The Measurement of (1/f) AM noise of Oscillators

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Outline

- Introduction
- Power detectors
- Experimental method
- Results
- Perspectives and conclusions

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Motivations for AM noise metrology

- Emerging need, after the progress of
  - oscillators and sources
  - phase noise metrology (bridge/interferometric) method
- Impacts on
  - frequency synthesis $\rightleftarrows$ AM/PM conversion
  - oscillators $\rightleftarrows$ power effects on the resonator
  - microwave photonic systems $\rightleftarrows$ laser RIN
  - ....
- Measurement the AM noise of a *source* relies on instruments

AM noise

polar coordinates

$$v(t) = V_0\,[1 + \alpha(t)]\cos[\omega_0 t + \varphi(t)]$$

Cartesian coordinates

$$v(t) = V_0 \cos\omega_0 t + n_c(t)\cos\omega_0 t - n_s(t)\sin\omega_0 t$$

In low noise conditions

$$\alpha(t) = \frac{n_c(t)}{V_0} \quad \text{and} \quad \varphi(t) = \frac{n_s(t)}{V_0}$$

Relates to power fluctuations

$$\alpha(t) = \frac{1}{2}\frac{\delta P}{P_0}$$

Same formulae as for frequency noise $\alpha(t) \Leftrightarrow y(t)$

Power-law

$$S_\alpha(f) = \sum_{i=-2}^{0} h_i f^i$$

h_{-2}/f^2	random walk
h_{-1}/f	flicker
h_0	white

Allan variance

$$\sigma^2_\alpha(\tau) = \frac{h_0}{2\tau} + 2\ln(2)\,h_{-1} + \frac{4\pi^2}{6}\,h_{-2}\,\tau$$

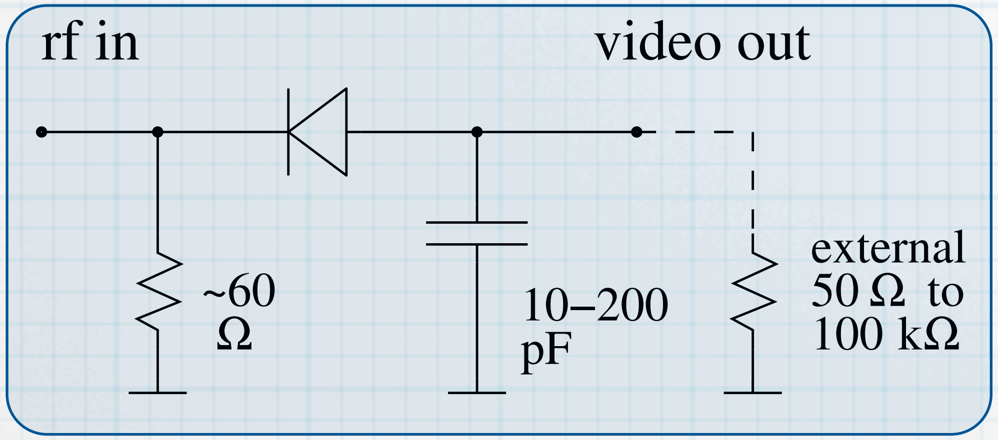
white flicker random walk

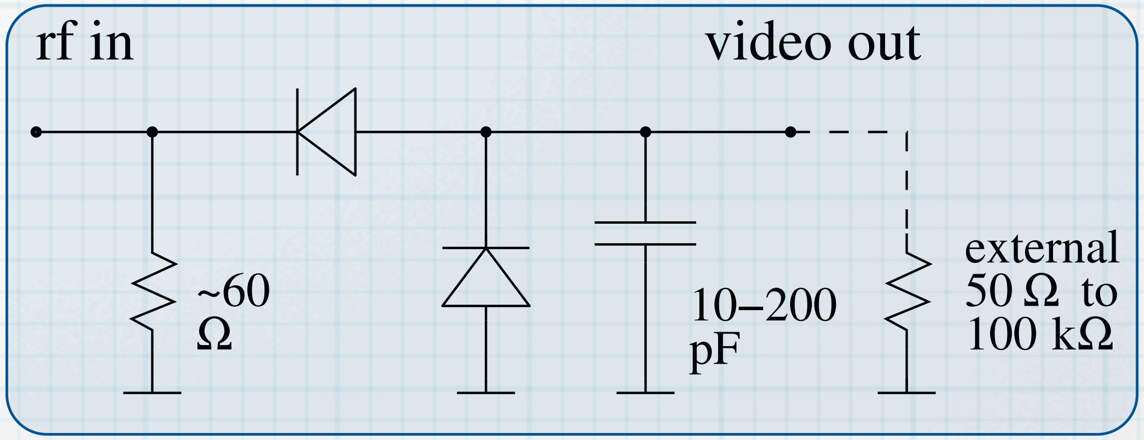
The diode power detector

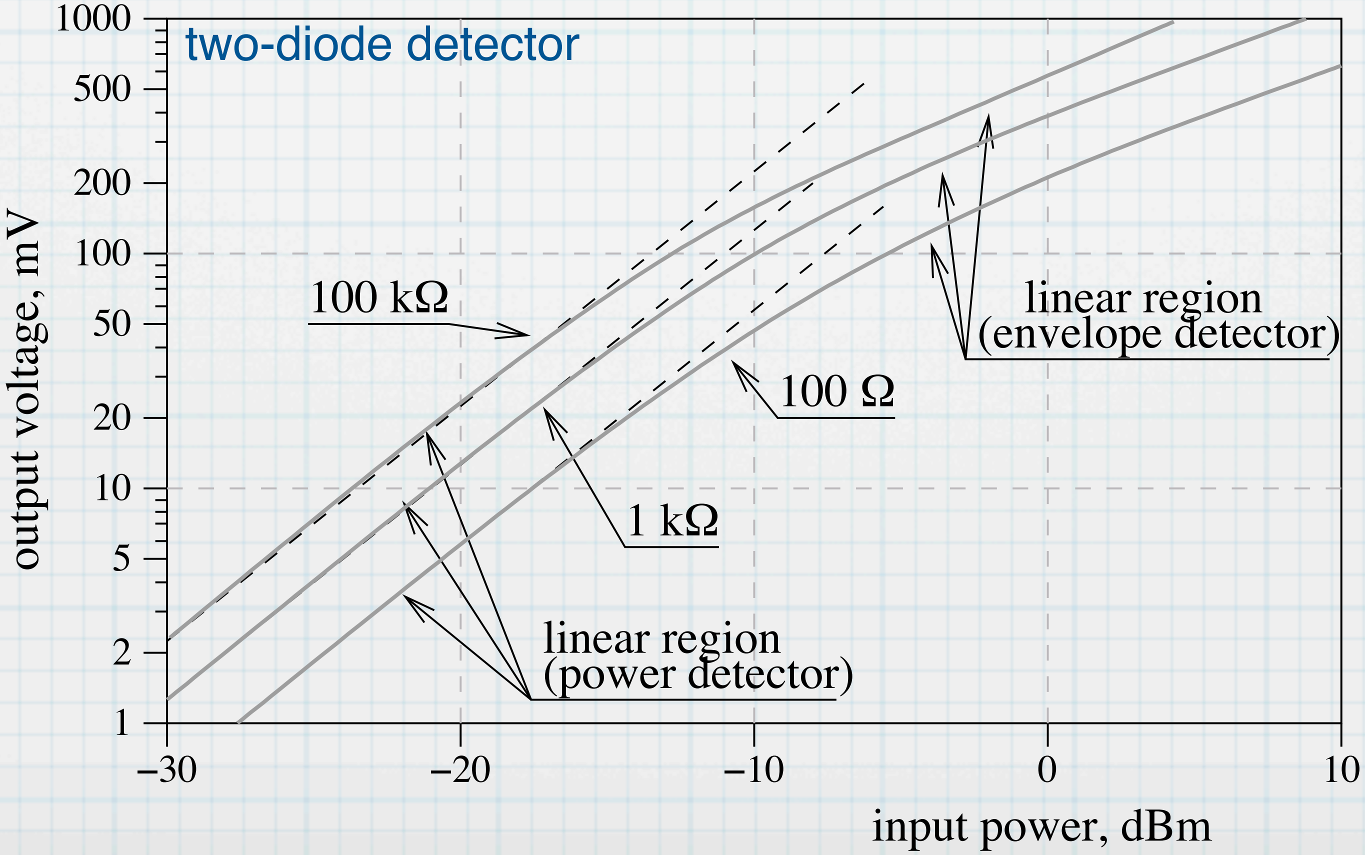
law: $v = k_d\, P$

same form as in optical quantum detectors

differential resistance $R_d = \dfrac{V_T}{I_0}$ $\quad V_T = kT/q \simeq 25$ mV thermal voltage







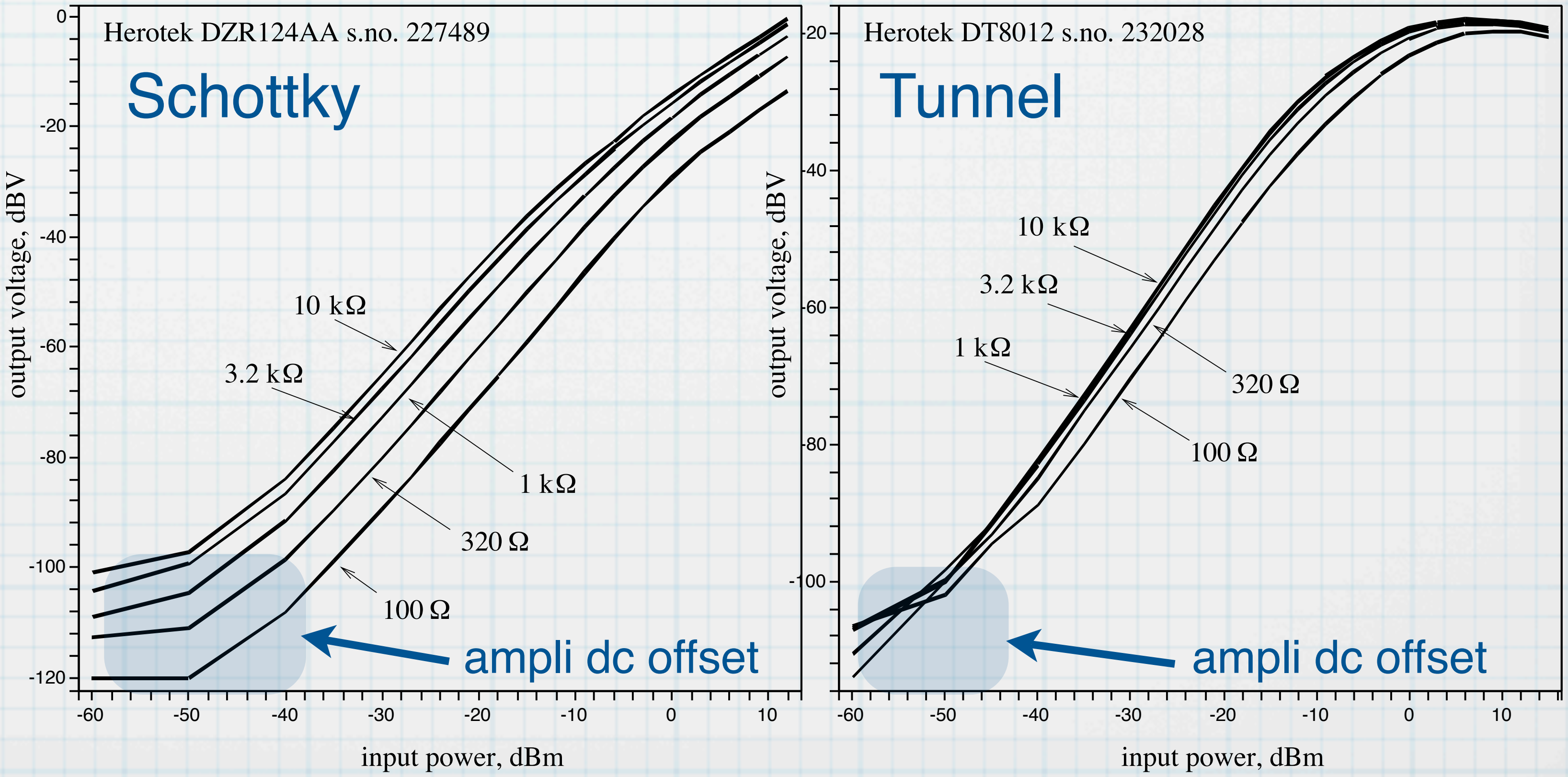
Tunnel and Schottky power detectors

parameter	Schottky	tunnel
input bandwidth	up to 4 decades 10 MHz to 20 GHz	1–3 octaves up to 40 GHz
VSVR max.	1.5:1	3.5:1
max. input power (spec.)	−15 dBm	−15 dBm
absolute max. input power	20 dBm or more	20 dBm
output resistance	1–10 kΩ	50–200 Ω
output capacitance	20–200 pF	10–50 pF
gain	300 V/W	1000 V/W
cryogenic temperature	no	yes
electrically fragile	no	yes

The “tunnel” diode is actually a backward diode. The negative resistance region is absent.

Measured

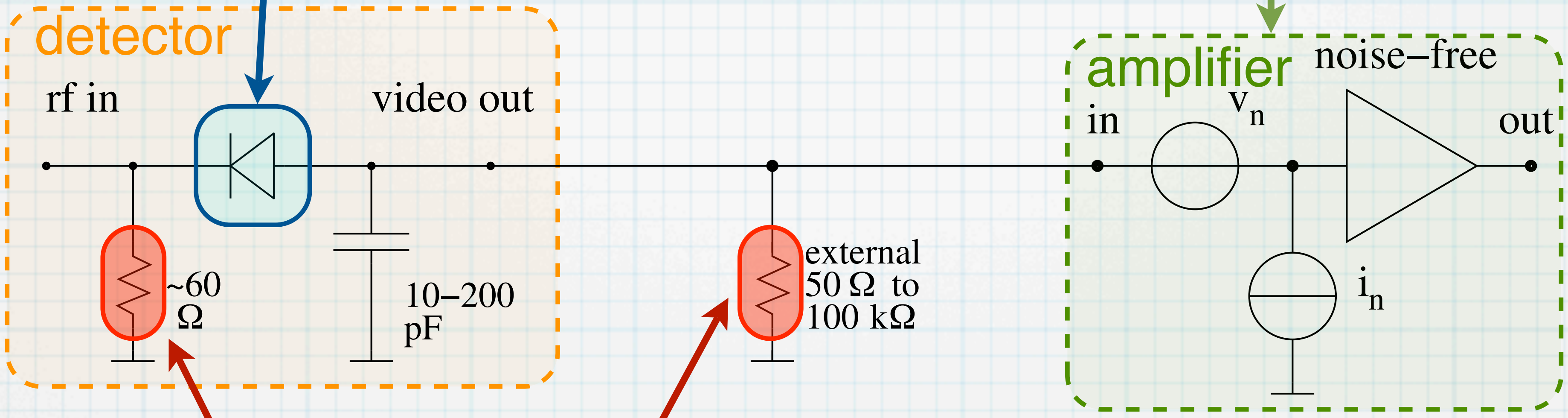
load resistance, Ω	detector gain, A^{-1} DZR124AA (Schottky)	 DT8012 (tunnel)
1×10^2	35	292
3.2×10^2	98	505
1×10^3	217	652
3.2×10^3	374	724
1×10^4	494	750
conditions: power −50 to −20 dBm		



Noise mechanisms

Rothe-Dahlke model of the amplifier

Shot noise $S_I(f) = 2qI_0$



Thermal noise $S_V(f) = 4k_BT_0R$

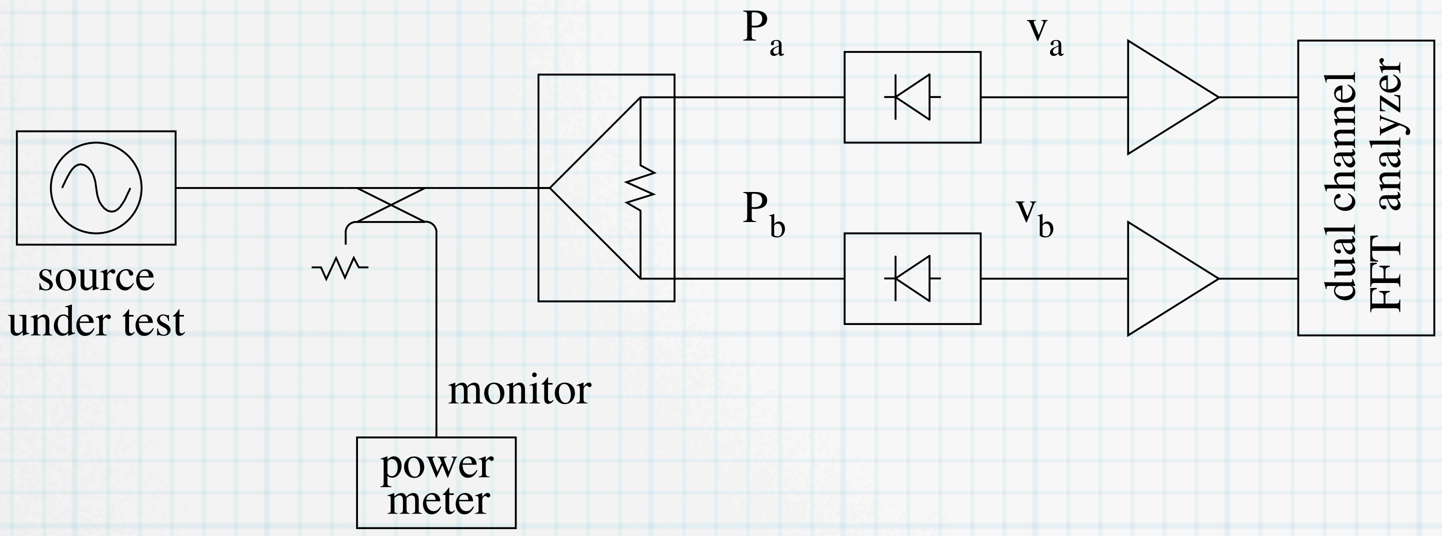
Flicker (1/*f*) noise is also present

Never say that it's *not fundamental*, unless you know how to remove it

In practice

the amplifier white noise turns out to be higher than the detector noise and the amplifier flicker noise is even higher

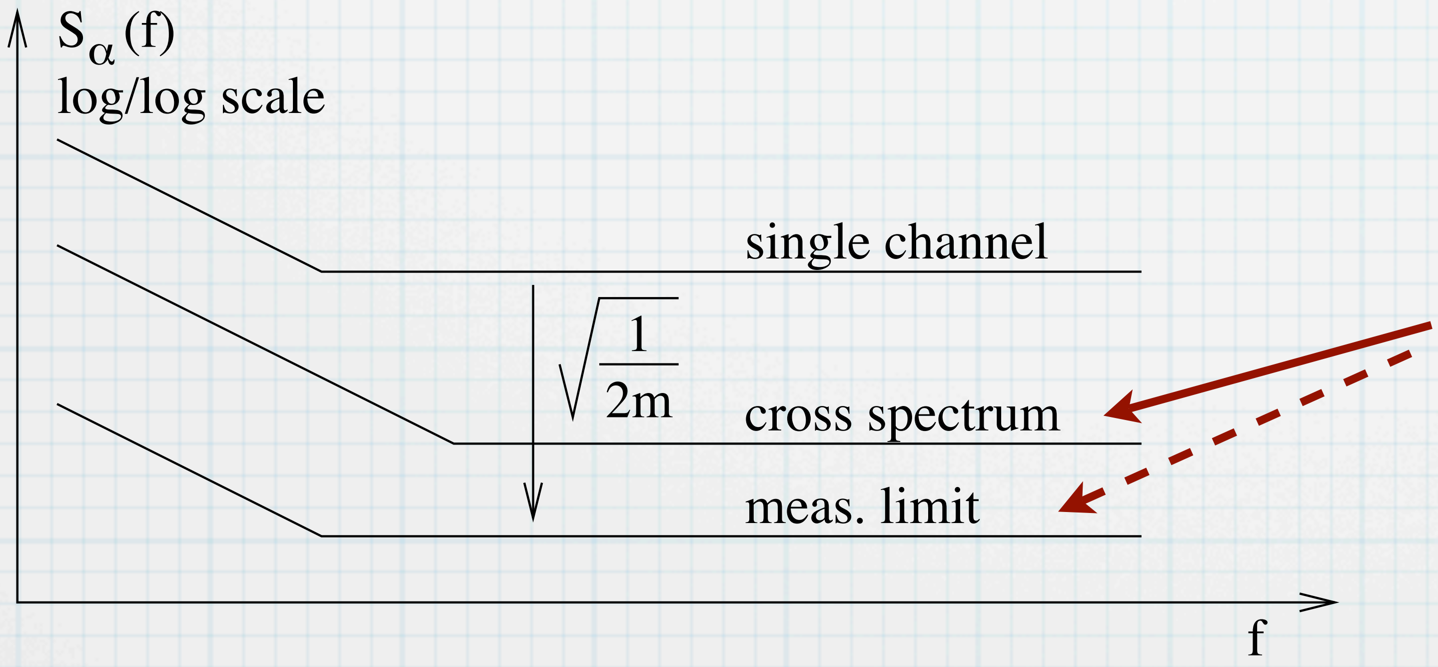
Cross-spectrum method



$$v_a(t) = 2k_a P_a \alpha(t) + \text{noise}$$
$$v_b(t) = 2k_a P_b \alpha(t) + \text{noise}$$

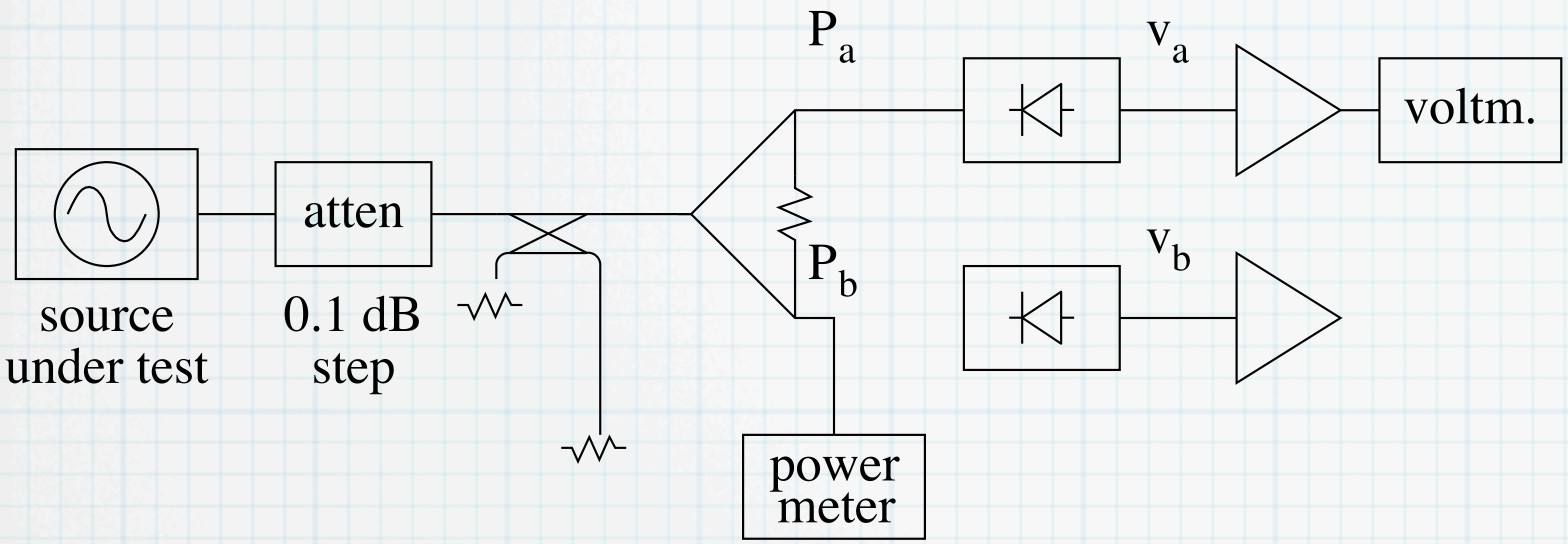
The cross spectrum $S_{ba}(f)$ rejects the single-channel noise because the two channels are independent.

$$S_{ba}(f) = \frac{1}{4k_a k_b P_a P_b} S_\alpha(f)$$



- Averaging on m spectra, the single-channel noise is rejected by $\sqrt{1/2m}$
- A cross-spectrum higher than the averaging limit validates the measure
- The knowledge of the single-channel noise is not necessary

Calibration



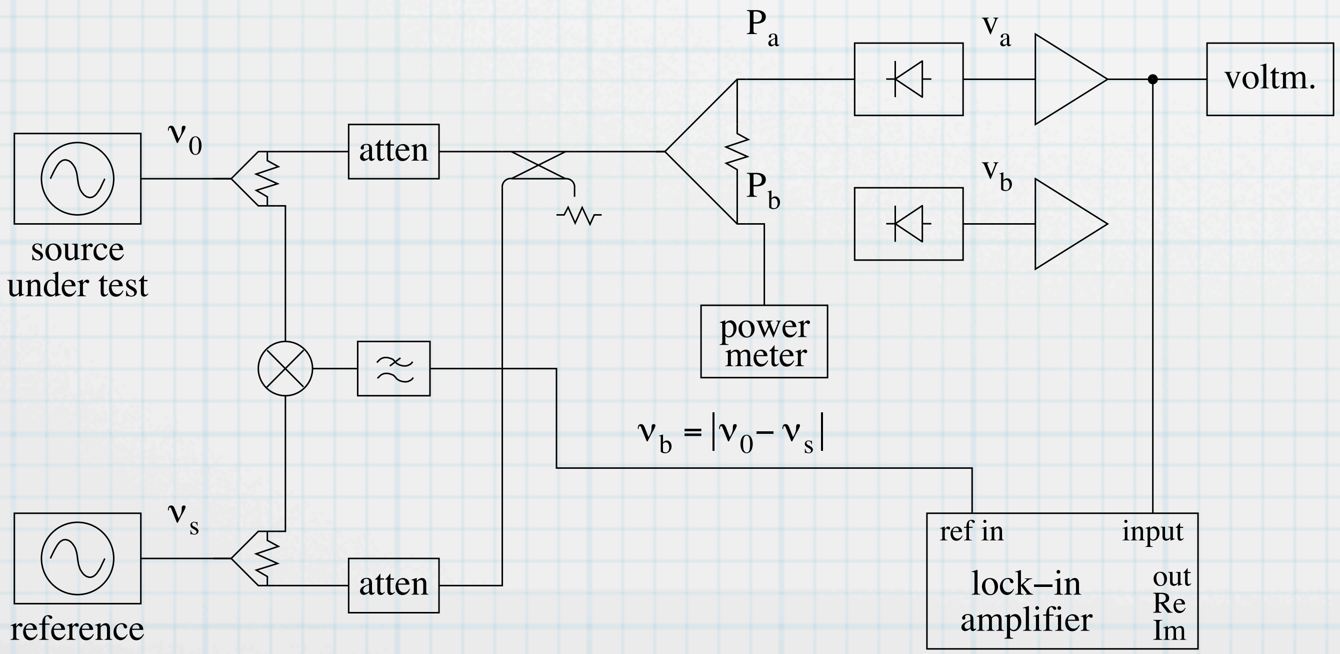
- Set a reference $\Delta P/P_a$ (0.1 dB) with a by-step attenuator
- Measure Δv_a at the output

$$k_a P_a = \frac{\Delta v_a}{\Delta P/P_a}$$

- Repeat interchanging the channels

Note that only the kP product is needed because

$$S_{ba}(f) = \frac{1}{4 k_a k_b P_a P_b} S_\alpha(f)$$

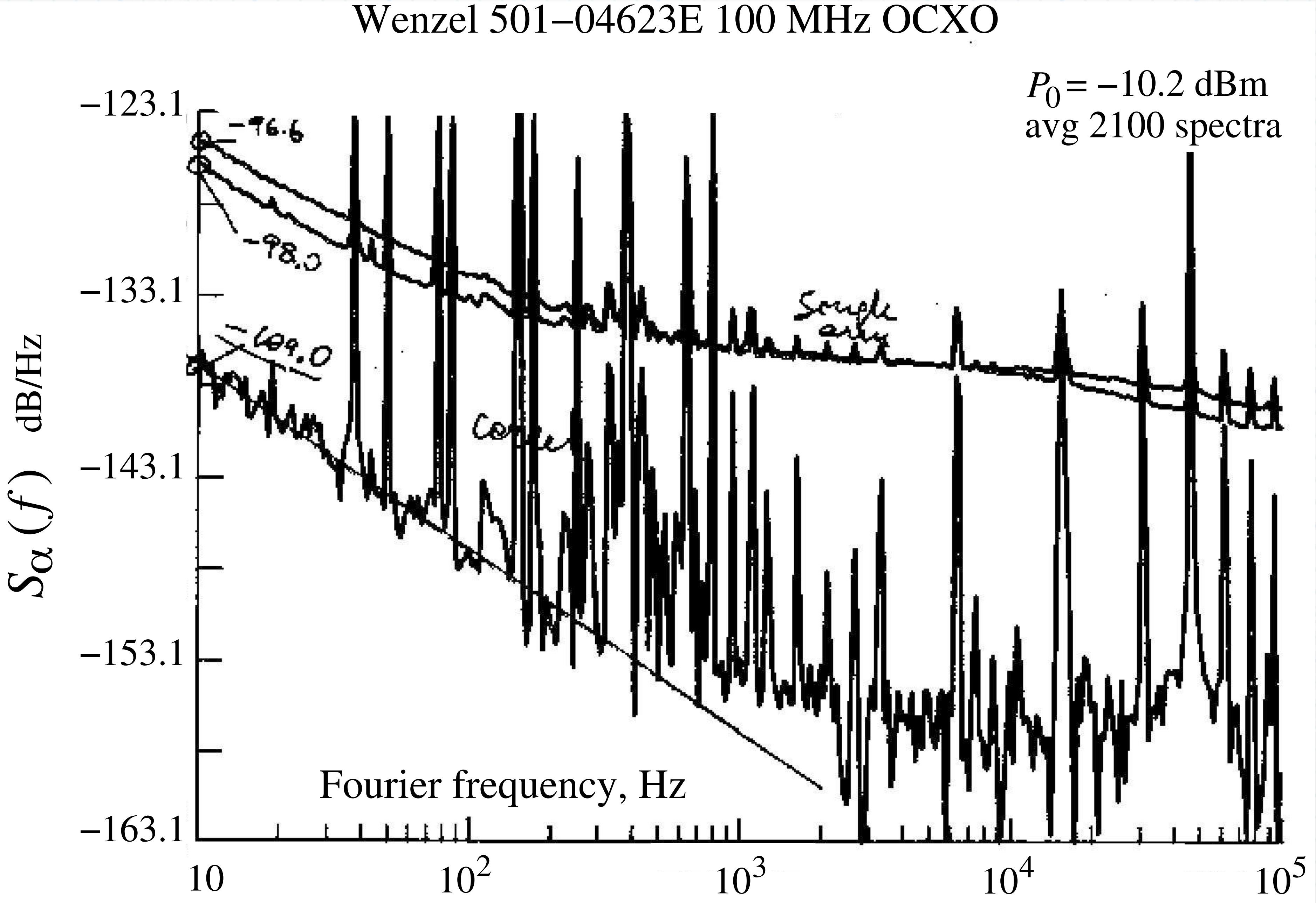


Alternate (and complex) calibration method.

– It exploits the sensitivity and the accuracy of a lock-in amplifier.

– As before, it requires a reference power-ratio

Example of AM noise spectrum



flicker: $h_{-1} = 1.5\times10^{-13}\ \mathrm{Hz}^{-1}\ (-128.2\ \mathrm{dB}) \quad\Rightarrow\quad \sigma_\alpha = 4.6\times10^{-7}$

Single-arm 1/f noise is that of the dc amplifier

(the amplifier is still not optimized)

AM noise of some sources

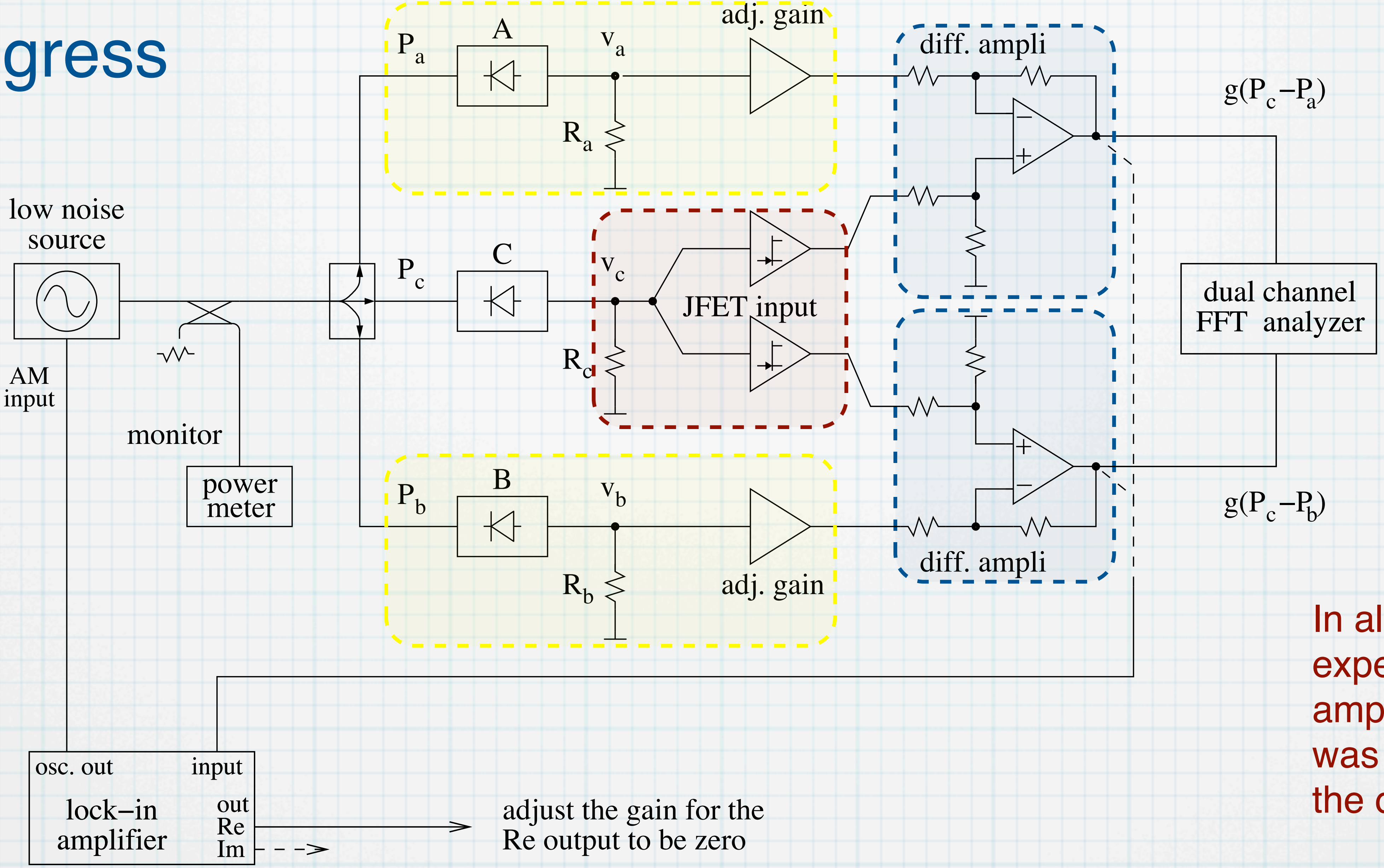
source	h_{-1} (flicker)		$(\sigma_\alpha)_{\text{floor}}$
Anritsu MG3690A synthesizer (10 GHz)	2.5×10^{-11}	-106.0 dB	5.9×10^{-6}
Marconi synthesizer (5 GHz)	1.1×10^{-12}	-119.6 dB	1.2×10^{-6}
Macom PLX 32-18 0.1 → 9.9 GHz multipl.	1.0×10^{-12}	-120.0 dB	1.2×10^{-6}
Omega DRV9R192-105F 9.2 GHz DRO	8.1×10^{-11}	-100.9 dB	1.1×10^{-5}
Narda DBP-0812N733 amplifier (9.9 GHz)	2.9×10^{-11}	-105.4 dB	6.3×10^{-6}
HP 8662A no. 1 synthesizer (100 MHz)	6.8×10^{-13}	-121.7 dB	9.7×10^{-7}
HP 8662A no. 2 synthesizer (100 MHz)	1.3×10^{-12}	-118.8 dB	1.4×10^{-6}
Fluke 6160B synthesizer	1.5×10^{-12}	-118.3 dB	1.5×10^{-6}
Racal Dana 9087B synthesizer (100 MHz)	8.4×10^{-12}	-110.8 dB	3.4×10^{-6}
Wenzel 500-02789D 100 MHz OCXO	4.7×10^{-12}	-113.3 dB	2.6×10^{-6}
Wenzel 501-04623E no. 1 100 MHz OCXO	2.0×10^{-13}	-127.1 dB	5.2×10^{-7}
Wenzel 501-04623E no. 2 100 MHz OCXO	1.5×10^{-13}	-128.2 dB	4.6×10^{-7}

worst

best

Measurement of the detector noise

In progress



adjust the gain for the
Re output to be zero

In all previous experiments, the amplifier noise was higher than the detector noise

Basic ideas

- Remove the noise of the source by balancing C–A and C–B
  - Use a lock-in amplifier to get a sharp null measurement
- Channels A and B are independent –> noise is averaged out
- Two separate JFET amplifiers are needed in the C channel
  - JFETs have virtually no bias-current noise
- **Only the noise of the detector C remains**

Conclusions

- Method for the measurement of AM noise in oscillators
  - High sensitivity and accurate calibration
  - Suitable to optics and to microwave photonics
  - Measurement of some RF/microwave sources

- Single-channel sensitivity still limited by the dc amplifier
- Measurement of the detector noise in progress

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Free downloads (text and slides)

http://arxiv.org/abs/physics/0512082 (text only)