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Analog Compendium

Circuit Design Considerations

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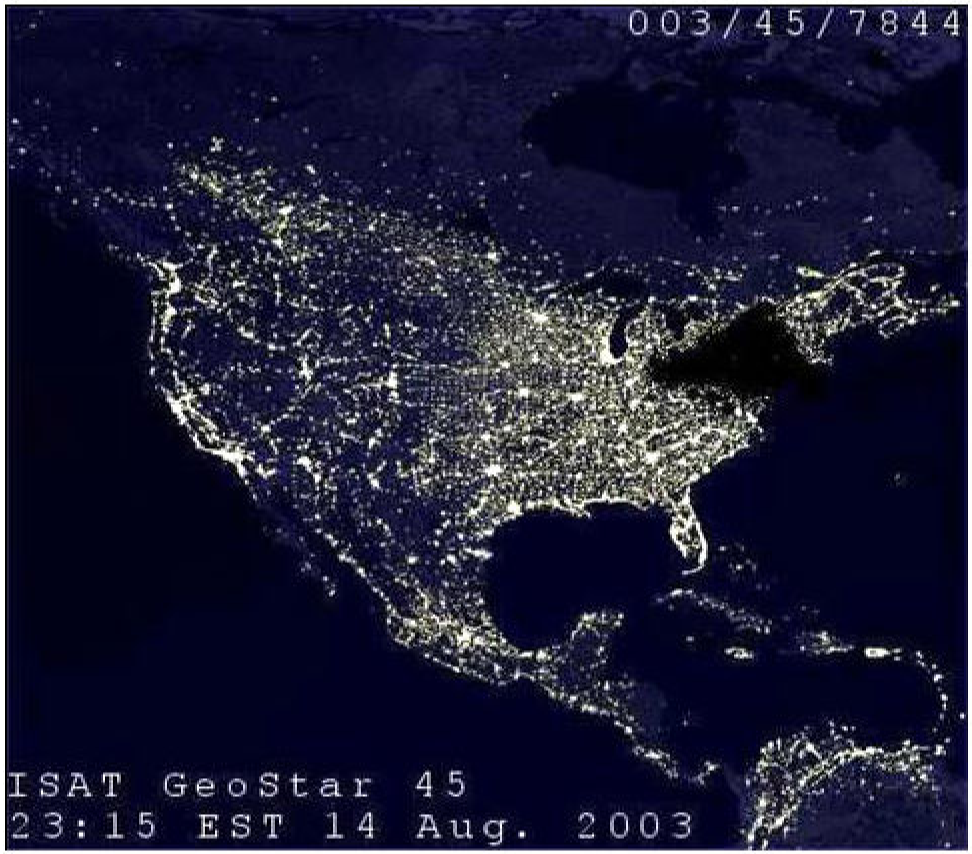
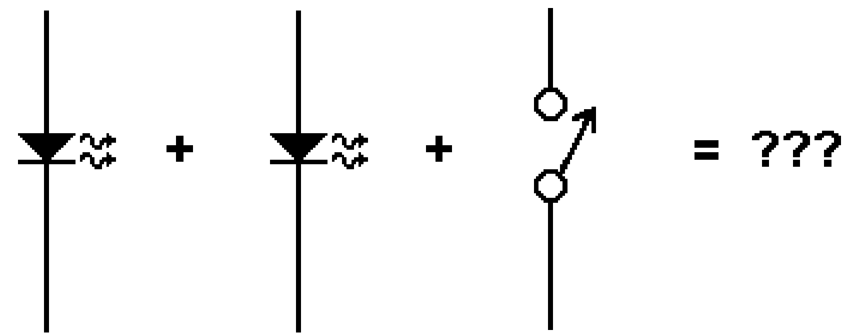
This is us:



LED Selection with SPST



Select one LED or the other to be lit with only an SPST switch available.

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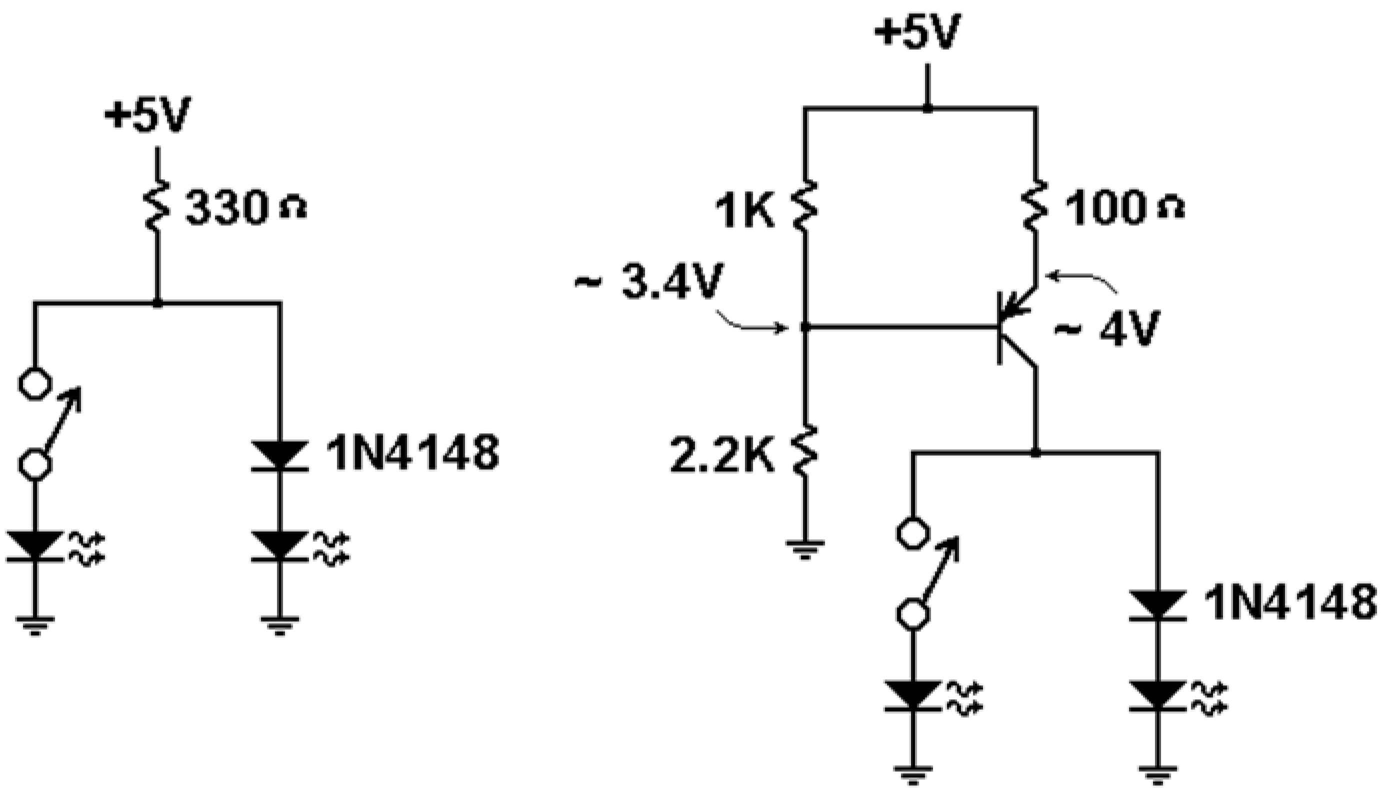
SPDT selection of LED with an SPST switch



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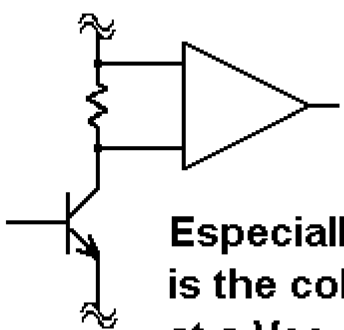
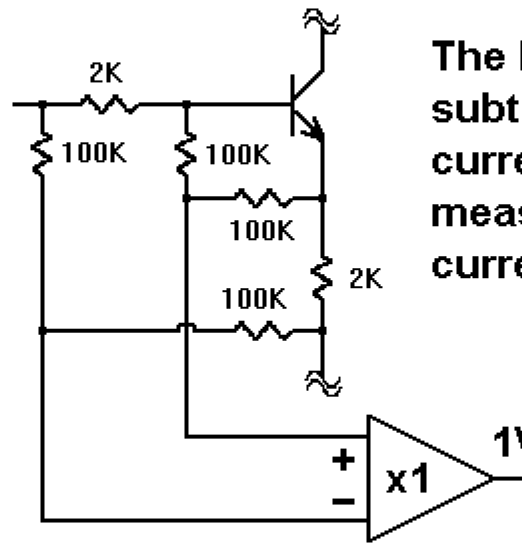
Measuring Collector Current Without Actually Measuring Collector Current

Differential amplifier directly sampling the collector current.



Especially difficult is the collector is at a Vce of some hundreds of volts.



1V / mA of collector current

The base current sample is subtracted from the emitter current sample to yield a measure of the collector current.

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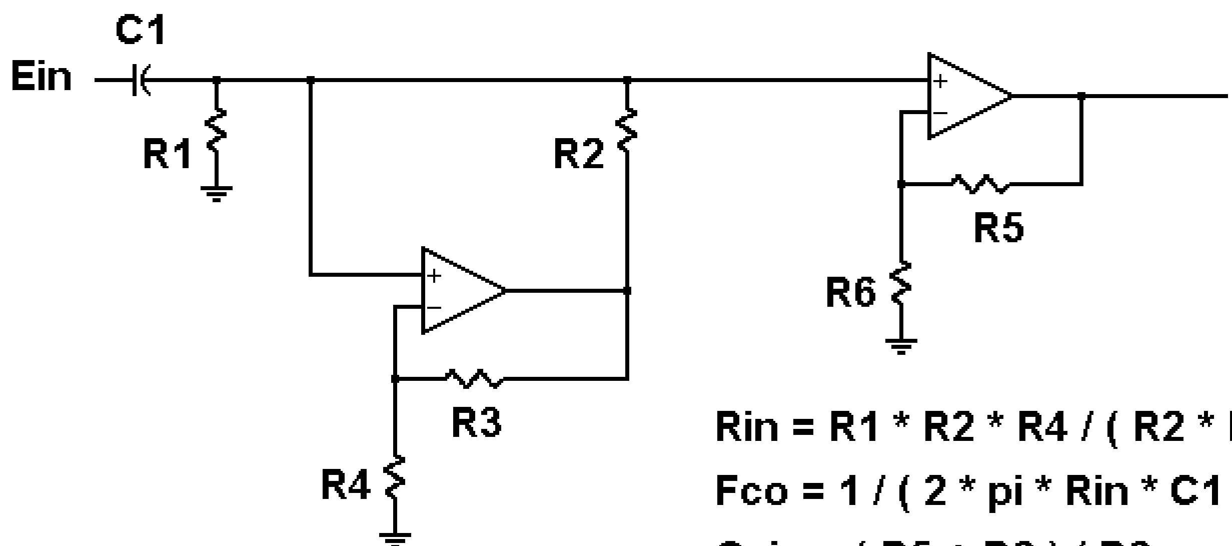
Ultra-Low Frequency AC Coupled Amplifier
Using Input Resistance Bootstrapping

Bootstrapping R1 to get an ultra-low cut-off frequency for an AC coupled input.



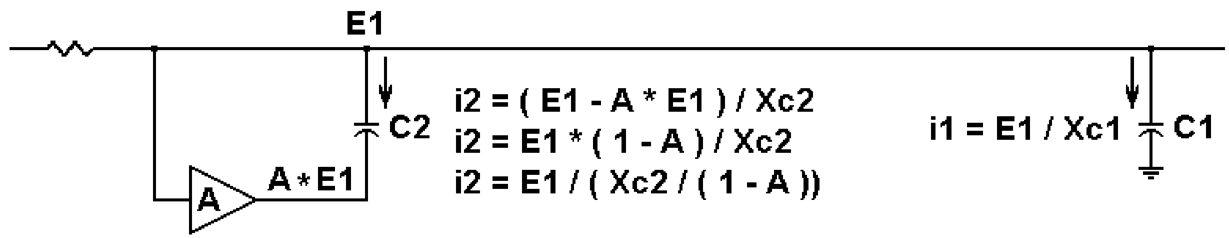
Rin = R1 * R2 * R4 / (R2 * R4 - R1 * R3)

Fco = 1 / (2 * pi * Rin * C1)

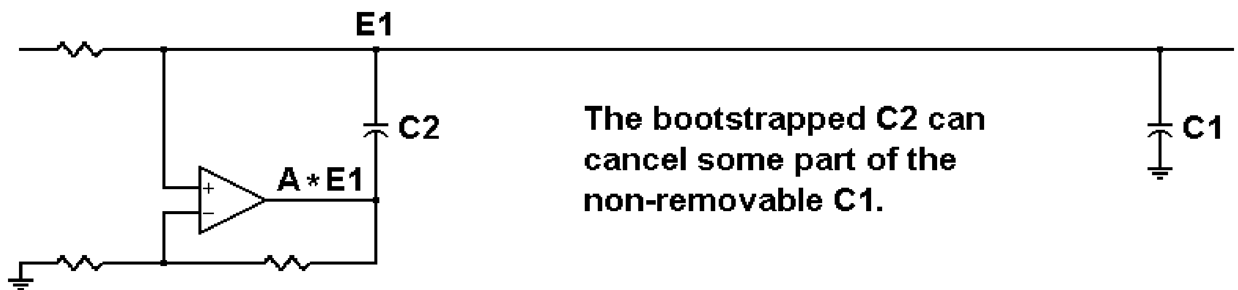
Gain = (R5 + R6) / R6

Bootstrapping of Capacitance Works Too!

Bootstrapping of C1 is analogous to resistor bootstrapping and can be used to negate part of C1 where C1 happens to be non-removable for one reason or another.



$$\text{Effective total capacitance} = C1 + \frac{C2}{(1 - A)}$$



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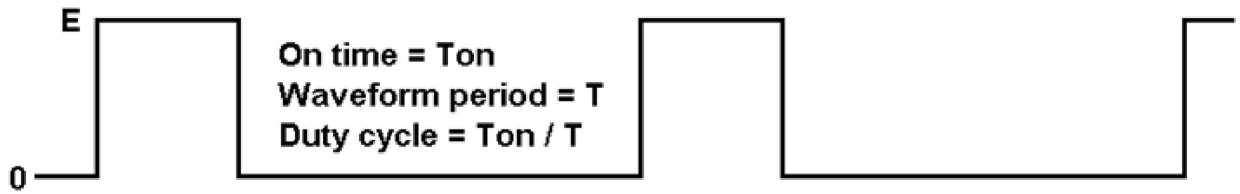
RMS Value versus Average Value



Amplitude is zero and E volts.

Average = Eav = E * Duty cycle

E = Eav / Duty cycle

Power = (E^2 / R) * Duty cycle

Power = $Erms^2$ / R

$Erms^2$ = E^2 * Duty cycle

Erms = E * Sqrt (Duty cycle)

E = Erms / Sqrt (Duty cycle)

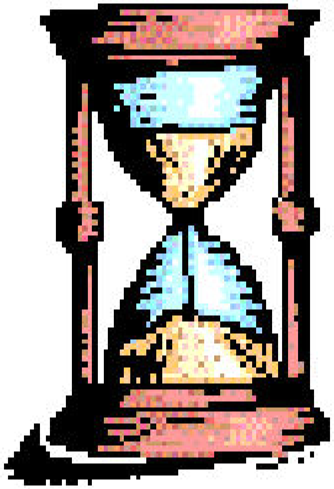
Erms = Eav * Sqrt (Duty cycle) / Duty cycle

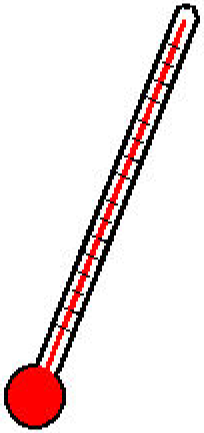
Erms = Eav / Sqrt (Duty cycle)

Resistor Aging (Don't we all.)

Svante Arrhenius (1859 - 1927)

Aging rates double for each
10 °C rise of temperature.





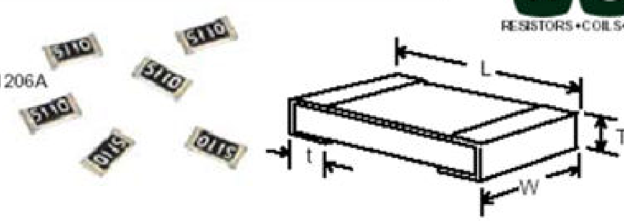
One Vendor's Resistor Aging Properties

RCD
RESISTORS•COILS•DELAY LINES

ULTRA PRECISION THIN FILM CHIP RESISTORS

BLU SERIES

Type BLU1206A



FEATURES

TYPICAL PERFORMANCE CHARACTERISTICS

Requirements	Characteristics (5-25ppm)*	Test Method
Extended Life (10,000 hrs)	± 0.25% (±0.4% Opt.B)	Rated W per Mil-PRF-55342 4.8.11.1
Shelf Life	100 ppm/year (Max.)	Room Temp. & Humidity, No-Load

At 70°C,
K70 = 0.25% per 10000 hours
= 2500 ppm / 10000 hours
= 0.25 ppm / hour

At 25°C,
K25 = 100 ppm / year
= 100 ppm / 8766 hours
= (1 / 87.66) ppm / hour
= 0.011407711... ppm / hour

The aging rate is multiplied by "alfa" for each 10°C increase above 25°C.

$$\therefore \frac{K70}{K25} = \text{alfa}^{\left(\frac{(70°C - 25°C)}{10°C}\right)} \Longrightarrow \text{alfa} = \left(\frac{K70}{K25}\right)^{\left(\frac{10°C}{(70°C - 25°C)}\right)} \Longrightarrow \text{alfa} = (0.25 * 87.66)^{(1/4.5)}$$

alfa = 1.985832207...

At 45°C, we find $K45 = K25 * 1.985832207...^2$ = 0.011407711... * 3.943529554... = 0.044986645... ppm / hour

∴ Aging drift = 0.044986645... ppm / hour * 8766 hours / year * 7 years = 2760.47... ppm –> <u>0.276 %</u>

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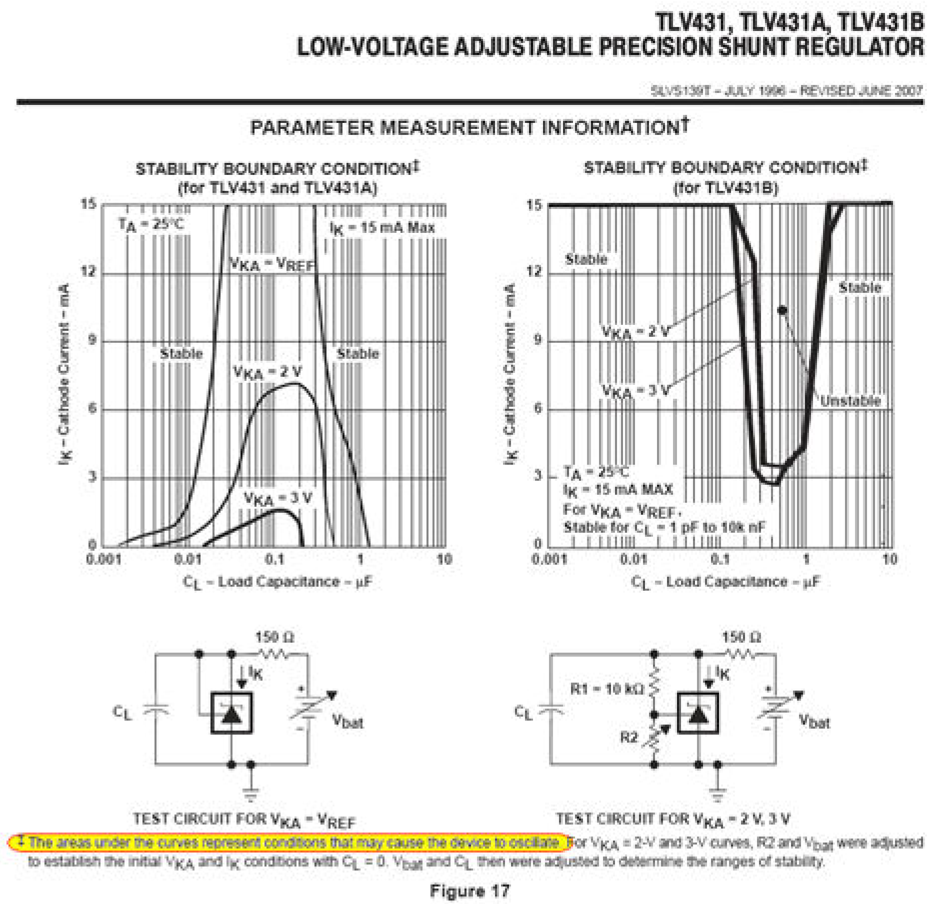
TLV431 Oscillatory Instability Issues



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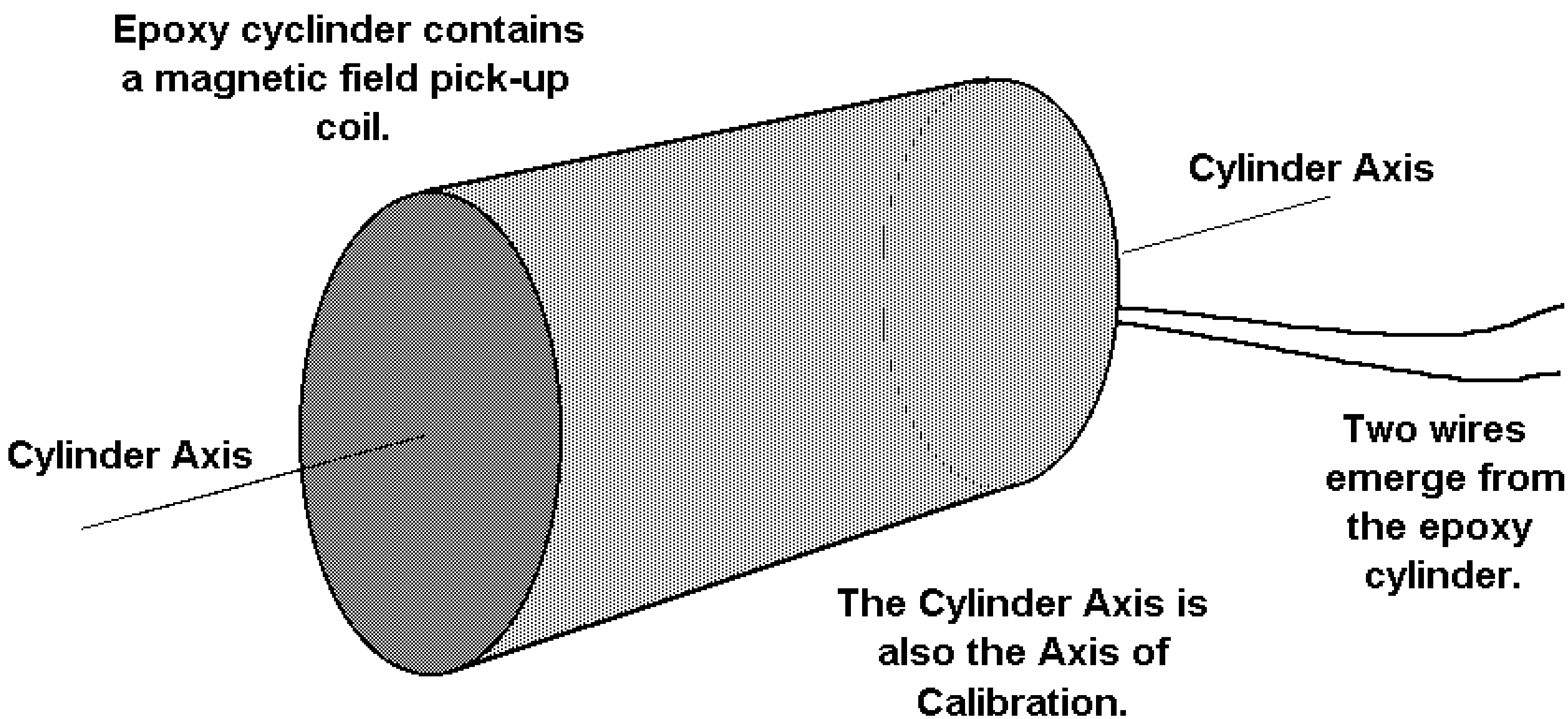
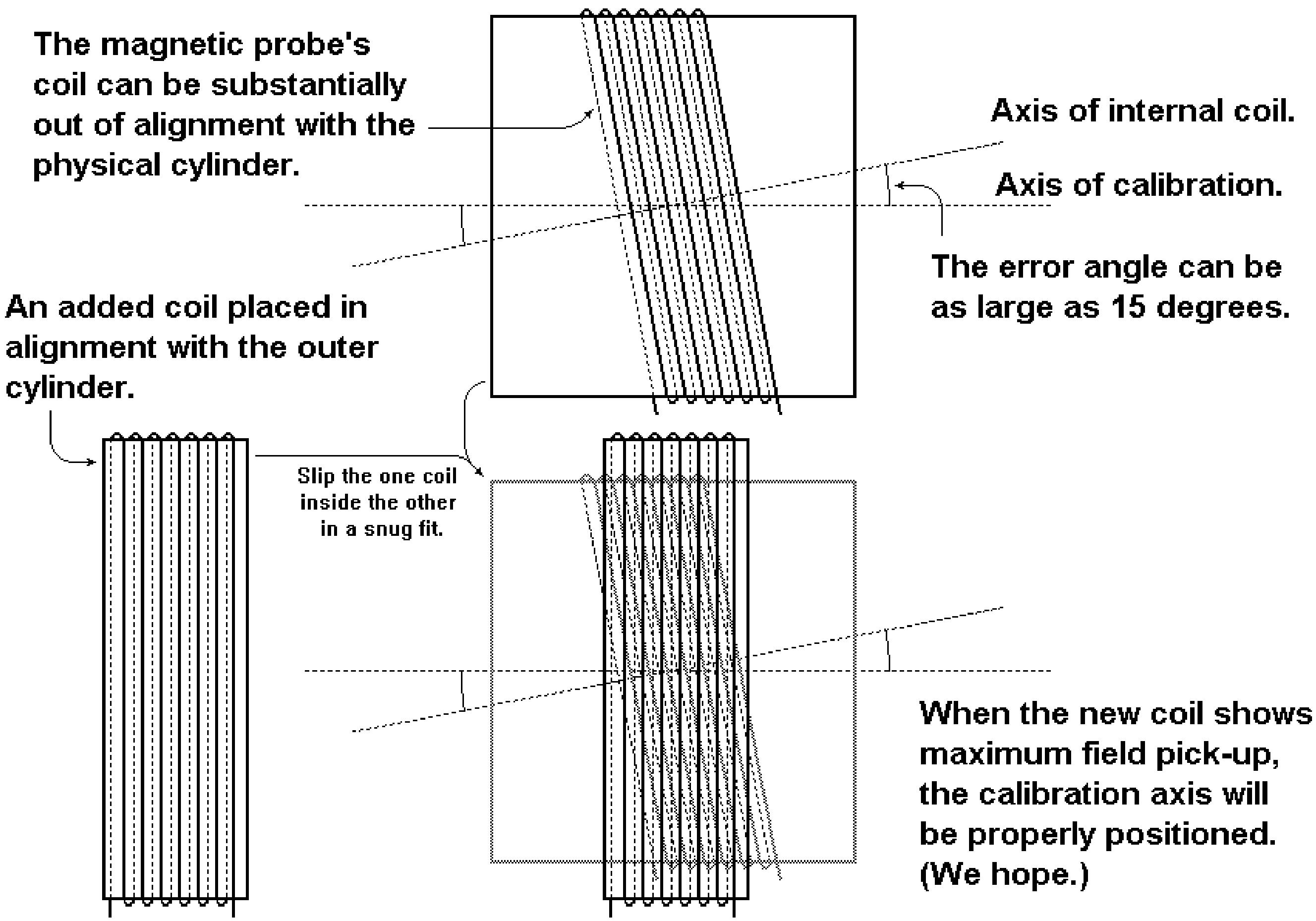
Magnetic Field Pick-up Coil, A Commercial Product



Magnetic Field Coil Alignment Error



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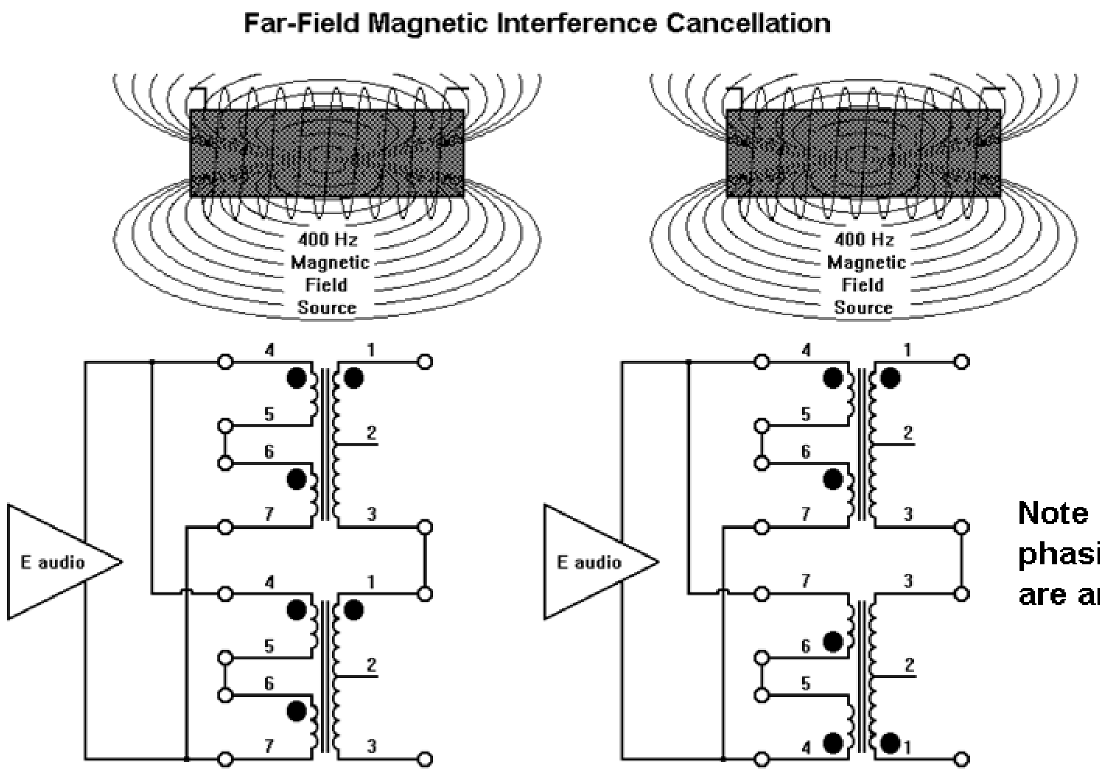
Dual Audio Transformers Give Far-Field Magnetic Interference Suppression



Note how the phasing dots are arranged.

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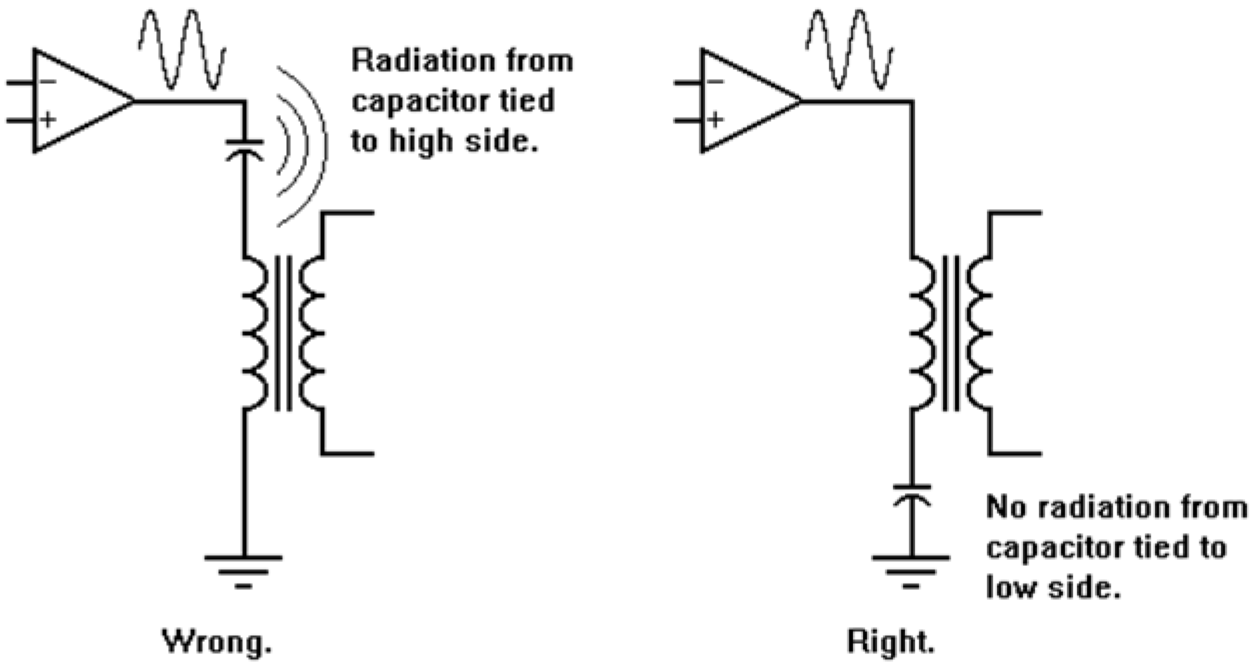
Transformers, DC Blocks and Signal Isolation



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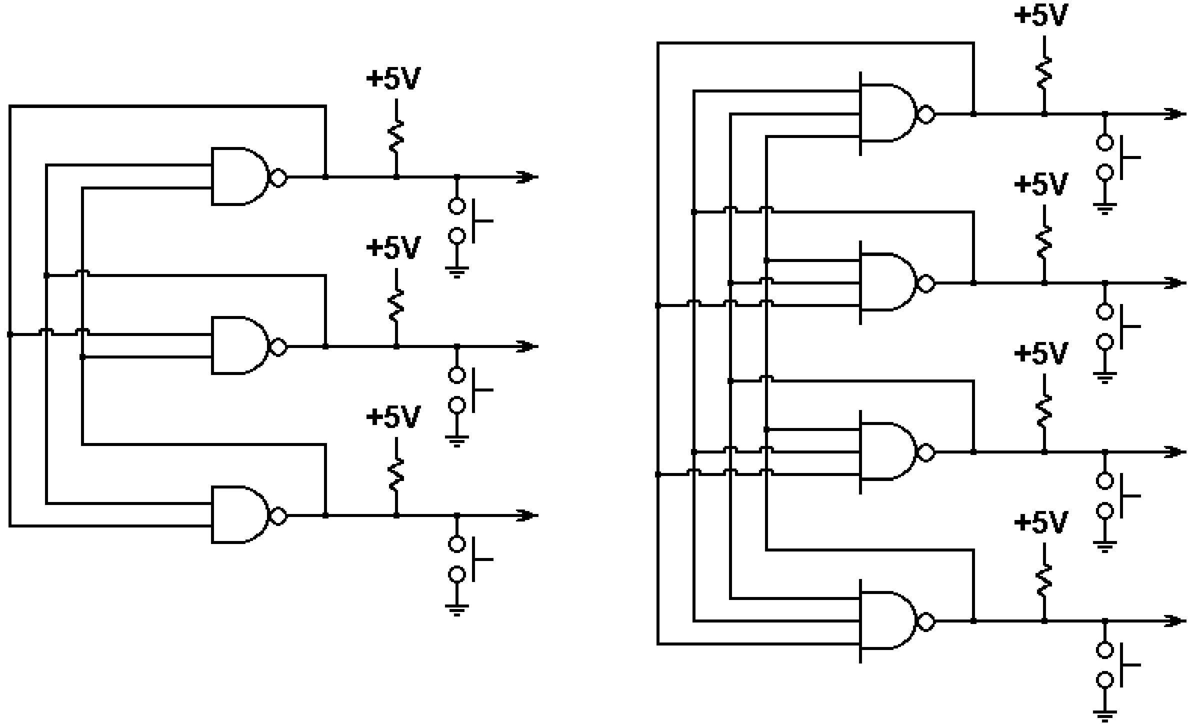
Polystable Memory Elements



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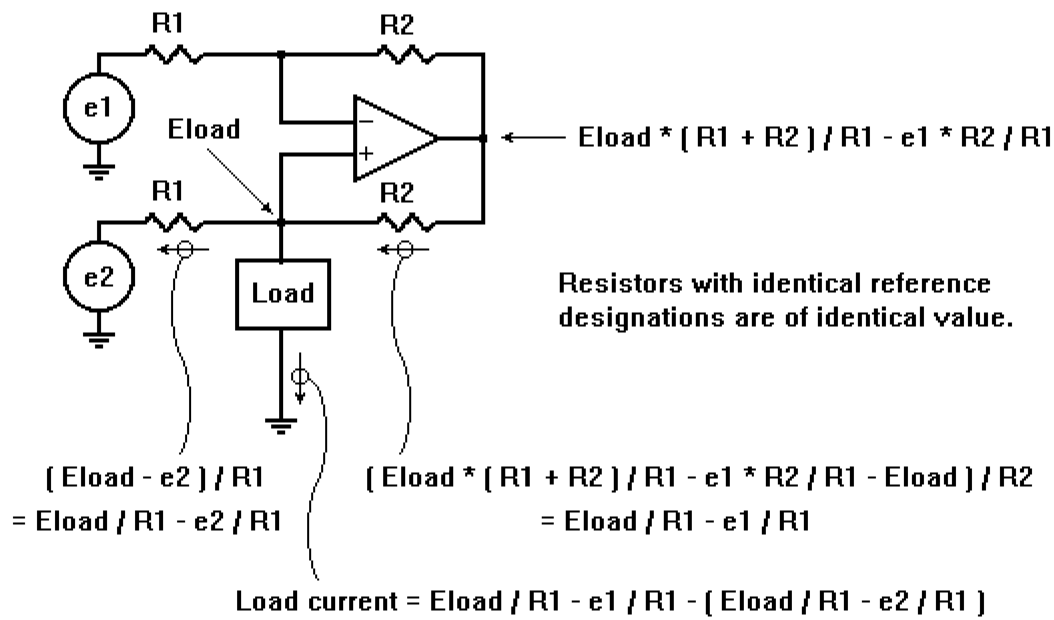
Howland Current Pump



Load current = e2 / R1 - e1 / R1

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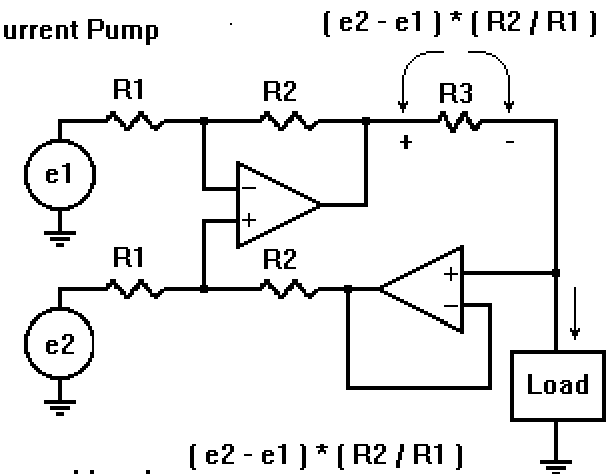
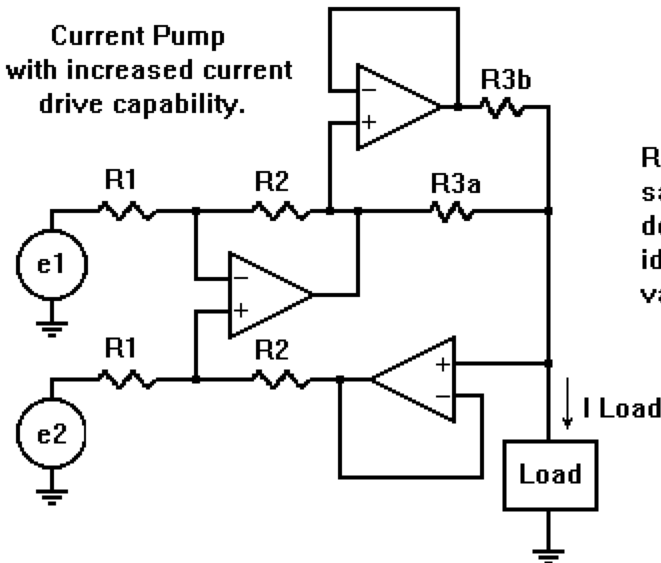
Two More Current Pumps

Current Pump



$$I\ Load = \frac{(e2 - e1) * (R2 / R1)}{R3}$$

Current Pump
with increased current
drive capability.



Resistors with the same reference designators are of identical resistance values.

$$I\ Load = (e2 - e1) * (R2 / R1) * (1 / R3a + 1 / R3b)$$

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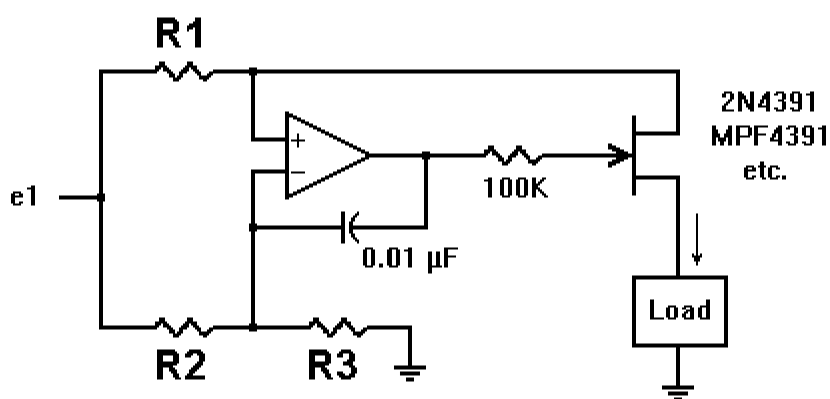
JFET Current Pump



This circuit behaves as a current pump because the JFET doesn't carry any appreciable gate current.

$$I\ Load = e1 * \frac{R2 / (R2 + R3)}{R1}$$

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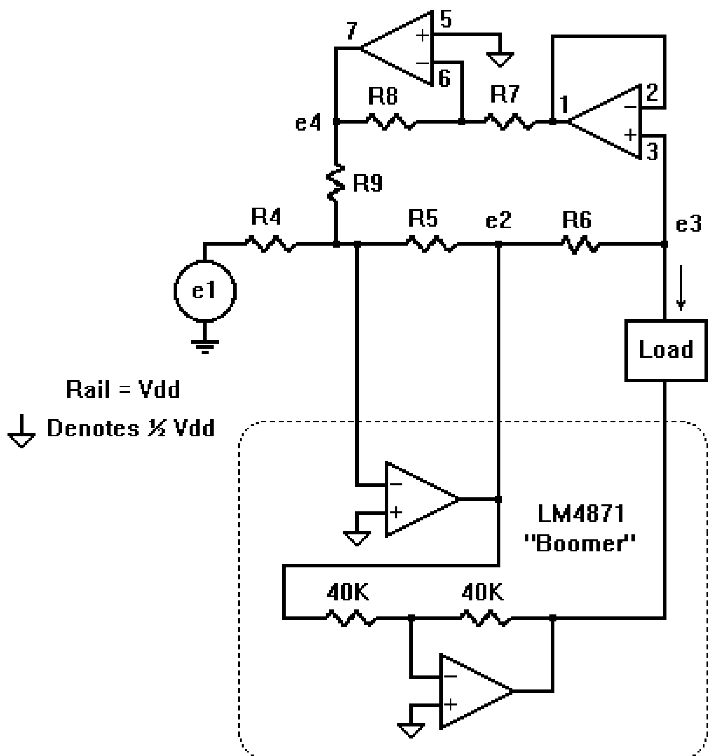
"Boomer" Amplifier Current Pump



e2 = - (R5 / R4) e1 - (R5 / R9) e4

e4 = - (R8 / R7) e3

e2 = - (R5 / R4) e1 + (R5 / R9) (R8 / R7) e3

(R5 / R4) e1 = (R5 / R9) (R8 / R7) e3 - e2

Let: (R5 / R9) (R8 / R7) = 1

For convenience, let R7 = R5, R8 = R5 AND R9 = R5

Then (e3 - e2) = (R5 / R4) e1

I load = (e2 - e3) / R6 = - (e3 - e2) / R6

I load = - e1 (R5 / R4) / R6

If we make R5 = R7 = R8 = R9 = 10K,
those four resistors can be in a SIP.

We then scale the current drive using R4 and R6.

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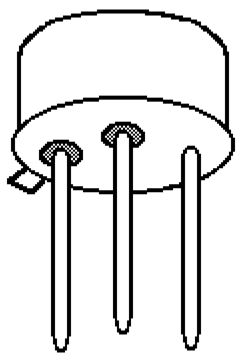
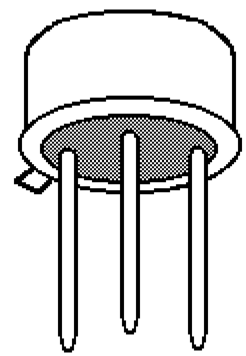
A Booby Trap with TO-5 and TO-39 Cans

These transistors can come either way!!



2N2905 with a metal can and glass beads on the base and the emitter.



2N2905 with a glass seal for all three leads.

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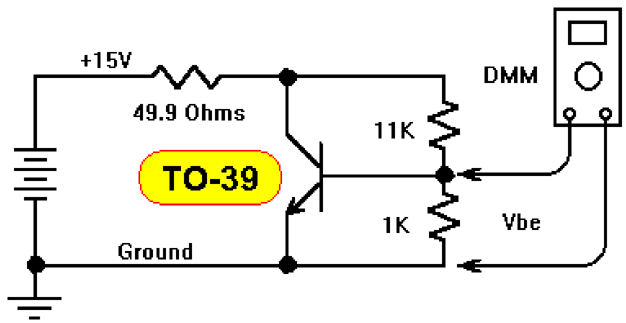
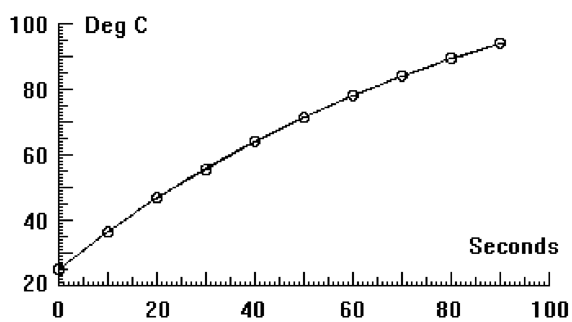
Thermal Rise Time of TO-39 Cans
Tau ~ 90 Seconds



0 Sec	Vbe =	729 mV	25.0	deg C
10 Sec	Vbe =	704 mV	36.4	deg C
20 Sec	Vbe =	681 mV	46.8	deg C
30 Sec	Vbe =	662 mV	55.5	deg C
40 Sec	Vbe =	643 mV	64.1	deg C
50 Sec	Vbe =	627 mV	71.4	deg C
60 Sec	Vbe =	612 mV	78.2	deg C
70 Sec	Vbe =	599 mV	84.1	deg C
80 Sec	Vbe =	587 mV	89.5	deg C
90 Sec	Vbe =	577 mV	94.1	deg C



The data points for temperature versus time are approximated by:

$$\text{Deg C} = 134.2 - 109.2 * e^{-t / 90.1}$$

where Deg C is temperature in degrees C and t is elapsed time in seconds.

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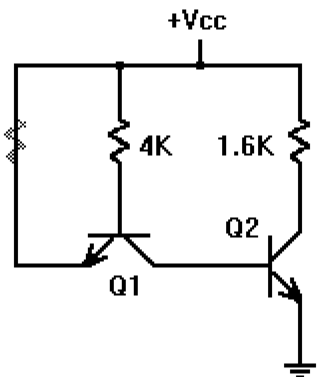
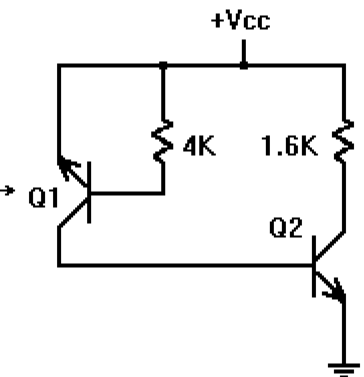
TTL Pull-ups

Here's the resistor
that we'll consider
not using.



To aid in visualization,
let's rotate the picture
of Q1 clockwise by 90°.



Next, consider that Q1, being an NPN device, has N material at its collector and N material at its emitter. The upshot of that is that the section we choose to call the collector is just as capable of being an emitter and the other section we choose to call the emitter is just as capable of serving as a collector.

With the functions of collector and emitter exchanged, Q1 becomes operative in its inverse mode, complete with a substantial gain term, ß, all its very own. The base current through the 4K gets multiplied by that ß value and flows down from the +Vcc rail to the base of Q2 with nothing in particular to limit it. This can get into a runaway mode and blow the device.

This is why TTL inputs shouldn't go directly to the +Vcc rail except for those particular parts where the vendor has specifically permitted this in the device data sheet. For garden variety forms of TTL, no.

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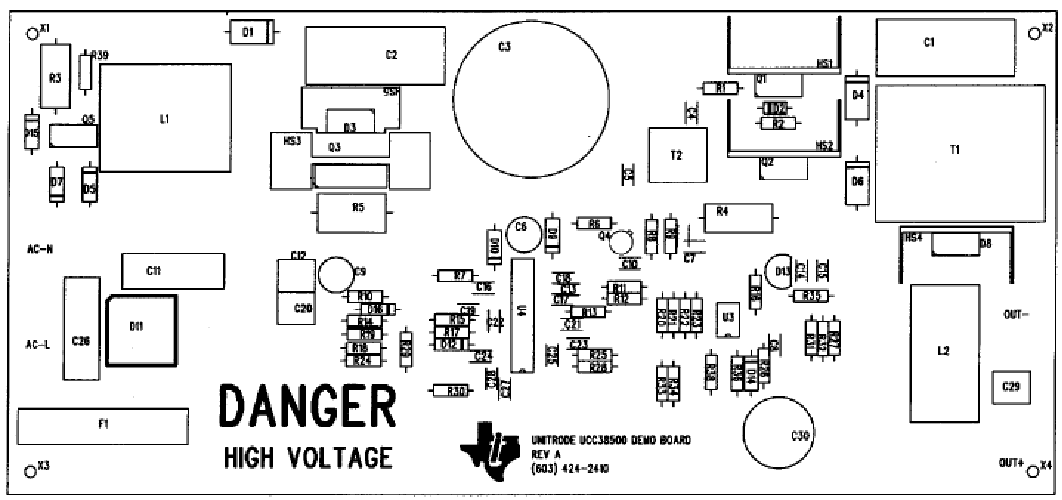
Power Factor Correction Prototyping Board
Texas Instruments number DM38500EVM

2.2 DM38500 Board Layout

Board layout example of the DM38500 EVM PCB is shown in the following illustration. It is not to scale and appear here only as a reference.

Figure 2–1. DM38500 EVM PC Board: Top Assembly



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Notes:

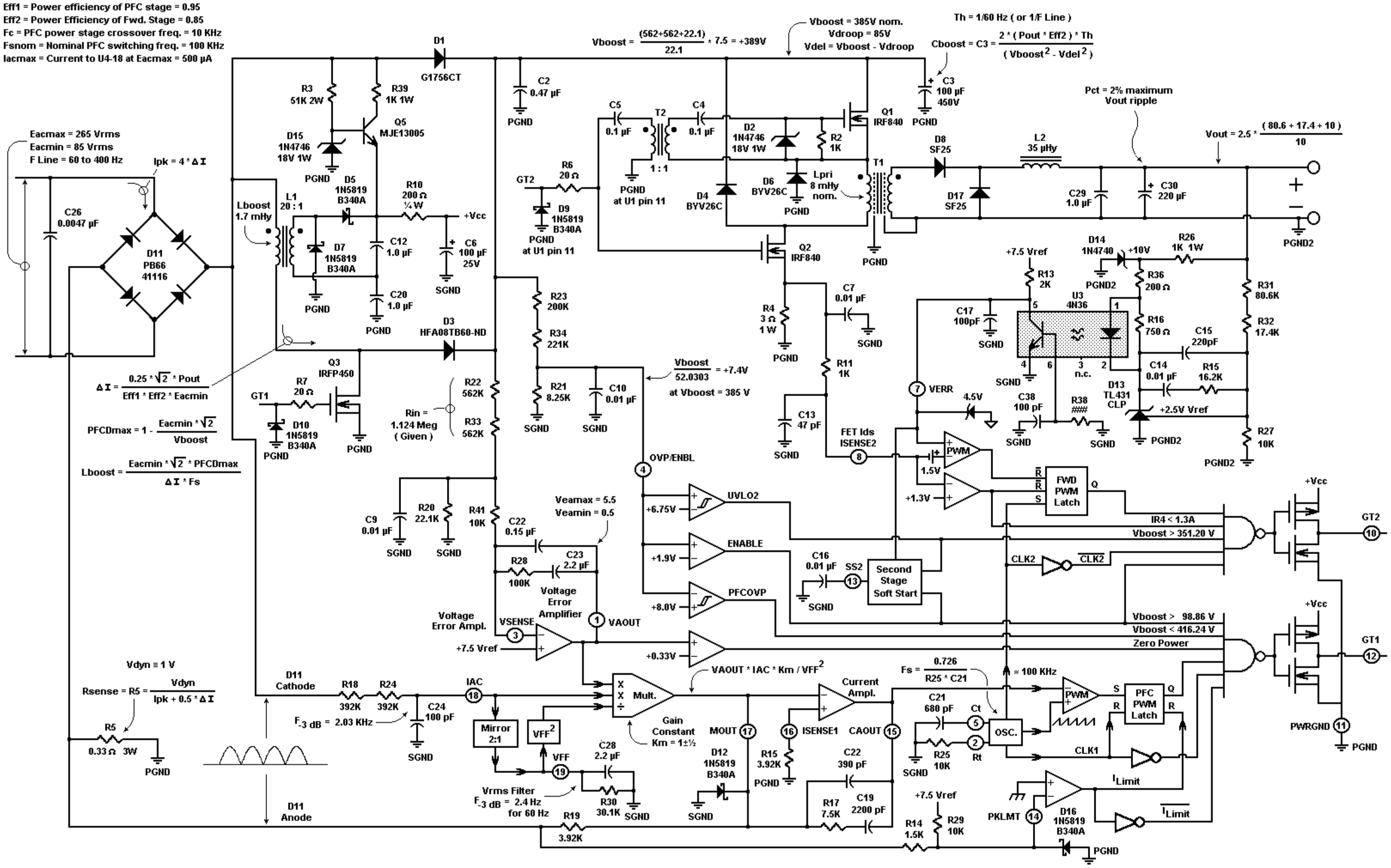
Eff1 = Power efficiency of PFC stage = 0.95

Eff2 = Power Efficiency of Fwd. Stage = 0.85

Fc = PFC power stage crossover freq. = 10 KHz

Fsnom = Nominal PFC switching freq. = 100 KHz

Iacmax = Current to U4-18 at Eacmax = 500 µA



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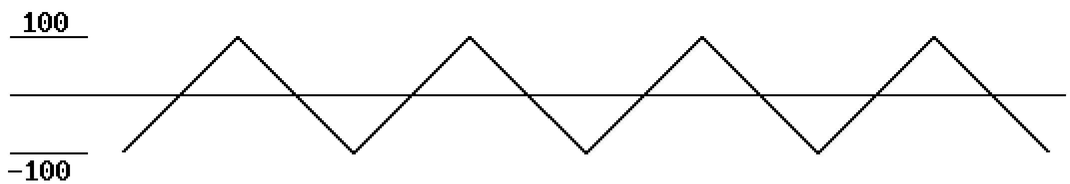
Maximum RMS Value of a Random Waveform

RMS of Random Wave = RMS of Triangle Wave

Number of samples	RMS
5000	57.27
10000	57.50
15000	57.68
20000	58.01
25000	57.57
30000	57.88
35000	57.54
40000	58.05
45000	57.74
50000	57.41

$$\frac{100}{\text{Sqrt}(3)} = 57.735......$$



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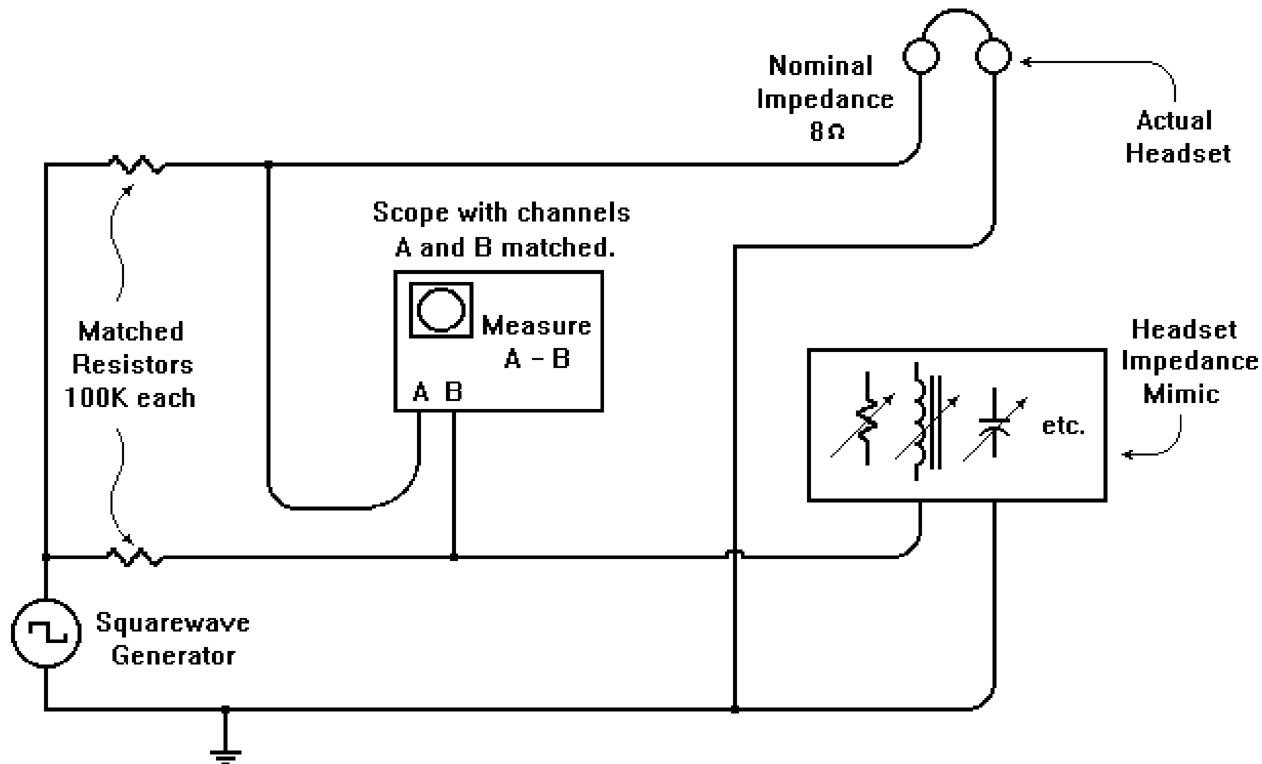
Using Mimicry to Find the True Equivalent Circuit of A Headset



The topology and the component values of the Headset Impedance Mimic are experimentally chosen so that the differential measurement of A - B goes to zero.

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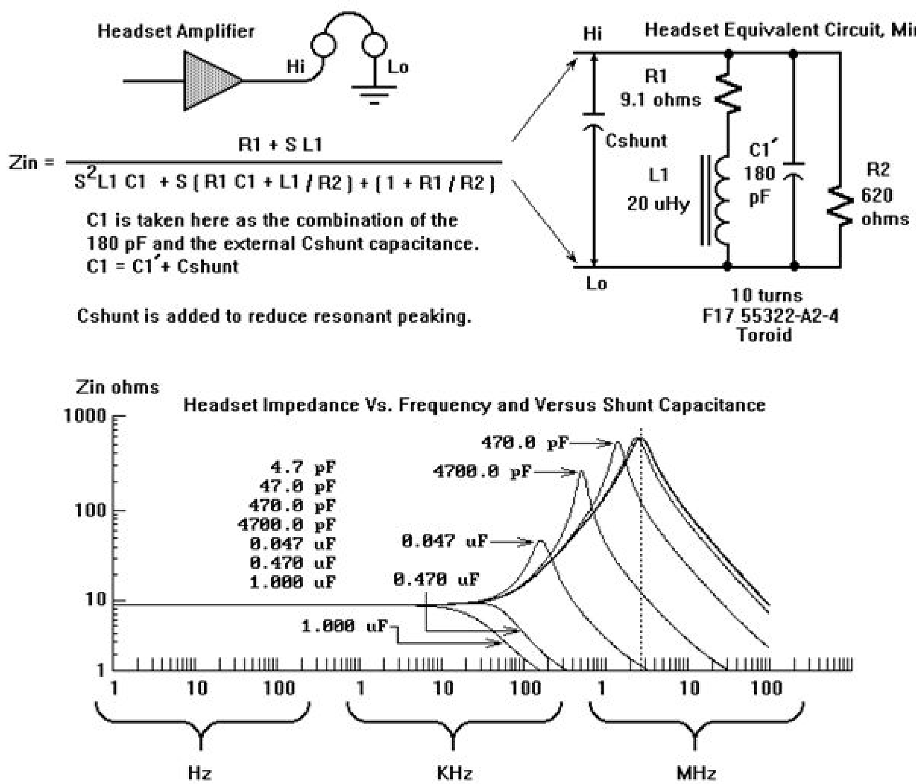
Headset Model Shows Resonant Peaking and A Suppression Method



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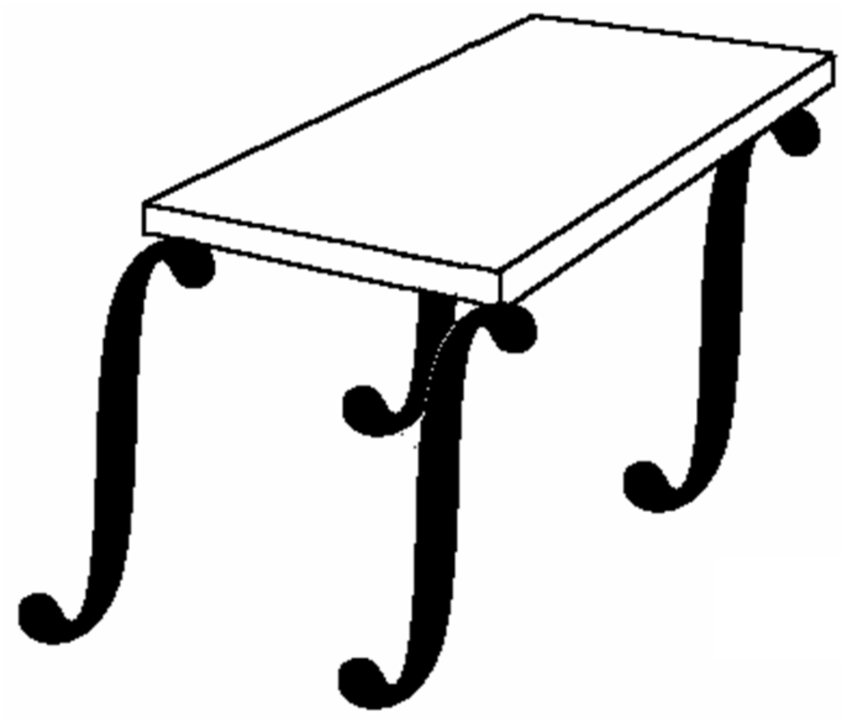
An Integral Table



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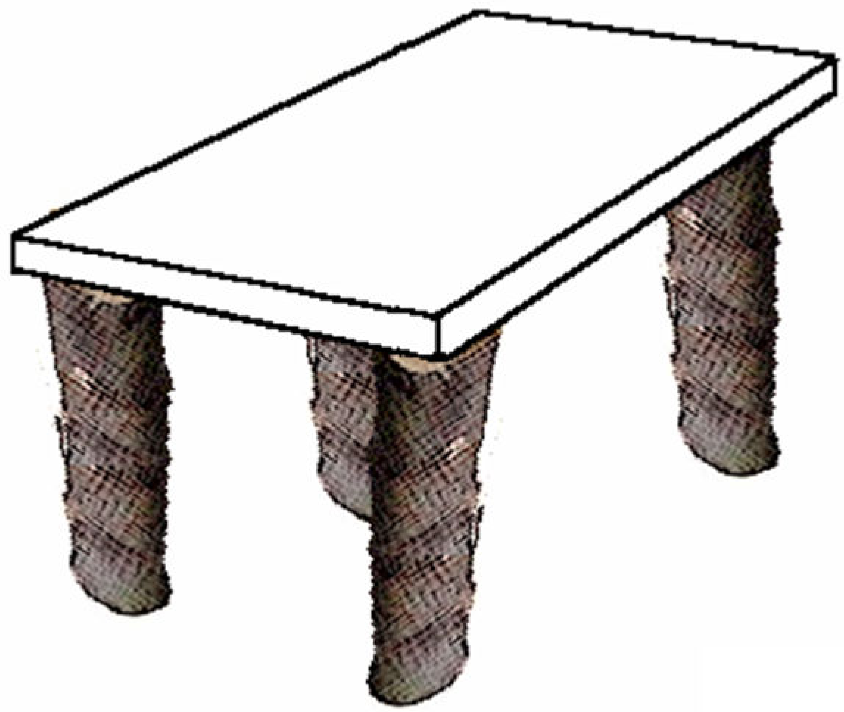
A Log Table



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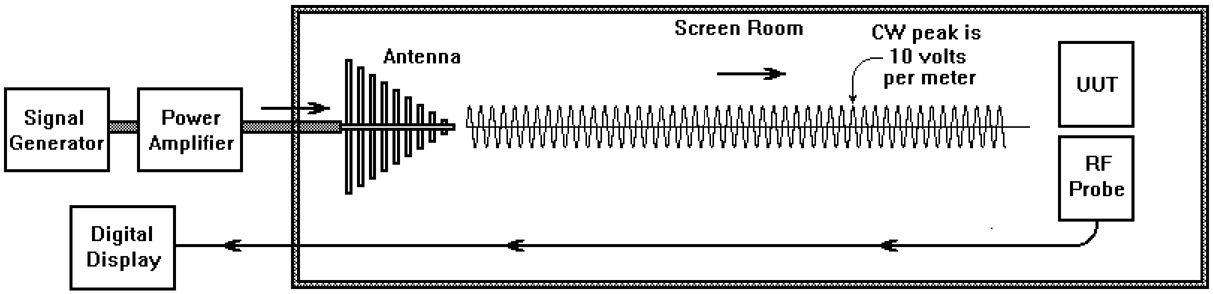
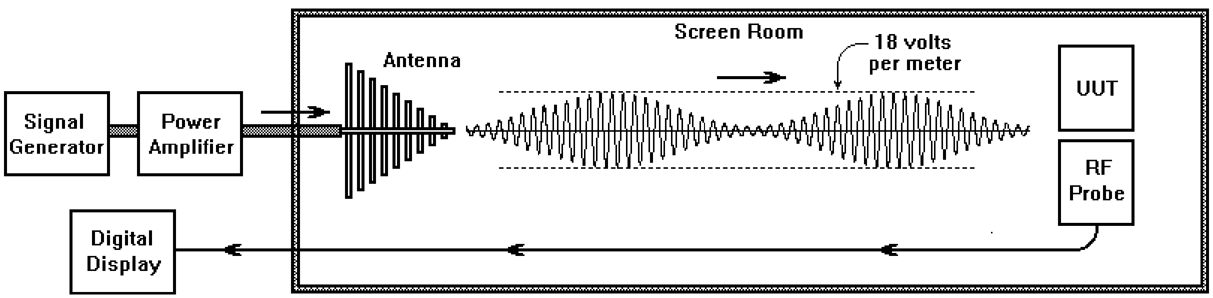
Radiated Susceptibility EMI Test

Preparatory level setting in CW mode:



In CW, the peak field is set for a Digital Display readout of 10 volts per meter.

Test level for 80% AM modulation:



In 80% AM, the peak field must go to 18 volts per meter. That value is supposed to be shown on the Digital Display readout.

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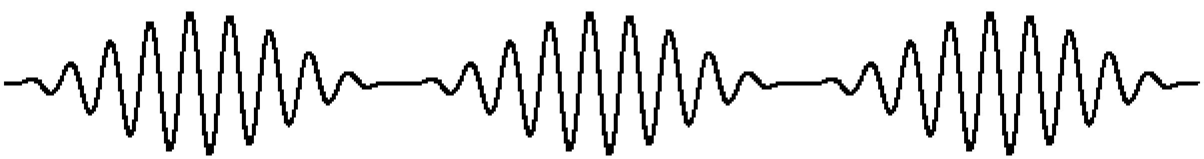
Radiated Susceptibility EMI Test

For an AM signal of E = Epk * Sin (Wc * t) * (1 + Km * Sin (Wm * t))

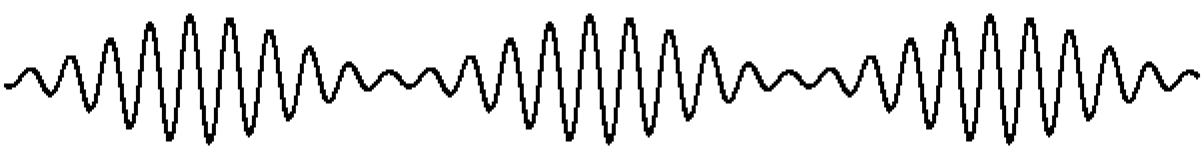
Erms = 0.5 * Epk * Sqrt (2 + Km²)

$$E_{rms} = 0.5 \cdot E_{pk} \cdot \sqrt{2 + K_m^2}$$

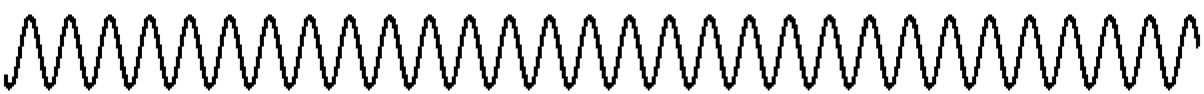
Amplitude Modulation of 10V peak Carrier



$$V_{rms} = V_{pk} \cdot .5 \cdot \sqrt{3}$$
$$V_{rms} = 8.660$$



$$V_{rms} = V_{pk} \cdot .5 \cdot \sqrt{2.64}$$
$$V_{rms} = 8.124$$



$$V_{rms} = V_{pk} \cdot .5 \cdot \sqrt{2}$$
$$V_{rms} = 7.071$$

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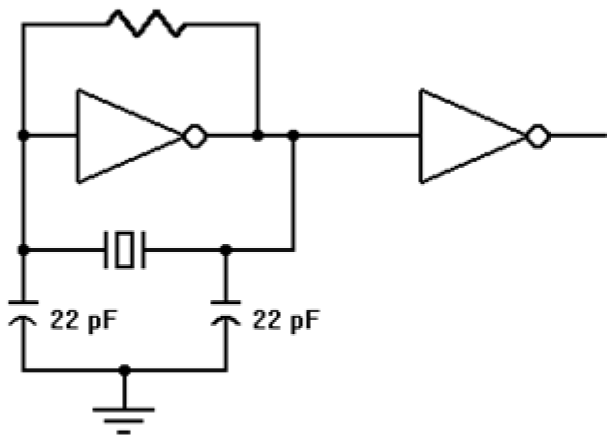
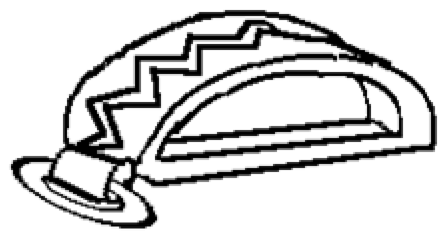
Basic Logic Gate Crystal Oscillator





Crystal's application in uP/uC or gate array clock oscillator.

The Requirement!

MIL-C-3098G
3.13 Unwanted modes.

3.13.1 Method I (excluding overtone units). When tested as specified in 4.9.9.1, unless otherwise specified (see 3.1), there shall be no unwanted modes of oscillation. .....

4.9.9.1

b. .... Adjust the output frequency of the test set to a frequency 20 percent lower than the specified frequency, and then to a frequency 20 percent higher than the specified frequency. ....

20% of 16 MHz comes to 3.2 MHz

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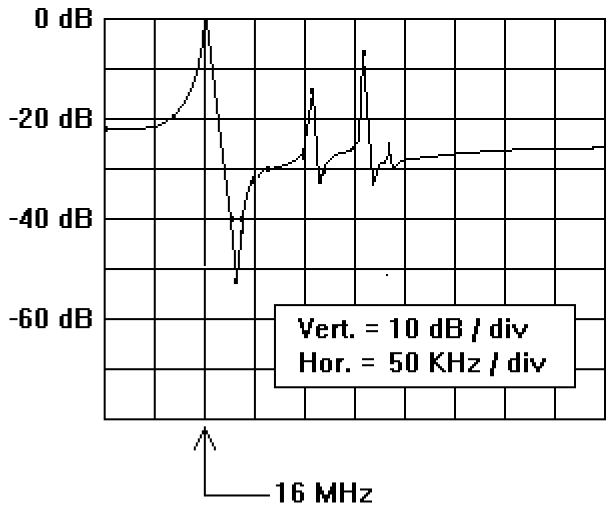
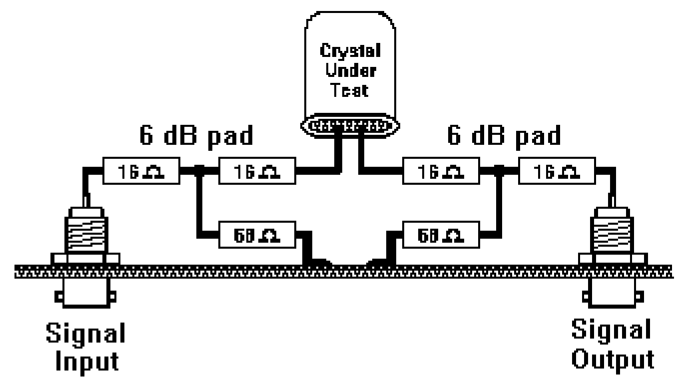
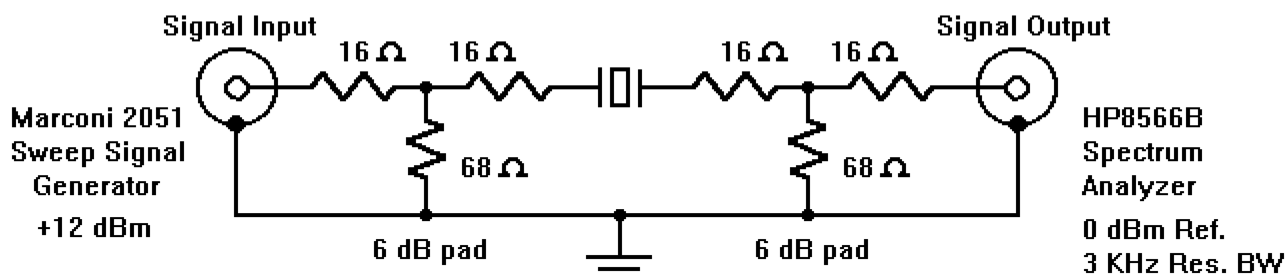
Bad Crystals in Violation of MIL-C-3098







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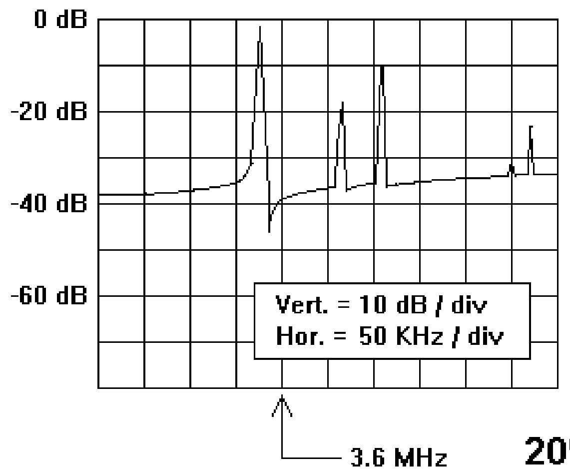
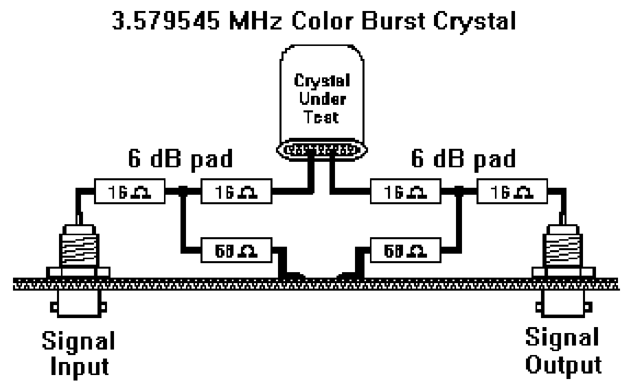
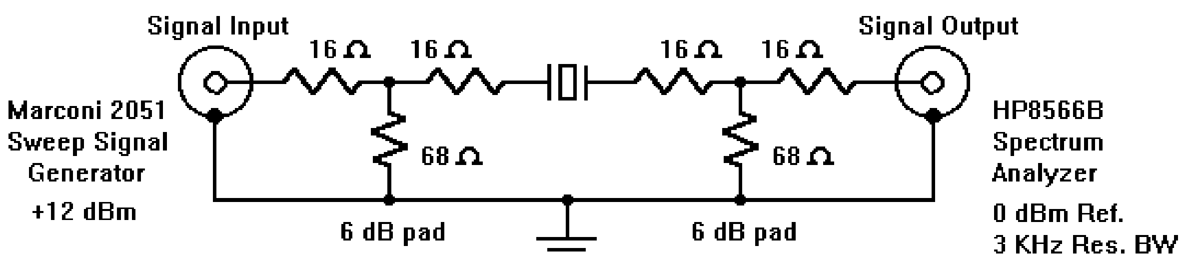
Some More Bad Crystals

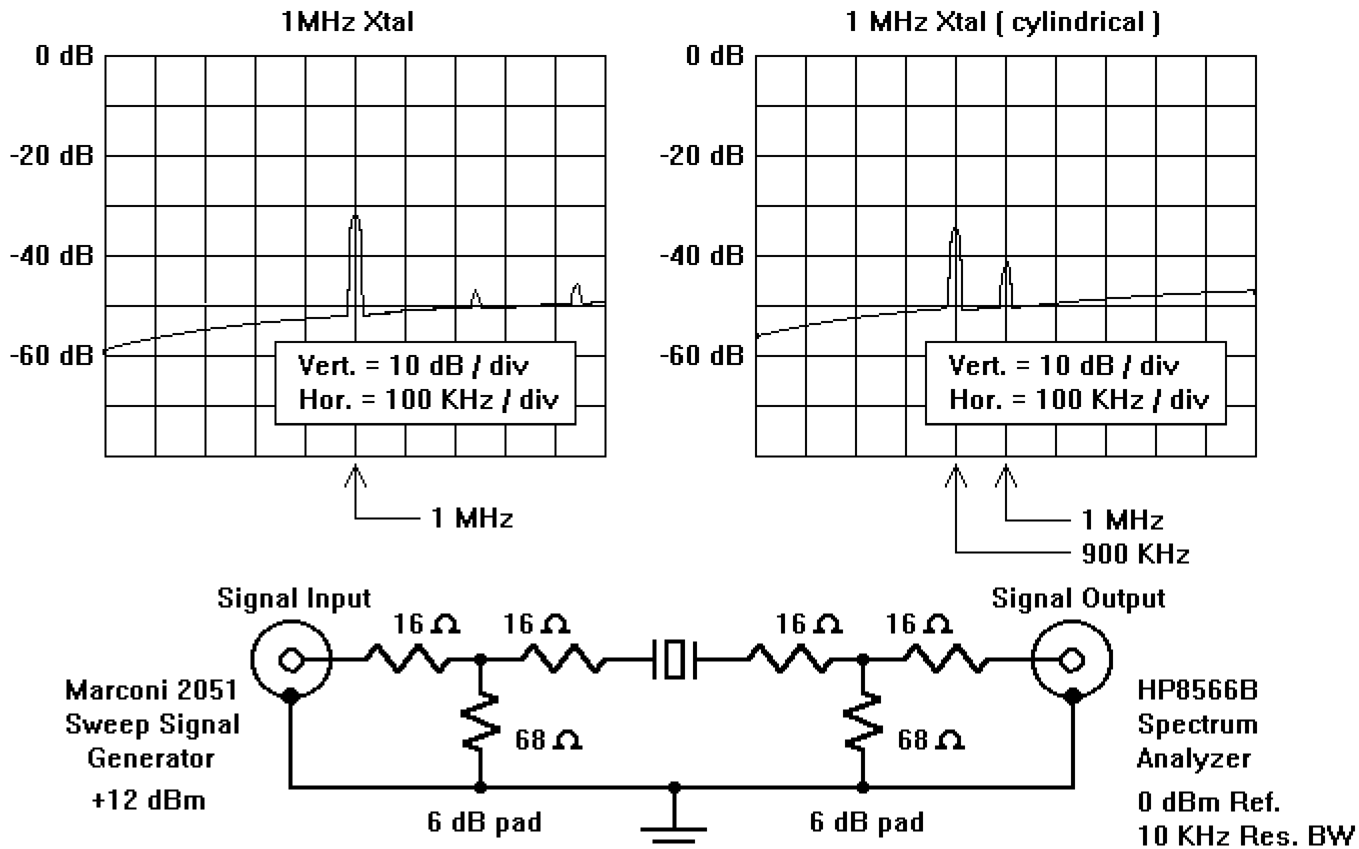




20% of 3.579545 MHz comes to 716 kHz



Still More Bad Crystals!!



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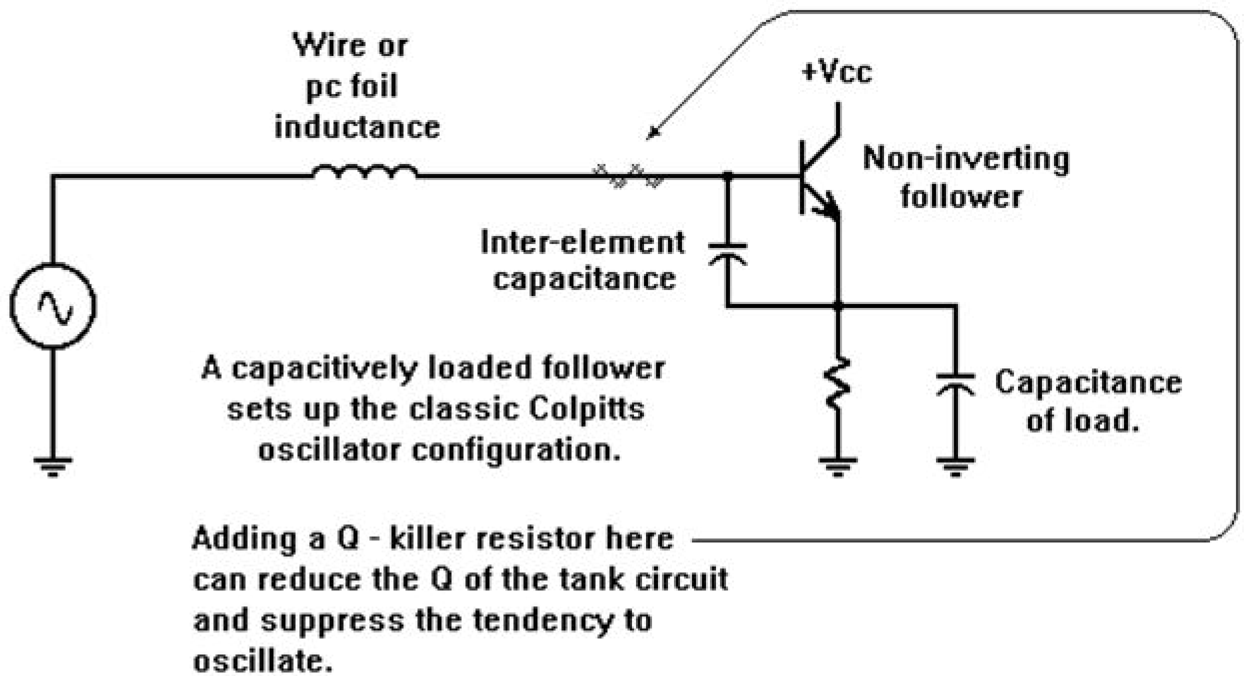
An Emitter Follower Driving A Capacitive Load Is Only One Step Away From Being a Colpitts Oscillator



Paralleled Rail Voltage Bypass Capacitors

Major boobytrap!!!

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A Typical Circuit Board

Permittivity = Dielectric constant

ϵ_0 = Dielectric constant of free space.
= 8.854 E-12 farads per meter
= 2.249 E-13 farads per inch
= 0.2249 pF per inch

ϵ_r = Relative dielectric constant of a material

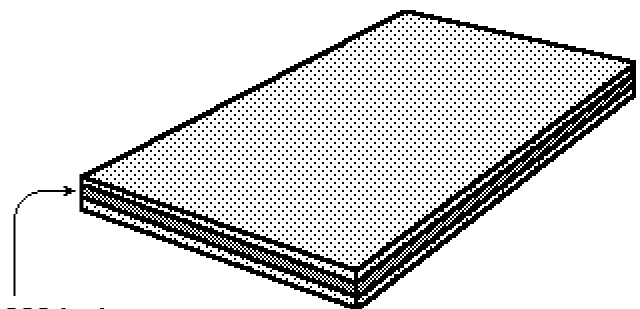
ϵ = Actual dielectric constant of a material
= $\epsilon_0 * \epsilon_r$

For G10 material, ϵ_r = 4.7

Dielectric layer thickness may typically be 3 mils = 0.003 inch.

For one square inch of 0.003 inch dielectric between two conductors, the capacitance per square inch is:

$$C = \frac{4.7 * 0.2249 * 1}{0.003} = 352.3 \text{ pF per square inch}$$



Let us assume a section of circuit board between a +5Vcc and ground with a foil to foil capacitance of 50 pF in parallel with bypass capacitors. (Approximately 0.14 sq. in.)

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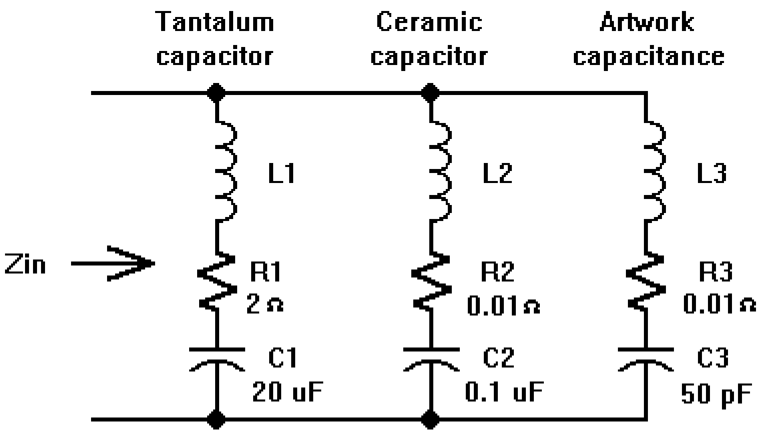
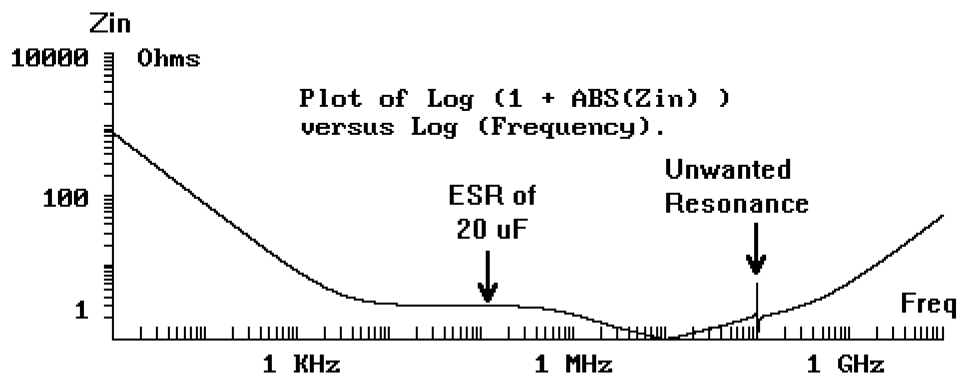
A Look At Rail Bypass Impedance Vs. Frequency

The parallel combination ot two bypass capacitors and the circuit board capacitance is modeled as shown for which the impedance versus frequency is calculated and plotted. Note the unwanted resonance at approximately 100 MHz.

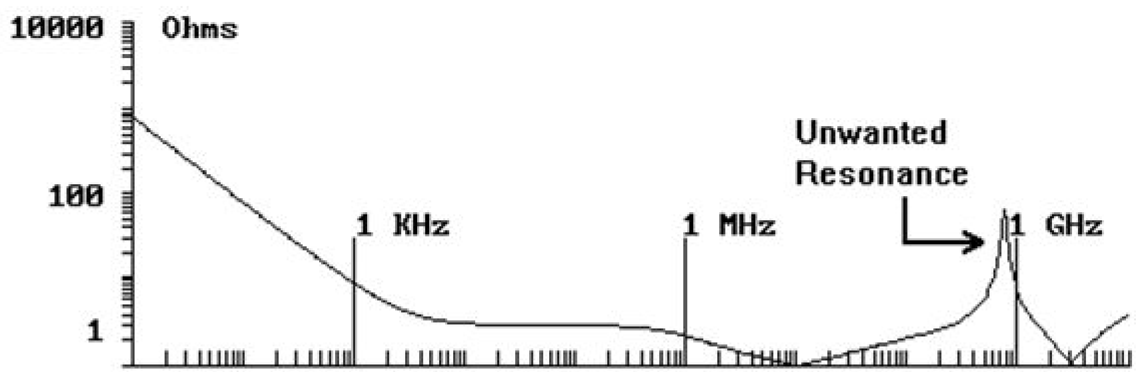


Cap.	20.00 uF	0.100 uF	50.0 pF
SRF	1.00 MHz	10.00 MHz	100.0 MHz
ESR	2.00 ohms	0.01 ohms	0.01 ohms



"Improved" Board Layout's Capacitance

Cap.	20.00 uF	0.100 uF	50.0 pF
SRF	1.00 MHz	10.00 MHz	3000.0 MHz
ESR	2.00 ohms	0.01 ohms	0.01 ohms



Whenever you have a set of paralleled bypass capacitors, each with its own self resonant frequency (SRF), whichever of those capacitors has the <u>highest</u> self resonant frequency will yield a

parallel resonant impedance peak

at some intermediate frequency where that highest SRF capacitor interacts with the residual inductance of that whole group of other capacitors.

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Silicone Rubber for High Voltage Applications

by R.L. Daileader, W.H. Filbert and J.W. Hawkins
General Electric Silicone Products Department

Publication CDS-2081

(This application note dates from 1958)

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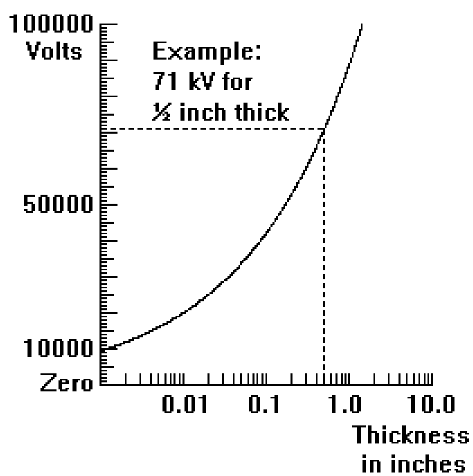
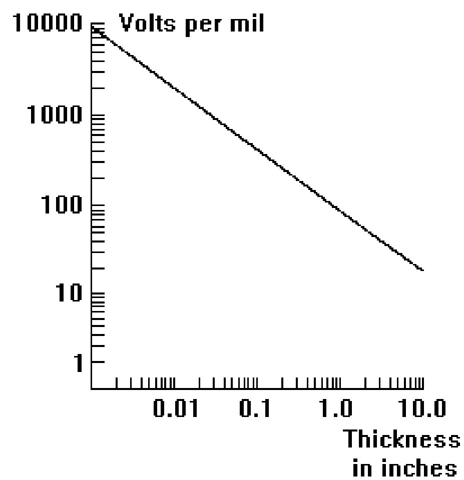
Silicone Rubber High Voltage Support

Estimate of Voltage Support Capability of General Electric RTV11 Silicone Rubber





$$\text{Volts} = 88626.71 * T^{0.324}$$

where T is in inches.

The "volts per mil" support capability declines as the RTV thickness increases.

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The identity of this supplier has been deliberately blocked.

2-Part Potting/Encapsulating Compound RTV11

Primary Characteristics

- White Flowable
- Condensation cure
- Primer required
- General purpose potting
- Room temp. cure
- Requires parts A and B

Use for :

- Medical molds/ instruments
- High voltage power supply potting
- General purpose electrical potting

A white, two component, low viscosity potting compound that cures at room temperature to a soft pliable rubber. Will cure in deep sections. The excellent electrical properties make it a candidate material for both high and low voltage electrical assemblies. Cushions against mechanical shock and vibration. The product comes complete with catalyst DBT. Specialized catalysts are avialable upon request.

Available Sizes

Catalog Number	Sizes Available	Description
RTV11-1P	1 pint	case of 12
RTV11-1G	1 gallon	12.1 lbs kit
RTV11 requires a primer. Visit our primer guide for details.		

Specifications

Use	General Purpose Potting
Special Feature	Cushions against mechanical shock
Standards	FDA
NSN	8030-01-104-5392
Cross Reference	RTV11
Uncured Properties	
Consistency	Flowable
Color	White
Specific Gravity	1.19
Pot Life (@ 25°C / 77°F)	1.5 hours
Cure Through Time	24 hours
Useful Temp. Range	-60°C to 204°C (-75°F to 400°F)
Cured Properties - MECHANICAL	
Hardness	41 (Shore A)
Tensile Strength	2.06 MPa (300 psi)
Elongation	160%
Tear Strength	3.5 Kg/cm (20 lb/in)
Cured Properties - ELECTRICAL	
Volume Resistivity	1×10^{13} ohm · cm
Dielectric Strength	515 V/mil
Dielectric Constant	3.3 @ 1000 Hz
Cured Properties - THERMAL	
Thermal Conductivity	0.29 W/m · °K
Brittle Point	-60°C (-75°F)
Thermal Expansion	25×10^{-5} (°C)$^{-1}$
Other	
Viscosity (@ 25°C)	11,000 cps
Mix Ratio (by weight)	100:0.5

Warning!! Beware of this rating. It is extremely misleading. The dielectric strength of any RTV is not a constant versus thickness, but actually degrades as thickness increases.

The function for this has been shown as:

Volts = 88626.71 x Thickness in inches ^ 0.324

515 volts per mil equals 515000 / 25.4 volts per mm equals 20.3 kV per mm

mm	Inch	kV	kV/mm		
1.9	0.074803	38.25733	20.13544	kV = 88.62671* Inches ^ 0.324	General Electric (Per Application Note of 1958)
1.9	0.074803	38.57	20.3	By data sheet specification.	The other company.

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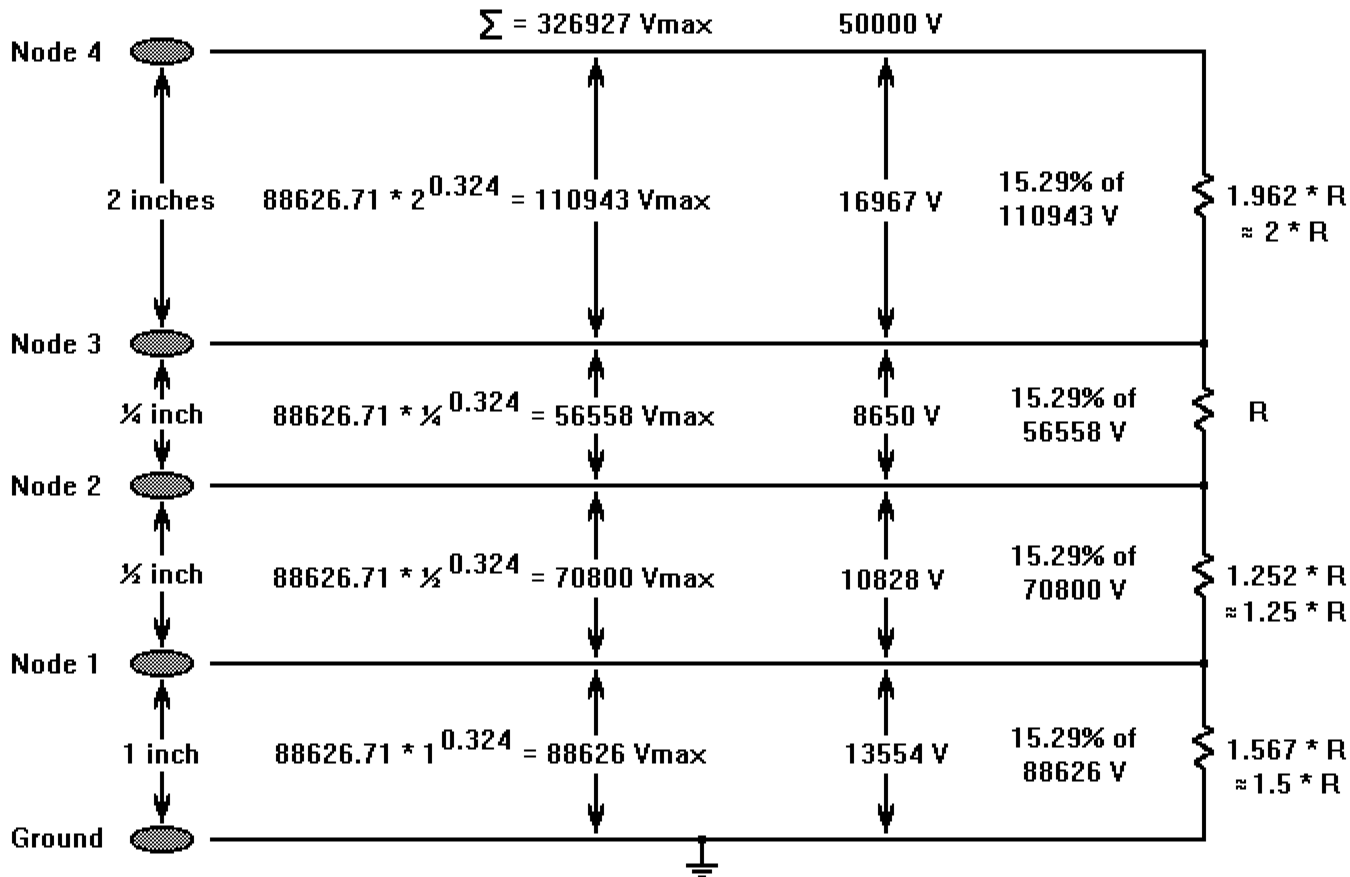
Optimizing Dielectric Stress



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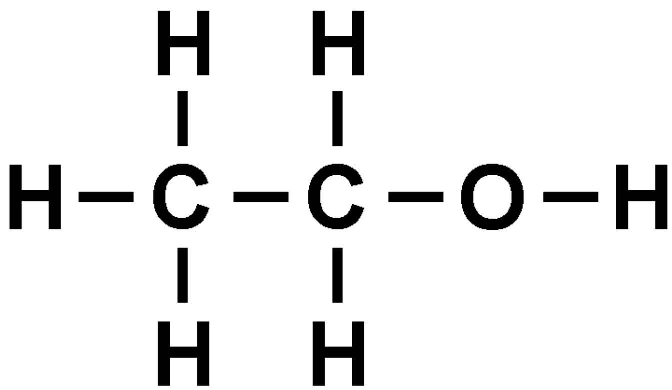
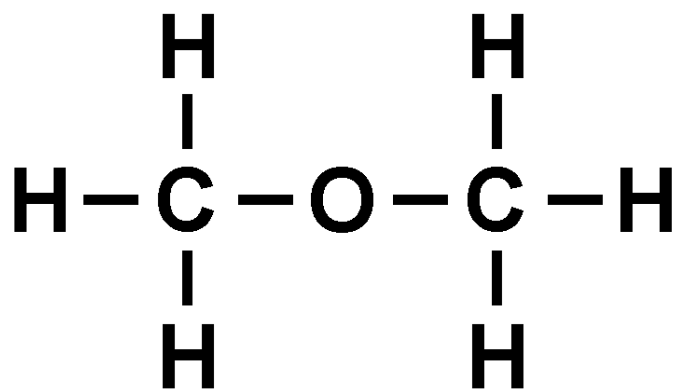
Dipole Moment



Ethyl alcohol has a finite, non-zero dipole moment.

Di-methyl ether has a zero dipole moment because its distribution of charge is symmetric in any axis.



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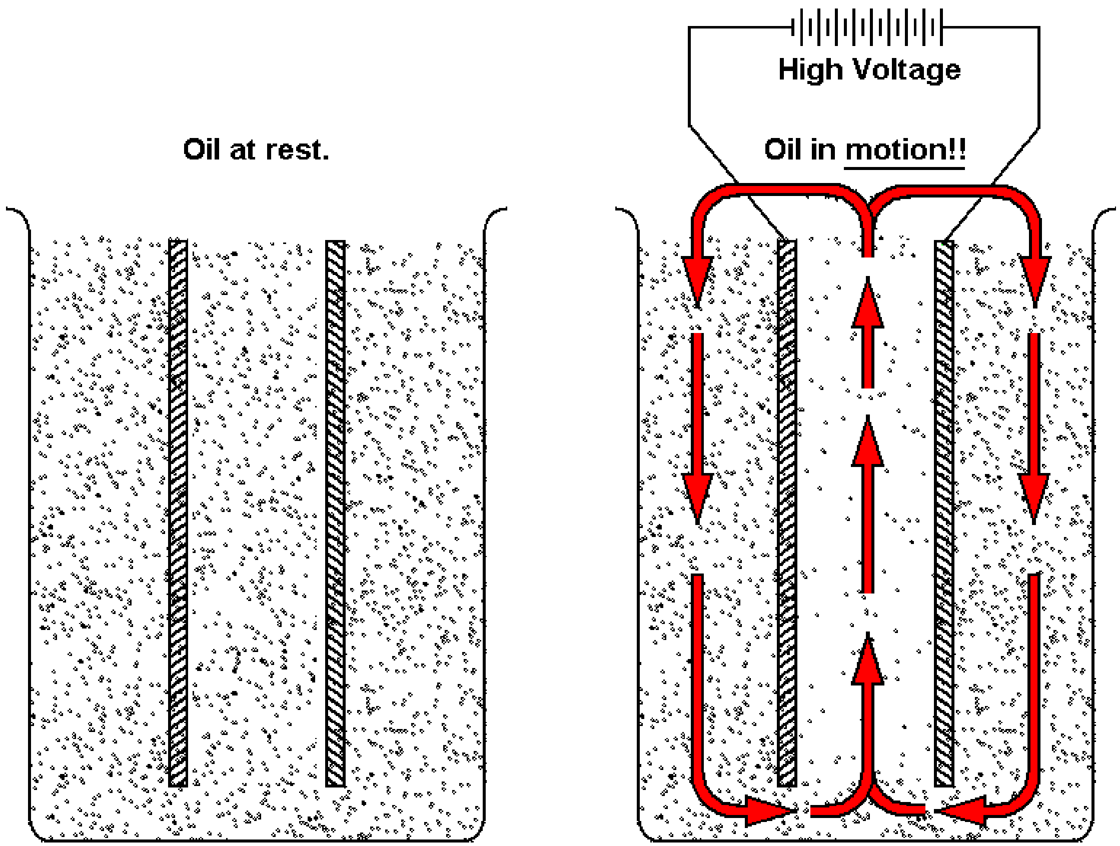
Dielectrophoresis



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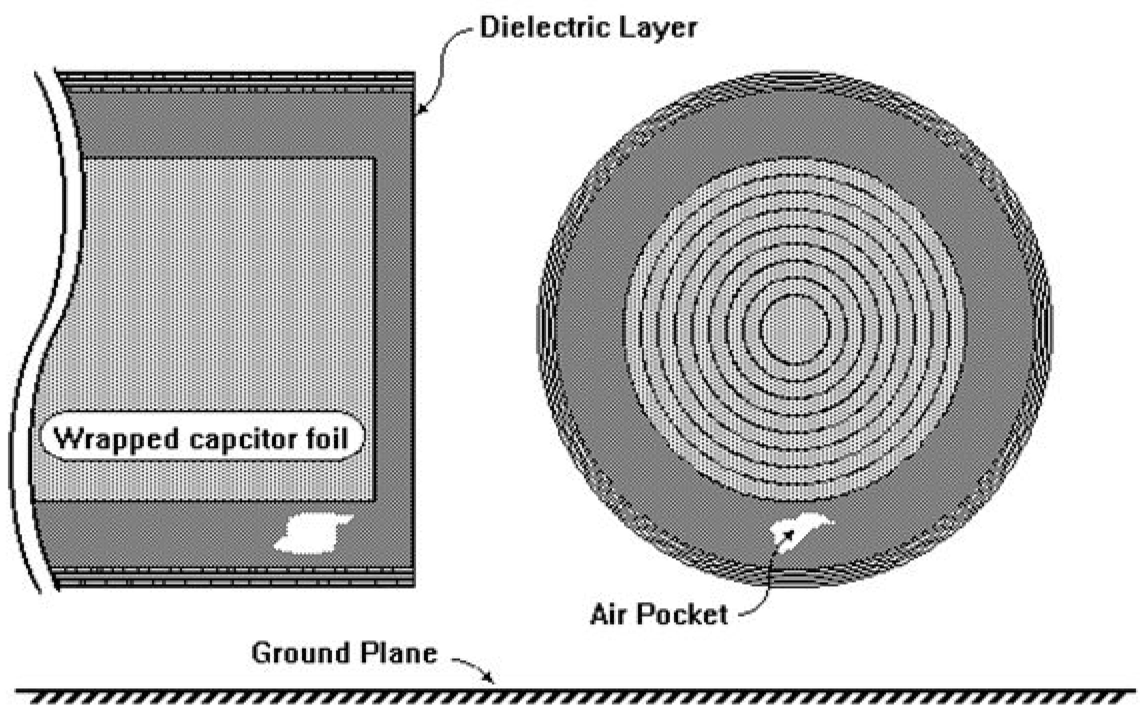
High Voltage Capacitor Flaw



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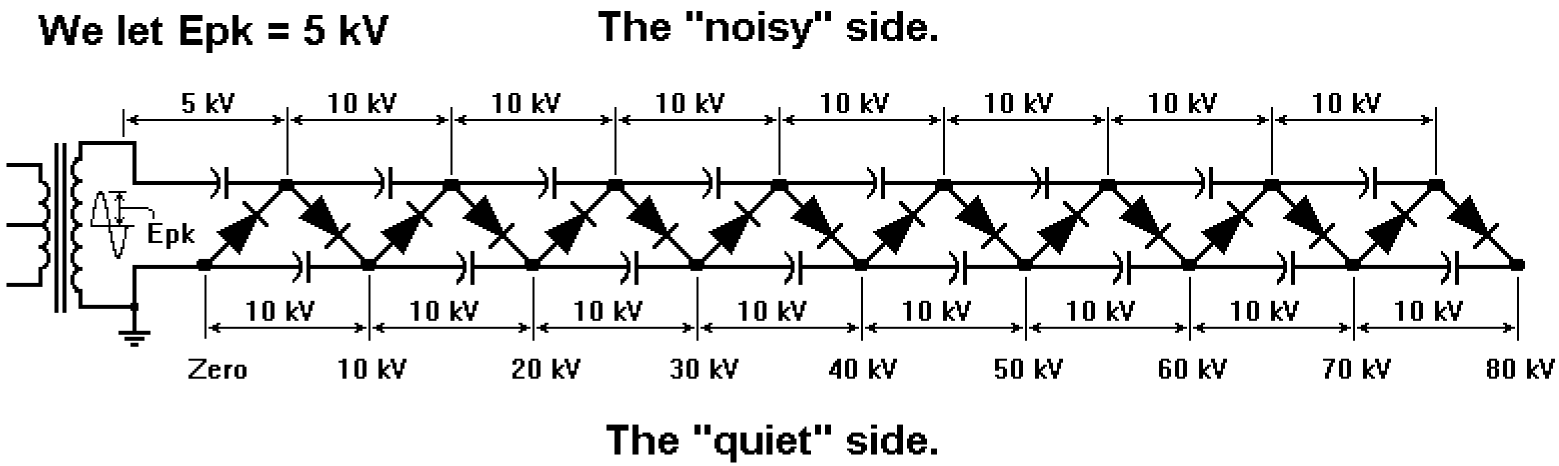
High Voltage Multiplier

Idealized x16 Voltage Multiplier for 80 kV

We let Epk = 5 kV



Each capacitor sees up to 10 kV from its own end-to-end, but almost all of the capacitors ride on a higher voltage with respect to ground.

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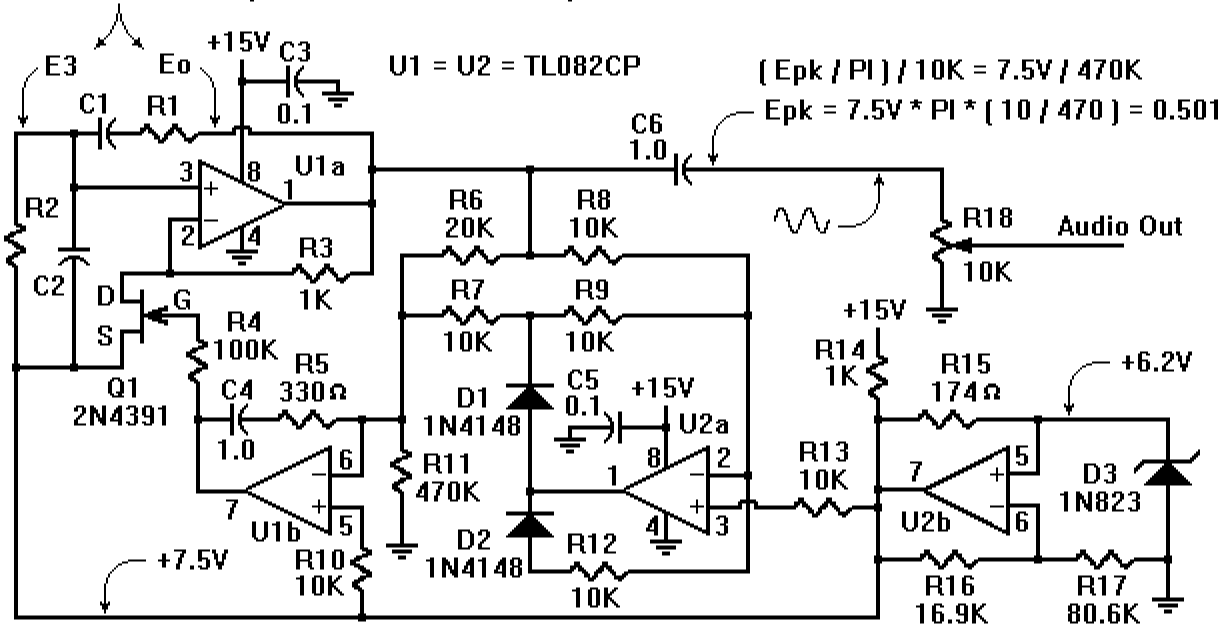
Wien Bridge Oscillator

Wien Bridge Oscillator with Output = 1.0 Volts Peak-to-Peak

$$\frac{E3}{Eo} = \frac{S\ R2\ C1}{1 + S\,(R1\ C1 + R2\ C2 + R2\ C1) + S^2\ R1\ R2\ C1\ C2}$$



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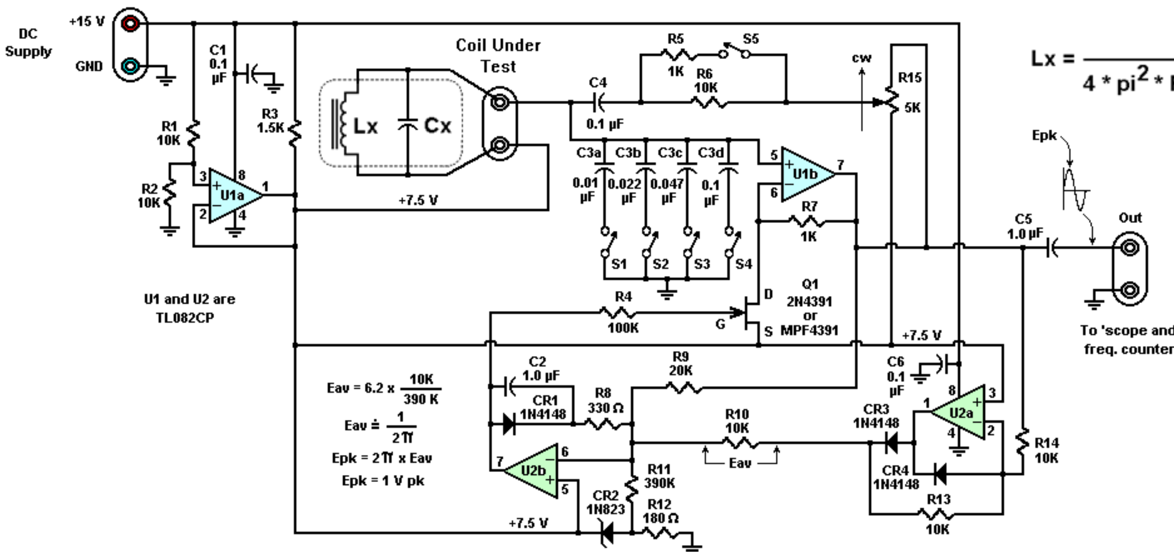
Dual-Resonance Test Oscillator



$$Lx = \frac{Fb^2 - Fa^2}{4 * pi^2 * Fa^2 * Fb^2 * (Ca - Cb)}$$

$$Cx = \frac{Fb^2 * Cb - Fa^2 * Ca}{Fb^2 - Fa^2}$$

Using switches S1 thru S4, find four oscillation frequencies, one for each capacitance of 0.01 µF, 0.022 µF, 0.047 µF and 0.1 µF. Taking these four frequency-capacitances in all combinations as Ca with Fa and Cb with Fb, find the values of Lx and Cx. You results will be reliable when all calculation combinations yield the same values for Lx and Cx.

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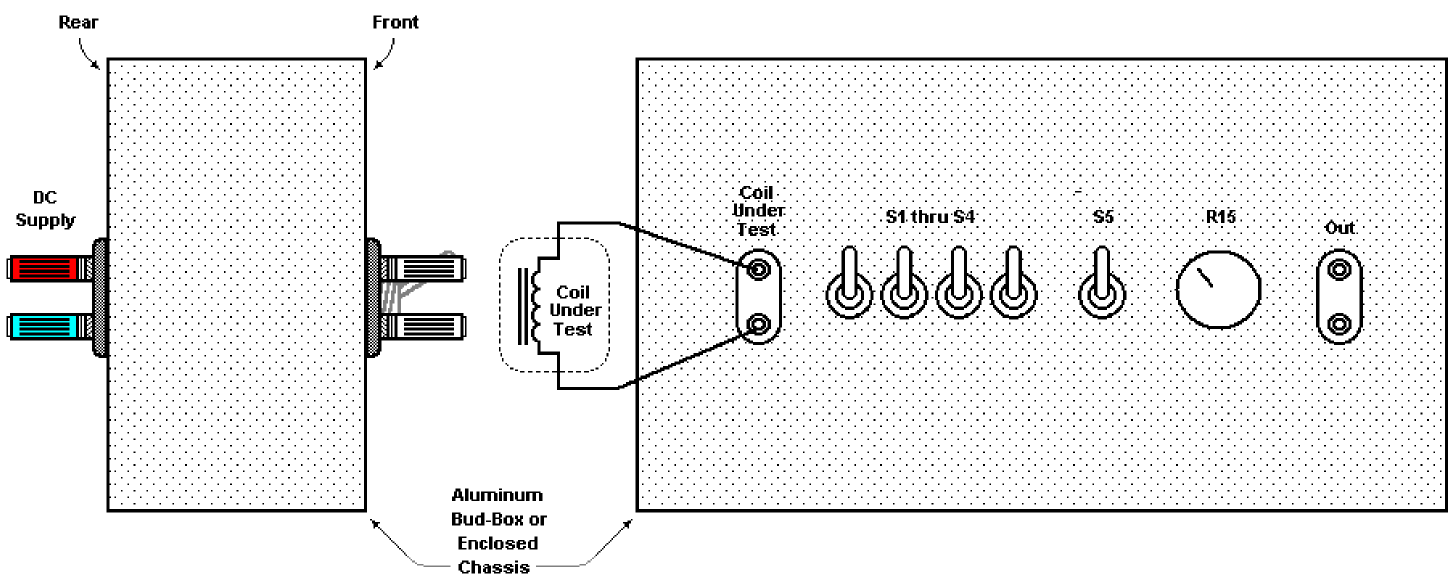
Dual-Resonance Test Set
Suggested Construction



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Sample Dual Resonance Test Results

With the four test set capacitances accurately known from prior results, we get four frequencies.

For each of the six possible combinations of the four results above, we calculate Lx and Cx.

Raw Data

	Test µF	Test kHz
1st	0.0230	19.210
2nd	0.0349	17.590
3rd	0.0492	16.070
4th	0.1039	12.640

Raw Calculations

	mHy	µF
1st and 2nd	1.111398	0.0388
1st and 3rd	1.123856	0.0381
1st and 4th	1.111265	0.0388
2nd and 3rd	1.134223	0.0373
2nd and 4th	1.111242	0.0388
3rd and 4th	1.105234	0.0395

Averages

Lpri avg
1.116203
Cpri avg
0.038534

Cxfmr
0.005534

SRF kHz
24.2676

Npri TCT
28
Core AL
1423.729

We take the final determination of Lx as the average of the six calculations.

We take the final determination of Cx as the average of the six calculations less the known 0.033 µF part.

We find the self resonant frequency of the coil structure from the resonance equation using Lx and Cx.

Then, if you know how many turns of wire are on the coil under test, you can find the core's AL coefficient.

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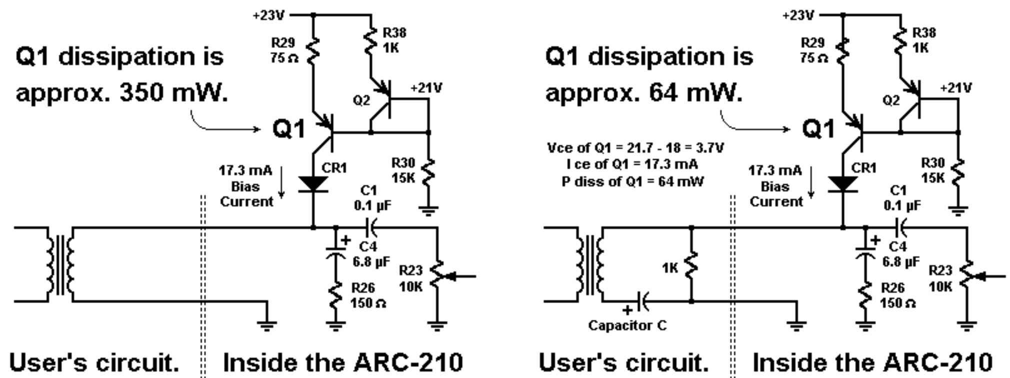
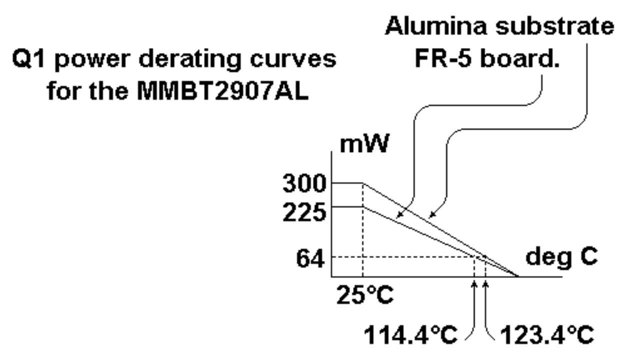
How to Kill an ARC-210





Do not assume that you can just connect any old thing into a microphone input connector.

In this case, an ARC-210 input circuit can get fried!

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