1–50 MHz VHF EMI Sensor Instrumentation Sensor Circuit

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Electromagnetic Interference (EMI)

- High-performance electronics → **Sensitive to EMI**
  - **Requirements**: → **Shielding**
    → **Monitoring**
- **Military Need**: U.S. Army's (Natick) **Standardized Integrated Command Post System Rigid Wall Shelter** (SICPS RWS)

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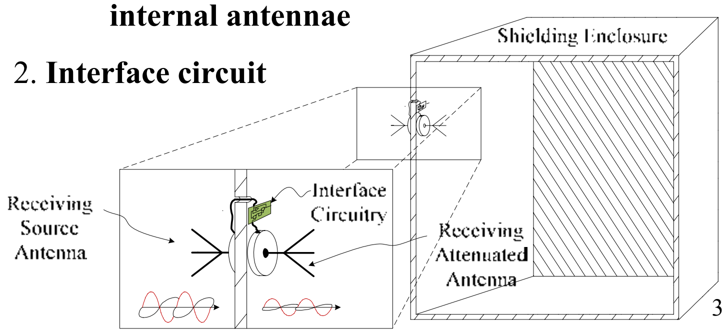
EMI Instrumentation Sensor

- **Purpose**: Ascertain **shielding integrity**
- **Means**: **Measure power attenuation** across shielded enclosure
- **System**: 1. Sense external/internal EMI presence w/ **external/ internal antennae**

  2. **Interface circuit**



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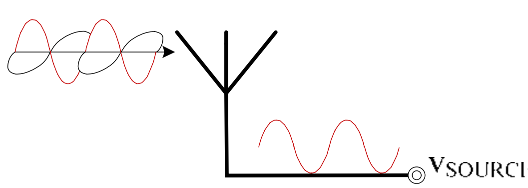
Sensors: Radiation

- **Approach**: Measure **VHF radiation** through a barrier
- **How**: **Translate electromagnetic (EM) signal to source voltage**



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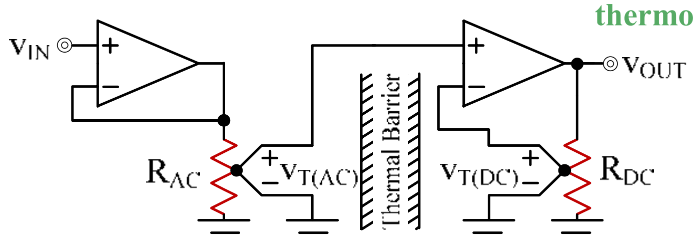
Power Measurement: Temperature

- **Approach**: Use EM source voltage to **induce thermal power & measure** equivalent DC power
- **How**: **Compare temperatures of matched resistors via a thermo couple**



- **Measurement**: **Modify $i_{R.DC}$ until $P_{R.DC} = P_{R.AC}$**

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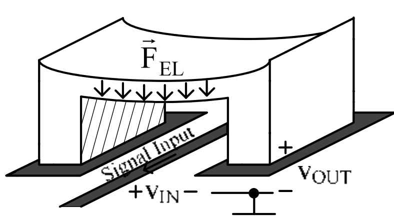
Power Measurement: Capacitance

- **Approach**: Use EMI source voltage to **induce capacitance variations & measure** capacitance **difference** from nominal
- **How**: **Compare capacitance with EMI signal and nominal**



$$\vec{F}_{EL} \propto v_{CAP}^{2}$$

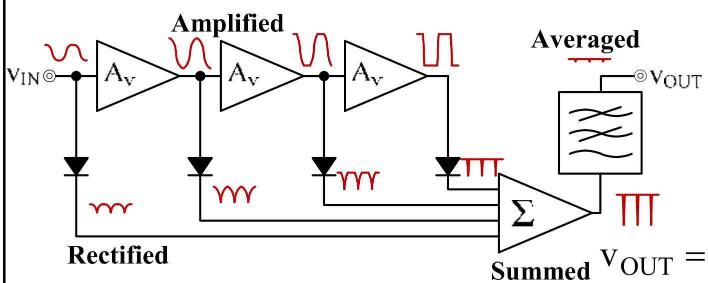
$$f_{SOURCE} >> f_{MECH.RES}$$

$$\vec{F}_{EL} \propto v_{SOURCE}^{2} = v_{SOURCE(RMS)}^{2}$$

- **Measurement**: **Monitor differences in capacitance with EMI source signal**

Power Measurement: Rectification

- **Approach**: Measure **peak of signal to relate to power** across a barrier
- **How**: **Compare rectified peak voltages**



$$V_{OUT} = \left(\sum_{k=1}^{N} A_V^{\,N} \left| v_{IN}(t) \right| \right)$$

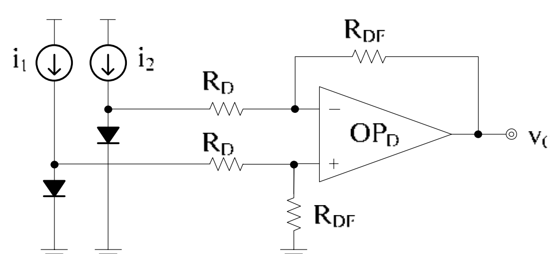
- **Measurement**: **Monitor differences in output voltage with source signal**

Measurement: Logarithmic

- **Approach**: **Logarithmically compress output**

  (decrease signal swing)

- **How**: **Monitor voltages across matched diodes**



$$\propto \log_{10}(i_1) - \log_{10}(i_2)$$

$$\propto \log_{10}\left(\frac{i_1}{i_2}\right)$$

- **Measurement**: **Monitor differences in diode voltages**

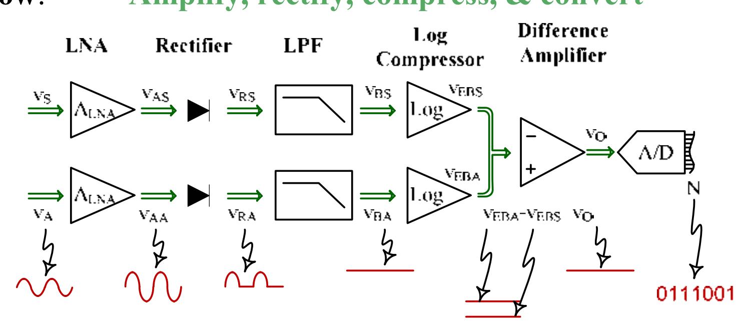
Comparison

Performance	Temperature	Capacitive	Logarithmic	Rectification
Accuracy	+/- 0.1 dB	Moderate	+/- 1 dB	Moderate
Dynamic Range	Low unless VGA	≤ 80 mW (≤ 19 dBm)	70 dB	Moderate
Power Requirements	Moderate	Minimal	High	Minimal
Bandwidth	Broad	100kHz- 4GHz	Broad	Broad
True RMS Detection	Yes	Yes	No	No
Output Voltage Swing	Linear	Linear	Logarithmic	Linear
Temperature Dependence	N/A	Minimal	Minimal	High
Integration	SiP	SiP	SoC (Monolithic)	SoC (Monolithic)
Signal Preservation	No	Yes	No	No

- **This Application**: **Measure radiation by rectifying & compressing antennae signals.**

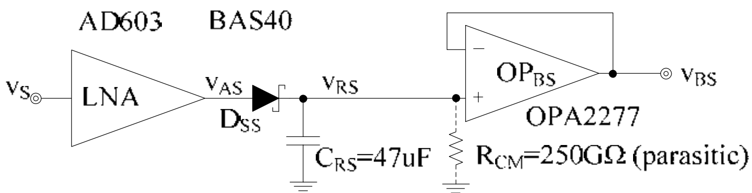
Proposed EMI Sensor

- **Approach**: Compare **signal strength difference**
- **How**: **Amplify, rectify, compress, & convert**



- **Measurement**: **Signal-strength difference expressed in dB & represented digitally**

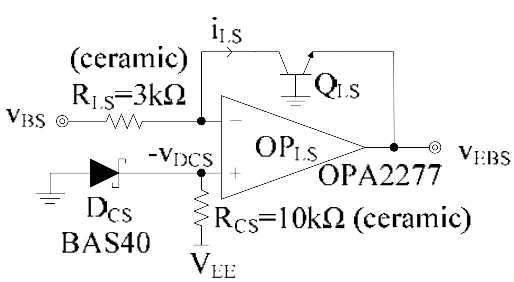
Amplification & Rectification



$$\Delta v_{RS(MAX)} \cong \frac{v_{RS(MAX)}}{f_{EMI} R_{CM} C_{RS}}$$

- **Low-Noise Amp**: **Amplify signal & decrease noise figure**
- **Schottky Diode D_{SS}**: **Reduce voltage drop** (for accuracy)
- **Capacitor C_{RS}**: **Sample & hold peak voltage** (sense v_{PP})

Logarithmic Compression

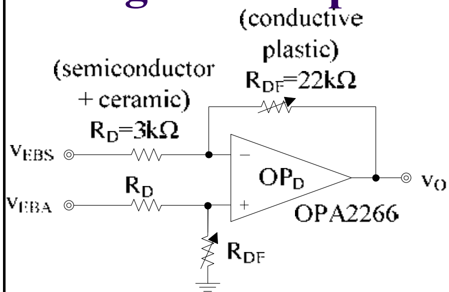


$$V_{EBS} = -\frac{kT_Q}{q}\ln(I_{LS})$$

$$V_{EBS} = -\frac{kT_Q}{q}\ln\left(\frac{V_{BS}+V_{DCS}}{R_{LS} I_S}\right)$$

- **Q_{LS}**: **Conducts input as current I_{LS}**
- **Q_{LS}'s Diode Voltage V_{EBS}**: **Logarithm of input current I_{LS}**
- **D_{CS}**: **Cancel D_{SS}'s voltage in rectification** (for accuracy)

Signal Comparison – Difference

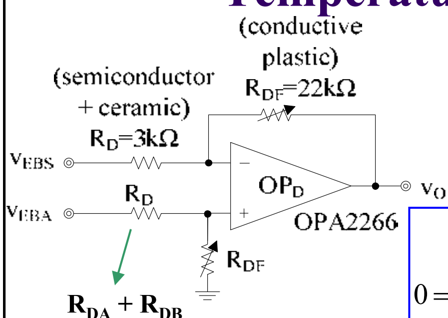


$$V_O = \frac{R_{DF}}{R_D}\left(V_{EBA} - V_{EBS}\right)$$

$$V_O \cong \frac{kT_Q}{q}\frac{R_{DF}\ln(10)}{20R_D}\left\{10\log\left[\left(\frac{v_{s(Peak)}}{v_{a(Peak)}}\right)^2\right]\right\} = \beta\left(P_{s(dB)} - P_{a(dB)}\right)$$

- **Input**: **In RMS**
- **Difference**: **Difference of logs ≡ log of ratio** → **V_O in dB**
- **Error**: **Diode voltage V_{DSS}** → **$A_{LNA}v_{IN.PP} >> V_{DSS} - V_{DCS}$**

Temperature Drift



$$V_O \cong \beta\left(P_{S(dB)} - P_{A(dB)}\right)$$

$$\frac{\partial V_O}{\partial T_Q} = \frac{\partial \beta}{\partial T_Q}\left(P_{S(dB)} - P_{A(dB)}\right) \equiv 0$$

$$0 = \frac{1}{R_D} + \frac{d\left(\frac{1}{R_D}\right)}{dT_Q}T_Q \Rightarrow TC_{DA} = \frac{R_{DA} + R_{DB}}{T_Q R_{DA}}$$

- **β α T_Q(R_{DF}/R_D): Proportional to Abs. Temp. (PTAT)**
- **Fix**: **Introduce Complementary to Abs. Temp. (CTAT)**
  - **Force R_{DF}/R_D to be CTAT →** Introduce **R_{PTAT} in R_D as R_{DA}**

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1–50 MHz VHF Sensor Prototype

- **Printed-circuit board (PCB):**
  - **Prototyped with commercially off-the-shelf (COTS) components**
  - **Tested with high-frequency signal generators** (to emulate antenna-generated outputs)

  - **Monitored** analog (v_O) & digital (**word**) outputs

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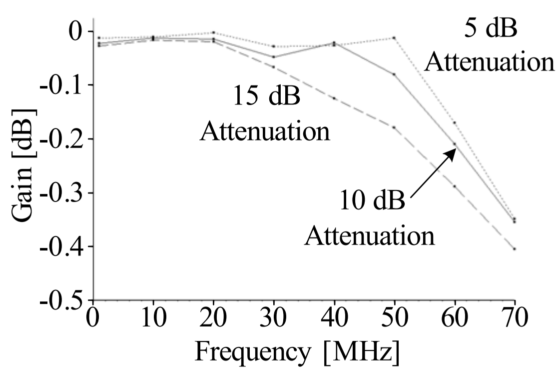
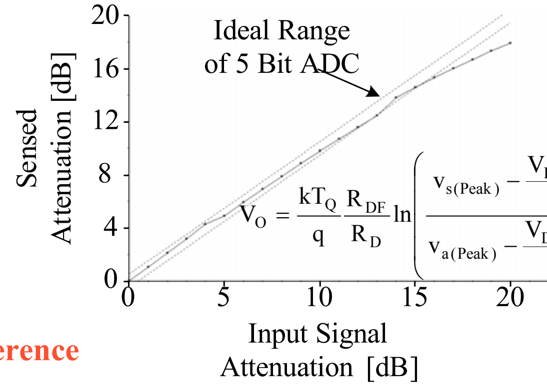
Experimental Results: Bandwidth



- **$f_{-3dB} \approx$ 50 MHz**
- **LNA's $f_{-3dB} \approx$ 60 MHz** (limit)
- Schottky diode **D_{SS}'s parasitic capacitance** also limits f_{-3dB}

Experimental Results: Accuracy



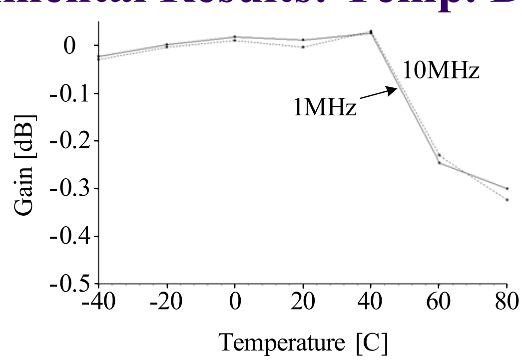
$$V_O = \frac{kT_Q}{q}\frac{R_{DF}}{R_D}\ln\left(\frac{v_{s(Peak)} - \frac{V_{DS}-V_{DCS}}{A_{LNA}}}{v_{a(Peak)} - \frac{V_{DA}-V_{DCA}}{A_{LNA}}}\right)$$

- **5-bit accuracy**
- **16 dB range**
- **D_{SS}-D_{CS}'s difference**

error voltage in log (limit)

- **Error (difference voltage) is greatest when $v_{EXTERNAL} >> v_{INTERNAL}$**

Experimental Results: Temp. Drift



- **Accurate within 0.03 dB up to 40^O C**
- **Drift of PCB potentiometer (R_{DF})** (limit)
- **R_D and R_{DF} do not track over temperature** (gain varies)

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Conclusions

- **Proposed VHF EMI Sensor Instrumentation Circuit:**
  - **Logarithmically compressed analog & digital output in dB**
  - **Compensates for rectification error** (i.e., diode voltage drop)
  - **Compensates for temperature drift** (i.e., introduces CTAT term)
- **Achieved Performance:**
  - **5-bit** accuracy
  - **16 dB of dynamic range** (measurable EMI difference)
  - **50 MHz** of bandwidth

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Questions?

Thanks.