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# Batteries NOT ~~Included~~ (or ~~Required~~) (or ~~Needed~~)

## The “Real” Tesla Electric Car Motor

**Mike Gamble**

**7/28/16**

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For those of you that haven’t met me, I am Mike Gamble. Presently, retired from (BR&T) Boeing Research and Technology.

This presentation is on my research into Tesla’s fabled electric car motor. It’s appropriately entitled “Batteries Not Included”!

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# INTRODUCTION

This presentation on the “Real” Tesla Electric Car was reverse engineered using sound (standard) electrical engineering design practices.

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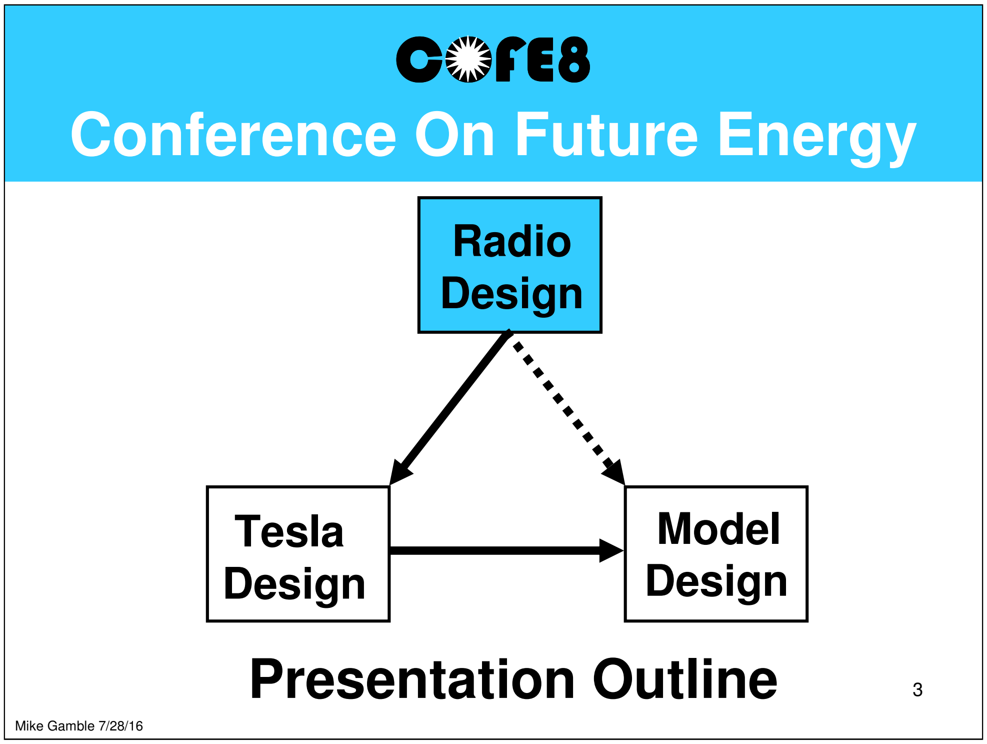
This presentation was reverse engineered using regular electrical engineering design practices.




The presentation is divided into three parts:

First is background material on radio communications

Second is the reverse engineering Tesla's electric car motor

Third is building a small demo motor based on this Tesla design

It is about 100 charts long; hope I don't bore you with all the details!

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# Basic Radio Communications

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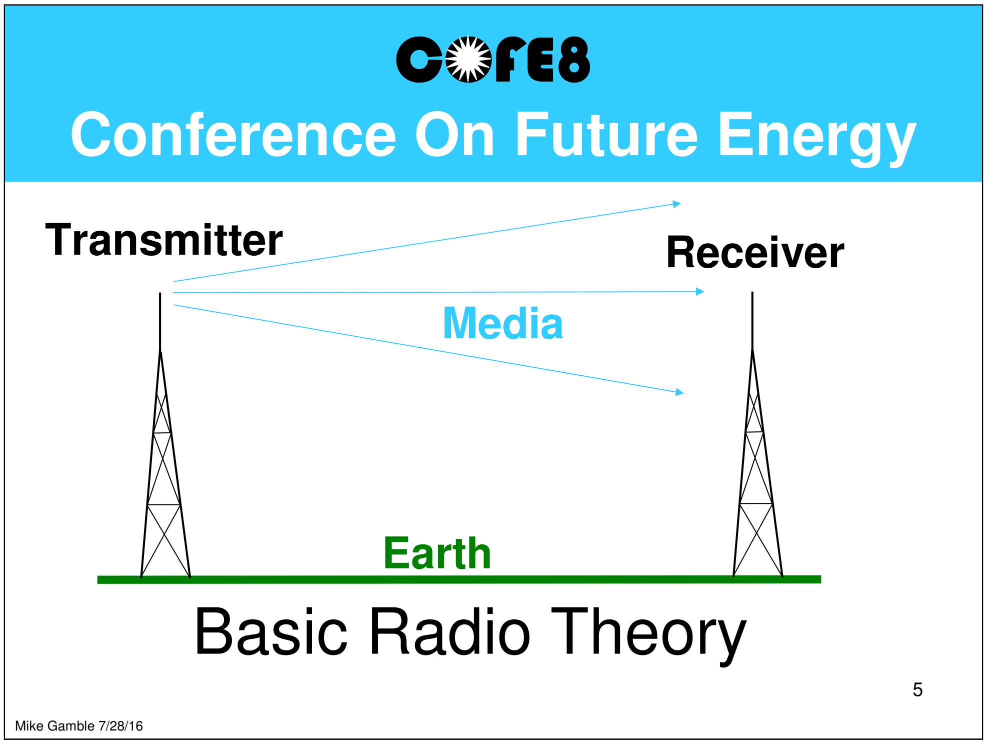
This tutorial on basic radio communications theory is background material for understanding Tesla's resonate electrical work.




Radio communication is composed of three parts.

The transmitter – wave generator (source)

The transmission media – wave conductor

The receiver – wave reproducer (sink)

The engineering definition is that if the receiver is working correctly it gives a good reproduction of the transmitter.

However, most people just turn “ON” the receiver; the rest is all “Black Magic”.

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# Transmission Media

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Starting with the Transmission media.

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## Transmission Media Names

Aether (Tesla)
Essence
Space
Cosmic Carrier Field
Electromagnetic Field (me)

Heavens (religious)
The Water (religious)

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Over time the transmission media has been called by various names: Aether (Tesla), Essence, Space, Cosmic carrier field, Electromagnetic field (me) or on the religious side: Heavens, The Water.

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# Transmission Media (cont)

a) It is a lossless elastic media of infinite strength through which both matter and energy can pass

b) It has both scientific and religious aspects

c) Only some of its properties are measurable (others are more esoteric):

i) $\varepsilon_o$ (permittivity) = 8.854e-12 Farad/meter

ii) $\mu_o$ (permeability) = $4\pi$e-7 Henry/meter

iii) $R_o$ (resistivity) = 377 Ohms

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Digging a little deeper into this media.

a) It is a lossless elastic media of infinite strength through which both matter and energy can pass.

b) It has both scientific and religious aspects.

c) However, only some of it's properties are measurable (others are more esoteric):

i) permittivity

ii) permeability

iii) resistivity

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# Radio Receiver

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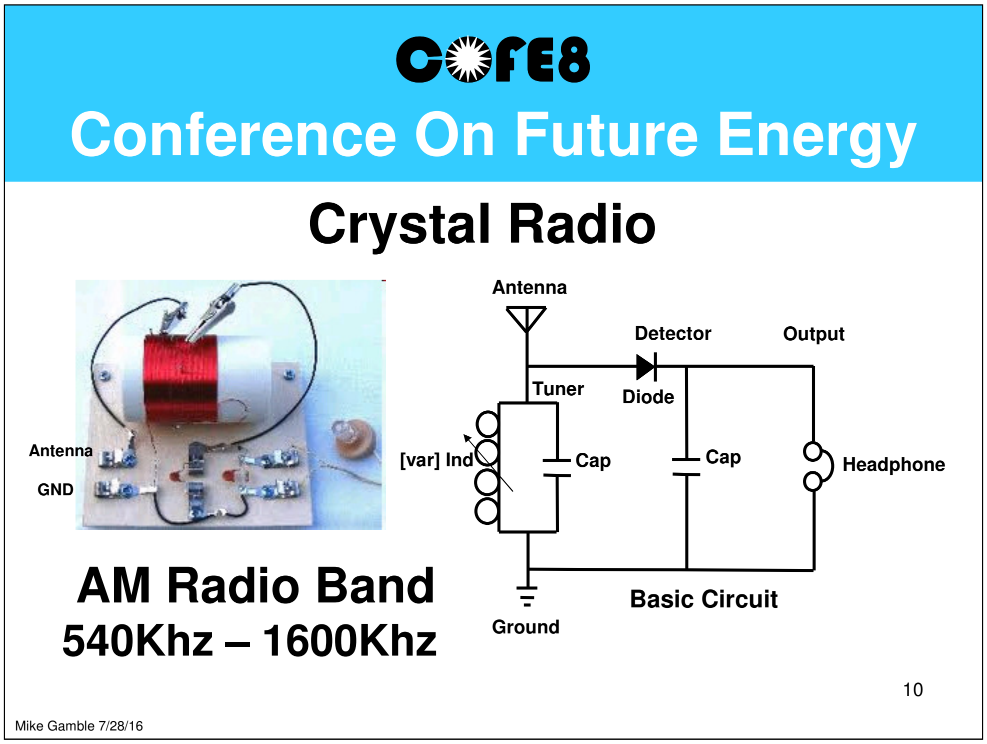
Continuing on with the radio receiver.



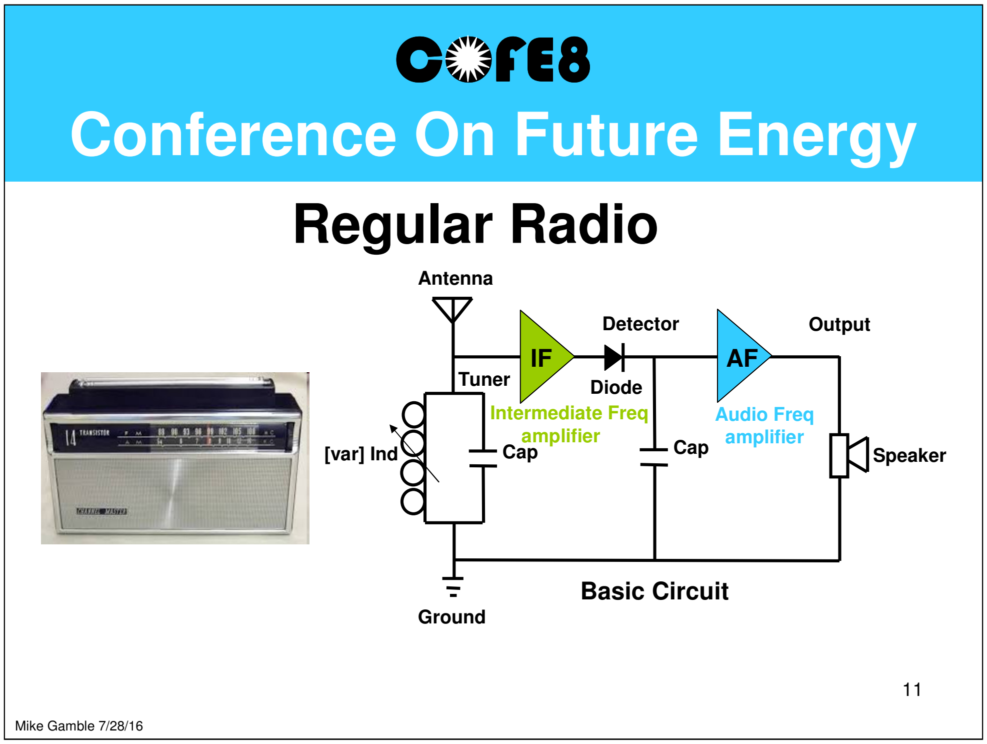

The receiver shown here in both picture and schematics is the most basic radio circuit;

that of a “Crystal Radio” which gets it name from the “germanium crystals” that were used as the detector.

Nowadays it’s built using silicon diodes; I have made many of these sets when I was a kid.

A radio is composed of four (4) sections or stages:

- Antenna
- Tuner (resonate circuit)
- Detector
- Output (headphone)

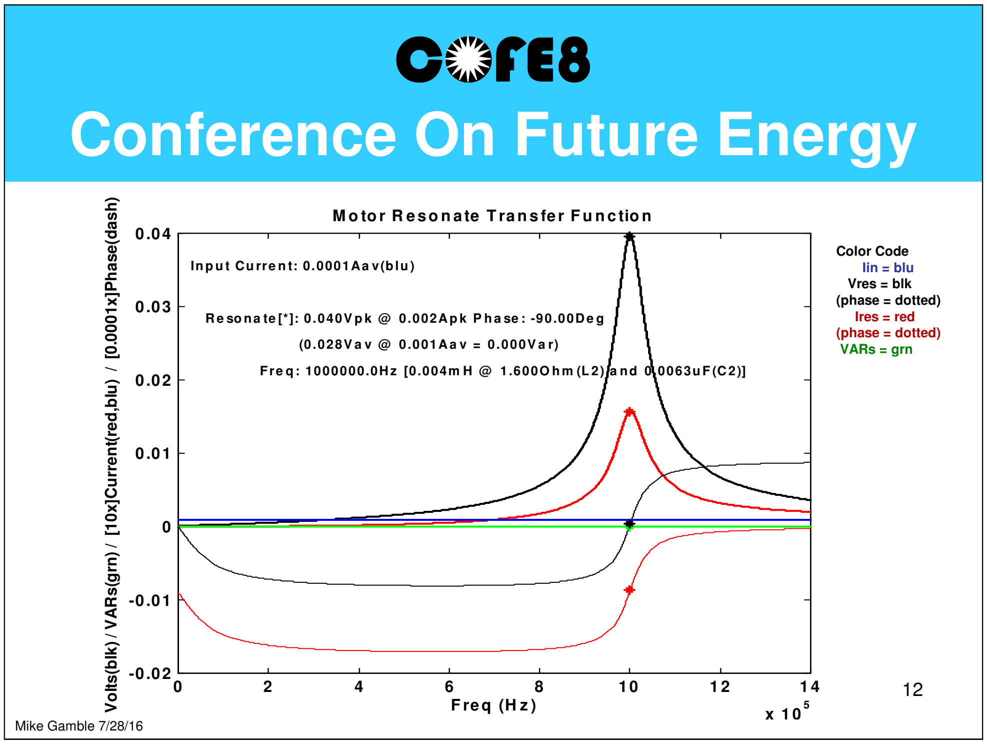



Normal radio design then adds two more stages to the basic system:

a) An “Intermediate Frequency” amplifier between the tuner and detector

b) And an “Audio Frequency” amplifier between the detector and output

This design makes a transistor radio (pictured on the left) which produces enough power to drive a speaker rather than just headphones.




MatLab Bode plot of a tuner's (resonate circuit) Gain and Phase frequency sweep. Note

the maximums for the voltage and current all occur at the resonate frequency. Also, the resonate

current's phase tracks the voltage phase by 90deg (standing wave). Taking a more detailed look

at the 1 Mhz resonate point (center of AM band):

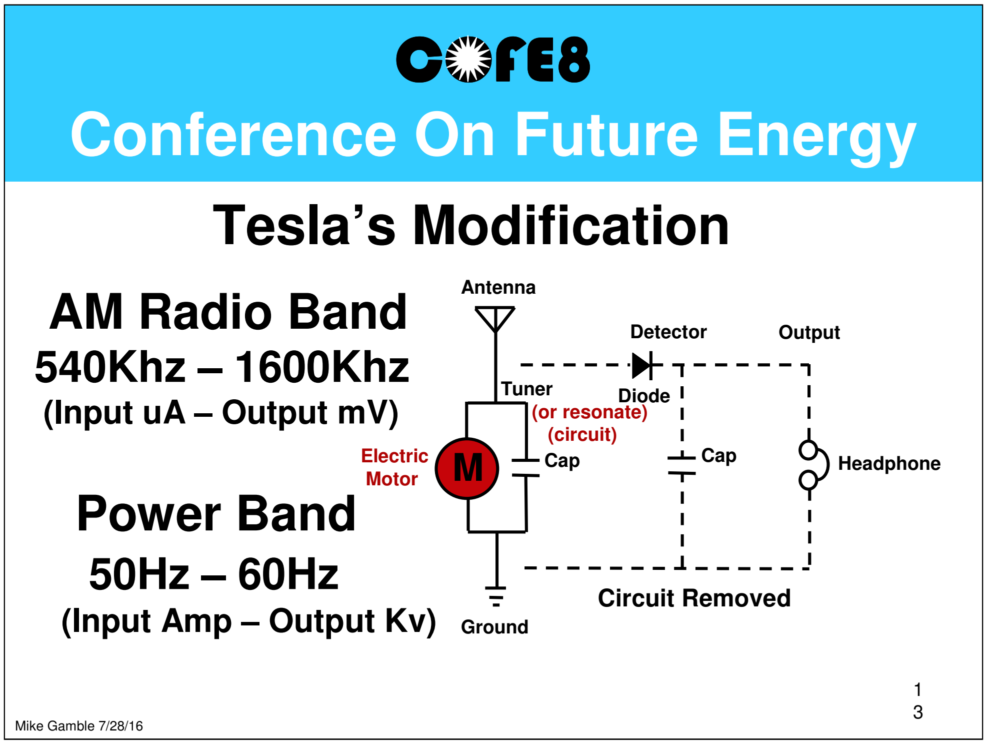
L = 4uH @ 1.6 Ohm

C = 6.3nF

Input = 100uA (antenna current)

Vres= 40mV

Ires = 2mA



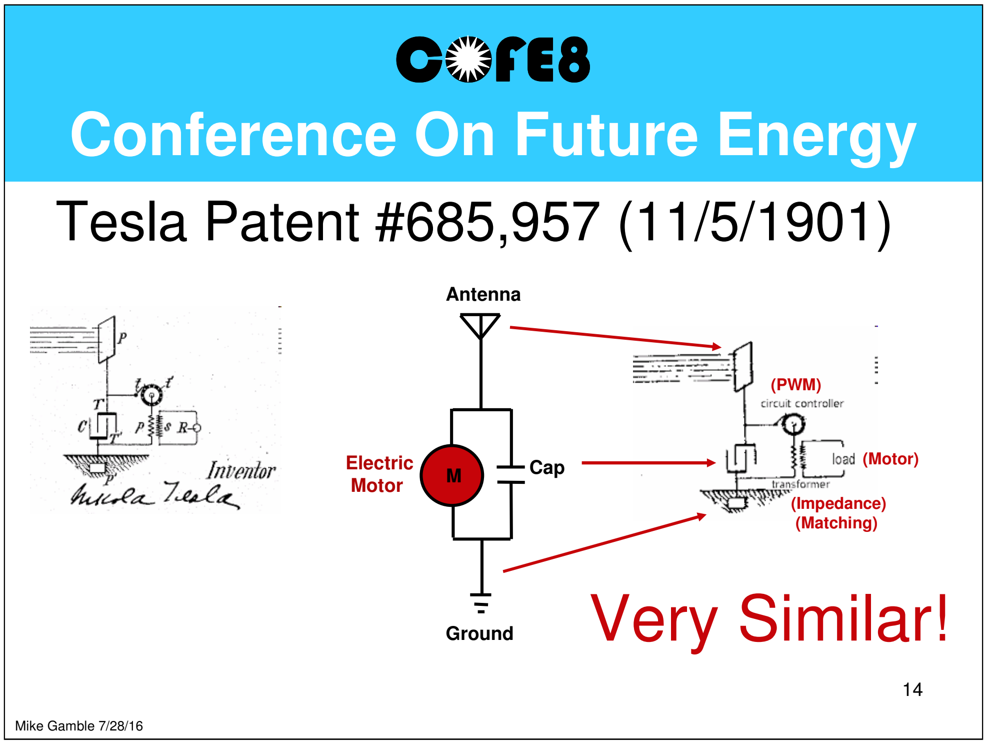

However, Tesla did not go in that direction.

a) First, he removed the detector and output stages;
he only used the tuner (resonate circuit).

b) Second, he replaced the resonate inductor with an electric motor;
motors are rotating inductance machines.

c) Third, he reduced the operating frequency (1Mhz to 60Hz)

d) Fourth, he increased the power level (mW to Kw)




This chart shows the schematics of Tesla's radiant energy device patent (#685,957) issued Nov 5,1901. The initial (first) cut of the modified radio circuit is "Very Similar" as both have a receiving antenna, a resonate capacitor and inductor.

The differences are as follows:

a) Patent uses the (old) term/symbol condenser rather than capacitor

b) Patent mentions mica as the dielectric (temp/HV)

c) May need a transformer for impedance matching

d) Type of controller used (mechanical/electrical) to start a low frequency resonate circuit

Tesla used what he called an interrupter (mechanical device); I would use a PWM (chopper) circuit to do the same thing.

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# Detailed Engineering Analysis of a Resonate LC (tank) Circuit

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The next step in the design process is to take an in depth look at a (parallel) resonate LC tank circuit.

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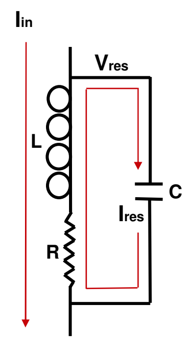
# S-Plane Transfer Functions




$$I_{res} = \frac{V_{res}}{1 / CS}$$

$$(I_{in} - I_{res}) = \frac{V_{res}}{LS + R}$$

$$[S = 2\pi(F_{res})j]$$

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The Highlighted (red) the current paths show that:

a) the input (Iin) current flows straight through the inductor

b) and the resonate (Ires) current only flows between the Inductor (L) and Capacitor (C)

Also, shown is that a “real” inductor contains both inductance (L) and resistance (R).

From this circuit two loop equations for the currents can be written.

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# S-Plane Transfer Functions (cont)

$$I_{res} = \frac{LCS\text{^}2 + RCS}{LCS\text{^}2 + RCS + 1} I_{in} = \frac{CS(LS + R)}{LCS\text{^}2 + RCS + 1} I_{in}$$

$$V_{res} = \frac{LS + R}{LCS\text{^}2 + RCS + 1} I_{in} = \frac{1}{CS} I_{res}$$

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Combining and rearranging these loop equations you get two transfer functions both based on the input current:

a) One for the resonate current (Ires) and

b) One for the resonate voltage (Vres)

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### LC Resonate Circuit @ 76.9KVar

| $I_{in}$ | Freq | $V_{res}$ | $I_{res}$ | L | R | C |
|---|---|---|---|---|---|---|
| 4A | 60 | 21.75Kv | 3.54A | 16321mH @ | 8.20K | 0.43uF |
| 7A | 60 | 12.43Kv | 6.19A | 5329mH @ | 2.68K | 1.32uF |
| 10A | 60 | 8.70Kv | 8.84A | 2611mH @ | 1.31K | 2.69uF |
| 12A | 60 | 7.25Kv | 10.61A | 1813mH @ | 912 | 3.88uF |
| 14A | 60 | 6.21Kv | 12.37A | 1332mH @ | 670 | 5.28uF |

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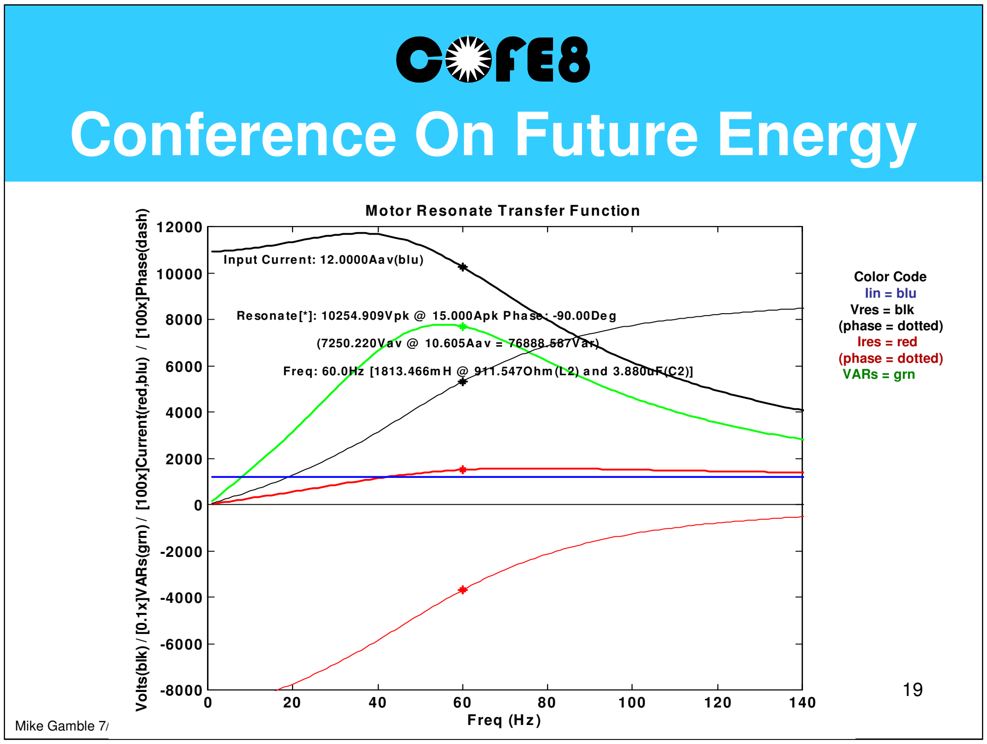
Running MatLab for different values of input current keeping the freq at 60Hz and

power at 76.9Kvar, you get this table for inductance (L) and capacitance (C) values.

The 7.25Kv and 12.47Kv values (red) are standard utility AC power distribution voltages.




MatLab Bode plot of the LC circuit’s Gain and Phase frequency sweep. Note the maximums for the voltage, current and Vars all occur at different frequencies,

therefore the 60Hz operating point is a compromise position compared to the 1Mhz resonator where everything lined up. This is why the circuit may not be self starting.

Also, the resonate current’s phase does track the voltage phase by 90deg (standing wave).

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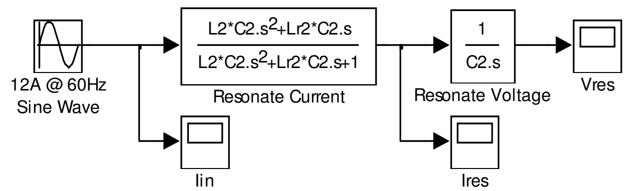
# Simulink Model

## LC Resonate Circuit

L2= 1813mH
Lr2= 912 Ohm
C2= 3.88uF
$I_{in}$ = 12A
$f_{res}$= 60Hz

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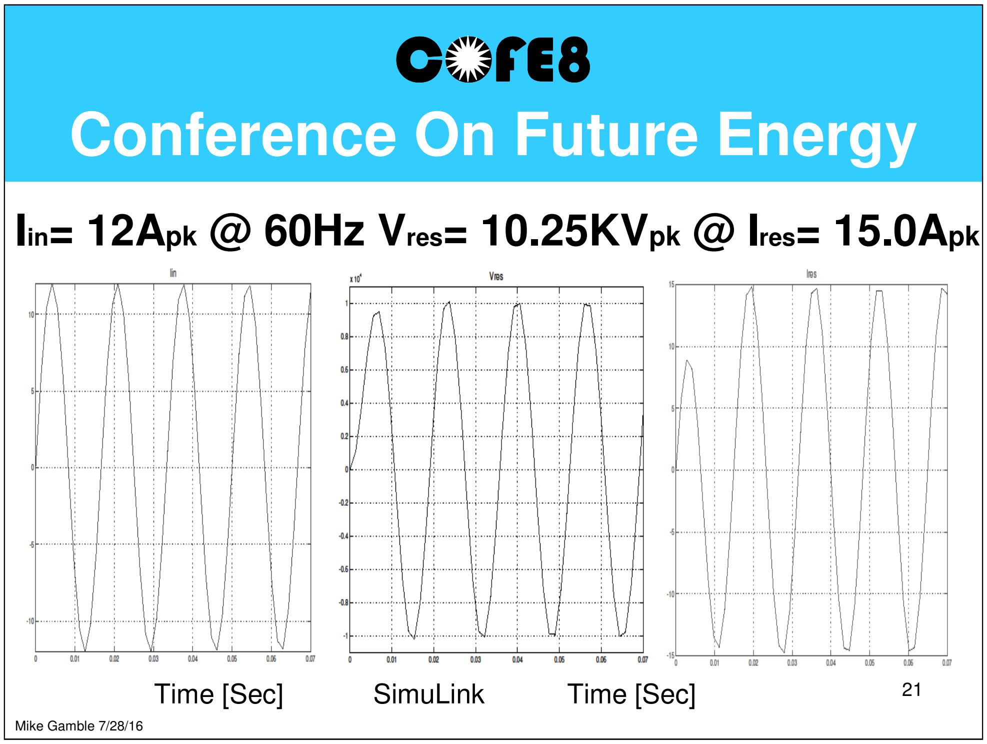
Simulink model of the same LC resonate circuit using 12A input current.




Running simulink with an input of 12A current outputs these resonate voltage and current plots:

a) There is only a slight current gain (12A to 15A)

b) But a very large voltage gain (12A to 10.25Kv)

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# High Voltage Capacitors

**Depending on the input current these are the resonate cap specs:**

| Iin | Cap | Volts(AC) |
|---|---|---|
| 14A = | 5.28uF | @ 20Kv |
| 12A = | 3.88uF | @ 20Kv |
| 10A = | 2.69uF | @ 25Kv |
| 7A = | 1.32uF | @ 50Kv |
| 4A = | 0.43uF | @ 60Kv |

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From the LC resonate table these are the capacitor specs for the different input current (Iin) values.

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# Tank Circuit Conclusions

1) **Small input current (antenna) generates a very large resonate voltage**
2) **Small input current (antenna) generates only a small resonate current**
3) **Resonate voltage is much higher than the current (>100:1)**
4) **Resonate voltage and current are determined by the input current**
5) **Resonate frequency is determined by the L and C component values**
6) **May need an impedance matching (step down) transformer**

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Resonate (tank) circuit conclusions based on the simulations:

a) Small input current produces a very large resonate voltage,

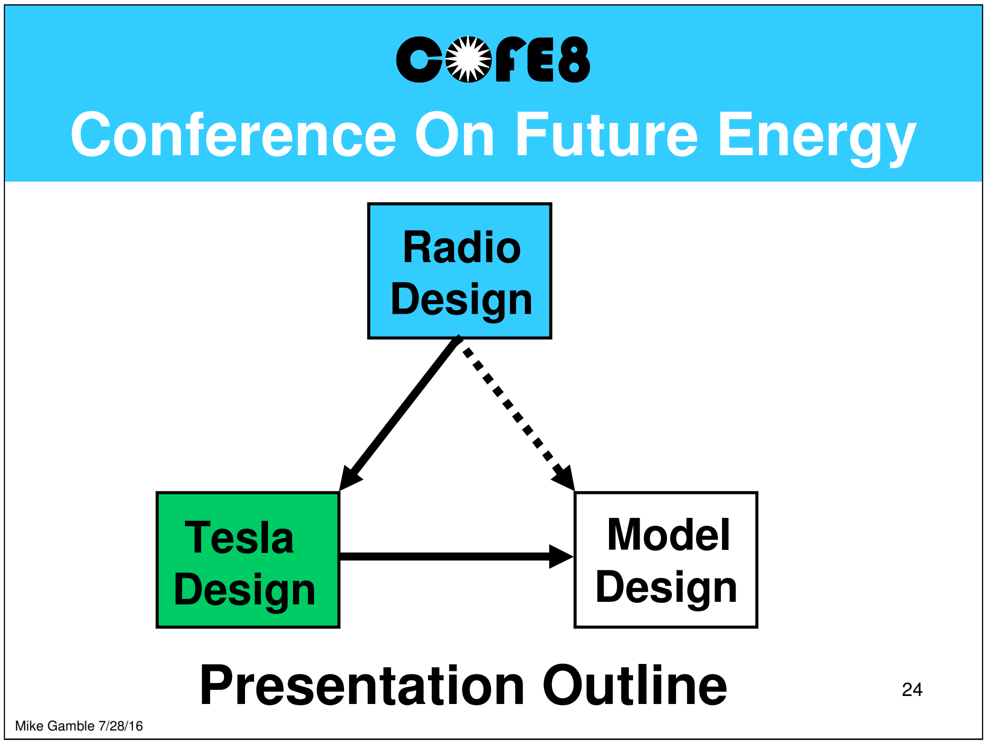
b) But only a small resonate current

c) The voltage gain will be greater than (100:1) over the current gain

d) Resonate voltage (Vres) and current (Ires) are determined by the input current (Iin)

e) Resonate frequency (fres) is determined by the inductance (L) and capacitance (C) values

f) May need an impedance (step down) matching transformer




With radio communications resonate theory and operations covered, we now proceed to the main part of this presentation - the reverse engineering of Tesla's electric car motor.

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# TESLA'S CAR MOTOR

## The Following Pictures and Stories are all Web Based

(Origin?)

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For those of you that haven't heard; It's rumored in books and on the web that Tesla built and drove

an electric powered Pierce Arrow car back in the early 1930s.

I picked a few of those stories off the web to see if there was

any truth to them and to correlate that data to see if it even came

close to a "real" motor design.

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**"Electrical power is everywhere present in unlimited quantities and can drive the world's machinery without the need for coal, oil or gas"** – Nikola Tesla, 1892

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I could not resist starting this section with a picture of a 1931 Pierce Arrow; I know it's been photo shopped (look at the tires). However, the quote by Tesla himself lends credibility to the story's truth; he certainly thought it was possible!

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**Nikola Tesla's 'Black Magic' Touring Car (1 of 4)**

In the summer of 1931, Nikola Tesla, the inventor of alternating current and the holder of some 1200 other U.S. patents, along with his nephew Peter Savo, installed a box on the front seat of a brand new **Pierce-Arrow** touring car at the company factory in Buffalo, New York. The box is said to have been **24 inches long, 12 inches wide and 6 inches high**. Out of it protruded a **1.8 meter long antenna** and **two ¼ inch metal rods**. Inside the box was reputed to be some **dozen vacuum tubes -- 70-L-7 type** -- and other electrical parts. **Two wire leads ran from the box to a newly-installed 40 inch long, 30 inch diameter AC motor** that replaced the gasoline engine.

As the story goes, Tesla inserted the two metal rods and announced confidently, "We now have power" and then proceeded to drive the car for a week, "often at speeds of up to 90 mph." One account says the motor developed **1,800 rpm** and got fairly hot when operating, requiring a **cooling fan**. The "converter" box is said to have generated enough electrical energy to also power the lights in a home.

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The first of four(4) Tesla car stories; highlighted in RED is data pertaining to the motor or controller. For those of you that haven't heard it.

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**Nikola Tesla's Wireless Electric Automobile Explained** **(2 of 4)**

Nikola Tesla proved in 1931 that it is possible to power our vehicles without a drop of fossil fuel. He removed the gasoline engine of a **Pierce Arrow** and replaced it with an **electric motor** and drove for hours, at speeds as high as 90 mph. Today, 81 years later, it is still possible to convert any gasoline engine vehicle into an all-electric vehicle and it will operate for hours – without having to stop and recharge. Not a drop of oil, gasoline, hydrogen fuel, natural gas or water. No combustion engine. No exhaust system. No pollution.

Supported by the Pierce-Arrow Co. and **Westinghouse** ~~General Electric~~ in 1931, Tesla took the gasoline engine from a new Pierce-Arrow and replaced it with an **80-horsepower alternating-current (AC) electric motor** with no external power source. At a local radio supply shop he bought **12 vacuum tubes**, some wires and assorted resistors, and assembled them in a circuit **box 24 inches long, 12 inches wide and 6 inches high, with a pair of 3-inch rods** sticking out. Getting into the car with the circuit box in the front seat beside him, he pushed the rods in, announced, “We now have power,” and proceeded to test drive the car for a full week, often at speeds of up to 90 mph. His car was never plugged into any electrical receptacle for a recharge. As it was an **alternating-current motor** and there were no batteries involved, where did the power come from?

Tesla used the collection of **vacuum tubes** (also called a valve amplifier), wires and assorted resistors to build a radio wave receiver/amplifier **24 inches long, 12 inches wide and 6 inches high, with a pair of 3-inch rods 1/4” in diameter** sticking out. The pair of rods that Tesla pushed in were used to close (complete) the circuit – like an on/off switch. The rod ends were most likely the positive and negative leads (connections) between the car antenna and the radio wave receiver/amplifier. By pushing them into the box containing the radio wave receiver/amplifier the connection was completed allowing the radio waves that were received from the air by the antenna to flow through the receiver/amplifier to the electric motor.



The second story similar to the first with a few additional details.
Tesla certainly did not work for Edison’s General Electric Co.
he worked for Westinghouse.

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**Tesla's Black Box Car (3 of 4)**
Mr. Savo reported that in 1931, he participated in an experiment involving aetheric power. Unexpectedly, almost inappropriately, he was asked to accompany his uncle on a long train ride to Buffalo. A few times in this journey, Mr. Savo asked the nature of their journey. Dr. Tesla remained unwilling to disclose any information, speaking rather directly to this issue.

Taken into a small garage, Dr. Tesla walked directly to a **Pierce Arrow**, opened the hood and began making a few adjustments. In place of the engine, there was an **AC motor. This measured a little more than 3 feet long, and a little more than 2 feet in diameter**. From it trailed **two very thick cables**, which connected with the dashboard. In addition, there was an ordinary **12-volt storage battery.**

The motor was rated at **80 horsepower**. Maximum rotor speed was stated to be **30 turns per second**. A **6-foot antenna rod** was fitted into the rear section of the car.

Dr. Tesla stepped into the passenger side and began making adjustments on a "power receiver" which had been built directly into the dashboard. The receiver, no larger than a short-wave radio of the day, used **12 special tubes, which Dr. Tesla brought with him** in a box-like case.

Mr. Savo told Mr. Ahler that Dr. Tesla built the receiver in his hotel room, a **device 2 feet in length, nearly 1 foot wide, a 1/2 foot high.**

These **curiously constructed tubes** having been properly installed in their sockets, Dr. Tesla pushed in **2 contact rods** and informed Mr. Savo that power was now available to drive. Several additional meters read values, which Dr. Tesla would not explain. No sound was heard. Dr. Tesla handed Mr. Savo the ignition key and told him to **start the engine**, which he promptly did.

Yet hearing nothing, the accelerator was applied, and the car instantly moved. Tesla's nephew drove this vehicle without other fuel for an undetermined long interval. Mr. Savo drove a distance of 50 miles through the city and out to the surrounding countryside. The car was tested to speeds of 90 mph, with the speedometer rated to 120.



The third story very similar to the first two.
This one mentions the normal car battery, starter motor and special/custom made tubes.

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**Nikola Tesla** **(4 of 4)** had an Electric **Pierce Arrow** back in 1931, the ICE engine was replaced with an **Electric Motor**. The power source was a **black box of radio tubes**, in the glove compartment. The **box had an antenna** sticking out. Tesla would fool with some tuners and tune in the right frequency and got **240 volts** delivered through the air to his car. The car ran almost silent.

Here is the story: It was a **Pierce Arrow**, one of the luxury cars of the period. The engine had been removed, leaving the clutch, gearbox and transmission to the rear wheels undisturbed. The gasoline engine had been replaced with a round, completely **enclosed electric motor of approximately 1m in length and 65cm in diameter, with a cooling fan in front**. Reputedly, it has no distributor. Tesla was not willing to say who had manufactured the engine. It was possibly one of the divisions of Westinghouse.

The **"energy receiver"** (gravitational energy converter) had been **built by Tesla himself**. The dimensions of the **converter housing were approximately 60 x 25 x 15cm**. It was installed in front of the dashboard. Among other things, the converter contained **12 vacuum tubes, of which three were of the 70-L-7 type**. A heavy **antenna approximately 1.8 meters long, came out of the converter**. This antenna apparently had the same function as that on the Moray converter (see chapter on Radiant Energy). Furthermore, two thick rods protruded approximately 10cm from the converter housing.

Tesla pushed them in saying "Now we have power." The motor achieved a maximum of **1800rpm**. Tesla said it was fairly hot when operating, and therefore a **cooling fan** was required. For the rest, he said there was enough power in the converter to illuminate an entire house, besides running the car engine. The car was tested for a week, reaching a top speed of 90 miles per hour effortlessly. Its performance data were at least comparable to those of an automobile using gasoline. At a stop sign, a passerby remarked that there were no exhaust gasses coming from the exhaust pipe. Petar answered "We have no motor." The car was kept on a farm, perhaps 20 miles outside of Buffalo, not far from Niagara Falls.

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The fourth and last story; this one mentions 240V operation and gives the dimensions in metric.

You are probably getting tired of hearing the same story by now so we will move on to the analysis!

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# The Following Charts are “Proposed” Tesla Motor Specs

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The following charts are the “proposed” Tesla motor design specs based on the previous stories.

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# Motor Specs: (red = Eng. Data)

| | |
|---|---|
| 80Hp AC Induction | 59.7Kw [74.6Kvar] |
| 1800RPM | 4-Poles [60Hz] |
| Fan cooled | External - Yes |
| Enclosed Housing | Yes |
| Two (heavy) Leads | Single Phase, HV and/or Hi Current? |
| Not Self Starting | Only Run Coil |
| Power Factor | .80 [.75 - .85] |
| 240Vac | 310.8Aac |
| (480Vac | 155.4Aac) |

Dimensions: 1m(40”)L x 65cm(25.5”)Dia.

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From the four stories highlighted data along with “real” electric motor specs, I pieced together this “proposed”

motor design. The story data (BLK) is on the left and the engineering specs (RED) are on the right.

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# Motor Specs(cont):

**Resistance R = Volt(PF) / Amp**

**= 240(0.8) / 310.8 = 0.6178 Ohms**

**Inductance L = (Volt)sin(Acos(PF)) / 2pi(Hz)Amp**

**= 240(0.6) / 2pi(60)310.8 = 1.229mH**

**Hp = Volts(Amps)PF / 746**

**= 240(310.8)0.8 / 746 = 79.99Hp**

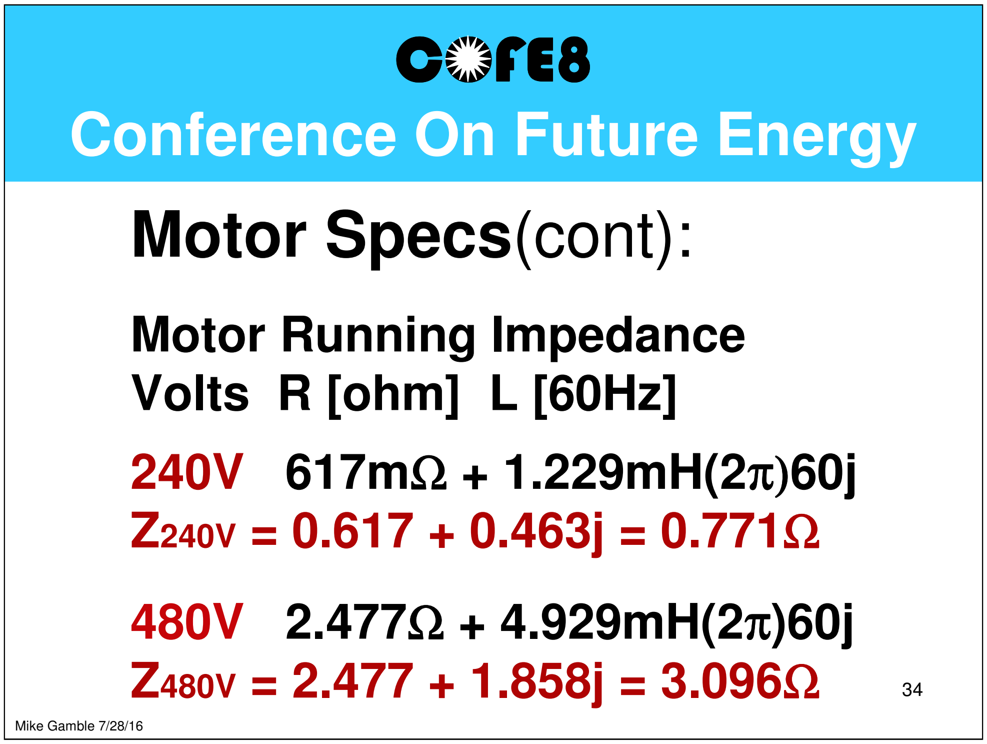
**RPM = 60(Hz) / N (N= number of pole pairs)**

**= 60(60) / 2 = 1800RPM**





Plugging the ”proposed” data into the four (4) electric motor design equations.




Plugging in the numbers for the resistance and inductance generates the motor's run impedance for both 240V and 480V power.

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## **Motor Specs**(cont):

**1800RPM Operation**

| Poles | N | Freq |
|---|---|---|
| 4 | 2 | 60Hz |
| 6 | 3 | 90Hz |
| 8 | 4 | 120Hz |
| 12 | 6 | 180Hz |

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This chart shows the different combinations of frequency and motor poles that will run at 1800RPM.

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Note: No one builds a 1-PH motor over 15Hp

75Hp 3-PH External Fan Enclosed

Baldor

BALDOR • RELIANCE Product Information Packet: CEM4316T - 75HP,1780RPM,3PH,60HZ,365TC,A36068M,TEFC

| Nameplate NP2383L | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CAT.NO. | CEM4316T | SPEC NO. | A36-1117-1816 | | | | | | |
| HP | 75 | AMPS | 169/84.9 | VOLTS | 230/460 | DESIGN | B | | |
| FRAME | 365TC | RPM | 1780 | HZ | 60 | AMB | 40 | SF | 1.15 |
| DRIVE END BEARING | 65BC03J30X | PHASE | 3 | DUTY | CONT | INSUL.CLASS | F | | |
| OPP D.E. BEARING | 65BC03J30X | TYPE | P | ENCL | TEFC | CODE | G | | |
| SER.NO. | | POWER FACTOR | 87 | NEMA-NOM-EFFICIENCY | 95.4 | | | | |
| | | MAX CORR KVAR | 14 | GUARANTEED EFFICIENCY | 94.5 | | | | |
| NEMA NOM/CSA QUOTED EFF | | | | | | | | | |
| | SUIT FOR 208V AT 186 AMPS | MOTOR WEIGHT | 907 | | | | | | |

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This is the closest present day motor I could find for comparison with Tesla's motor.

a) No one builds a single phase motor greater than 15HP.

b) Standard electric motor sizing is: 50, 75, 100Hp

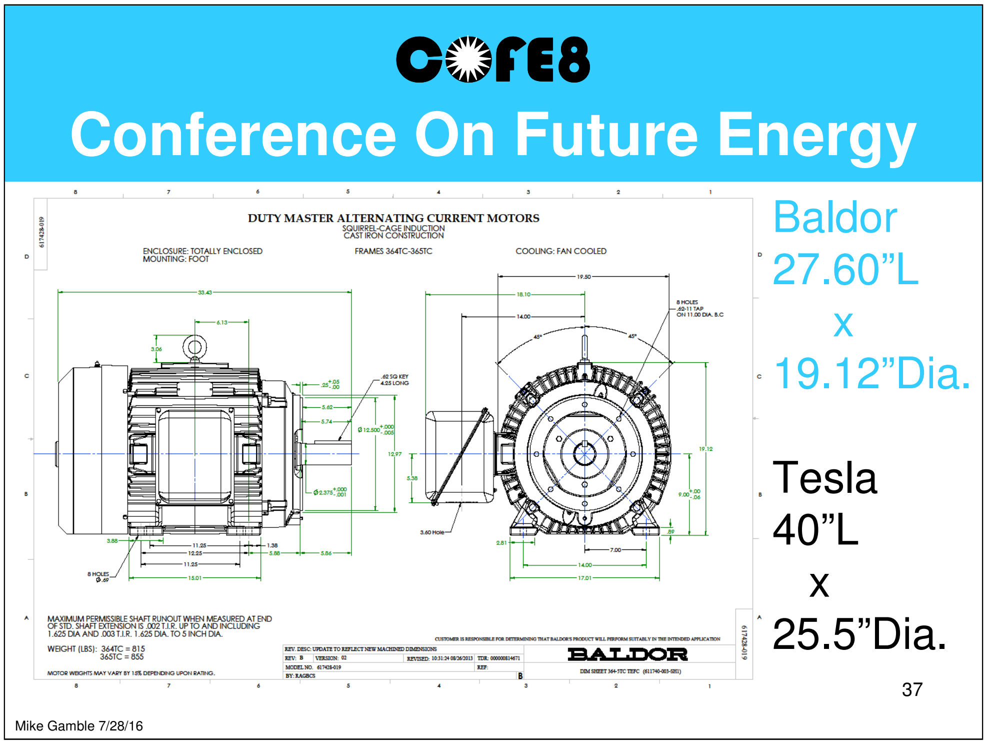
c) It is a 75Hp, 3-ph, 1800RPM, fan cooled, fully enclosed motor made by Baldor

Nameplate Specs:

a) Power Factor is 0.87 – 3-phase is more efficient

b) Runs on both 230V@169A / 460V@84.9A – much lower current

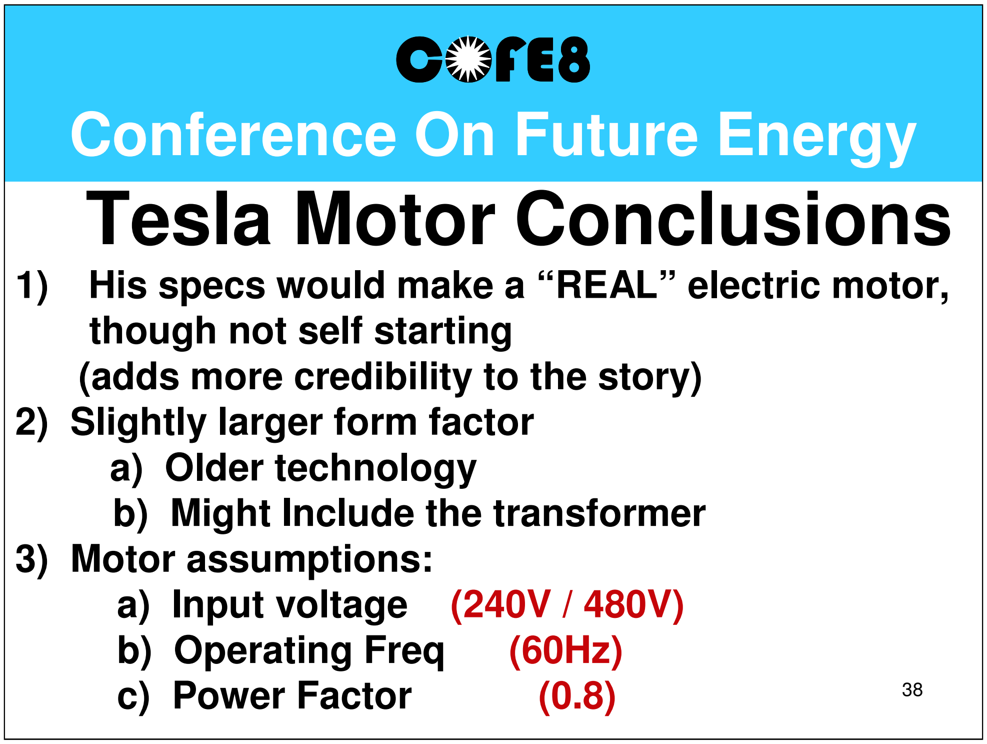
c) Weight is 907lbs (twice the weight of a gas engine)




The motor's mechanical dimensions state it's 27.6" long and 19.12" in diameter.

Compared to Tesla's motor of 40" long and 25.5" in diameter.

The diameters are similar, however it is about 1ft shorter than Tesla's motor.




Comparing Tesla's motor design to a present day one, his specs are close enough
to be "real" (adds more credibility to the story). However, it was not self starting.

It's longer length might include the transformer or just be older technology.

However, we are left with three (3) assumptions:

a) the input voltage,

b) the running frequency and

c) the power factor


The next few charts are a short tutorial on impedance matching transformers.

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# Utility Step-Down Transformers (Tesla design)


### Standard Specs:

(30:1) 7.25Kv to 240V @ 75Kva
(51:1) 12.47Kv to 240V @ 75Kva

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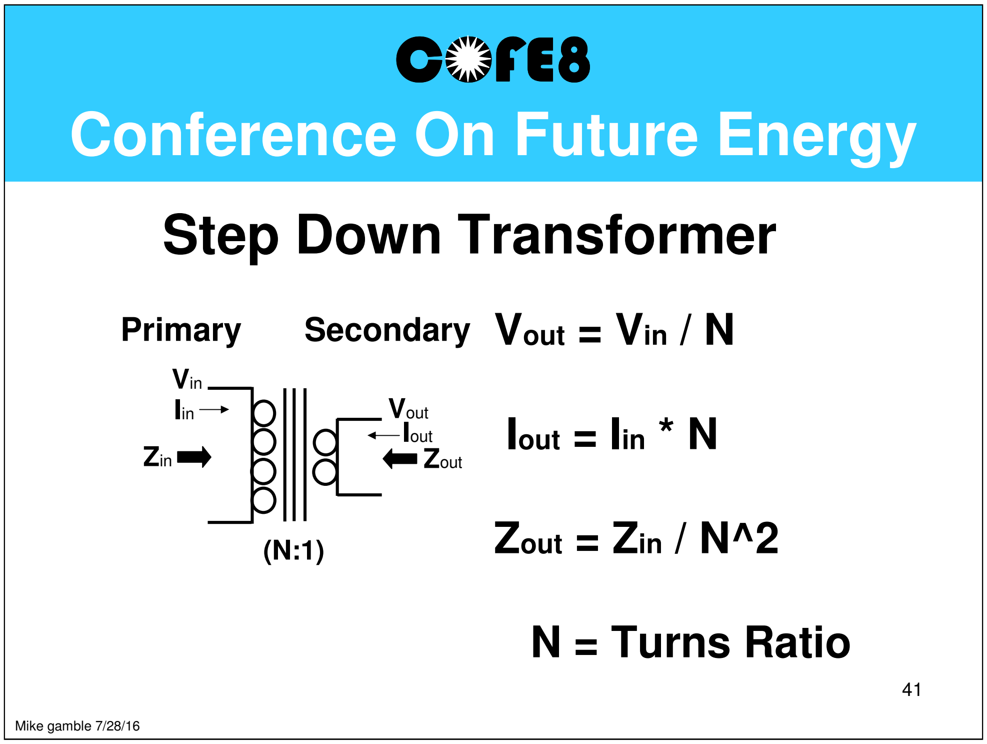
Mike gamble 7/28/16

Standard utility power distribution voltages are 7.25Kv and 12.47Kv (also Tesla designed).

Westinghouse made these 240V (center tapped) step down transformers

(5Kva to 100Kva); Tesla could have used one right off the assembly line!




Step down transformer schematics and it’s design equations.

Output voltage = input voltage / turns ratio

Output Current = input current * turns ratio

Output impedance = Input impedance / turns ratio squared

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# Step Down Transformer

$$N = \left[\frac{(7.25Kv)(310.8A)}{(10.61A)\ (240V)}\right]^{0.5} = 29.75\ (30{:}1)$$

**Turns Ratios**

$$N = \left[\frac{(7.25Kv)(155.4A)}{(10.61A)\ (480V)}\right]^{0.5} = 14.87\ (15{:}1)$$

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The turns ratio “N” calculation for a step down transformer is the square root (input voltage * output current) / (input current * output voltage). Examples shown are for a 7.25Kv step down to both 240V (30:1) and 480V (15:1) power outputs.

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# Step Down Transformer

| Input | Ratio | Output | [real] |
|---|---|---|---|
| 7.25Kv | / 30 | = 238V | [240V] |
| 10.61A | * 30 | = 313A | [311A] |
| 911.55Ω | / 30^2 | = 0.98Ω | [0.77Ω] |

| Input | Ratio | Output | [real] |
|---|---|---|---|
| 7.25Kv | / 15 | = 476V | [480V] |
| 10.61A | * 15 | = 157A | [155A] |
| 911.55Ω | / 15^2 | = 3.93Ω | [3.09Ω] |

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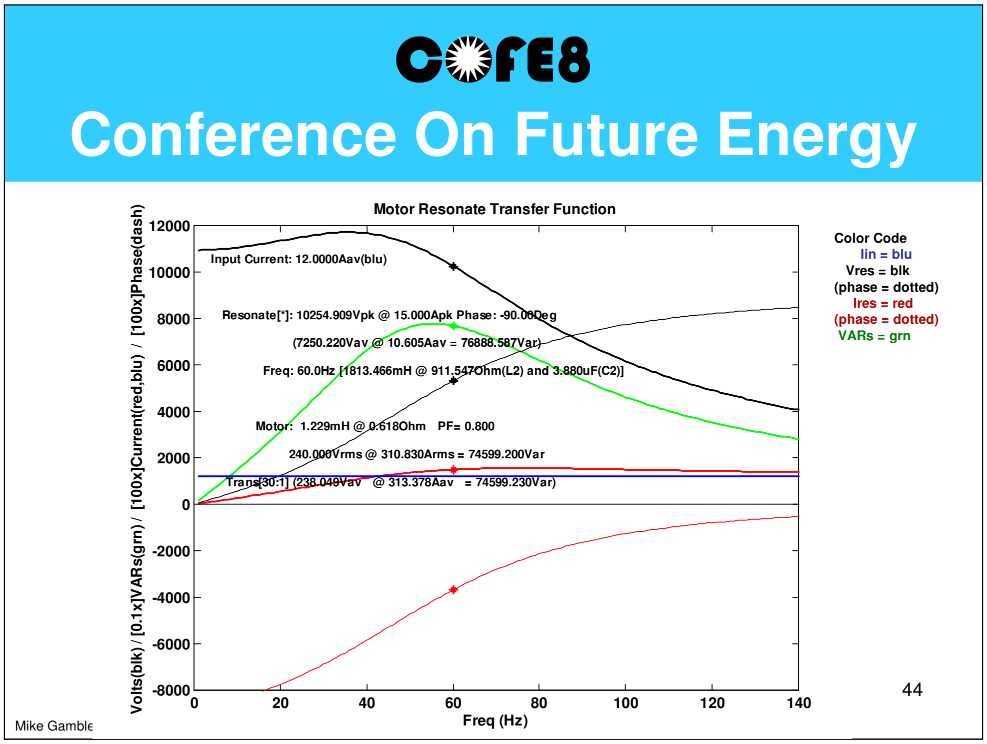
The calculated step down transformer numbers compared to the “real” motor values for both 240V and 480V. They are a very close match and good enough to run!




MatLab bode plot of Gain and Phase for a 7.25Kv (30:1) step down transformer coupled resonate motor design operating at 240Vac.

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# Simulink Model

## With (30:1) Transformer

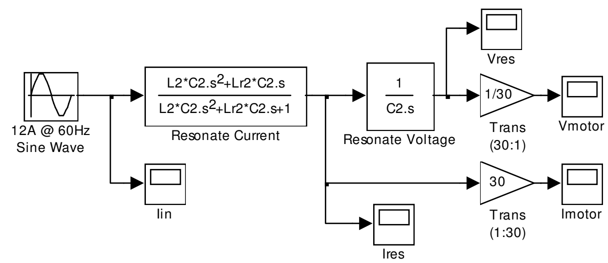
L2= 1813mH

Lr2= 912 Ohm

C2= 3.88uF

$I_{in}$ = 12A

$f_{res}$= 60Hz

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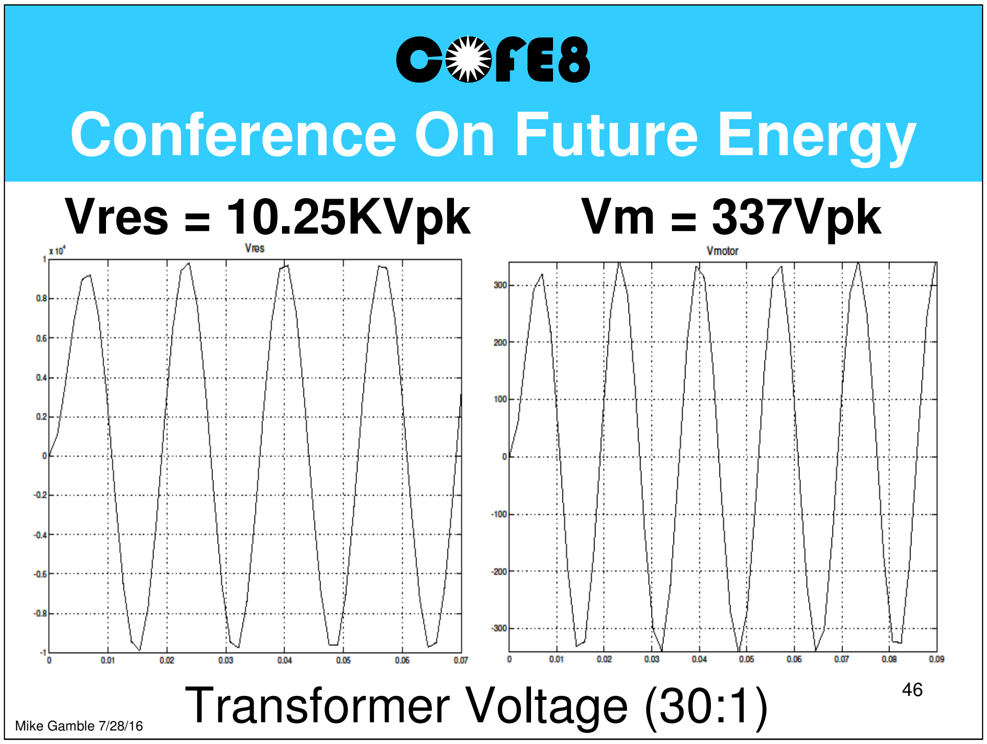
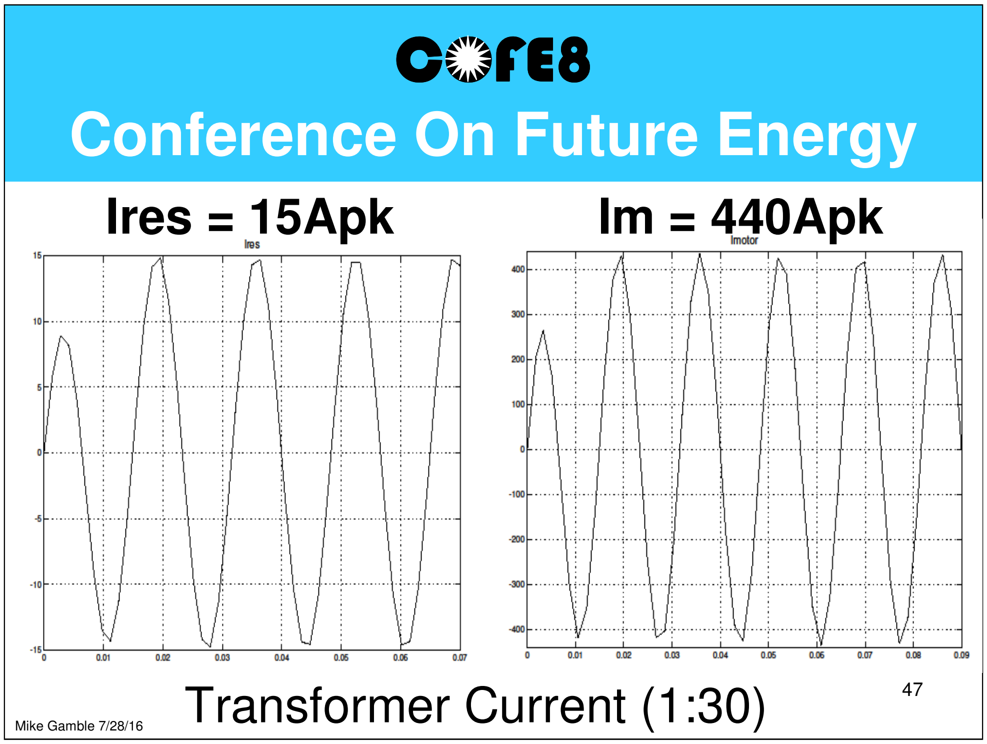
Simulink model using the same numbers with a (30:1) step-down transformer to convert the resonate voltage and current to the motor voltage and current.




Simulink wave shapes of resonate voltage and (30:1) step-down transformer motor voltage.




Simulink wave shapes of resonate current and (30:1) step-down transformer motor current.

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# Step Down Transformer

$$N = \left[\frac{(12.47Kv)(310.8A)}{(6.16A)\,(240V)}\right]^{0.5} = 51.22\ (51:1)$$

**Turns Ratios**

$$N = \left[\frac{(12.47Kv)(155.4A)}{(6.16A)\,(480V)}\right]^{0.5} = 25.61\ (26:1)$$

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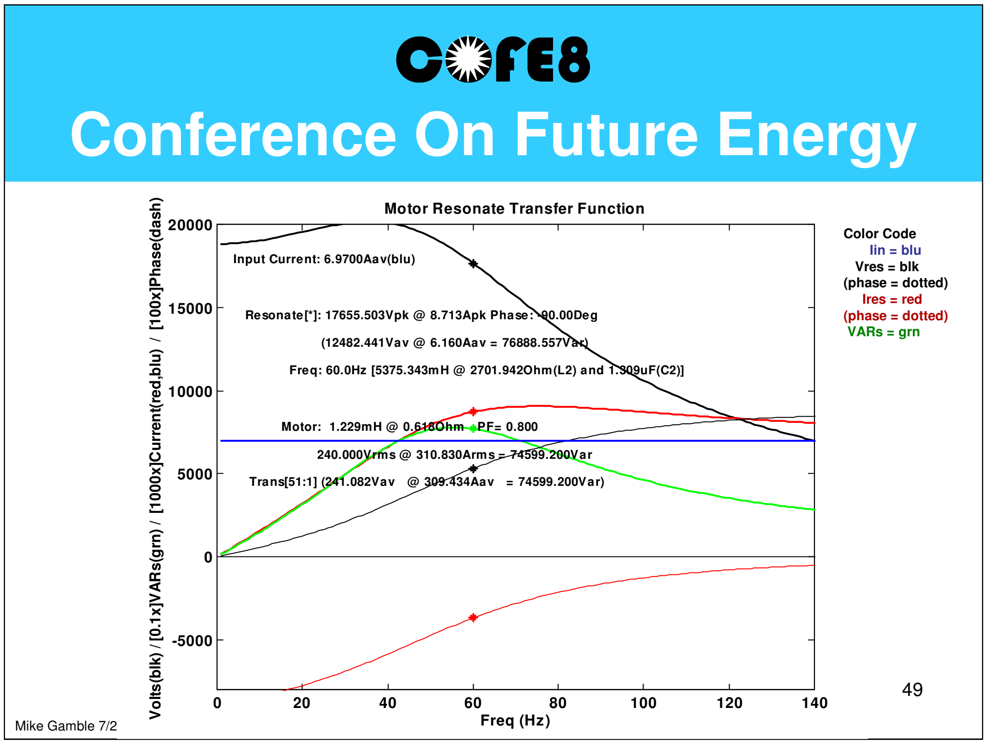
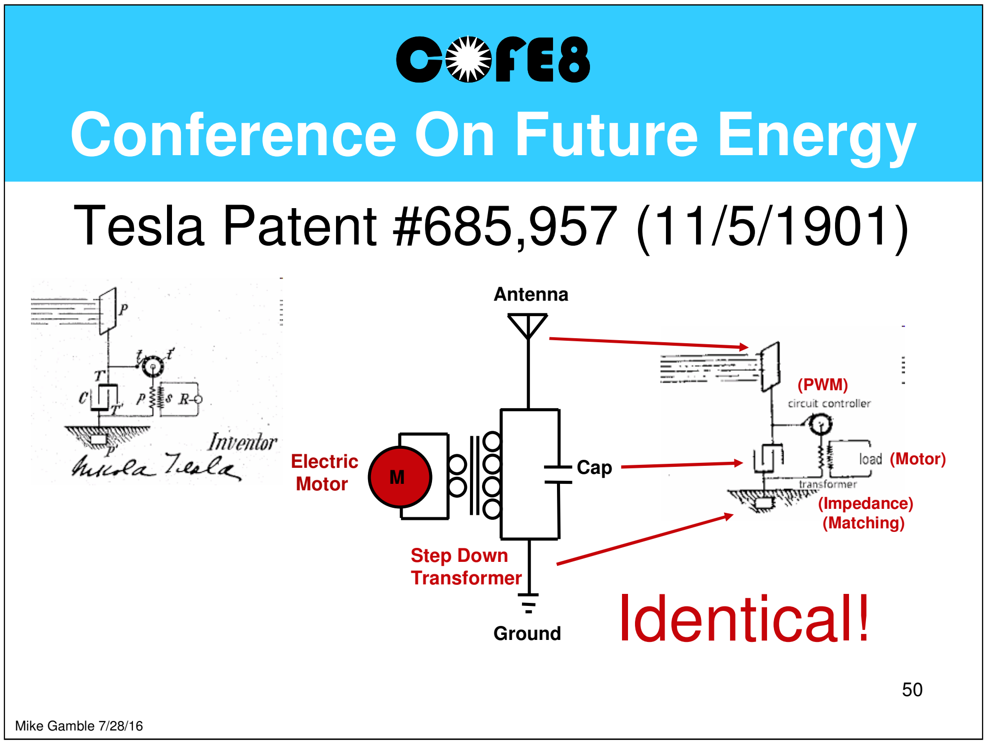
Examples shown are for a 12.47Kv step down to both 240V (51:1) and 480V (26:1) power outputs.




MatLab bode plot of Gain and Phase for a 12.5Kv (51:1) step down transformer coupled resonate motor design operating at 240Vac.




Impedance matching the motor to the resonate circuit with a step down transformer produces an “Identical” system to that of Tesla’s patent. That leaves only the controller design.

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# The Following Charts are “Proposed” Tesla Controller Specs

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The following charts are the “proposed” Tesla motor controller design based on the same previous stories.

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# Controller Specs: (red = Eng. Data)

| | |
|---|---|
| Tesla built box | Custom Design |
| Contained 12 tubes | |
| Tesla brought with him | |
| Curiously constructed tubes | Non Standard? |
| Three were 70L7 tubes | Standard MFG |
| Two 3” removable rods (1/4”dia) | Iron/Ferrite |
| One 6’ heavy duty antenna | <<1/4λ @ 60Hz |
| Box connected to two (heavy) motor leads | |
| 240Vac | 7.25Kv@10.61A |
| (480Vac) | |
| Dimensions: 24”L x 12”W x 6”H | |

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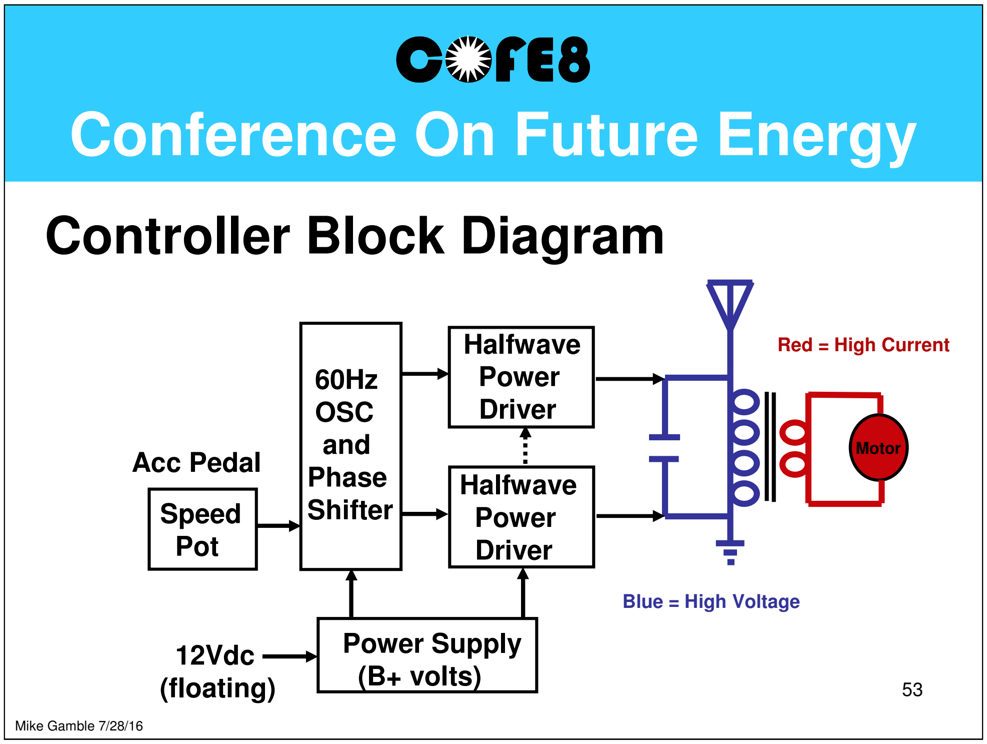
Using a similar design process, I pieced together this proposed controller design.

The story data (BLK) is on the left and the engineering specs (RED) are on the right.

The control box dimensions are too small to include the 75VA step down transformer; therefore

it must have been located in the motor housing. This makes the two heavy motor leads HV insulation.




Based on the previous specs this is what I get for the controller's block diagram.

Now comes the hard part of designing this circuit with vacuum tubes!

I had to dig out some of my 40 year old college textbooks on tubes as design references.

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# Power Supply Specs:

## DCDC Converter (B+ Supply)

Input: 12Vdc

Output: 70Vdc

**Multivibrator (OSC)**

One Dual Triode Tube

12V Heater

## Fullwave Rectifier

CT – Transformer

Two Diode Tubes

6V / 12V Heater

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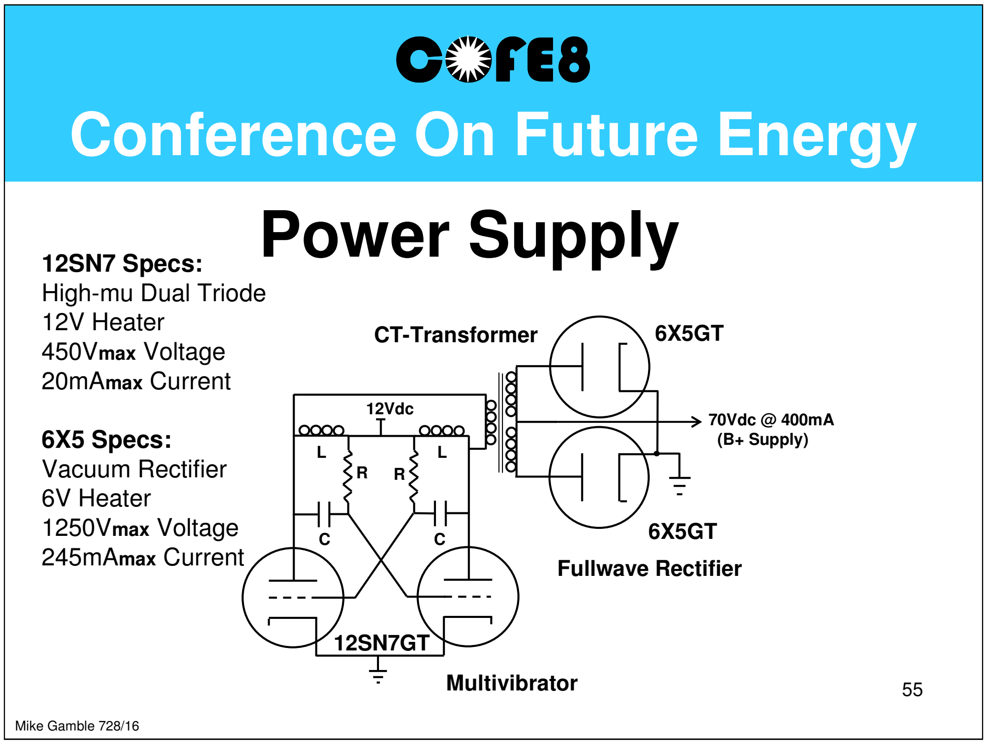
The system power supply is basically a DCDC converter that takes 12V up to 70V (B+ supply). To design this circuit using tubes would require one dual triode tube with a 12V heater for the multivibrator circuit, a center tapped transformer and two half wave rectifier diode tubes with a 6V (or 12V) heater.




The power supply schematics would look something like this. For each tube type, I picked

the oldest tubes I could find in a 1963 RCA tube manual (discontinued 8-pin octals);

assuming these tubes were the standard in the 1930s.

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# Reference Osc Specs:

## 60Hz Multivibrator (OSC)

- Two Power Triode Tubes (70L7)
- 70V Heater
- About 100V Output

## Phase Shifter (May need to shift both sides)

- One / Two Power Triode Tube (70L7)
- 70V Heater

## Speed Control (accelerator pedal)

- Potentiometer

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The reference OSC circuit is also a multivibrator running at about 100V and 60Hz. To design it

would require two power triode tubes. One or both of the multivibrator tube grids would have to be phase

shifted for speed control; this circuit would require another (1) triode tube.

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# Power Driver Specs:

**Half Wave Design**

Input: 12V @ 12A

**Ignitron Arc Tubes (curiously constructed)**

Trigger: aprox. 100V

Output: 10.25Kv @ 15.0A

May have to parallel (2-3x)

**Spike Inductors**

Two half wave channels

Adjustable Core Rods (3”Lx1/4”dia) 57

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The power amplifier stage consists of two half wave drivers that generate the 12 amps of current from

the 12V power supply. This is done by alternately charging and discharging two big inductors. The two

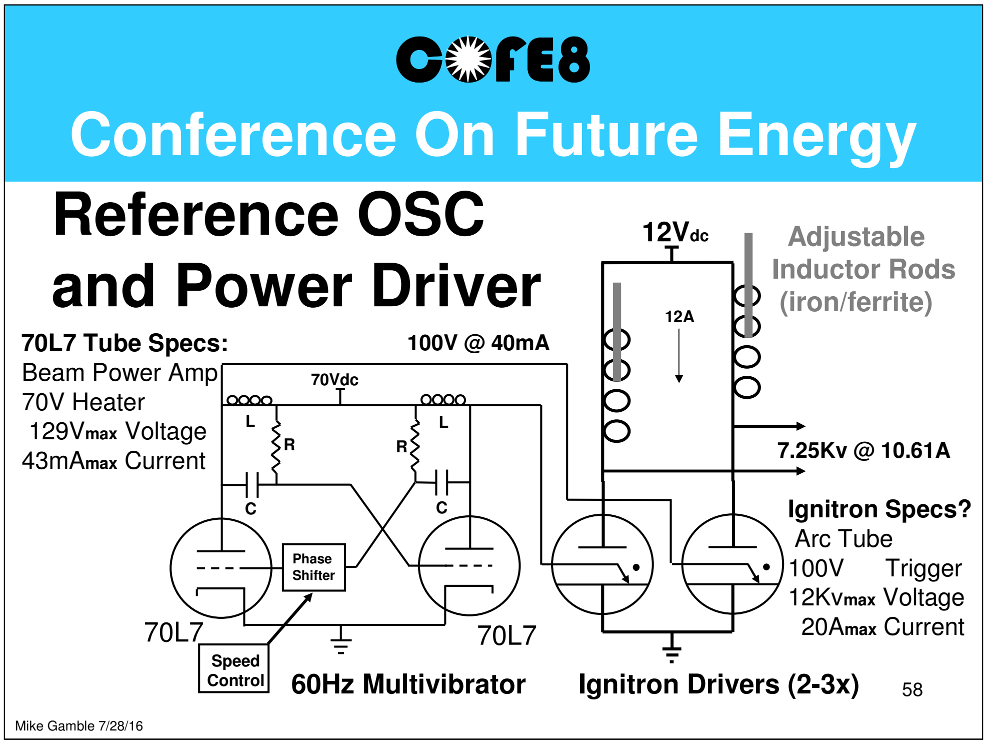
3” by ¼”dia. rods were the adjustable iron/ferrite cores of these inductors. The system was started (brought up to resonance)

at low power and then the rods were inserted to generate the high power. The “curiously constructed” tubes

Tesla used for the power drivers turn out to be Westinghouse “Ignitrons”. He may have had to parallel these tubes

to get the proper current levels. I have not been able to track down any specs of the very early Westinghouse Ignitrons;

the best to date is a 1938 WL-654 rated at 480V @ 12.5A.




The schematic of the 60Hz reference oscillator, phase shifter and half wave power driver circuits would look something like this. The phase shifter would move the frequency off the 60Hz resonate point thereby reducing the power output. The oscillator circuit alternately fires the two ignitrons which drove the step-down transformer. Tesla may have had to parallel these ignitron tubes to get the proper current rating.

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**Ignitron**

From Wikipedia, the free encyclopedia

An **ignitron** is a type of gas-filled tube used as a controlled rectifier dating from **1930**. Invented by Joseph Slepian while employed by **Westinghouse**. Westinghouse was the original manufacturer and owned trademark rights to the name "Ignitron".

Tesla would have had access to these curiously constructed “Ignitron” tubes. Ignitrons were the predecessors of modern day (SCRs) Silicon Controlled Rectifiers.

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Ignitrons tubes had a big pool of mercury in the bottom which vaporized when struck by an arc from the igniter

electrode. They ran hot with a blue glow; some of the bigger ones were water cooled. If the EPA thinks a little

mercury vapor in florescent lights is bad they would really love these tubes.

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# Tesla Motor Conclusions

a) Tesla's resonate motor system design would certainly "RUN" (antenna, LC tuner, transformer, AC motor)

b) The controller could also be made to function, but would need some tweaking (tubes)

c) However, a single phase power system using tubes is not very efficient (3-Ph, FETs)

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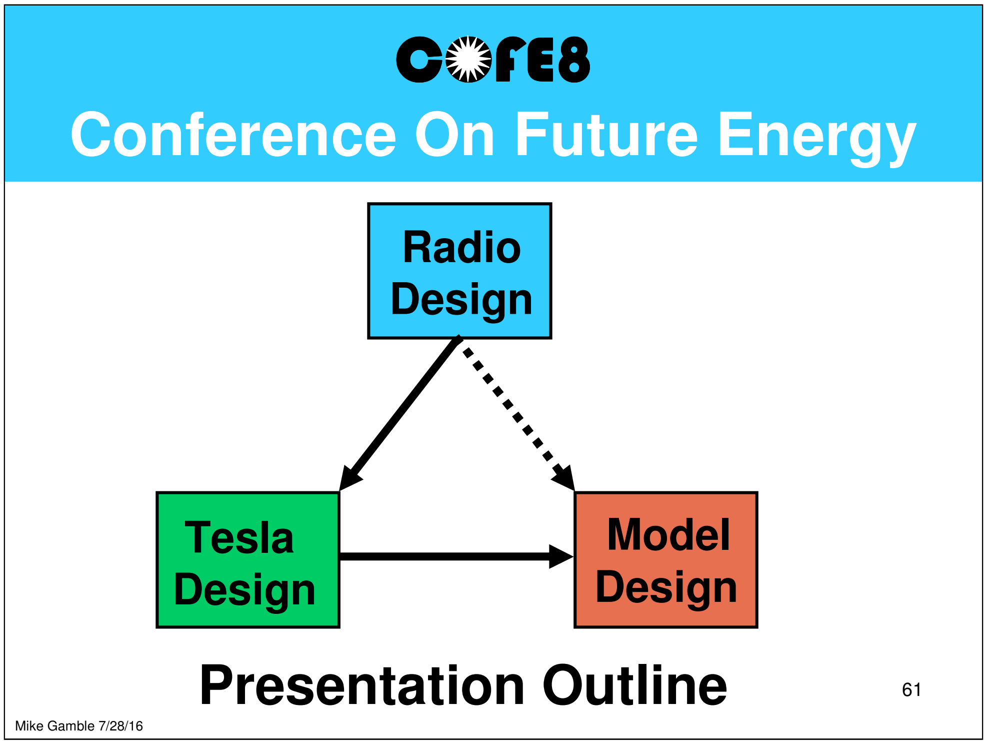
From an electrical engineering standpoint Tesla's resonate motor drive system (antenna, LC tuner, step-down transformer, AC motor) would

certainly "run"; he did not break any rules. The controller circuit most likely gave him some problems as tube circuits are not all that

stable (tweaking); they tend to drift. However, a three phase power system would be far more efficient than a single phase one.




With Tesla's resonate motor system reverse engineered and documented, we will now try and duplicate his design with a demo model.

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# Demo Fan Model

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To demonstrate Tesla’s design we will build, test and document a demo model.

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## OBJECTIVE

To prove Tesla’s resonant power system works I scaled his 80Hp car motor down to a small 1/22Hp fan motor. This reduced the complexity/size/cost of the demo model. Besides 1931 Pierce-Arrows are a little hard to come by now days!

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To prove Tesla’s resonant power system works we will scale his 80Hp car motor down to a 1/22Hp fan motor.
This will reduce the complexity/size/cost of the demo model. Besides 1931 Pierce-Arrows are hard to come by now days!

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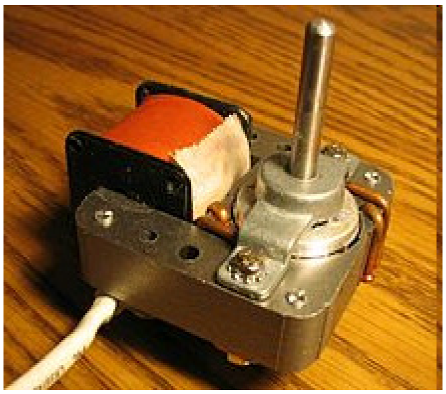
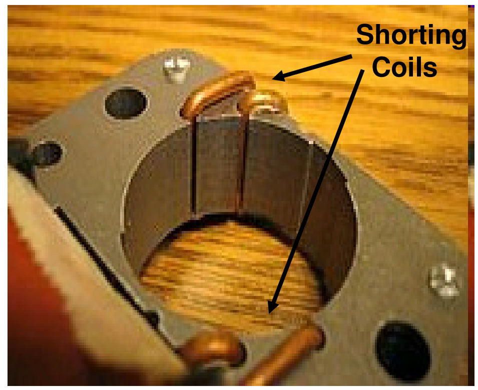
# Shaded Pole Fan Motor



Fractional 1/22 Hp Motor




Detail of Shaded Pole

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Picture is a fractional (1/22) HP shaded pole AC induction motor and a detail of it's shaded pole shorting coils.

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## Motor Specs: (red = Eng. Data)

| | |
|---|---|
| 1/22Hp AC Induction | 33.3W or 56.0Var |
| 3000RPM | 2-Pole @ 60Hz |
| Fan cooled | Yes |
| Enclosed Housing | No - open |
| Two Leads | Single Phase |
| Self Starting | Yes – shaded poles |
| Power Factor | 0.5939 |
| 115Vac | 0.488Aac |

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Using a similar design process to that of Tesla’s car motor we now calculate the specs for the fan motor.

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### Motor Specs(cont):

**Resistance R = (Volt)cos(Acos(PF)) / Amp**

**= 115.24(0.5939)/0.488 = 140.24Ohm**

**Inductance L = (Volt)sin(Acos(PF)) / 2π(Hz)Amp**

**= 115.24(0.805)/2π(60)0.488 = 503.98mH**

**HP = Volts(Amps)PF / 746**

**= 115.24(0.488)0.5939 / 746 = 1/22.3Hp**

**RPM = 60(Hz) / N (N= number of pole pairs)**

**= 60(60) / 1 = 3600RPM**

**(3000RPM high slippage – 0.59PF)**

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The four (4) electric motor design equations showing the data (red) from the previous ”proposed” chart.

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## Motor Specs(cont):

**Motor running impedance**

**Volts  R [ohm]  L [60Hz]**

$Z_{115V} = 140.24\Omega + 503.89mH(2\pi)60j$

$Z_{115V} = 140.24 + 189.96j = 236.12\Omega$

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The numbers for the resistance and inductance generates the motor’s run impedance for 115V power.

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## Motor Specs(cont):

$Q = 2\pi FL / R$

$= 2\pi 60(503.98e\text{-}3)/140.24 = 1.355$

$\theta = \text{Acos}(PF) = \text{Atan}(2\pi FL/R) = \text{Atan}(Q)$

$= \text{Acos}(0.5939) = -53.57\text{deg}$

Q(infinity) = tan(-90) or [standing wave]

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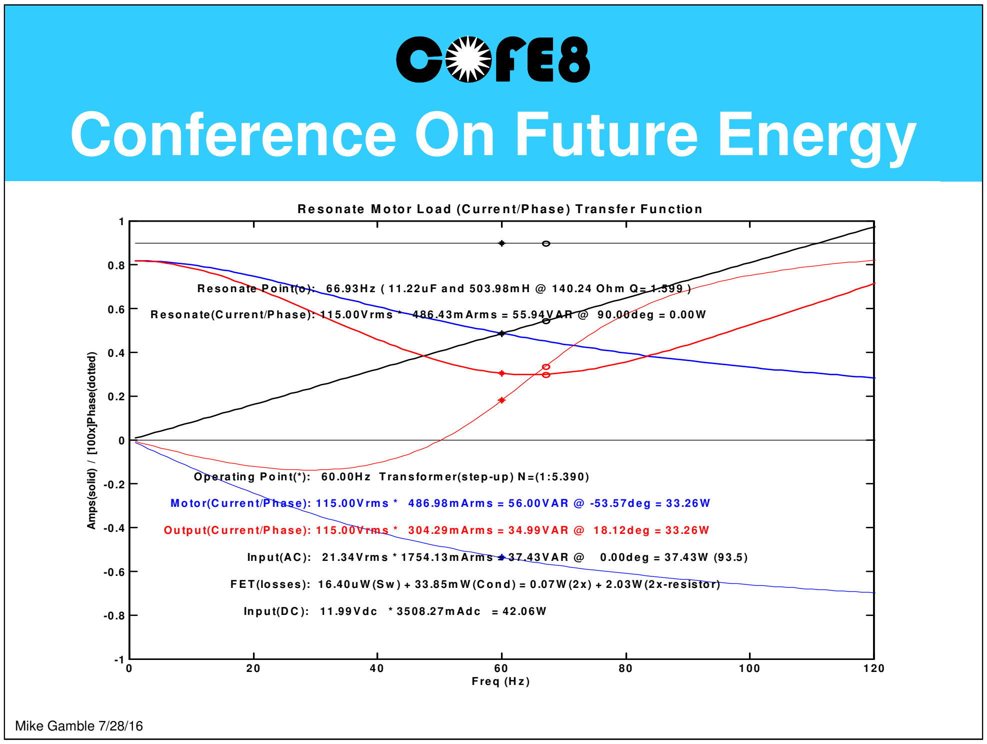
The numbers for the motor’s “Q” factor and phase angle.




Plugging the proceeding numbers into MatLab Bode plot you get the motor's operating point data.

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# Simulink Model

L2= 503.89mH

Lr2= 140.24Ohm

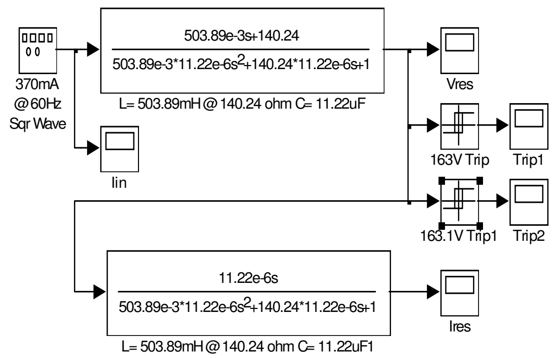
C2= 11.22uF

$I_{in}$ = 370mApk

f= 60Hz

Vres= 163Vpk

Ires= 1.1Apk

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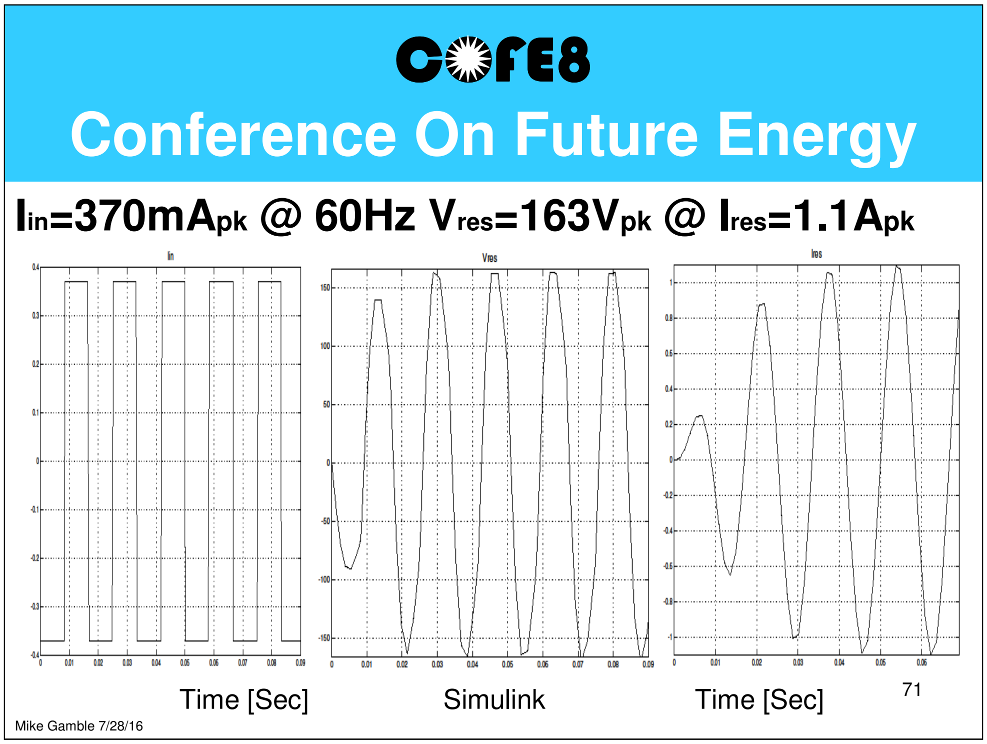
Simulink model of the same resonate fan motor data.




Running simulink with an input of 370mA outputs these resonate voltage and current plots:

a) There is only a slight current gain (370mA to 1.1A)

b) But a very large voltage gain (370mA to 163V)

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## LRC Resonate Circuit: 56.24Var @ 0.59PF

| L | R | C |
|---|---|---|
| 503.89mH @ | 140.24Ω | 11.22uF |

| | $I_{in}$ | Freq | $V_{res}$ | $I_{res}$ |
|---|---|---|---|---|
| MatLab | 304mArms | 60 | 115.00Vrms | 486mArms |
| Simulink | 262mArms | 60 | 115.24Vrms | 778mArms |
| | (370mApk | 60 | 163Vpk | 1.1Apk) |

**Both show the motor will run per MFG spec.**

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Table shows the data from the previous MatLab and simulink runs; they are not identical but close enough to run the motor correctly.

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# FAN Motor Controller

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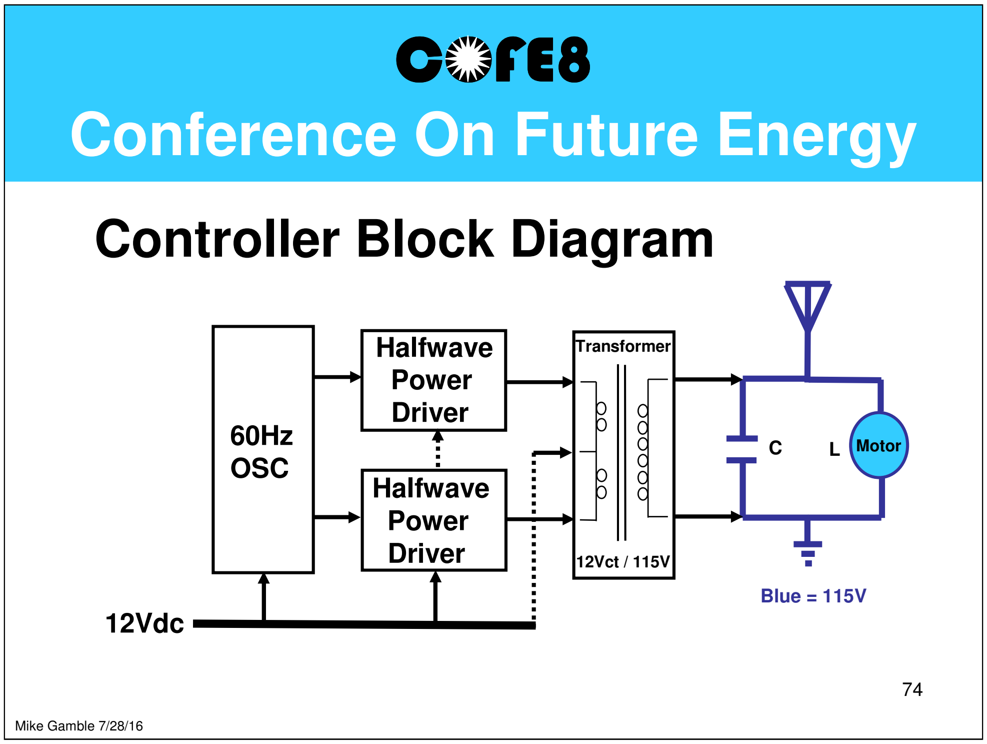
The following charts are on the fan motor controller design.




The fan motor controller would be similar to Tesla's motor controller except for the following items:

a) No speed pot – fixed freq

b) Direct 12V input power (no B+ supply)

c) No tubes (FET design)

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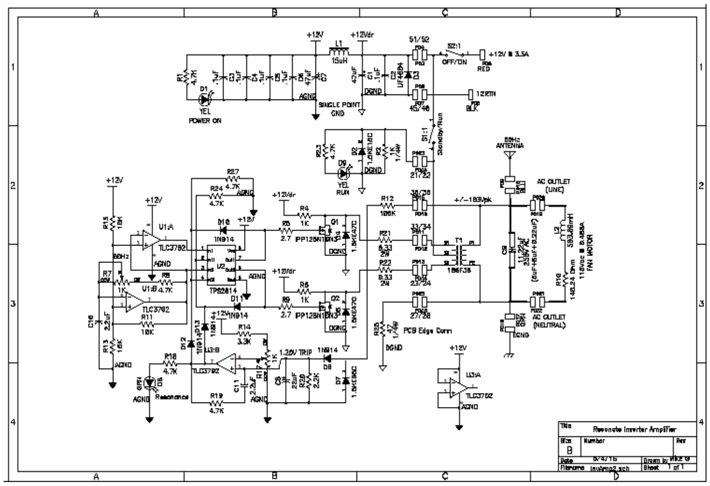
# Controller Schematic



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The circuit schematic would look something like this.

It’s a much simpler design using FETs rather then tubes.

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# Resonate Antenna

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This next section is on the resonate antenna design.

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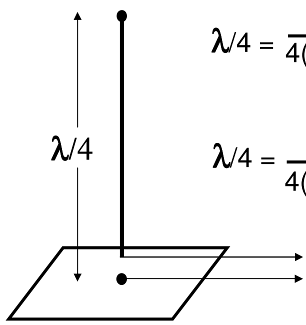
## ¼ Wave Vertical Antenna design




$$\lambda/4 = \frac{C}{4(freq)} = \frac{3e8(3.28083)}{4(41Mhz)} = 6.0ft$$

$$\lambda/4 = \frac{C}{4(freq)} = \frac{3e8(3.28083)}{4(60Hz)} = 4.1Mft$$

(776.7miles)

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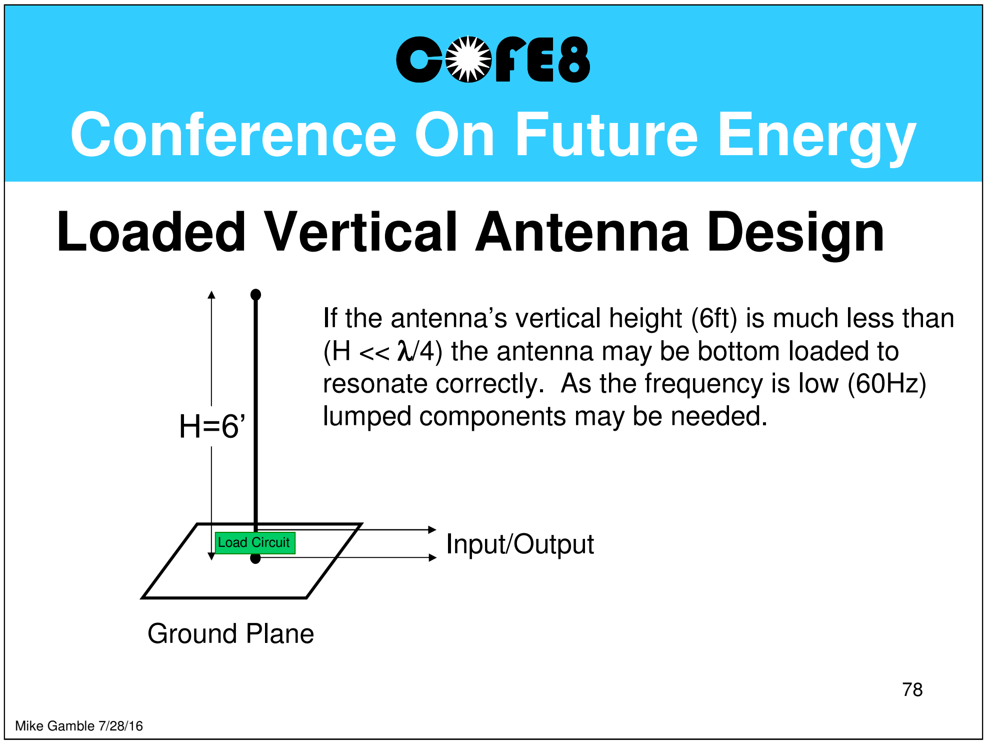
A normal vertical (whip) antenna is tuned at a height of ¼ wave length.
At 6ft the antenna's normal operating frequency is 41Mhz.
However, at 60Hz this same antenna is now 776.7 miles tall; not very portable!
That's twice the orbital altitude of the space station (ISS).




Have to “LOAD” the vertical antenna to shorten it electrically for resonance.

Normally an antenna is loaded using tuning stubs, however at 60Hz these are also too long.

Therefore, you have to use lumped components.

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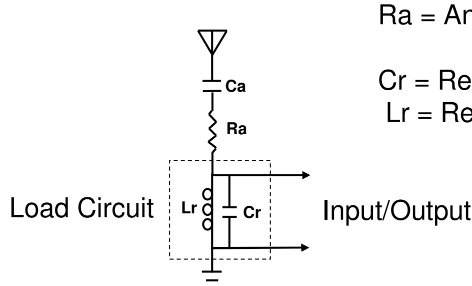
## Loaded Vertical Antenna Design (cont)

Ca = Antenna Capacitance
Ra = Antenna Radiation Resistance

Cr = Resonate Capacitance
Lr = Resonate Inductance

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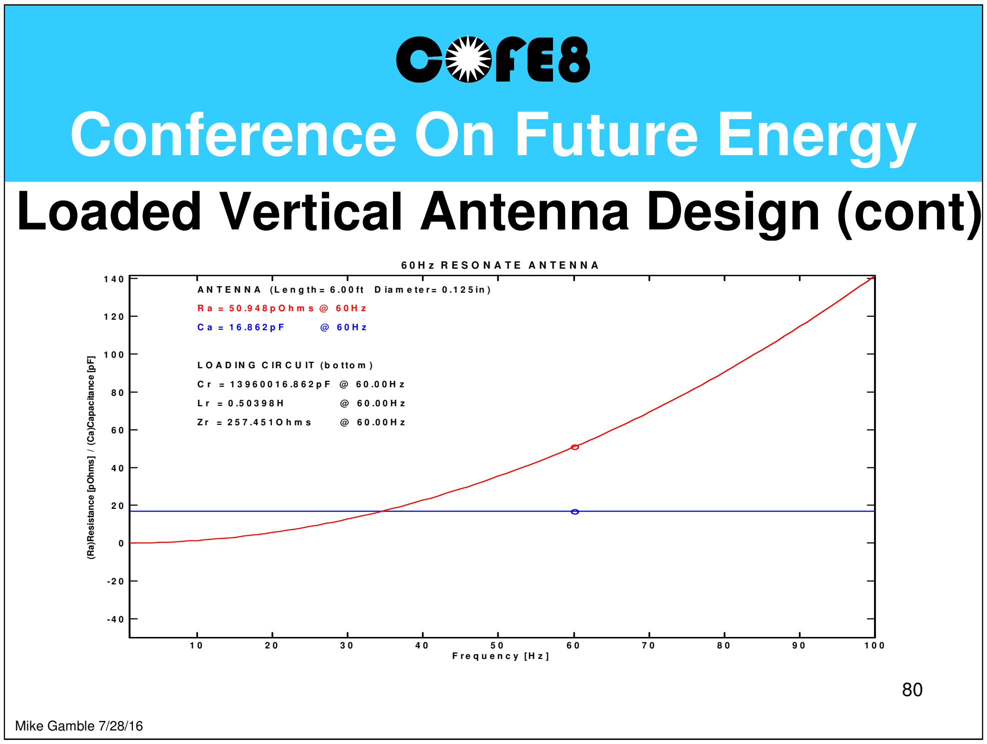
Schematics of a loaded antenna showing the antenna specs along with the resonate loading components.




MatLab simulation of a loaded 60Hz vertical antenna.

Dimensions: 6ft long by 1/8” diameter

Radiation Resistance (red) changes with freq

Antenna capacitance (blu) is constant

Loading component values:

Cap(C) = 13.96uF

Ind(L) = 503.9mH

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# Actual (Real) Run Data

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Now for the fun part - actual “run data” taken with the fan motor demo model.

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These pictures are two views of the “running” resonate inverter power system.

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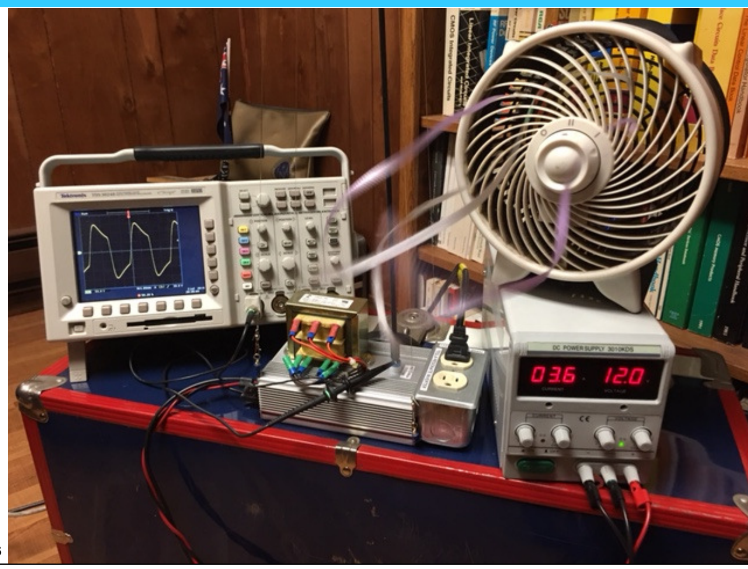

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Close up of the resonate inverter test setup showing the running wave shape and input power numbers.

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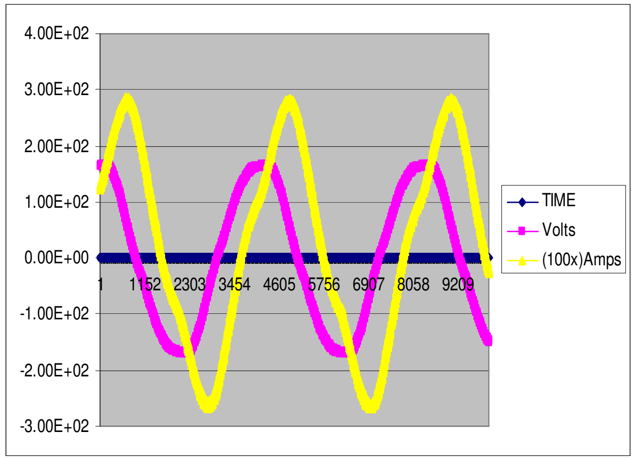
## MOTOR DATA

**Power Line**

Volts = 163Vpk (115.24Vrms)
Amps = 2.30Vpk (3.3ohm)
= 0.697Apk (0.493Arms)
Phase = -54.32deg
Freq = 59.88Hz

[Tek TDS3024]

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Measured power line (fan) motor data using a scope. As you can see it is very similar to the calculated numbers.

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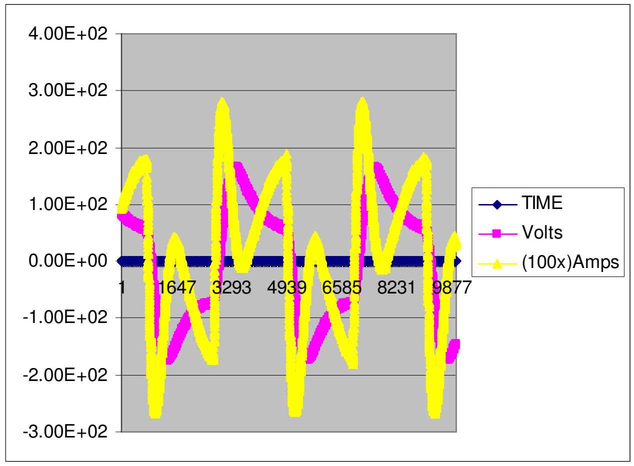
## MOTOR DATA

**Resonate Inverter**

Volts = 165Vpk (114.73Vrms)
Amps = 2.68Vpk (3.3ohm)
= 812mApk (0.304Arms)
Phase = +11.14deg
Freq = 59.53Hz

Input: 12.0V @ 3.6Adc
Cap: 11.22uF

[Tek TDS3024]

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Measured inverter data running the resonate (motor/cap) load using a scope. As you can see the current wave shape carries multiple chopper harmonics. And the phase is way short of 90deg; low “Q” factor.

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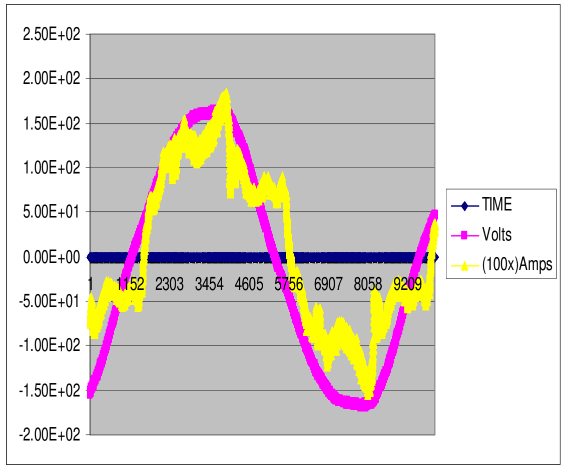
## MOTOR / CAP DATA

**Power Line - Resonate**

Volts = 163Vpk (115.24Vrms)
Amps = 1.62Vpk (3.3ohm)
= 0.491Apk (0.347Arms)
Phase = -20.34deg
Freq = 59.88Hz

Cap: 11.22uF

[Tek TDS3024]

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Measured power line data driving the resonate (motor/cap) load using scope.

As you can see the power grid does not like resonate (VARs) harmonics.

In his Colorado testing Tesla put Kvars back on the power line and blew out the generator.

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# Motor "Q" factor

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The following charts are on the (fan) motor's "Q" factor.

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# "Q" vs Motor Impedance

**$Z_{115}$ = 115.24Vac / 0.488Aac = 236.12Ω**

| Q(cal) | Q(mea) | θ | PF | Lr | L |
|---|---|---|---|---|---|
| 1.355 | 1.599 | -53.57deg | 0.5938 | 140.24Ω | 503.98mH |
| 3.000 | 3.119 | -71.57deg | 0.3162 | 74.67Ω | 594.19mH |
| 5.000 | 5.071 | -78.69deg | 0.1961 | 46.31Ω | 614.16mH |
| 7.000 | 7.049 | -81.87deg | 0.1414 | 33.39Ω | 620.03mH |
| 10.00 | 10.03 | -84.29deg | 0.0995 | 23.50Ω | 623.22mH |

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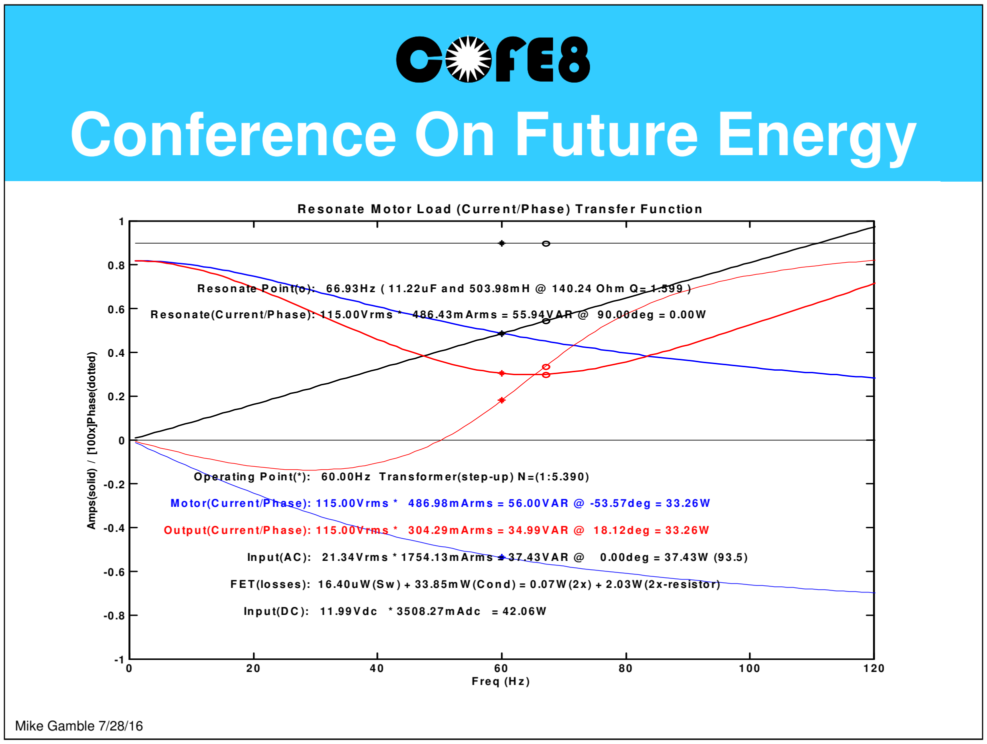
This chart shows different "Q" factors and their corresponding impedances. Highlighted in red is the fan motor data; low "Q" factor.

Q(cal) = w*L/Lr

Q(mea) = Ires/Iin

As you can see the higher the "Q" the closer the phase gets to 90deg:

1) PF decreases rapidly
2) Resistance decreases rapidly
3) Only a small Inductance increase



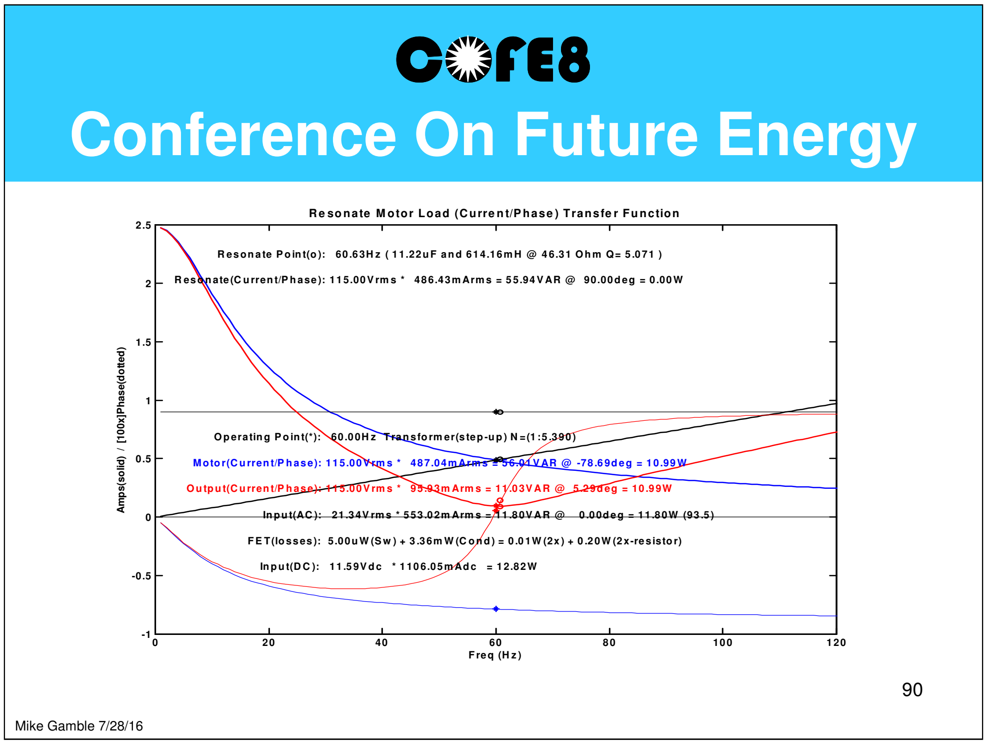

Previous fan motor run data chart.

Will draw your attention to three things:

1) Resonate point and 0deg phase don't line up

2) Low "Q" factor [1.7]

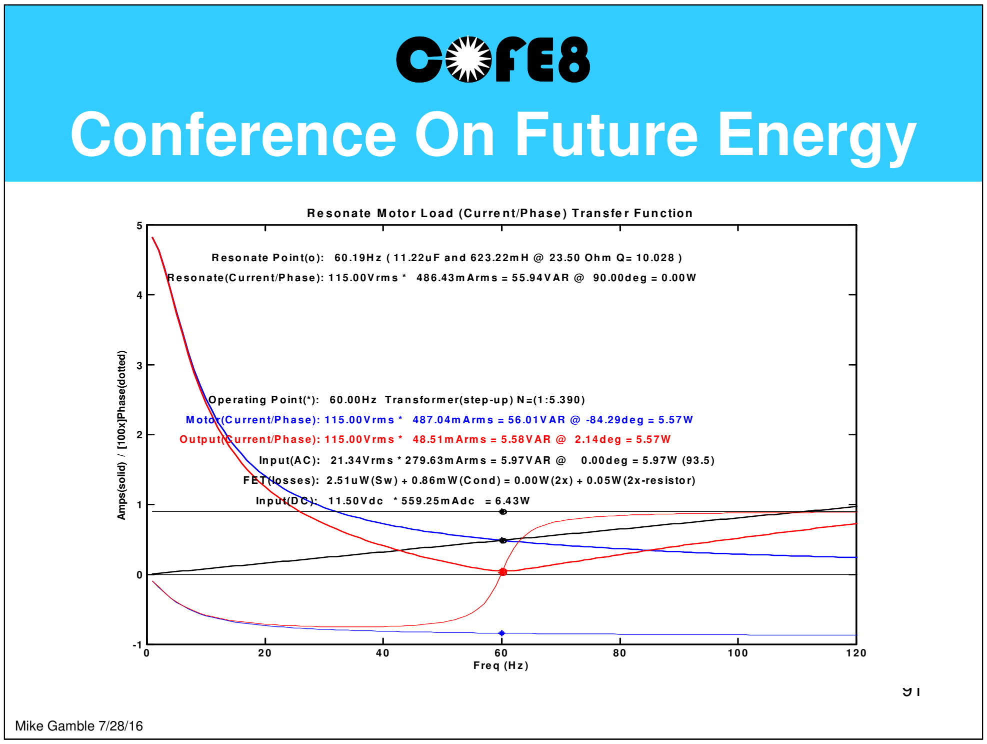
3) Resonance is supplying only 30% (180mA) of the motor's total current




Increasing the “Q” factor up to 5:

1) Resonate point and 0deg phase are getting closer together

2) Resonance is now supplying 80% (390mA) of the motor’s total current




Increasing the “Q” factor further to 10:

1) Resonate point and 0deg phase now coincide

2) Resonance is now supplying 99% (480mA) of the motor’s total current

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# Conclusions

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The following are my conclusions on the resonate motor system.

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# Proposed Circuit Improvements (mods)

1) Top load antenna (capacitance)
2) Increase resonate frequency (60Hz to 20Khz – 100Khz)
    a) Better antenna matching (tuning)
    b) Use smaller components
    c) Use high “Q” air core inductors
    d) Use “beat” frequencies (PWM) to reduce operating frequency (60Hz)
3) These improvements could achieve “self resonance”
4) The simulations show it would work!

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1) Top load antenna
2) Increase resonate freq
3) Better antenna match
4) Use smaller parts
5) Use high “Q” coils
6) Use “beat” freq to reduce the operating freq back down

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# Demo (Fan) Motor Conclusions

1) Demo **PROVES** An induction motor will run off a resonate power system
2) The (first cut) demo design only shows a small resonate current gain (low Q= 1.6),
3) which just about equals the inverter (losses) inefficiencies (89% circuit, 93% transformer)
4) Not enough resonate gain (Q) to achieve "standalone" operation
5) Need an inductor with a higher Q factor (Q= 5-10) and
6) Need a better tuned antenna (loading)
7) However, the demo **PROVES** Tesla's resonate design **VALID** (real) he did not break any electrical rules (no black boxes or black magic)!
8) Based on this research, my engineering experience, a working demo model and the many rumored accounts; would have to conclude Tesla **"ACTUALLY"** built and drove an electric powered Pierce-Arrow! 94

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1) An induction motor will run off a resonate power system
2) However, the system needs a high Q motor and a well tuned antenna
3) Demo proves Tesla's design was valid and would work
4) Have to conclude Tesla really did build and drove an electric car

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**Will close with the $64,000 question:**

# Who’s Transmitting?

**“the resonate power has to come from somewhere!”**

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This leaves one open item I will close with; call it the $64K dollar question if you like: Who’s Transmitting?

As there’s no such thing as a free lunch; the resonate power has to come from somewhere!

If the receiver is working correctly you can assume (by the rules) the transmission media is valid and there is an operating transmitter;

because the receiver can only reproduce the transmitter’s signal!

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# THANK YOU

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Old engineer’s saying the “devil’s in the details” – hope I haven’t bored you with too many of them!

Here’s where you can find me or just catch me in the hall if you have more questions.