This is us:
LED Selection with SPST

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

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

1V / mA of collector current
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.

\[ \text{Rin} = \frac{R1 \times R2 \times R4}{(R2 \times R4 - R1 \times R3)} \]

\[ \text{Fco} = \frac{1}{(2 \times \pi \times \text{Rin} \times C1)} \]

\[ \text{Gain} = \frac{(R5 + R6)}{R6} \]
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.

\[ i_2 = \frac{(E_1 - A \cdot E_1)}{Xc_2} \]
\[ i_2 = \frac{E_1 \cdot (1 - A)}{Xc_2} \]
\[ i_1 = \frac{E_1}{Xc_1} \]

Effective total capacitance = \( C_1 + \frac{C_2}{1 - A} \)

The bootstrapped C2 can cancel some part of the non-removable C1.
RMS Value versus Average Value

Amplitude is zero and E volts.

Average = \( E_{av} = E \times \text{Duty cycle} \)

\[ E = \frac{E_{av}}{\text{Duty cycle}} \]

\[ \text{Power} = \left(\frac{E^2}{R}\right) \times \text{Duty cycle} \]

\[ \text{Power} = \frac{E_{rms}^2}{R} \]

\[ E_{rms}^2 = E^2 \times \text{Duty cycle} \]

\[ E_{rms} = E \times \sqrt{\text{Duty cycle}} \]

\[ E = \frac{E_{rms}}{\sqrt{\text{Duty cycle}}} \]

\[ E_{rms} = \frac{E_{av} \times \sqrt{\text{Duty cycle}}}{\text{Duty cycle}} \]

\[ E_{rms} = \frac{E_{av}}{\sqrt{\text{Duty cycle}}} \]
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

**ULTRA PRECISION THIN FILM CHIP RESISTORS**

**BLU SERIES**

**FEATURES**

**TYPICAL PERFORMANCE CHARACTERISTICS**

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Characteristics (5-25ppm)*</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extended Life (10,000 hrs)</td>
<td>± 0.25% (±0.4% Opt B)</td>
<td>Rated W per MIL-PRF-55342 4.8.11.1</td>
</tr>
<tr>
<td>Shelf Life</td>
<td>100 ppm/year (Max.)</td>
<td>Room Temp. &amp; Humidity. No-Load</td>
</tr>
</tbody>
</table>

At 70°C,

\[
K_{70} = 0.25\% \text{ per 10000 hours} = 2500 \text{ ppm / 10000 hours} = 0.25 \text{ ppm / hour}
\]

At 25°C,

\[
K_{25} = 100 \text{ ppm / year} = 100 \text{ ppm / 8766 hours} = \left( \frac{1}{87.66} \right) \text{ ppm / hour} = 0.011407711... \text{ ppm / hour}
\]

The aging rate is multiplied by \( \alpha \) for each 10°C increase above 25°C.

\[
\alpha = \frac{K_{70}}{K_{25}}
\]

\[
\alpha = \left( \frac{70°C - 25°C}{10°C} \right)
\]

\[
\alpha = \left( \frac{10°C}{70°C - 25°C} \right)
\]

\[
\alpha = \left( \frac{0.25 \times 87.66}{1 / 4.5} \right)
\]

At 45°C, we find \( K_{45} = K_{25} \times 1.985832207...^2 = 0.011407711... \times 3.943529554... = 0.044986645... \text{ ppm / hour} \)

\[
\alpha = 0.044986645... \text{ ppm / hour} \times 8766 \text{ hours / year} \times 7 \text{ years} = 2760.47... \text{ ppm} \rightarrow 0.276 \%
\]
TLV431 Oscillatory Instability Issues

PARAMETER MEASUREMENT INFORMATION

STABILITY BOUNDARY CONDITION

For TLV431 and TLV431A

STABILITY BOUNDARY CONDITION

For TLV431B

TEST CIRCUIT FOR $V_{KA} = V_{REF}$

TEST CIRCUIT FOR $V_{KA} = 2V, 3V$

The areas under the curves represent conditions that may cause the device to oscillate. For $V_{KA} = 2V$ and $3V$ curves, $R2$ and $V_{out}$ were adjusted to establish the initial $V_{KA}$ and $I_{K}$ conditions with $C_L = 0$. $V_{out}$ and $C_L$ then were adjusted to determine the ranges of stability.

Figure 17
Magnetic Field Pick-up Coil, A Commercial Product

Epoxy cylinder contains a magnetic field pick-up coil.

Cylinder Axis

The Cylinder Axis is also the Axis of Calibration.

Two wires emerge from the epoxy cylinder.
Magnetic Field Coil Alignment Error

The magnetic probe's coil can be substantially out of alignment with the physical cylinder.

An added coil placed in alignment with the outer cylinder.

Axis of internal coil.

Axis of calibration.

The error angle can be as large as 15 degrees.

Slip the one coil inside the other in a snug fit.

When the new coil shows maximum field pick-up, the calibration axis will be properly positioned. (We hope.)
Dual Audio Transformers Give Far-Field Magnetic Interference Suppression

Far-Field Magnetic Interference Cancellation

Note how the phasing dots are arranged.
Transformers, DC Blocks and Signal Isolation

Wrong.

Radiation from capacitor tied to high side.

Right.

No radiation from capacitor tied to low side.
Polystable Memory Elements
Howland Current Pump

\[ \text{Load current} = \frac{e2}{R1 - e1/R1} \]
Two More Current Pumps

Current Pump

\[ I_{\text{Load}} = \frac{(e_2 - e_1) \cdot (R_2 / R_1)}{R_3} \]

Current Pump with increased current drive capability.

\[ I_{\text{Load}} = (e_2 - e_1) \cdot \left( \frac{R_2}{R_1} \right) \cdot \left( \frac{1}{R_{3a}} + \frac{1}{R_{3b}} \right) \]

Resistors with the same reference designators are of identical resistance values.
This circuit behaves as a current pump because the JFET doesn't carry any appreciable gate current.

\[ I_{\text{Load}} = e_1 \times \frac{R_2}{(R_2 + R_3)} \times \frac{1}{R_1} \]
"Boomer" Amplifier Current Pump

\[
e_2 = -\left( \frac{R_5}{R_4} \right) e_1 - \left( \frac{R_5}{R_9} \right) e_4
\]

\[
e_4 = -\left( \frac{R_8}{R_7} \right) e_3
\]

\[
e_2 = -\left( \frac{R_5}{R_4} \right) e_1 + \left( \frac{R_5}{R_9} \right) \left( \frac{R_8}{R_7} \right) e_3
\]

\[
\left( \frac{R_5}{R_4} \right) e_1 = \left( \frac{R_5}{R_9} \right) \left( \frac{R_8}{R_7} \right) e_3 - e_2
\]

Let: \( \left( \frac{R_5}{R_9} \right) \left( \frac{R_8}{R_7} \right) = 1 \)

For convenience, let \( R_7 = R_5 \), \( R_8 = R_5 \) AND \( R_9 = R_5 \)

Then \( e_3 - e_2 = \left( \frac{R_5}{R_4} \right) e_1 \)

\[
I_{load} = \left( \frac{e_2 - e_3}{R_5} \right) = -\left( \frac{e_3 - e_2}{R_6} \right)
\]

\[
I_{load} = -\frac{e_1}{R_4} \left( \frac{R_5}{R_4} \right) / R_6
\]

If we make \( R_5 = R_7 = R_8 = R_9 = 10K \),

those four resistors can be in a SIP.

We then scale the current drive using \( R_4 \) and \( R_6 \).
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.
Thermal Rise Time of TO-39 Cans
Tau ~ 90 Seconds

The data points for temperature versus time are approximated by:

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

where Deg C is temperature in degrees C and t is elapsed time in seconds.
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, $\beta$, all its very own. The base current through the 4K gets multiplied by that $\beta$ value and flows down from the $+V_{cc}$ 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 $+V_{cc}$ 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.
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
Maximum RMS Value of a Random Waveform

RMS of Random Wave = RMS of Triangle Wave

\[
\frac{100}{\sqrt{3}} = 57.735\ldots
\]
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.
Headset Model Shows Resonant Peaking and A Suppression Method
An Integral Table
A Log Table
Radiated Susceptibility EMI Test

Preparatory level setting in CW mode:

Test level for 80% AM modulation:
Radiated Susceptibility EMI Test

For an AM signal of \( E = E_{pk} \sin ( Wc \cdot t ) \cdot ( 1 + Km \sin ( Wm \cdot t ) ) \)

\[
 Erms = 0.5 \cdot E_{pk} \cdot \sqrt{2 + Km^2} 
\]

Amplitude Modulation of 10V peak Carrier

\[
 V_{rms} = V_{pk} \cdot 0.5 \cdot \sqrt{3} \\
 V_{rms} = 8.660
\]

\[
 V_{rms} = V_{pk} \cdot 0.5 \cdot \sqrt{2.64} \\
 V_{rms} = 8.124
\]

\[
 V_{rms} = V_{pk} \cdot 0.5 \cdot \sqrt{2} \\
 V_{rms} = 7.071
\]
Basic Logic Gate Crystal Oscillator

Crystal's application in uP/uC or gate array clock oscillator.
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
Bad Crystals in Violation of MIL-C-3098
Some More Bad Crystals

20% of 3.579545 MHz comes to 716 kHz
Still More Bad Crystals!!

![Graphs of Crystal Performance](image)

- **1 MHz Xtal**
  - Vert. = 10 dB / div
  - Hor. = 100 KHz / div
  - 1 MHz

- **1 MHz Xtal (cylindrical)**
  - Vert. = 10 dB / div
  - Hor. = 100 KHz / div
  - 1 MHz
  - 900 KHz

![Diagram of Circuit](image)

- **Marconi 2051 Sweep Signal Generator**
  - +12 dBm

- **Signal Input**
  - 16 Ω
  - 68 Ω
  - 6 dB pad

- **Signal Output**
  - 16 Ω
  - 68 Ω
  - 6 dB pad

- **HP8566B Spectrum Analyzer**
  - 0 dBm Ref.
  - 10 KHz Res. BW
An Emitter Follower Driving A Capacitive Load Is Only One Step Away From Being a Colpitts Oscillator

A capacitive loaded follower sets up the classic Colpitts oscillator configuration.

Adding a $Q$-killer resistor here can reduce the $Q$ of the tank circuit and suppress the tendency to oscillate.
Paralleled Rail Voltage Bypass Capacitors

Major boobytrap!!!
A Typical Circuit Board

Permittivity = Dielectric constant
$\varepsilon_0$ = Dielectric constant of free space.
$= 8.854 \times 10^{-12}$ farads per meter
$= 2.249 \times 10^{-13}$ farads per inch
$= 0.2249$ pF per inch
$\varepsilon_r$ = Relative dielectric constant of a material
$\varepsilon$ = Actual dielectric constant of a material
$= \varepsilon_0 \times \varepsilon_r$
For G10 material, $\varepsilon_r = 4.7$
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:

$$C = \frac{4.7 \times 0.2249 \times 1}{0.003} = 352.3$$

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.)
A Look At Rail Bypass Impedance Vs. Frequency

The parallel combination of 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.

### Capacitor Values

- **Tantalum capacitor:**
  - R1: 2 Ω
  - C1: 20 μF

- **Ceramic capacitor:**
  - R2: 0.01 Ω
  - C2: 0.1 μF

- **Artwork capacitance:**
  - R3: 0.01 Ω
  - C3: 50 pF

### Frequency and Impedance Values

- **Capacitance (μF):**
  - 20.00 μF
  - 0.100 μF
  - 50.0 μF

- **SRF (MHz):**
  - 1.00 MHz
  - 10.00 MHz
  - 100.0 MHz

- **ESR (Ω):**
  - 2.00 ohms
  - 0.01 ohms
  - 0.01 ohms

### Impedance Plot

- **Log (1 + ABS(Zin))** versus **Log (Frequency)**.

- **Plot Note:**
  - ESR of 20 μF
  - Unwanted Resonance

- **Frequency (Hz):**
  - 1 kHz
  - 1 MHz
  - 1 GHz
“Improved” Board Layout’s Capacitance

<table>
<thead>
<tr>
<th>Cap.</th>
<th>20.00 μF</th>
<th>0.100 μF</th>
<th>50.0 pF</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRF</td>
<td>1.00 MHz</td>
<td>10.00 MHz</td>
<td>3000.0 MHz</td>
</tr>
<tr>
<td>ESR</td>
<td>2.00 ohms</td>
<td>0.01 ohms</td>
<td>0.01 ohms</td>
</tr>
</tbody>
</table>

Unwanted Resonance

Skull and Crossbones
Whenever you have a set of paralleled bypass capacitors, each with its own self resonant frequency (SRF), whichever of those capacitors has the highest 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.
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)
Silicone Rubber High Voltage Support

Estimate of Voltage Support Capability of General Electric RTV11 Silicone Rubber

Volts = 88626.71 \times T^{0.324}

where T is in inches.

The "volts per mil" support capability declines as the RTV thickness increases.
2-Part Potting/Encapsulating Compound RTV11

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 D27. Specialized catalysts are available upon request.

Available Sizes

<table>
<thead>
<tr>
<th>Catalog Number</th>
<th>Sizes Available</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTV11-1P</td>
<td>1 pint</td>
<td>case of 12</td>
</tr>
<tr>
<td>RTV11-10</td>
<td>1 gallon</td>
<td>12.1 lbs</td>
</tr>
<tr>
<td>RTV11</td>
<td></td>
<td>requires a primer. Visit our online code for details.</td>
</tr>
</tbody>
</table>

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 = 88.62571 x Thickness in Inches x 0.324

<table>
<thead>
<tr>
<th>mm</th>
<th>Inch</th>
<th>kV</th>
<th>kV/mm</th>
<th>General Electric (Per Application Note of 1958)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.9</td>
<td>0.074803</td>
<td>38.25733</td>
<td>20.13544</td>
<td>By data sheet specification. The other company.</td>
</tr>
<tr>
<td>1.9</td>
<td>0.074803</td>
<td>38.57</td>
<td>20.3</td>
<td></td>
</tr>
</tbody>
</table>

515 volts per mil equals 515000 / 25.4 volts per mm equals 20.3 kV per mm
Optimizing Dielectric Stress

\[ \Sigma = 326927 \text{ V}_{\text{max}} \]

- Node 4: 2 inches \( 88626.71 \times 2^{0.324} = 110943 \text{ V}_{\text{max}} \)
  \( 16967 \text{ V} \) (15.29% of 110943 V)

- Node 3: \( \frac{3}{4} \) inch \( 88626.71 \times \frac{3}{4}^{0.324} = 56558 \text{ V}_{\text{max}} \)
  \( 8650 \text{ V} \) (15.29% of 56558 V)

- Node 2: \( \frac{1}{8} \) inch \( 88626.71 \times \frac{1}{8}^{0.324} = 70800 \text{ V}_{\text{max}} \)
  \( 10828 \text{ V} \) (15.29% of 70800 V)

- Node 1: 1 inch \( 88626.71 \times 1^{0.324} = 88626 \text{ V}_{\text{max}} \)
  \( 13554 \text{ V} \) (15.29% of 88626 V)

Ground
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.
Ambertec, P.E., P.C.

Dielectrophoresis

Oil at rest.

High Voltage

Oil in motion!!
High Voltage Capacitor Flaw

Ambertec, P.E., P.C.
High Voltage Multiplier

Idealized x16 Voltage Multiplier for 80 kV

We let $E_{pk} = 5 \text{ kV}$

The "noisy" side.

The "quiet" side.

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.
Wien Bridge Oscillator

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

\[
\frac{E_3}{E_0} = \frac{s R_2 C_1}{1 + s \left( R_1 C_1 + R_2 C_2 + R_r C_1 \right) + s^2 R_1 R_2 C_1 C_2}
\]
**Dual-Resonance Test Oscillator**

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. Your results will be reliable when all calculation combinations yield the same values for Lx and Cx.
Dual-Resonance Test Set
Suggested Construction
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 \( L_x \) and \( C_x \).

We take the final determination of \( L_x \) as the average of the six calculations.

We take the final determination of \( C_x \) as the average of the six calculations less the known 0.033 \( \mu \)F part.

We find the self resonant frequency of the coil structure from the resonance equation using \( L_x \) and \( C_x \).

Then, if you know how many turns of wire are on the coil under test, you can find the core’s AL coefficient.
How to Kill an ARC-210

Q1 dissipation is approx. 350 mW.

Q1 dissipation is approx. 64 mW.

User's circuit. Inside the ARC-210

User's circuit. Inside the ARC-210

Q1 power derating curves for the MMBT2907AL

Alumina substrate FR-5 board.

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!

mW

300
225
64

deg C

25°C

114.4°C

123.4°C
Ambertec, P.E., P.C.

ambertec@ieee.org