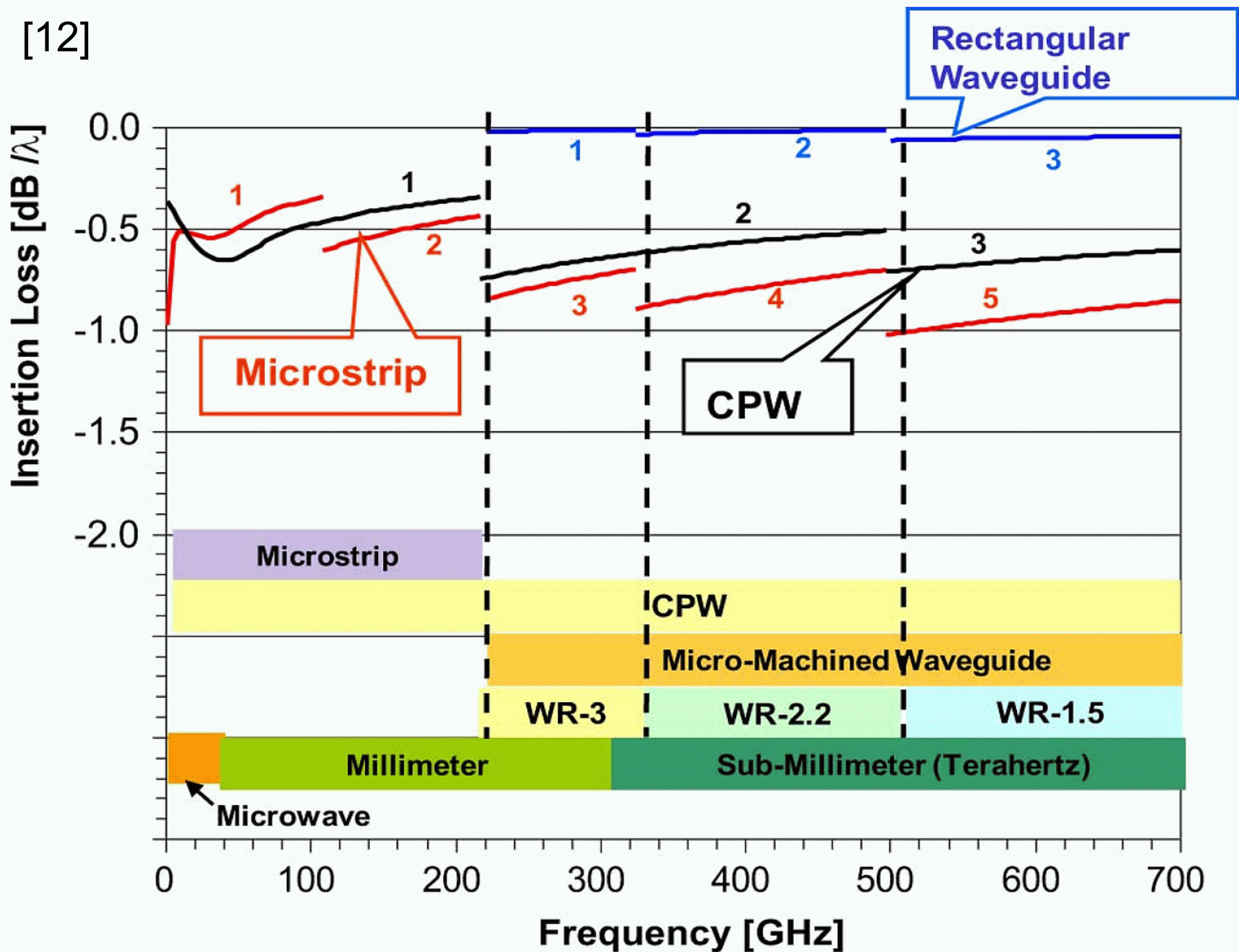
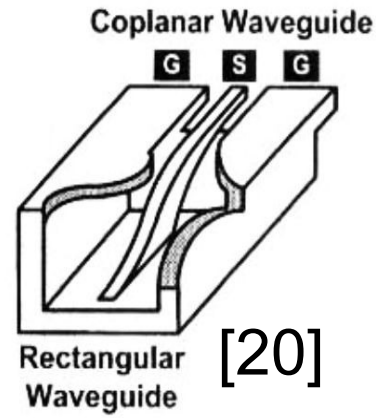
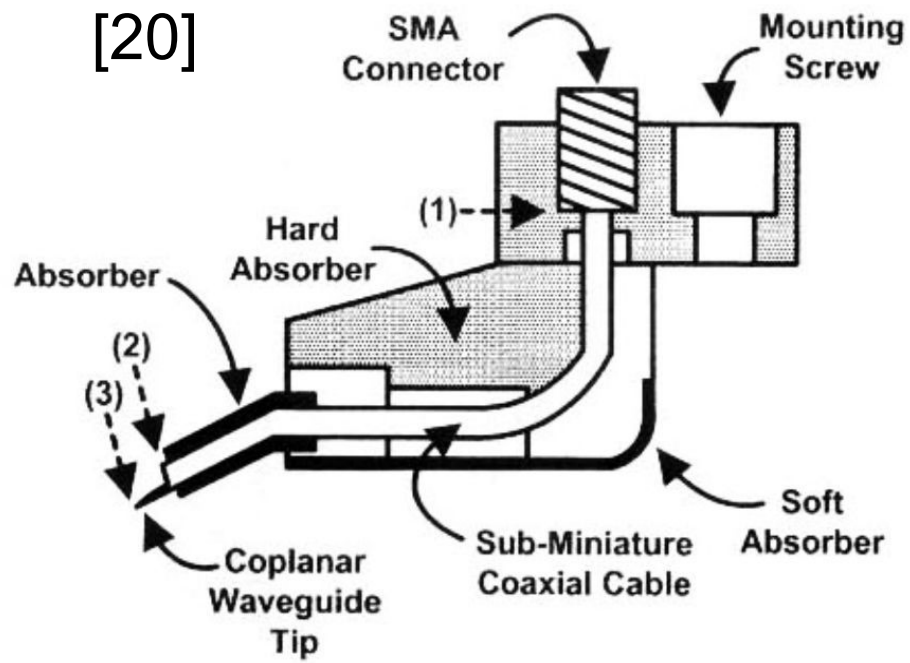


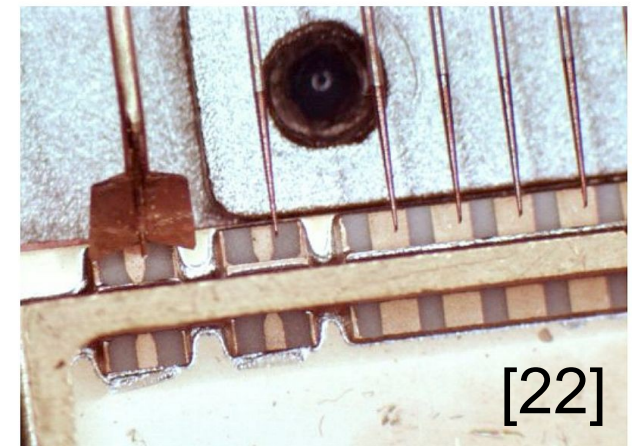
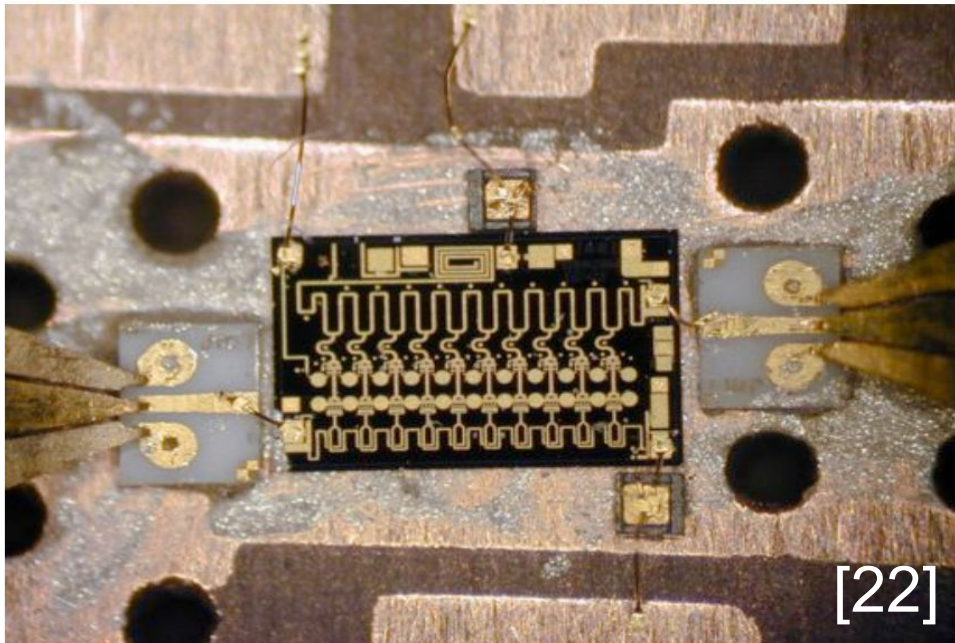
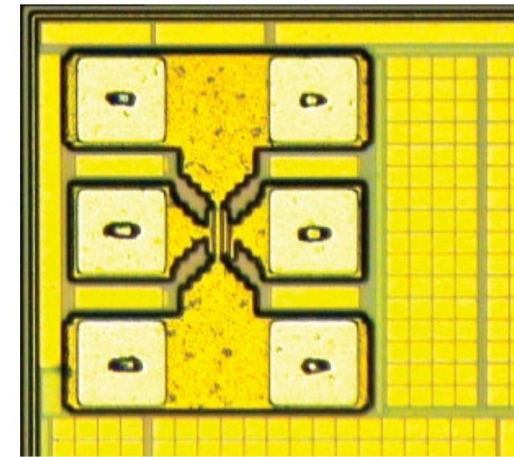
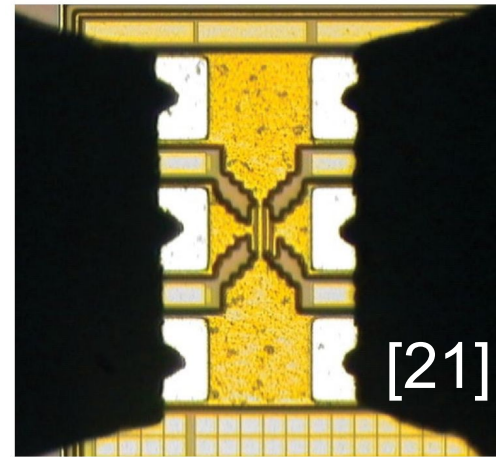
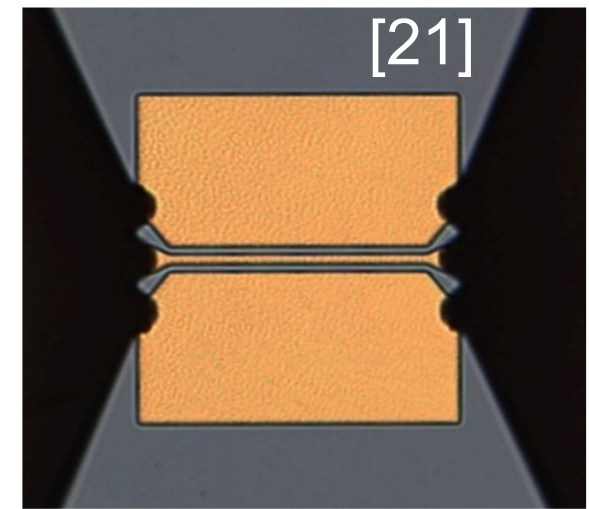
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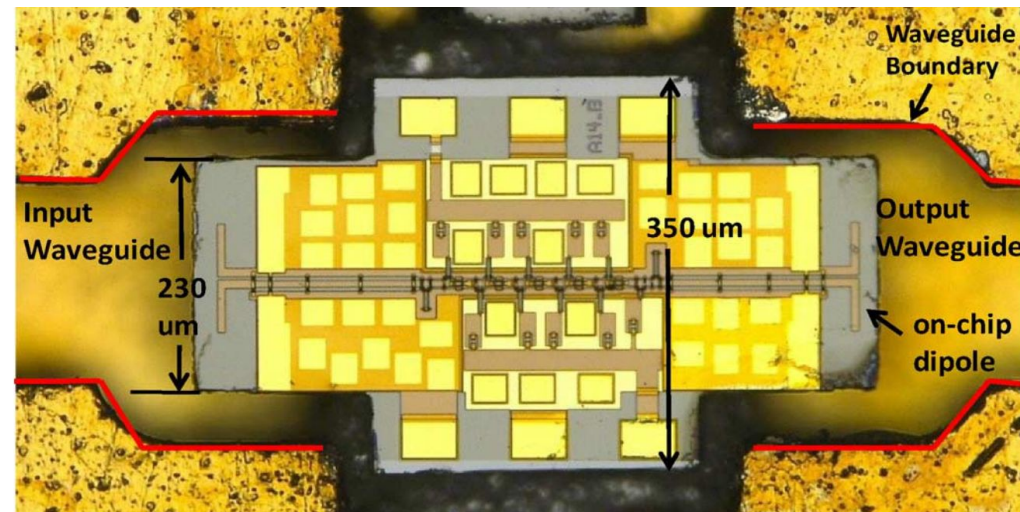
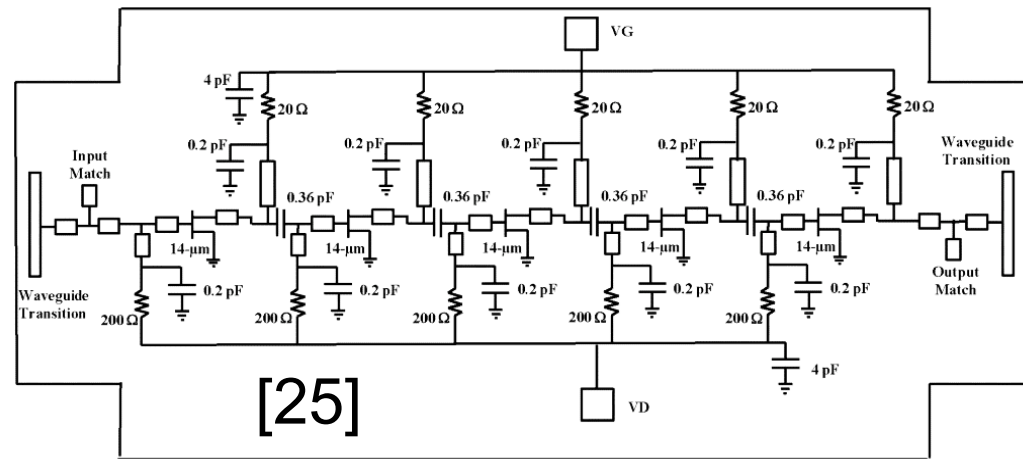
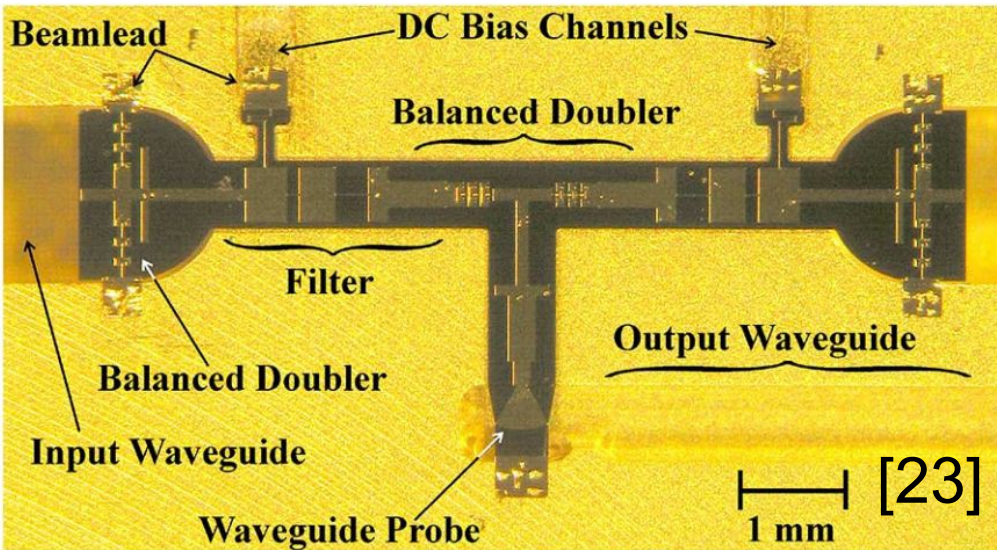
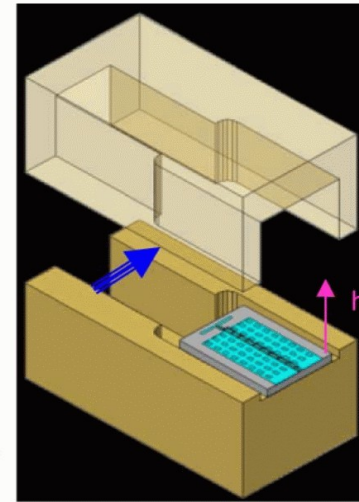
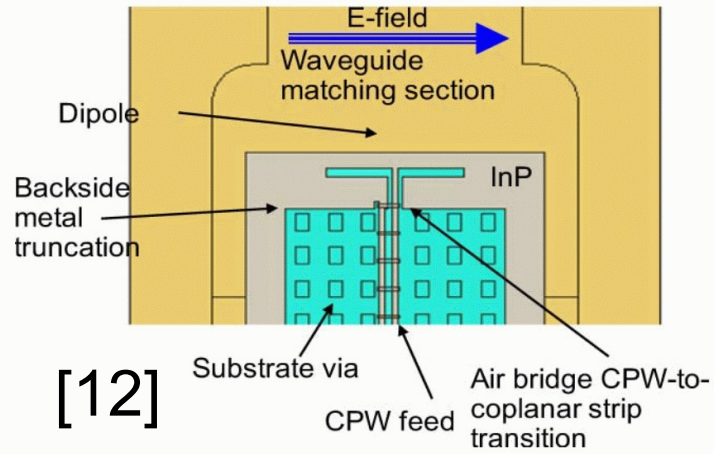
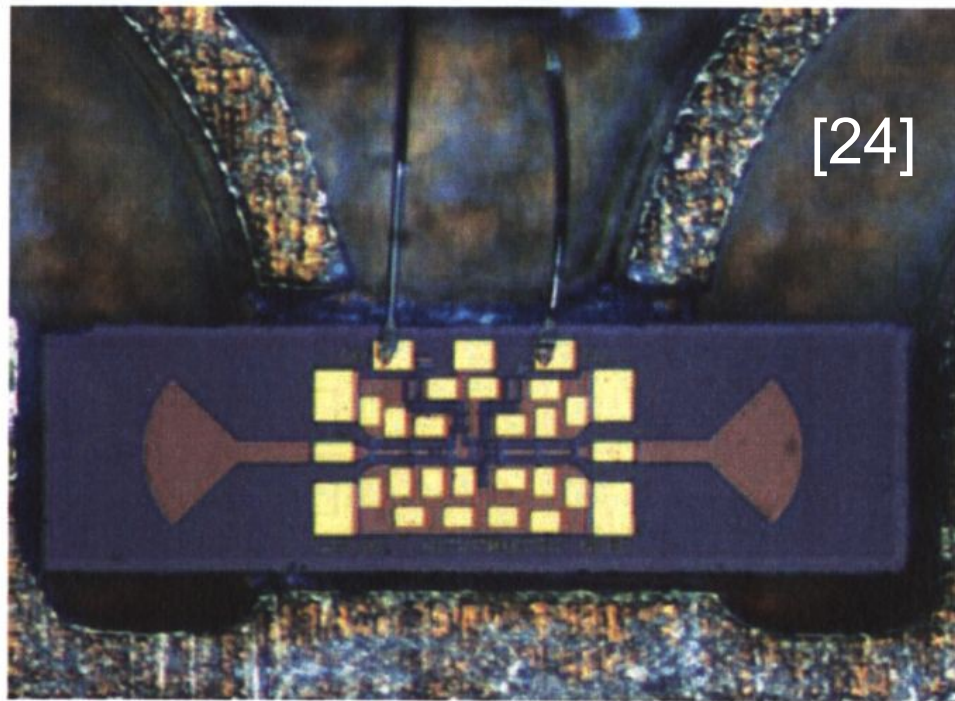
14 - Transmission-line losses in the mm / THz range

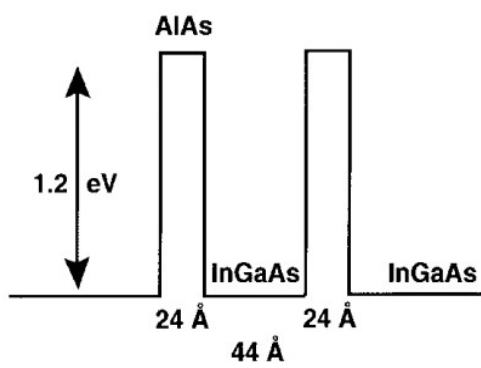
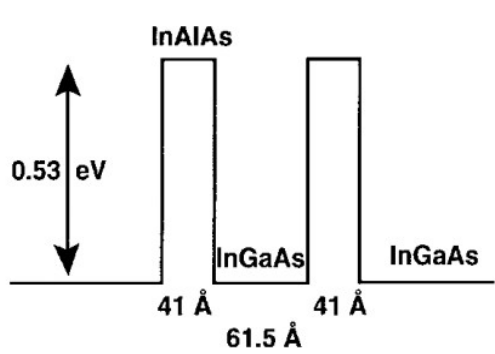


[20]

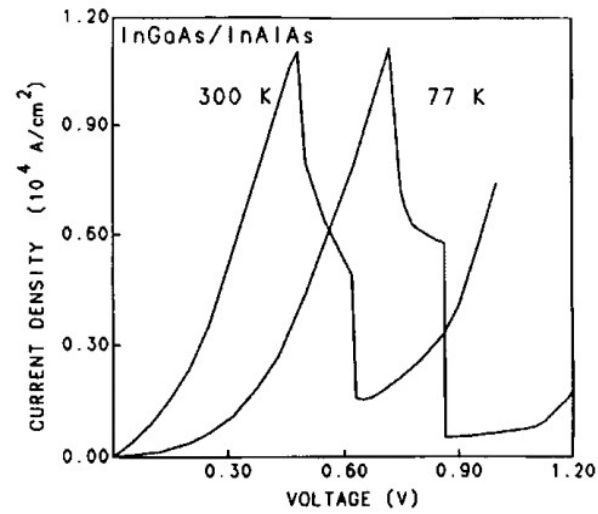
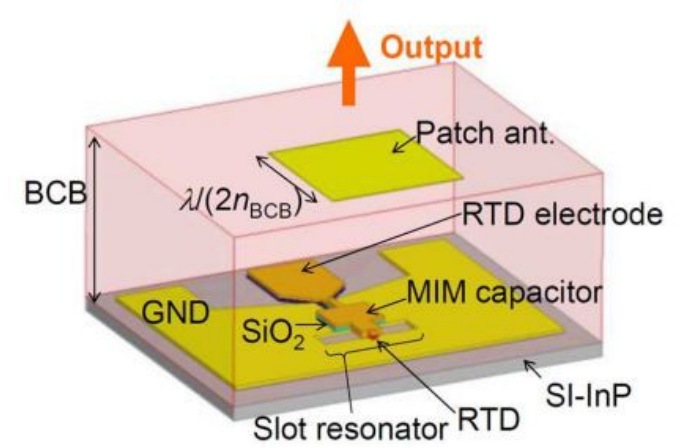


15 - Coplanar-waveguide (CPW) GSG probes

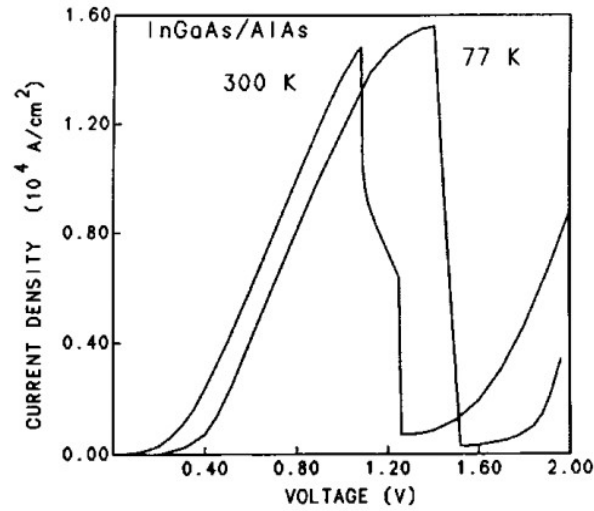




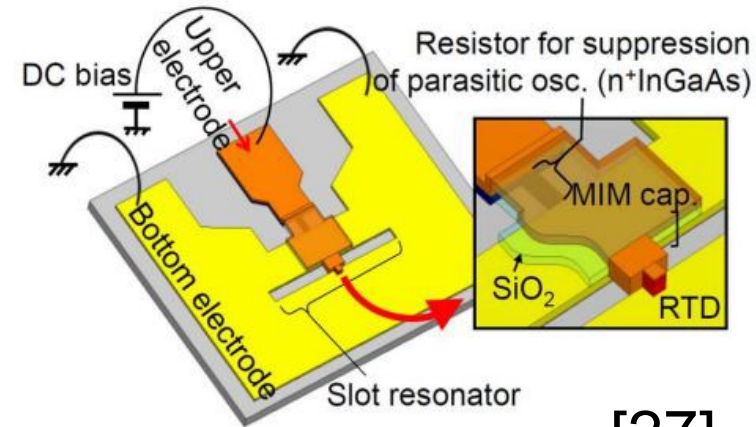
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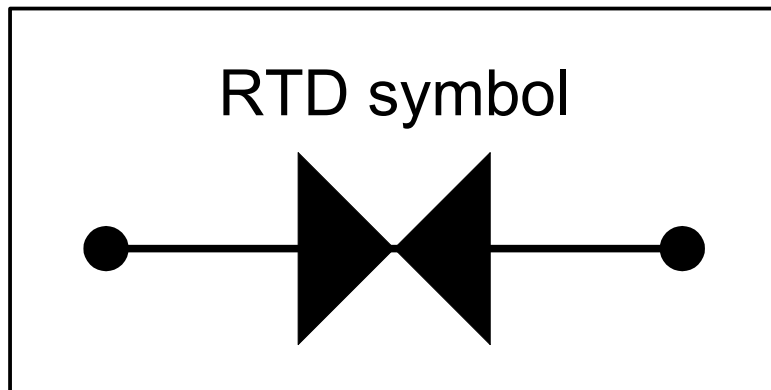
PVR ~ 6 @ 300 K
16 @ 77 K



PVR ~ 23 @ 300 K
53 @ 77 K

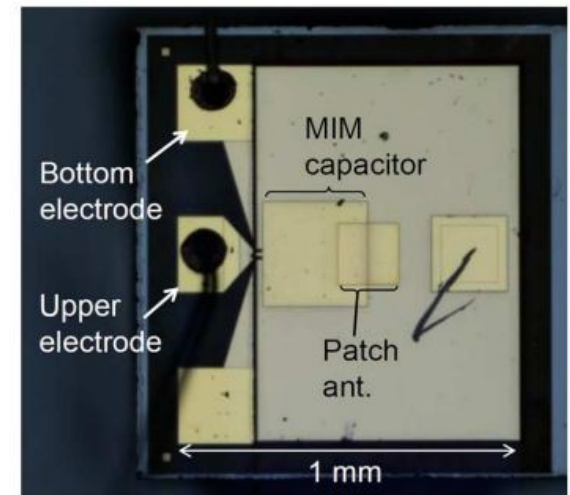


[27]

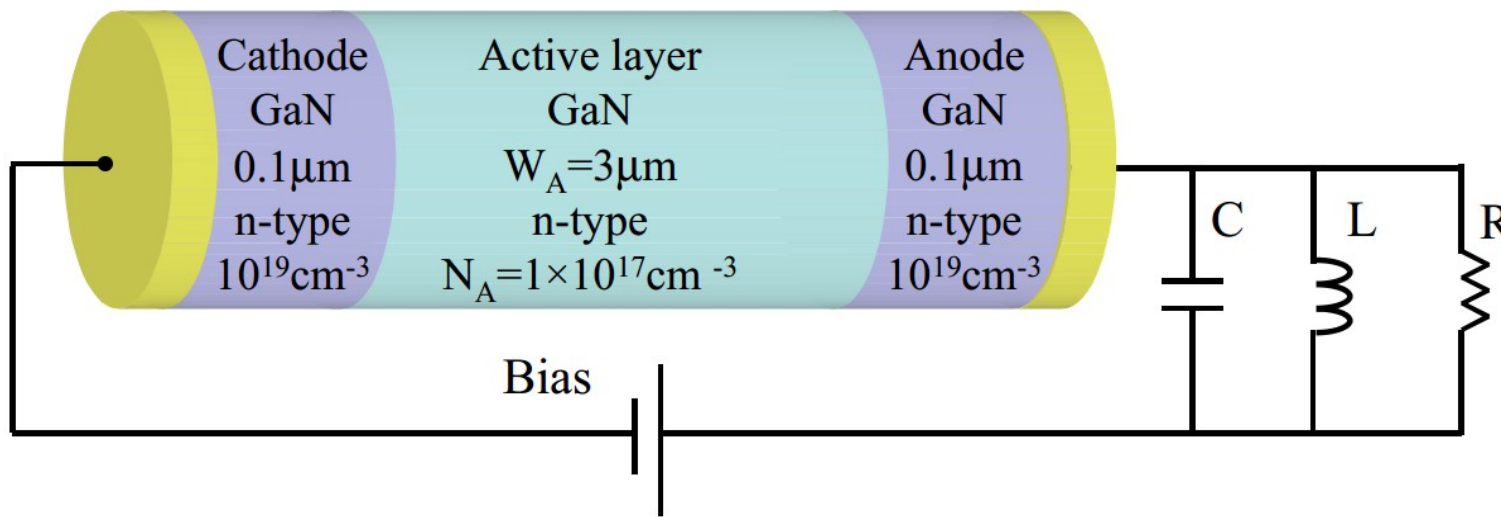


$f \approx 510$ GHz

$P \approx 40$ μ W



17 - Resonant tunnel diode (RTD)



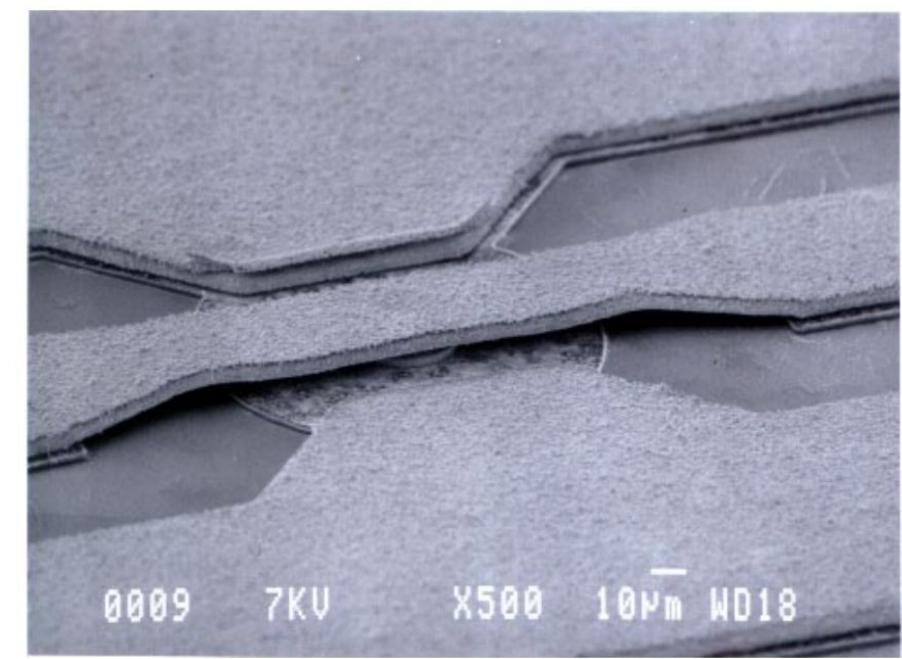
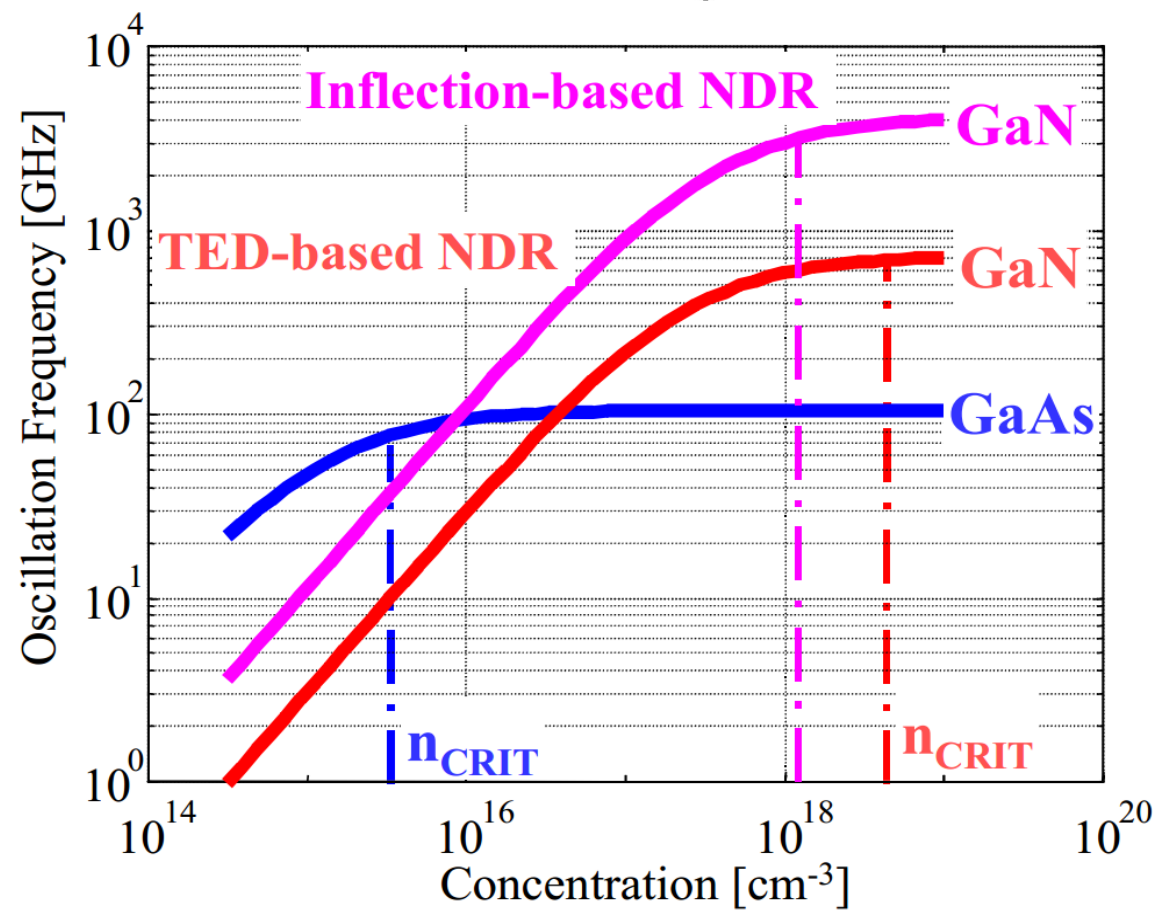
$$f_{\text{GaAs}} \approx 100 \text{GHz}$$

$$f_{\text{InP}} \approx 250 \text{GHz}$$

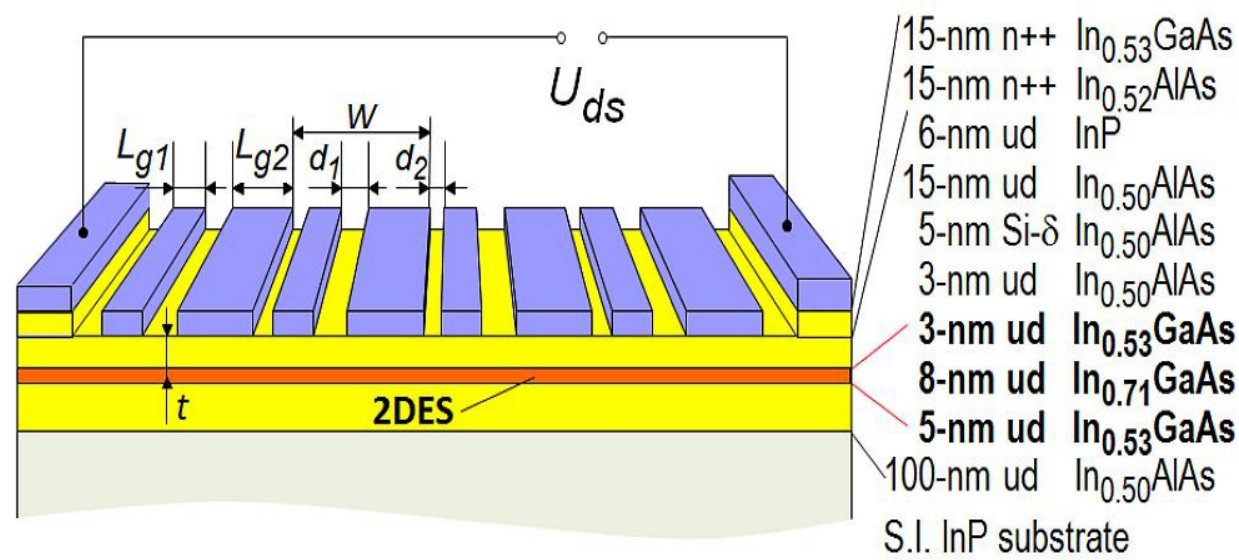
$$f_{\text{GaN}} \approx 3 \text{THz}$$

$$P \approx 100 \text{mW}$$

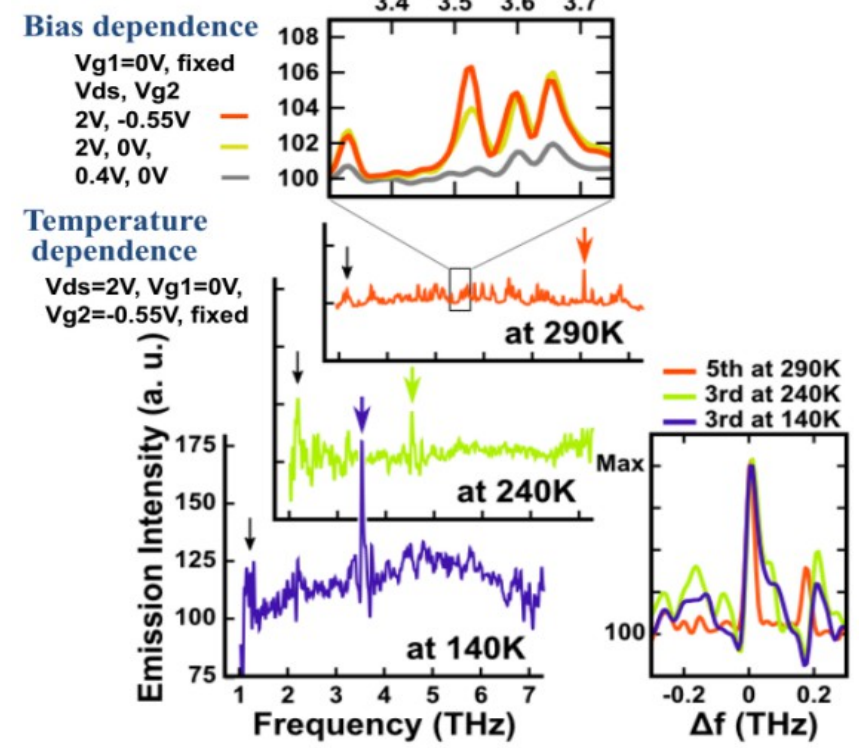
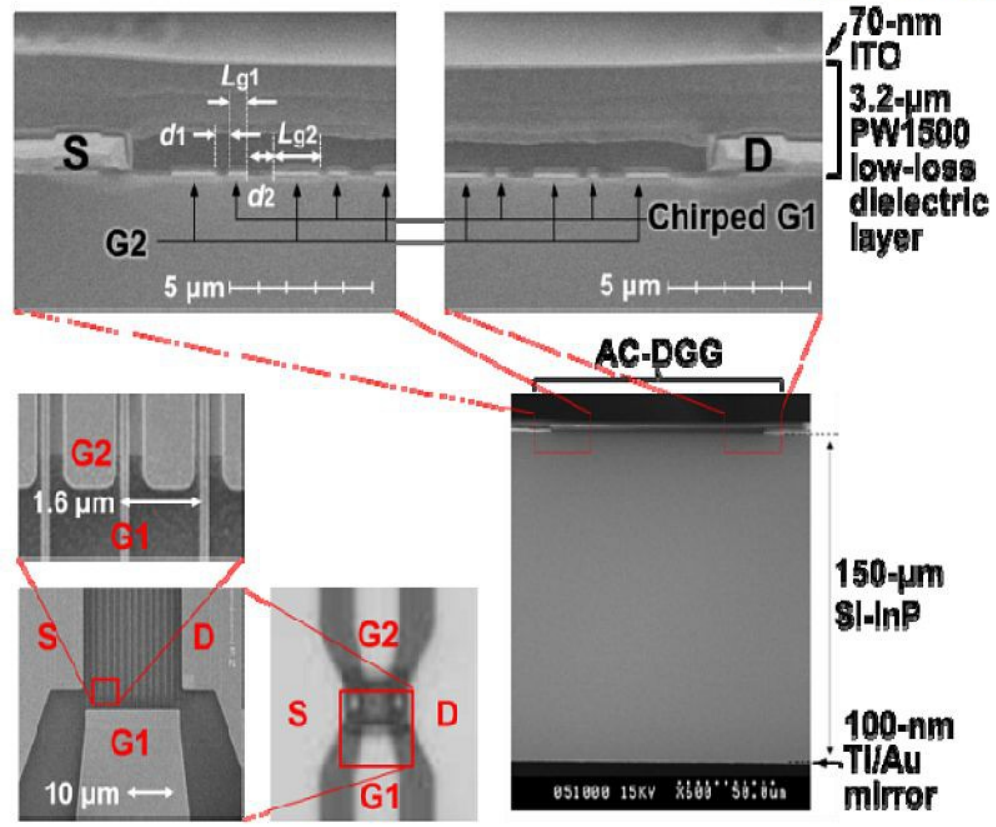
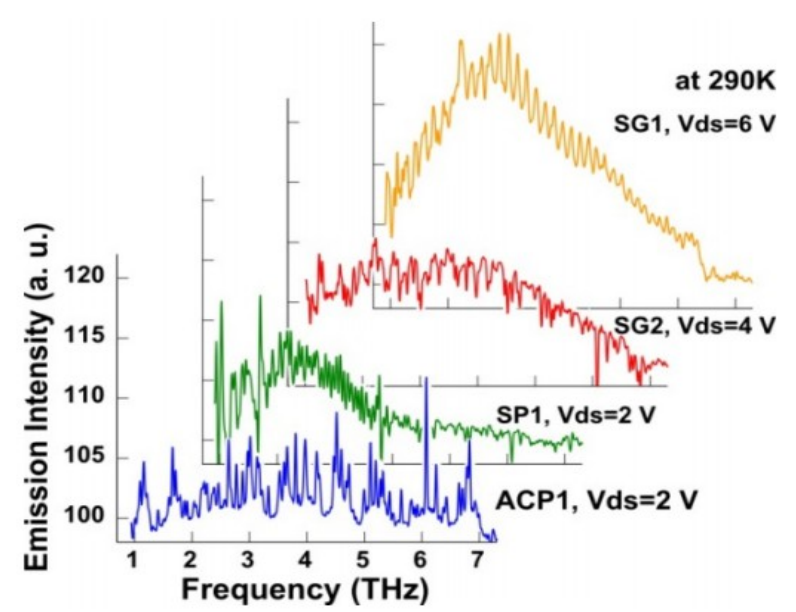
[28]

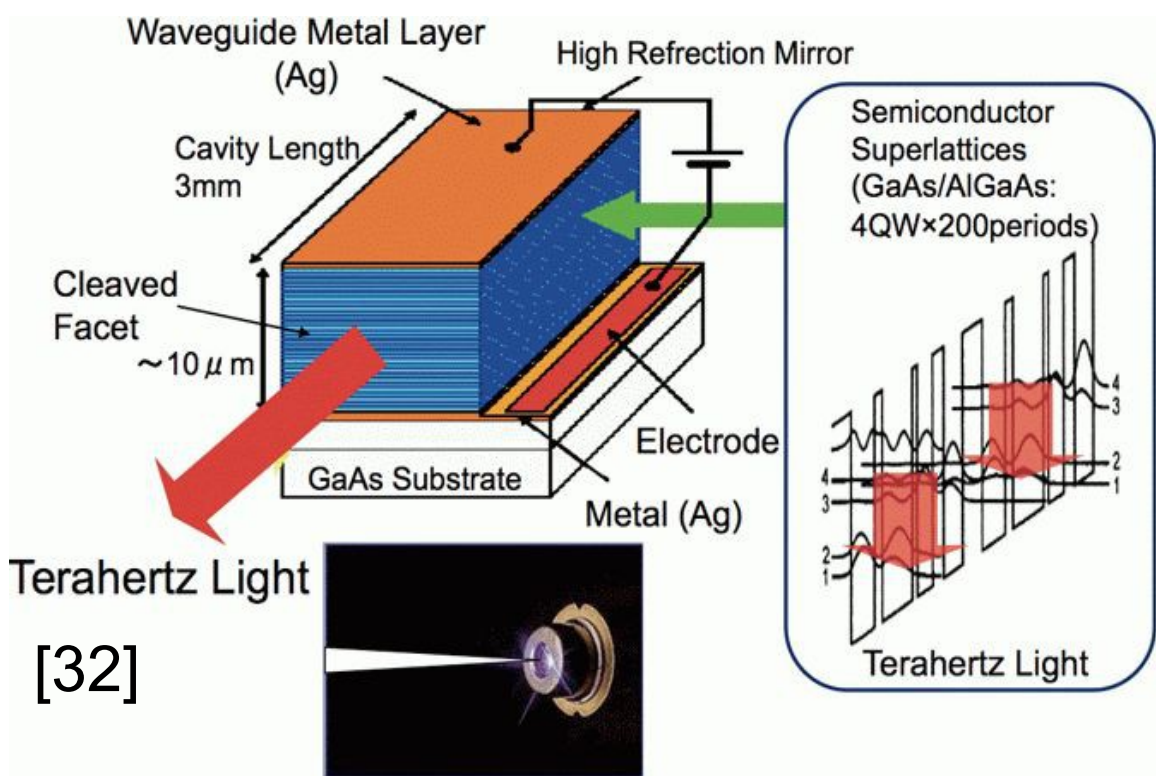


18 - Negative-differential-resistance (NDR) diodes (Gunn, TED)

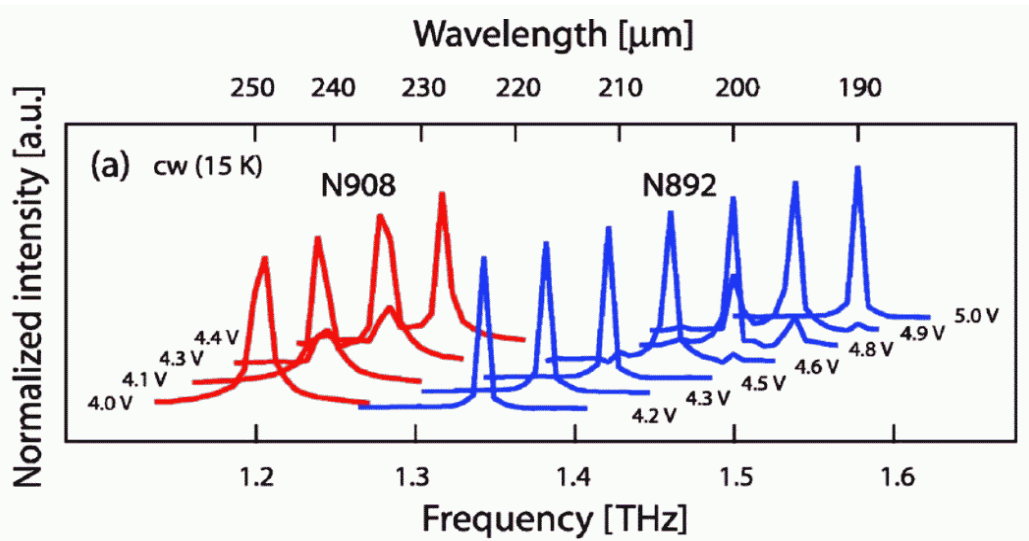


[29] P ≈ 100 nW ... 1 μW



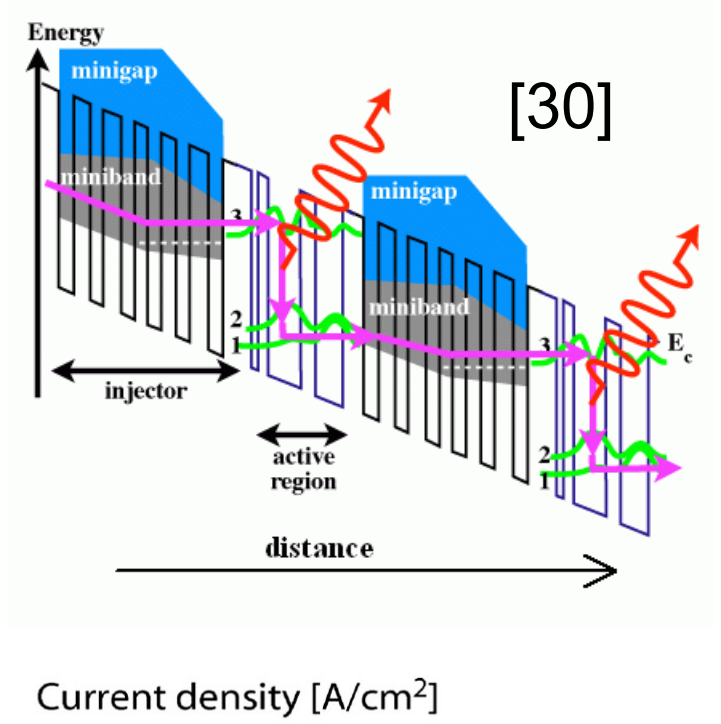
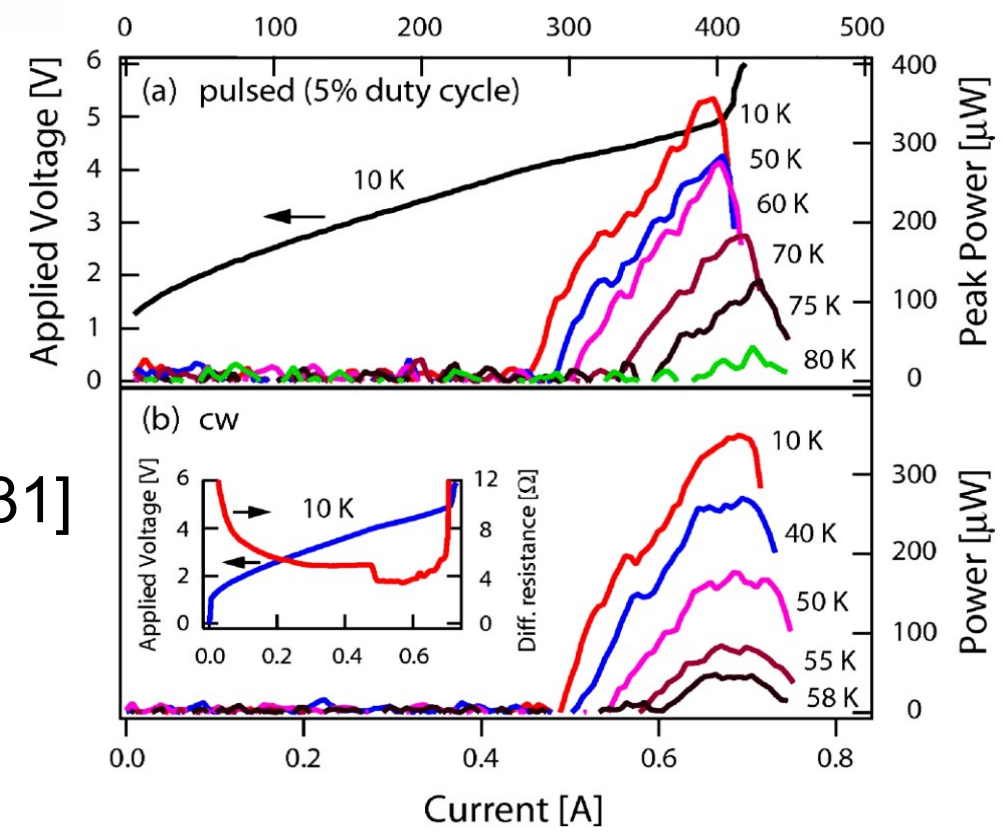


Terahertz Light
[32]

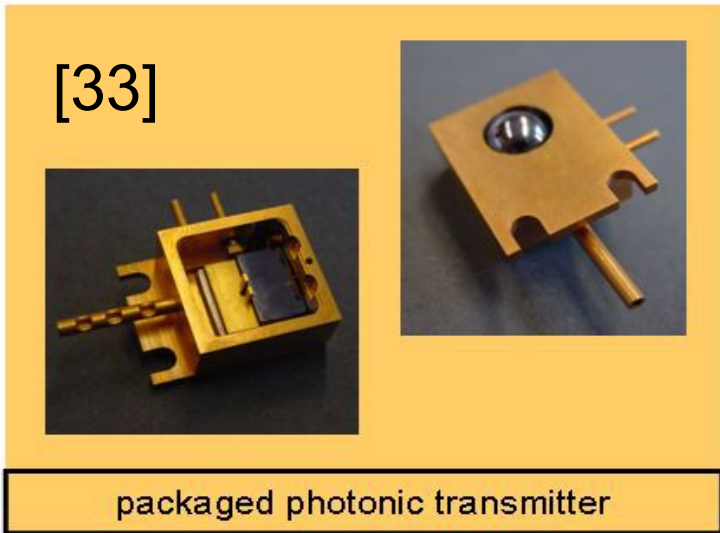
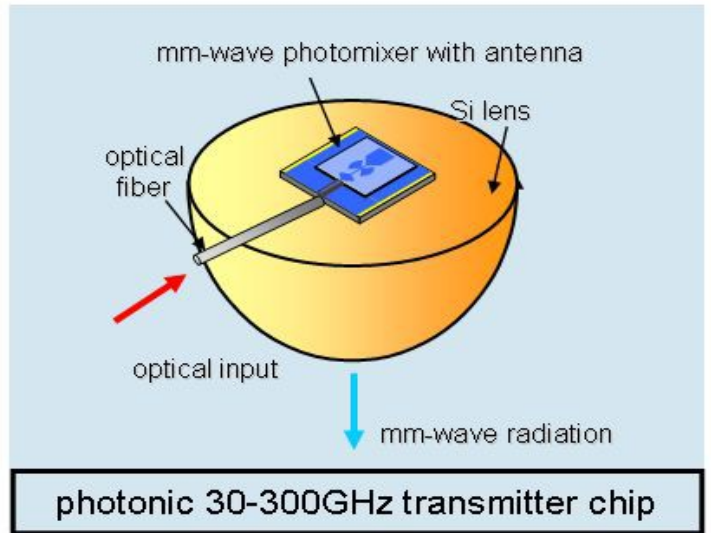
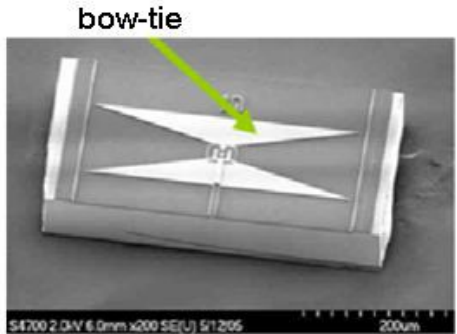
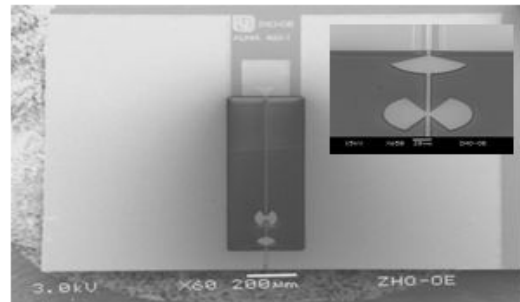
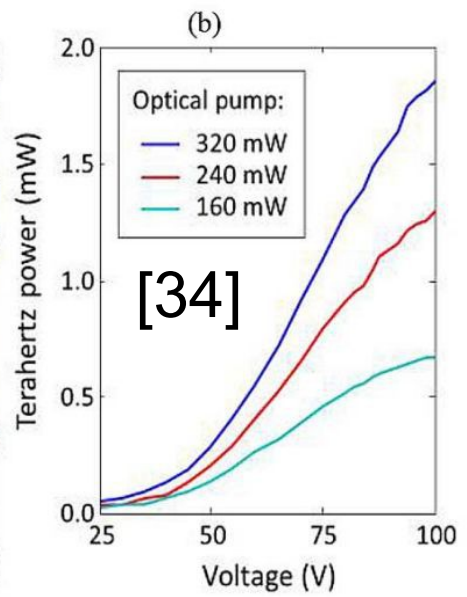
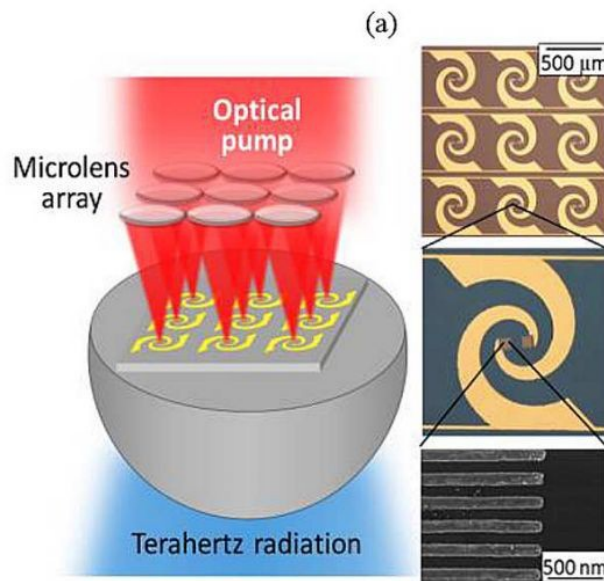
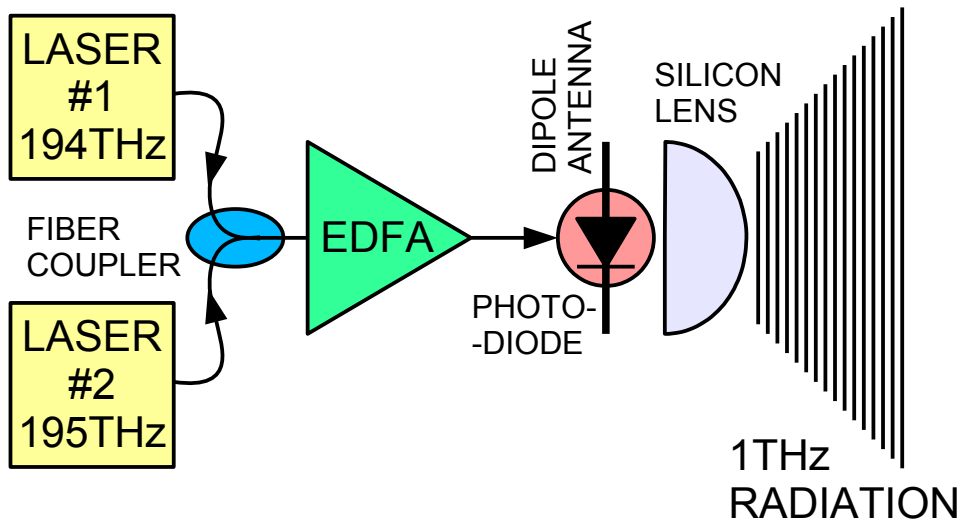


20 - Quantum-cascade laser

[31]



[30]



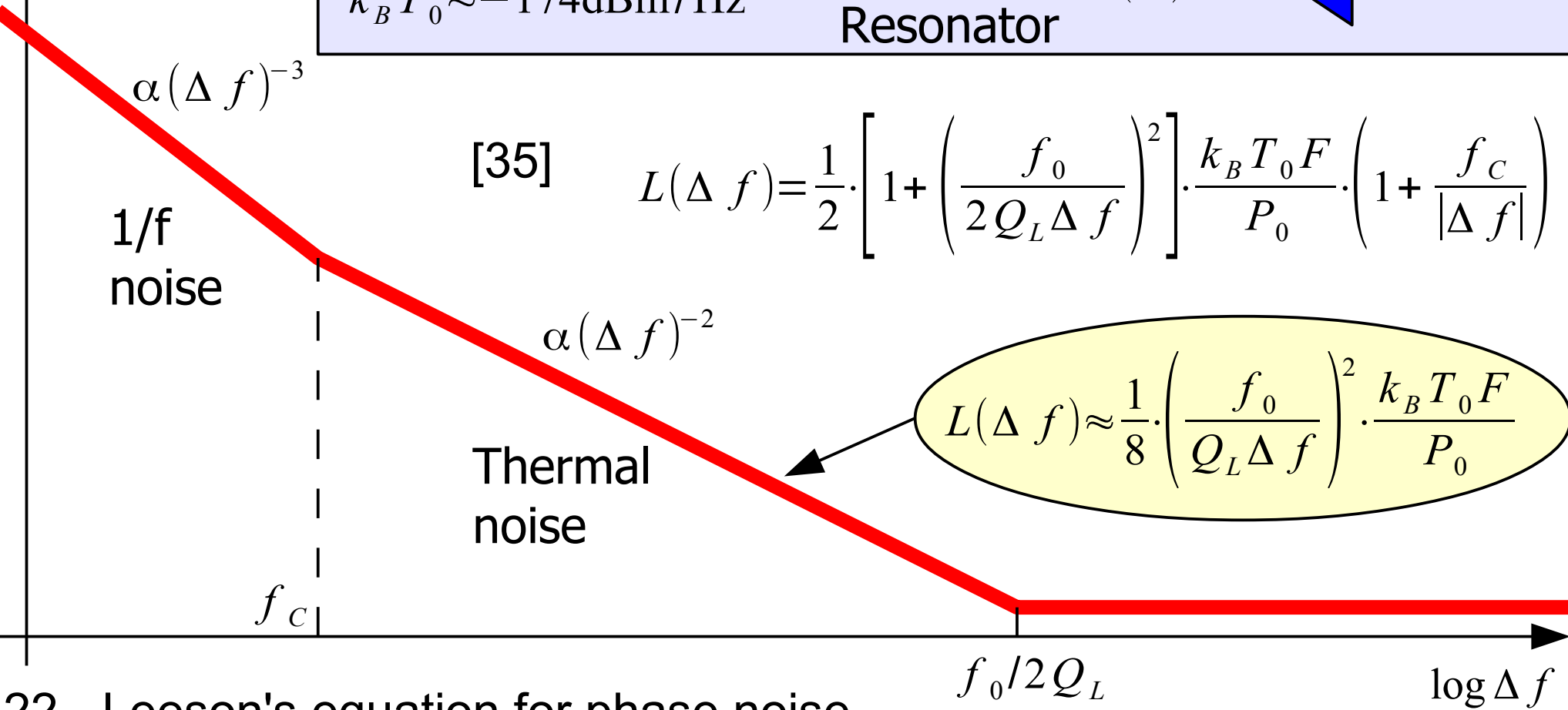
WIDE
 FREQUENCY
 RANGE

LOW POWER
 $P \approx 10\mu\text{W} \dots 1\text{mW}$

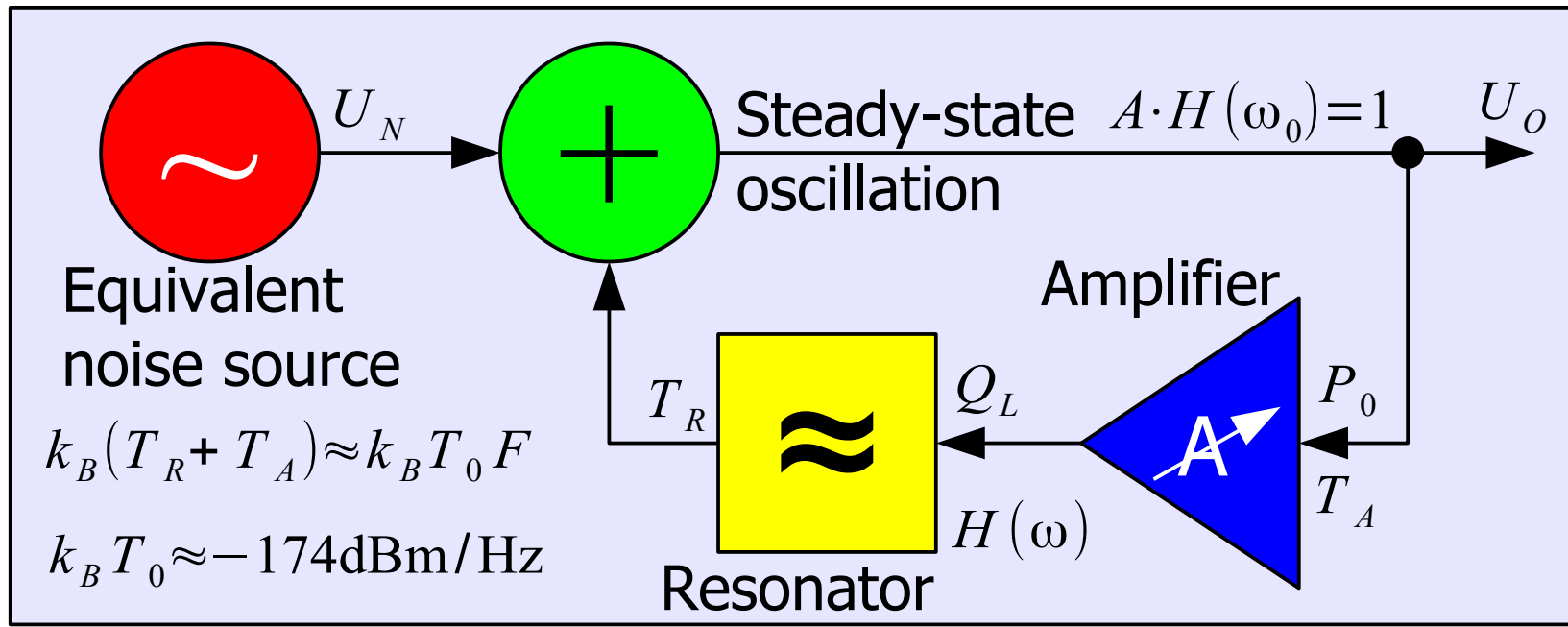
LASER PHASE
 NOISE?

Phase-noise spectral density

$\log L(\Delta f)$
[dBc/Hz]



22 - Leeson's equation for phase noise



[35]
$$L(\Delta f) = \frac{1}{2} \cdot \left[1 + \left(\frac{f_0}{2Q_L \Delta f} \right)^2 \right] \cdot \frac{k_B T_0 F}{P_0} \cdot \left(1 + \frac{f_c}{|\Delta f|} \right)$$

$$L(\Delta f) \approx \frac{1}{8} \cdot \left(\frac{f_0}{Q_L \Delta f} \right)^2 \cdot \frac{k_B T_0 F}{P_0}$$

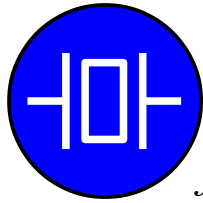
Active device	Noise temperature
Schottky diode	~300K
Transistor (BJT or FET)	~300K
Tunnel diode	~300K
Gunn diode	~300K
Vacuum tube	~10000K
Avalanche diode (Impatt diode)	~3000000K

Resonator	Q_L
RC (~BWO) tunable (VCO)!	~1
LC (~EIK) tunable or fixed!	~30
YIG @3GHz tunable!	~300
Metal cavity @3GHz fixed!	~3000
Ceramic dielectric @3GHz fixed!	~3000
Quartz crystal @100MHz fixed!	~30000
Electro-optical delay @6GHz fixed!	~100000
Sapphire dielectric @6GHz fixed!	~300000

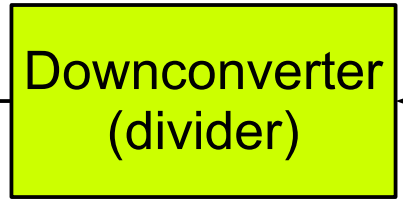
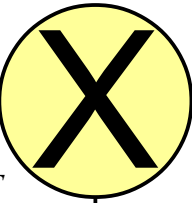
Phase-noise spectral density

$\log L(\Delta f)$
[dBc/Hz]

Reference (XTAL)



f_{REF}



f_{OUT}

Phase comparator



Loop delay=?

Loop filter

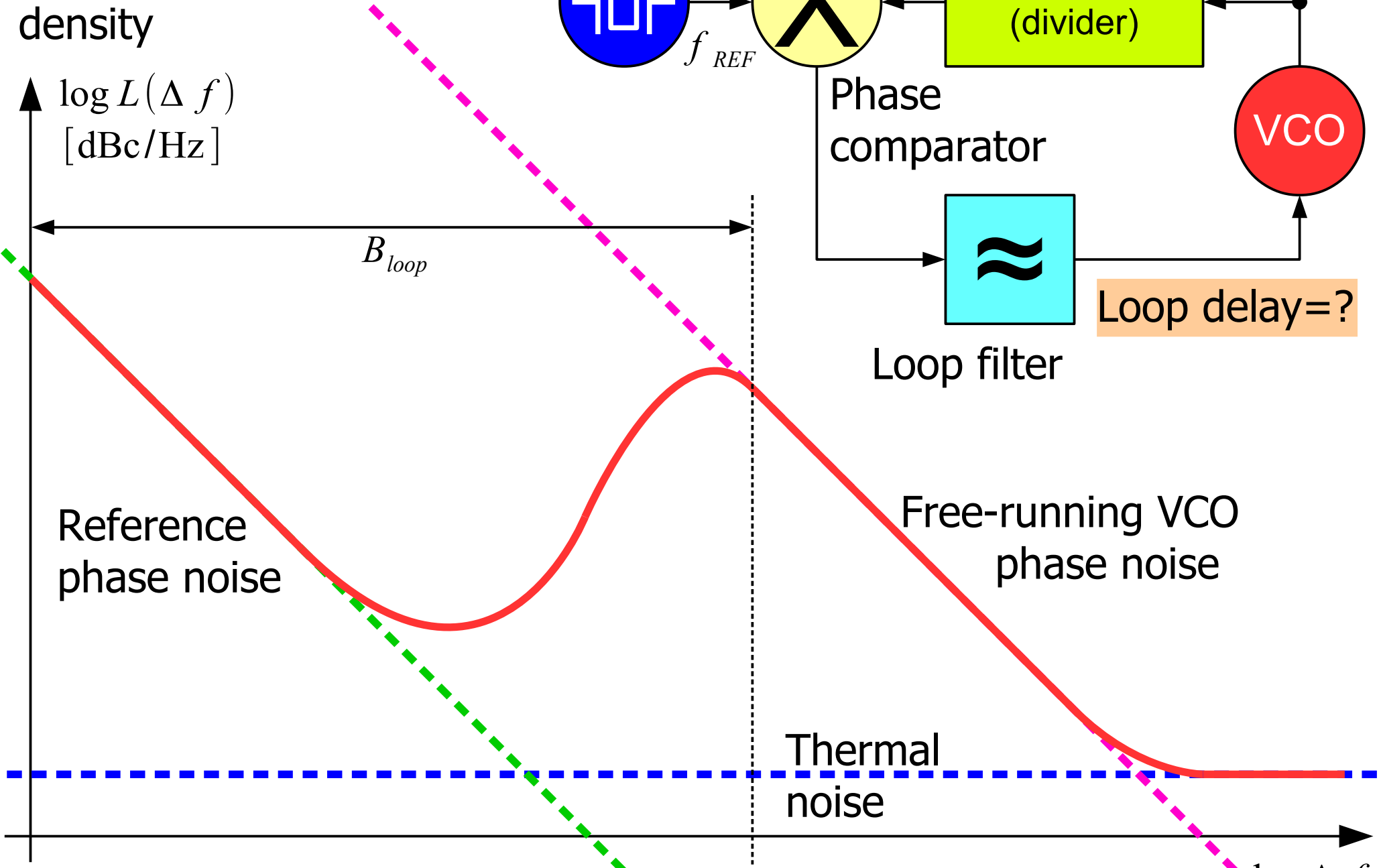
B_{loop}

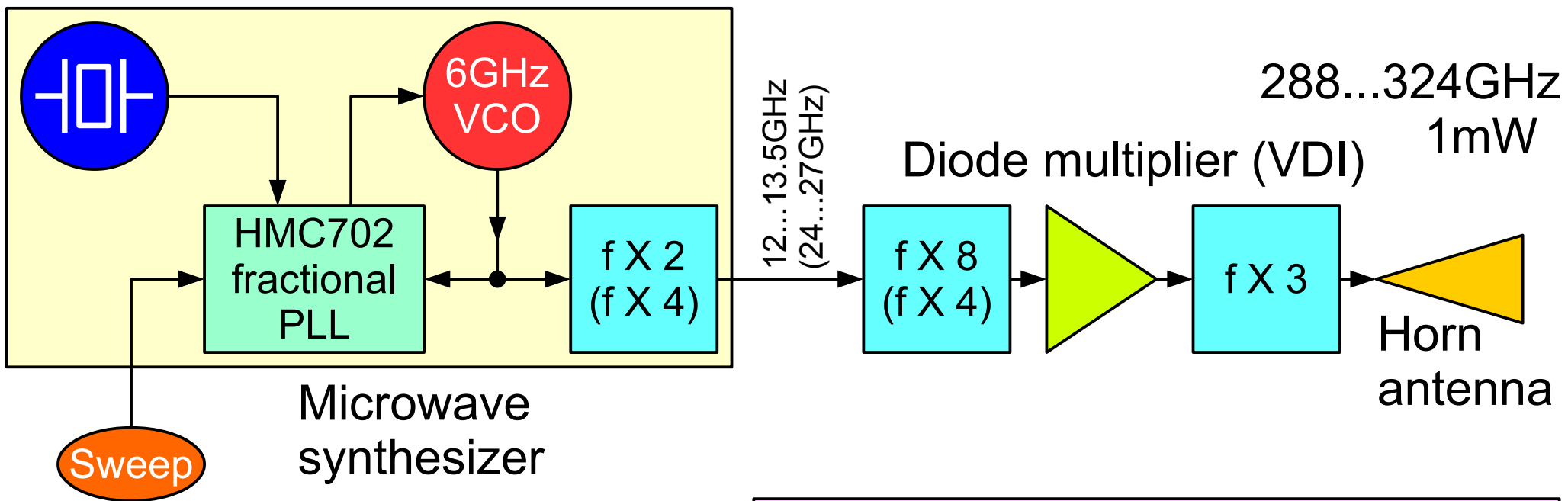
Reference phase noise

Free-running VCO phase noise

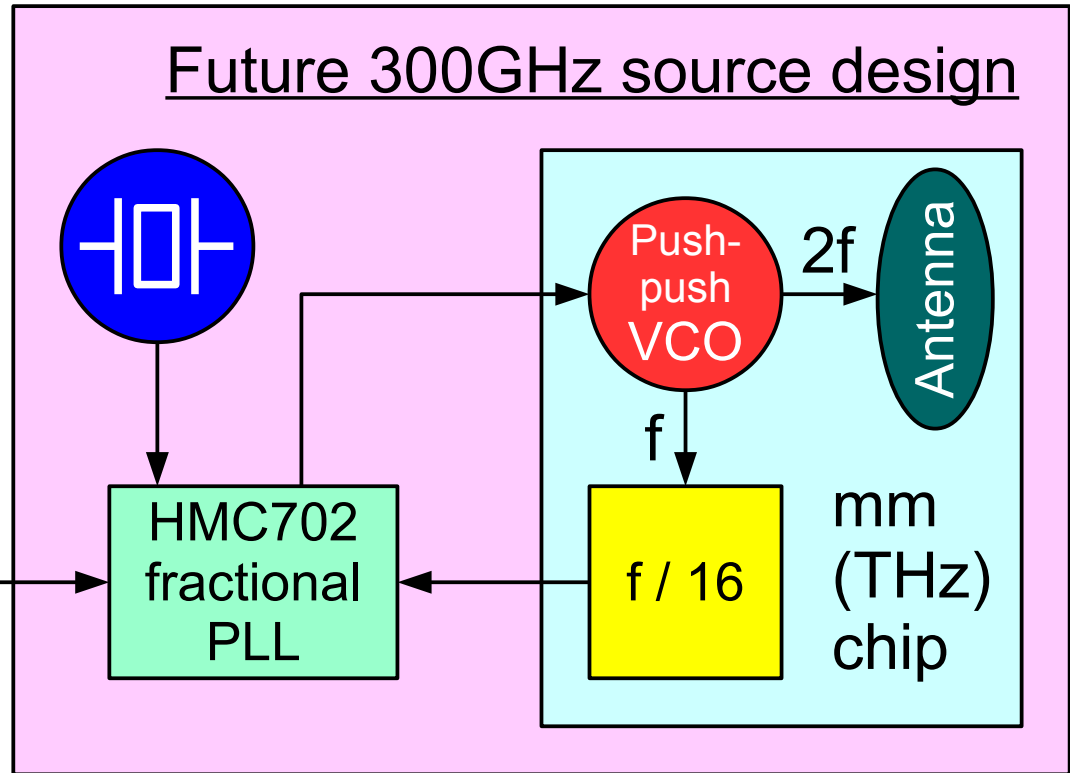
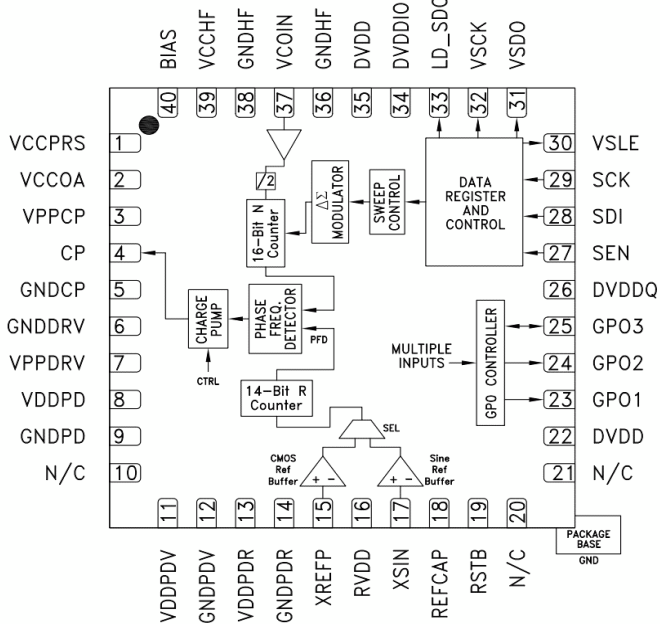
Thermal noise

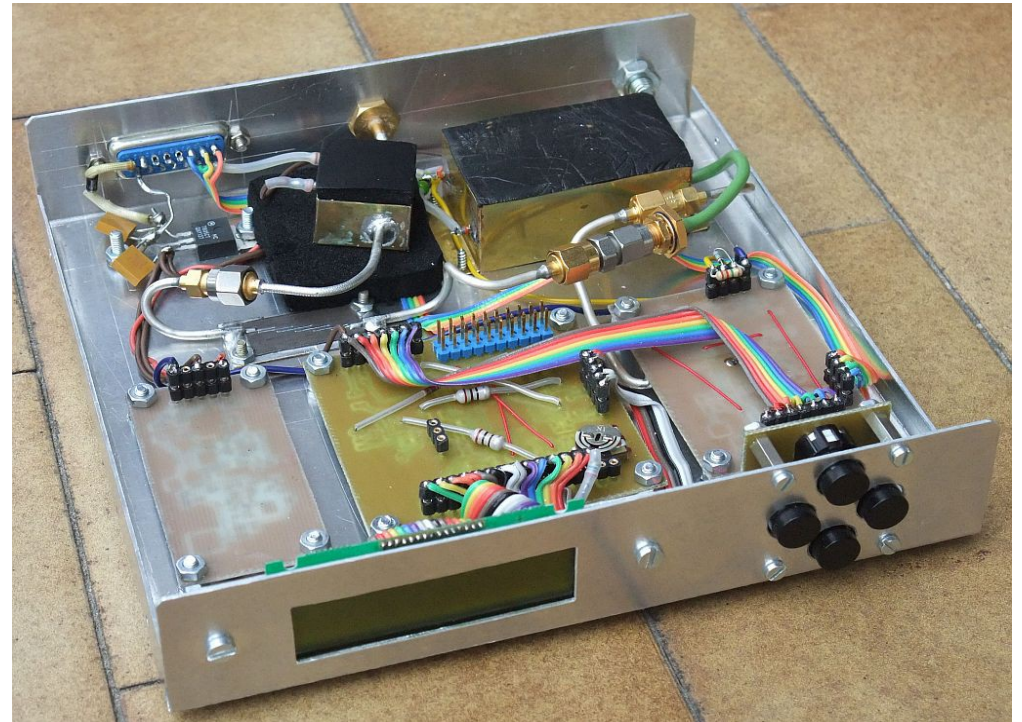
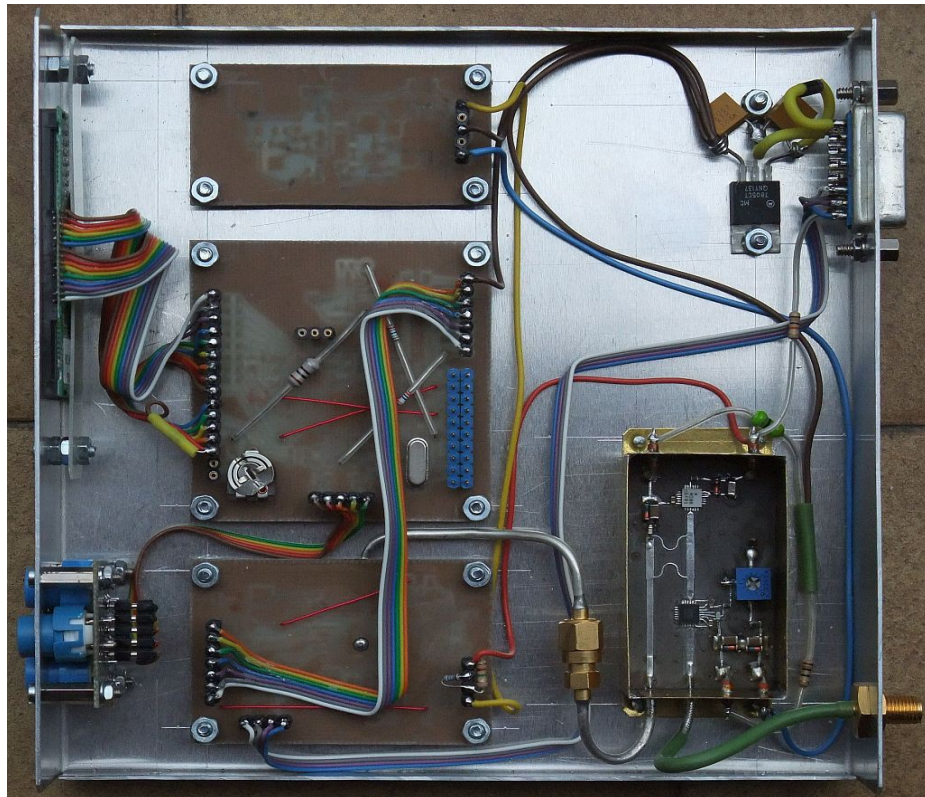
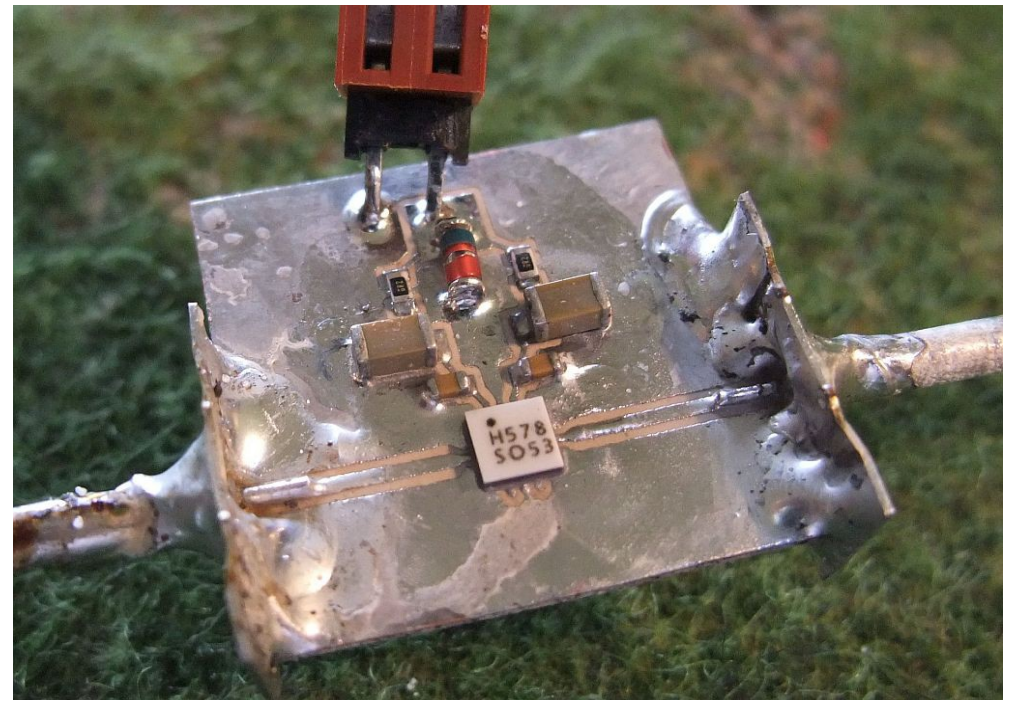
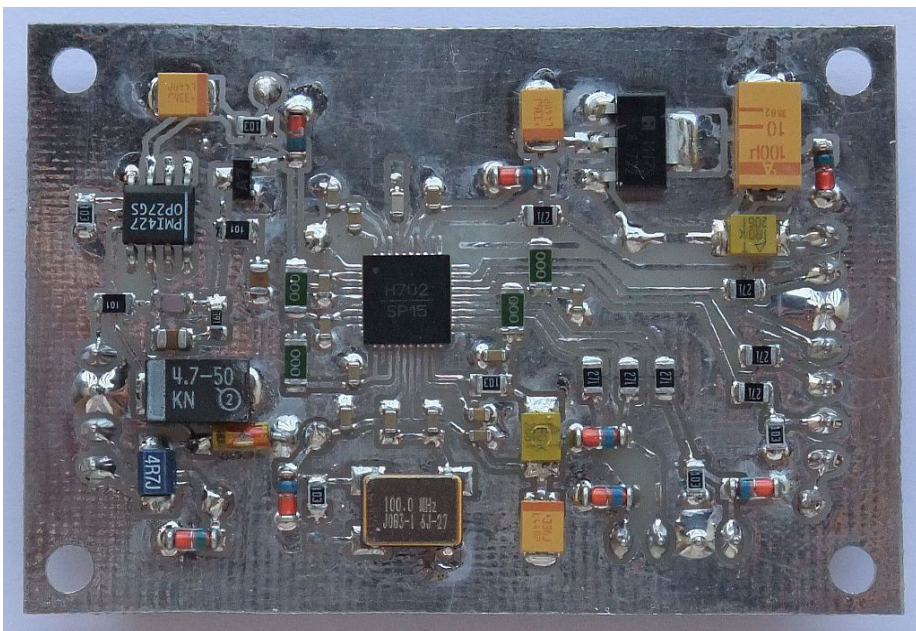
$\log \Delta f$





HMC702 [36]





26 - Microwave synthesizer for a high-resolution FM radar

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