance of element **122** is made high enough (for example, in the microfarad range), then the NPN collector is not influenced very much when the superposed signal passes by. However, if at the same time the capacitance of element **124** is made low enough (for example, in the picofarad or nanofarad range), then element **124** acts like a plain wire for the same signal. Then, during passage of certain data window, displacement current flows in NPN transistor **112**. NPN transistor **112** "turns on" to displacement current, but only during the passage of the signal data window. (Note that in this example, the entire ENL circuit is enabled at all times signal is turned on).

To explain this desired level of current flow, we note that for elements **122** and **124**, the capacitor plate connected to the positive voltage supply becomes positive. The bottom or transistor side of the capacitor draws negative current, electrons, from wherever is available until it is at -12 V. That means that on the collector, there exists a situation in which the N-type material the collector is made from is +12 V from its normal electron-rich state. The NPN collector cannot draw electrons from the circuits on the right side of Figure 13 because there is no current flowing in the base of either NPN transistor **112** or PNP transistor **114**. In other words, these circuits are not complete. Likewise, in the quiescent state, the circuits on the left side of the figure are not complete either, again because there is no current in the PNP base and as a result, the battery or DCPS circuit is open.

However, when a data window passes by, some very rapid changes start to occur. Because of the way the voltage changes in the data window, when the first spike of the data window just does hit element **122**, everything gets more positive. That positive change is reflected by a positive change on the NPN collector, but because of the reactance of element **122** the change is relatively small. On the other hand, immediately thereafter, the data window then hits element **124**. In element **124**, the reactance is low so current flows essentially unimpeded. Additionally, base current now flows. This therefore activates the ENL and the ENL's quantization function.

The final step is picking a quiescent point, in our case a quiescent current, for NPN transistor **112**. The question now becomes what values of capacitance to choose for elements **122** and **124** in order to obtain the desired results. It is well known that capacitive reactance is given by the formula,

$$X_C = \frac{V_0}{I_0} = \frac{1}{\omega C} \tag{74}$$

where V_0 and I_0 are peak values and where ω is the angular frequency of the signal. X_c is measured in ohms.

For this example, assume the biasing voltage on the ENL matches the voltage used by a CCD (i.e., about 12 V). If the CCD voltage-spikes are about 12 mV in magnitude and positive then, for this example, Vo would be at most about 12.012 V.

For element **122**, we would like the reactance to be high for a given ω. That reactance, however, should be set based on the frequency components that are present in the input signal. To get at that information, the CCD data window should be represented by a Fourier series expansion. With such an expansion, the dominant frequencies that make up the CCD data window can be determined. The function shown in Figure 14, is representative of an individual voltage-spike in a digital camera.

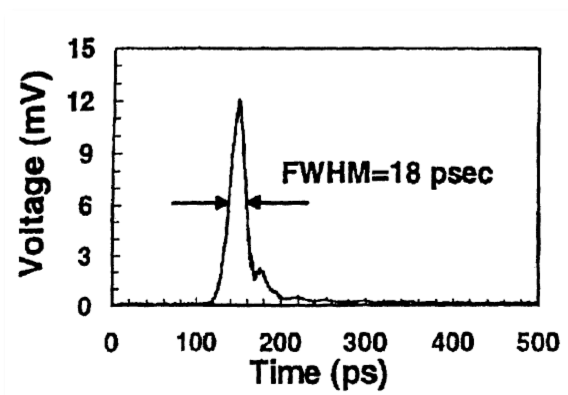

Figure 14. A Gaussian peak commonly produced by electronic devices.

Figure 14 looks like a sharply peaked Gaussian probability function. Therefore, for the purposes of this example, this function is represented as a Gaussian probability distribution of the form,

$$f(x) = Ne^{-\sigma x^2} \tag{75}$$

The Fourier transform of that function is,

$$F(k) = N\sqrt{\frac{1}{2\sigma}}e^{-\frac{k^2}{4\sigma}} \tag{76}$$

where the above functions have been centered on the origin; where N, often taken as the normalization constant, is here going to be taken as N=12 mV; σ is the standard deviation and where ω is the angular frequency. F(k) is the distribution of "frequencies."

Note that according to Figure 14, the full-width-at-half-maximum (FWHM), is 18 ps. And, because FWHM=2.355, σ is a standard normal distribution relationship, 18 ps=2.355 σ, so that,

$$\sigma = 7.64 \times 10^{-12} \text{ sec} \tag{77}$$

To make the form of the above equations match the variables herein, there needs to be a substitution of variables according to the formula,

$$x = c_i t \tag{78}$$

where $c_i = 1.5 \times 10^8$ is as usual the electronic speed in the medium and is taken to constant. When making this kind of substitution, k also needs to be changed according to the formula,

$$k = \frac{\omega}{c_i} \tag{79}$$

Making this substitution gives us,

$$f(t) = Ne^{-\sigma c^2 t^2} \tag{80}$$

$$F(\omega) = N\sqrt{\frac{1}{2\sigma}}e^{-\frac{\omega^2}{4\sigma c^4}} \tag{81}$$

where N and σ still refer to the original Gaussian parameters. The above expressions are centered on the origin. The value of Equation (81) at $\omega = 0$ is just,

$$F(0) = N\sqrt{\frac{1}{2\sigma}} \tag{82}$$

where it is found that $F(0) = 3.0669 \times 10^3$. In that case, half-max is 1.5350×10^3. Now the question becomes, what frequency characterizes half-max. To answer that question use equation (10), insert the value for half-max, then solve for ω, to find,

$$\omega = 46.27 \times 10^{10} \text{ rad/s} \tag{83}$$

Since, $\omega = 2\pi f$,

$$f = 7.37 \times 10^{10} \text{ Hz} \tag{84}$$

From Equation (82), one can calculate σ for the transform Gaussian. And, at half-max, most of the non-thermal information in the CCD signal data window has been incorporated. Additionally, Equation (84) demonstrates the size of the ENLs that should be used to build an AFA.

We note that Equation (83) gives a number for ω in the 10^{11} order-of-magnitude range. If that number is inserted into Equation (75), with $C = 10$ pF then $X_C = 1\ \Omega$, whereas for $C = 1$ μF then $X_C = 10$ KΩ. Thus, the high frequency informational input associated with the CCD photo sites discharging will pass virtually unimpeded through the picofarad capacitor, whereas the same window will encounter a good deal of resistance to passage through the microfarad capacitor. This then confirms the exemplary values of capacitance for elements **122** and **124**.

During the quiescent period,

$$V_{Cnpn} = V_{Bnpn} = 12.012\,V \approx 12\,V \qquad (85)$$

In addition, when the data window hits, the NPN collector is only slightly affected but the NPN base current varies directly according to the input signal. From the above rules and equations governing the behavior of transistors, Equation (67) can be applied to ascertain that V_{Enpn}=11.4 V. If it is assumed that the connector between the emitters of NPN transistor **112** and PNP transistor **114** is of minimal resistance then V_{Epnp}=11.4 V. From Equation (68) we find that V_{Bpnp}=10.8 V.

Now if, in the circuit shown, the base of NPN transistor **112** is 12 V and the base of the PNP transistor **114** is 10.8 V, then connector **118** should have some significant resistance to reduce the voltage. The issue here is that to make the base connector have that resistance, a resistor should be inserted into the circuit or connector **118** should be doped in such a way that it comprises that resistance.

The so-called "standing wave" is created by a particular frequency EM wave traveling around the ENL, coming back on itself, in phase, adding the energy of the initial wavefront cycle to the next cycle following the trailing edge.

+[Simplify, add Bandwidth, Bifocality]
+[Trace Frequency Peaks through Circuit]
+[Add Amplitude Monitor Subsystem]

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