Impedance Matching

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When I was young, baseball was my favorite game. It was also my father's. He was catcher for the Ogden White Sox of Ogden, Utah, a minor team in the northern Utah/ southern Idaho area.

I mentioned baseball in a prior story entitled *School Bullies*. I was good at baseball and hit more than my share of home runs in playing with the other boys. But I was ridiculed for always using a lightweight bat that the girls used in playing softball (we boys played hard ball).

We had a good selection of bats for playing hardball and the other boys, who were heavier, taller, and more muscular, would always use a very heavy bat. Their reasoning: "A heavy bat will knock the ball farther, dummy. That's obvious."

I did not argue with them over the matter of light bats versus heavy bats. I had experimented with using the whole range of bats (for girls and boys)-- their lengths, and their weights--and by trial and error discovered the particular bat best for me.

At that time in my life at the Marriott School, the physics to understand why my trial and error selection of a bat was correct did not exist. In fact, I did not learn the necessary concepts until I had spent who years as a World War II Navy Ensign in the extensive study of electronics and radar at a number of schools: Bowdoin College (founded in 1794 in Brunswick, Maine), MIT in Boston, Harvard in Cambridge, and study at an advanced Navy Radar Training School in Honolulu, Hawaii. With that introduction, we'll return to baseball and other matters later.

There I was, laying flat on my back on the deck of a battleship, the name of which I have forgotten, eating a banana. I was returning to the mainland from my last assignment, the Advanced Radar Training School at Pearl Harbor. The deck was awash with sailors and other servicemen who were returning home from the Pacific Conflict now that the war was over. Ordinarily, as an officer, I would have had a bunk to sleep in; but every nook and cranny of that ship had a body in it. It was every man for himself. As the ship rolled slowly from side to side, I mused about the relaxed assignment I expected to have at Pacific Fleet Headquarters Command at Oakland, California.

I was to be the officer in charge of electron tube storage! Up to now, I had done nothing but study, study, and study. Not that I didn't really like to study, but a body does need an occasional change of pace. The standard pattern that I had been following for the better part of two years was this:

<u>Monday through Friday</u>:
8:00 am to 12:00 noon—four 50-minute lecture sessions by four different teachers
12:00-1:00 pm—study while eating lunch
1:00 pm-5:00 pm—laboratory studies and experiments
Evening: supper and "wee hour" study to prepare for the next morning's classes
<u>Saturday</u>:
8:00 am to 12:00 noon—a four-hour examination
12:00 noon until ? On your own
<u>Sunday</u>:
Go to church if an LDS facility is available

As I was finishing my banana, a message came over the ship's horn: "Is there a radar officer aboard? If so, report to the bridge." I answered the call and found my way to the bridge and the commanding officer. He informed me that his radar was not working and that he did not wish to go into San Francisco harbor without his radar (at this time, we were about 100 nautical miles from shore). I was taken to the radar room and immediately set about to ascertain the problem. Incidentally, radar technology was a most important World War II secret and all radar officers and technicians had to have government *secret* clearance. At school, while in training, we had to clear guard-armed security posts to enter radar technology areas.

At the ship's radar room, I was confronted with the usual array of electronic components: a se of twin triode 6SN7 electron tubes. Their combined heating elements alone consumed 15 kilowatts of electricity, a lot of heat energy to dissipate. Then there were the klystrons that generated the centimeter wavelength electromagnetic waves that sent out the pulse of energy that would bounce back as an echo to the ship's antenna from objects that were in the air or on the sea. Also, there were the very large Eimac^{TM}, quadruple element, triode power tubes (manufactured in Salt Lake City) whose rare, tantalum plates, operating at 4000 volts, glowed white hot from electron bombardment.

Additionally, there were myriads of other electronic elements such as cathode ray tubes, meters, relays, timers, capacitors, inductors, transformers, resistors, delay lines, wave-guides, coaxial cables, and of course ***impedance matching networks***.

After several hours of checking, with one hand behind my back, a safety measure deeply ingrained in us in our training to avoid electrocution, I found a defective relay in the system. Spare parts aboard ship are carried in a number of steel trunks, but a replacement relay could not be found. Consequently, I had to improvise a repair on the bad relay itself. The repair worked and our ship was able to some into port with its radar working.

Interestingly, my schooling in electronics must have cost the U.S. Navy many thousands of dollars. Fixing the relay was the only constructive thing, relating to my training, that I ever did for it. However, I suppose that being trained and available does have a compensating monetary value.

After engaging in some light banter with my friend, Dean Barnett, concerning this story, he said that fixing the relay was probably the most important thing that I had done in my life. I believe he said it in jest, but on reflection, he may be right.

A ship without radar is a ship with impaired vision. Who knows what may have happened if the ship had gone into port without its radar working? The battleship was probably worth a few billion dollars. Additionally, there were more than 10,000 souls aboard, who had survived the Pacific Conflict. How awful it would be if this enormously overcrowded vessel would collide with another object at this time.

Now, I'm going to get a bit technical for a while but stay with it: it will widen your horizons. I will talk about energy and work. The dimensional units of energy and work are identical: millimeters squared divided by time squared. Energy may also be defined as the capacity for producing effect, said effects being of widely different character. Energy may be classified as being stored or in transition. Examples of stored energy are:

1. Mechanical, as in a rotating flywheel
2. Heat, as in an insulated hot object
3. Electricity, as electrons stored in a condenser

Examples of transitional energy include:

1. Mechanical, in which a force moves its point of application
2. Electrical, where current flows under a potential difference
3. Heat, that enigmatic form of unidirectional energy that flows only from a higher to a lower temperature.

Energy in transition can often be expressed as the product of two factors: a capacitive or extensive factor and an intensive factor. At the end of this text, several types of energy, together with these factors, are listed. The product of these two quantities is equivalent to the energy, which is commonly measured in the units indicated.

Wherever I turn in the scientific world, I see parallels to gospel principles. There are so many things that have a dual nature, or conjugate relationship: man & woman, the celebrated particle & wave nature of light, the Father & the Son, the body & the spirit, the good & the bad, the positive & negative (electricity), the north & south magnetic poles, and so it goes.

Somehow, I feel these relationships to be fundamental principles from a former sphere whispering to me of the truthfulness of the Latter-day Gospel of Jesus Christ. Just for myself, in this present discussion concerning energy, I see the spirit as the intensive factor and the body as the extensive or capacity factor. In science, as well as in the gospel, the intensive factor is responsible for promoting changes.

We often use the phrase "being in tune" usually with the Spirit, our Heavenly Father, or our Savior. Sometimes we say, "We are on the same wavelength, or have the same vibes." This comes from the early days of radio and is a very good analogy. But we need to be more than "in tune." We need to be empowered by *impedance matching.*

All of us have impedance matching devices. For example, I have an impedance matching device descending from the TV antenna on top of my house that connects to my TV set. Mine is of the twin lead type where two copper wires are embedded in a plastic ribbon about one-half inch apart. Stamped at intervals along the ribbon are the words: *Impedance—300 ohms*. You may have an alternative matching device called a coaxial cable.

Physical science requires mathematics to empower its usefulness. In the field of electricity and magnetism of which World War II radar was a practical branch, functions of a complex variable or so-called imaginary numbers are important.

I previously suggested that the intensive factor is responsible for promoting changes. I also likened our spirits to the intensive factor of energy. Given the opportunity, our bodies should respond to the promptings of the inborn goodness of our spirit to make righteous changes in our behavior.

Carl Friederich Gauss, the 18th century scientific genius and "Prince of Mathematics" incorporated the square root of minus one (an imaginary number designated as *(i)* into a framework to deal with practical electromagnetism at high frequencies. Simplistically, impedance takes the mathematical form $Z= (a + ib)$, the starting point for mathematical elaboration needed in radar electronics. You don't need to remember that, only remember that Z stands for impedance.

Z is *all-important* for the transmission of power. In such a system, there must be a source of power and a receiver of power, often referred to in electronics as a source and a sink. *Importantly, the Z of the source must match the Z of the sink for the maximum transfer of power.*

The mathematics developed for electronics has exact counterparts in other areas, particularly in mechanical systems.

In an automobile, the necessity of matching the energy available at the source (the engine) to the sink (the wheels) is manifest by the gearshift box or automatic transmission. Gears, levers, pulleys, coaxial cables, and parallel 300-ohm twin lead TV cables all serve the same purpose—the effective transfer of energy from source to sink by impedance matching.

Think of it! Our source of power is our Heavenly Father, through his son, Jesus Christ. If $Z_{ME}=Z_{HF}$ where Z_{ME} stands for my impedance and Z_{HF} represents the impedance of our Heavenly Father, unimpeded power could flow from Him to me. Of course, this couldn't happen unless I had our Heavenly Father's perfection. It follows, however, that one is on this earth to strive for this ideal.

Well, this is getting quite metaphysical; so just regard this discussion as some thoughts floating through Tracy's brain.

Take a look, again, at the energy chart at the end of this story. Under "Type of Energy," find kinetic. The extensive factor is the mass (weight of an object). The intensive factor is velocity (speed of travel). Note that the intensity of the velocity factor increases with its square (a velocity of 10 miles per hour increases the intensity to 100 miles per hour). Note that the one half factor decreases the intensity to only 50 miles per hour but a five-fold increase is certainly a lot!

Now we take this to baseball where this story began. The mass of the baseball is a fixed quantity (invariant). That I cannot change. But I can certainly control the velocity with which I swing the bat within the limits of my physique, and I can swing a lightweight bat with a higher velocity than a heavy one.

A heavy bat swinging slowly could contain less energy than a light, fast swinging bat because energy increases with the square of the velocity but only linearly with the weight of the bat. Here, we have to deal with a complex situation, *impedance matching*. I must match the energy available at the source (myself) to the sink (the ball).

It has only been since World War II that professional baseball players began to investigate this situation in detail. They too, like my muscular classmates at the Marriott School, considered a heavy bat to be the best.

I will ever be grateful for the unknown blessings in store for that boy of long ago, standing at the plate, waiting for the pitch, ready to swat the ball out of the lot with a girl's softball bat!

Type of Energy	Extensive Factor	x Intensive Factor	= Energy (commonly measured in)
Electrical	Coulombs	Potential	Joules
Heat	Heat capacity	Temperature	Calories
Radiation	Planck's constant	Frequency	Ergs
Kinetic	Mass	$1/2$ (Velocity)^2	Ergs
Pressure	Volume	Pressure	Liter-atmospheres
Chemical	Moles	Chemical potential	Calories