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Microwave Laboratory

The impact of CMOS technology on mass market applications in the submillimeter/terahertz spectral region: chemical sensors and imaging through obstruction

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Enthalpy Analytical

The submillimeter/terahertz (smm/thz) spectral region has played a major role in the development of important scientific disciplines, including interstellar astrophysics, upper atmosphere remote sensing, and physical chemistry. However, none of these are mass market, public applications. There are two public applications that have long been recognized and demonstrated by use of the specialized technology that has been developed for the aforementioned scientific applications: chemical sensors and imaging through obstructions. With the rapid growth of the wireless community and its desire for ever more bandwidth, a public technology for smm/thz is beginning to emerge to support these public applications. The development of a CMOS technology will greatly accelerate the movement of the smm/thz into the mainstream. The fundamental advantages of an electronic approach for these applications and examples of both the applications and the technology required to support them will be presented.

TxACE e-seminar
Dallas
September 24, 2010

Overview

The Gas Sensor (Imaging) Application

- Background: Why has it taken so long? Why is now the time?
- The underlying physics
- Consequences of the physics: strengths, weaknesses, impact on design strategy

A Current Implementation

- DARPA one cubic foot box

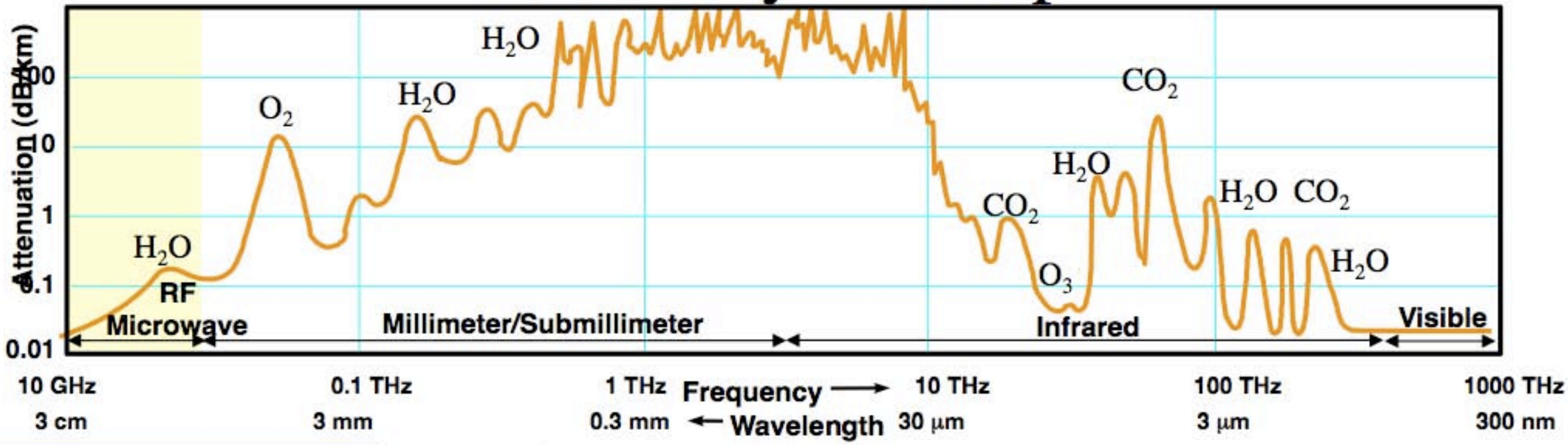
Technical considerations for submillimeter sensors

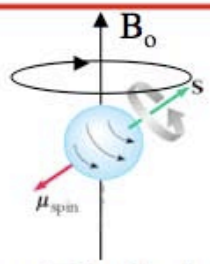
- The submillimeter technology
- A small absorption is a large amount of power
  - New noise sources / Townes noise
  - Dynamic range issues

Moving Forward with CMOS

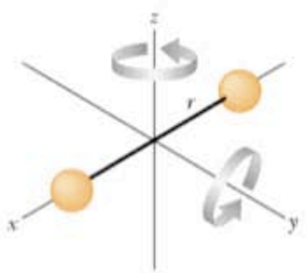
- The high frequency requirements
- Frequency control and relation to cell phones

THz Analytical Gap





Bruker BioSpin MRI



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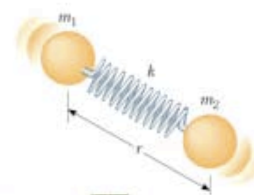
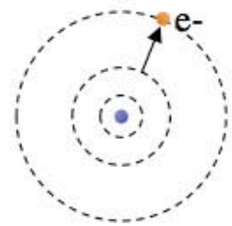
A Small FTIR-like Instrument?



Bruker FTIR's



International Light

AT THIS POINT IN TIME -- GAS ANALYSIS EMERGES FROM A CONFLUENCE OF SCIENCE AND TECHNOLOGY

Physics Always Favorable (1955)

MICROWAVE SPECTROSCOPY

C. H. TOWNES
Professor of Physics
Columbia University

A. L. SCHAWLOW
Bell Telephone Laboratories

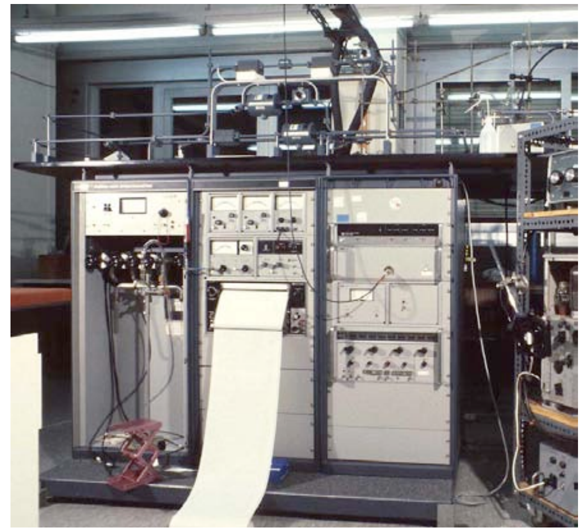
CHAPTER 18

THE USE OF MICROWAVE SPECTROSCOPY FOR CHEMICAL ANALYSIS

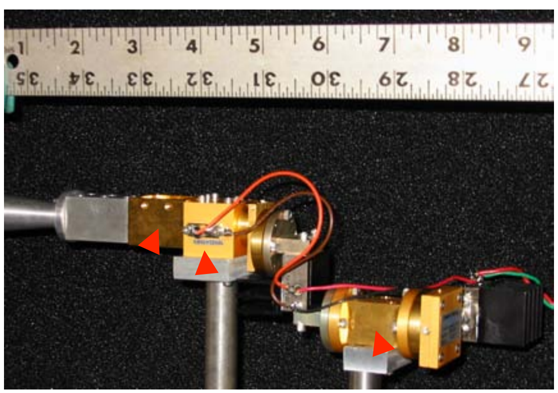
The well-known varieties of spectroscopy have been so widely and successfully used for chemical analysis that the reader has undoubtedly already wondered whether or not microwave spectroscopy can also be successfully applied in this way. Although microwave spectroscopy appears to be well suited for certain varieties of analytical work, actual applications of this type have so far been very limited.

McGRAW-HILL BOOK COMPANY, INC.
New York Toronto London
1955

HP 40 GHz MW Spectrometer(1974)



Microfabrication => small, inexpensive in quantity (2001)

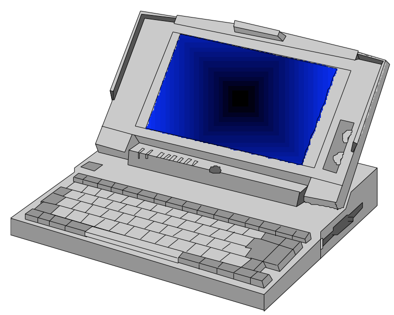


x3 multiplier

W-band amplifier

x8 multiplier

Enablers



Growth in computing power to handle information

Broadband wireless market

CMOS?

Spectroscopic and Analytical Background

A Fast Scan Submillimeter Spectroscopic Technique, **Rev. Scient. Instrum. 68, 1675-1683 (1997).**

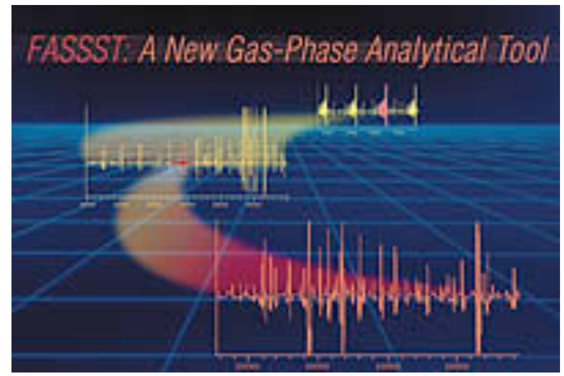
FASSST: A new Gas-Phase Analytical Tool**, Anal. Chem. 70, 719A-727A (1998).**

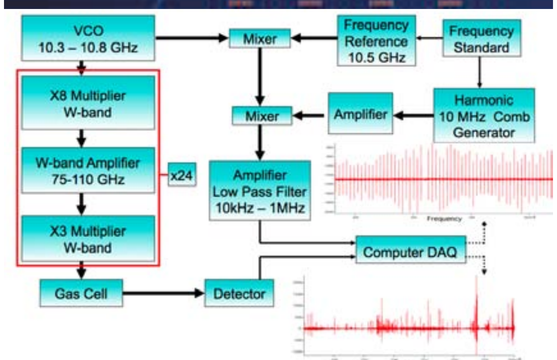
Fast analysis of gases in the submillimeter/terahertz with "absolute" specificity, **Appl. Phys. Lett. 86, 154105 (2005).**

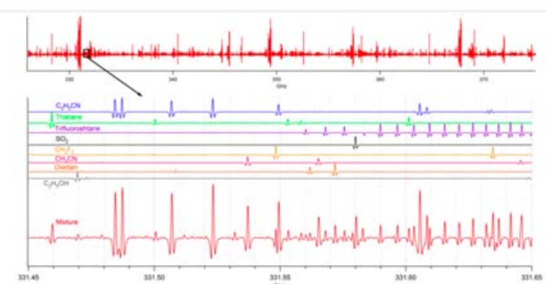
Chemical analysis in the submillimeter spectral region with a compact solid state system, **Analyst 131, 1299-1307 (2006).**

A new approach to astrophysical spectra: The complete experimental spectrum of ethyl cyanide (CH_3CH_2CN) between 570 and 645 GHz, **Astrophysical Journal 714, 476 - 486 (2010)**

Submillimeter spectroscopy for chemical analysis with absolute specificity, I. R. Medvdev, C. F. Neese, G. M. Plummer, and F. C. De Lucia, **Opt. Lett. 35, 1533 - 1535 (2010).**



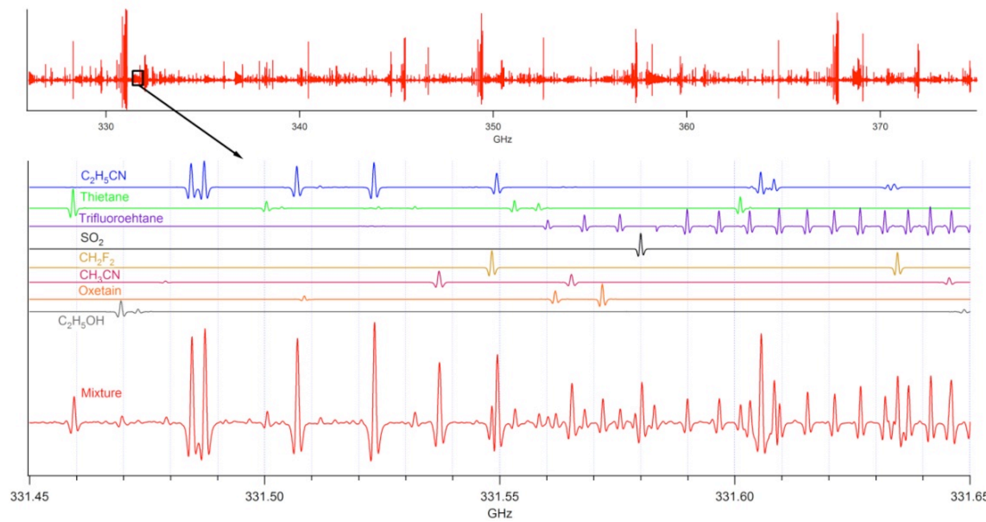




Sub-Millimeter Spectroscopy Introduction

•**High resolution SMM spectroscopy exploits rotational transitions of molecules**
•**100 000 resolution elements and complex thermally excited signature provides ‘absolute’ specificity**

Technique ideal for gas phase detection
- **High specificity**
- **High sensitivity**
- **Low false alarm rate**
- **Fast measurement and analysis**
- **Broad range of analytes**
- **Small, low power technology**



Rapid technology commercialization in the MM/SMM makes this long held promise a practical foundation for a entirely new sensor approach

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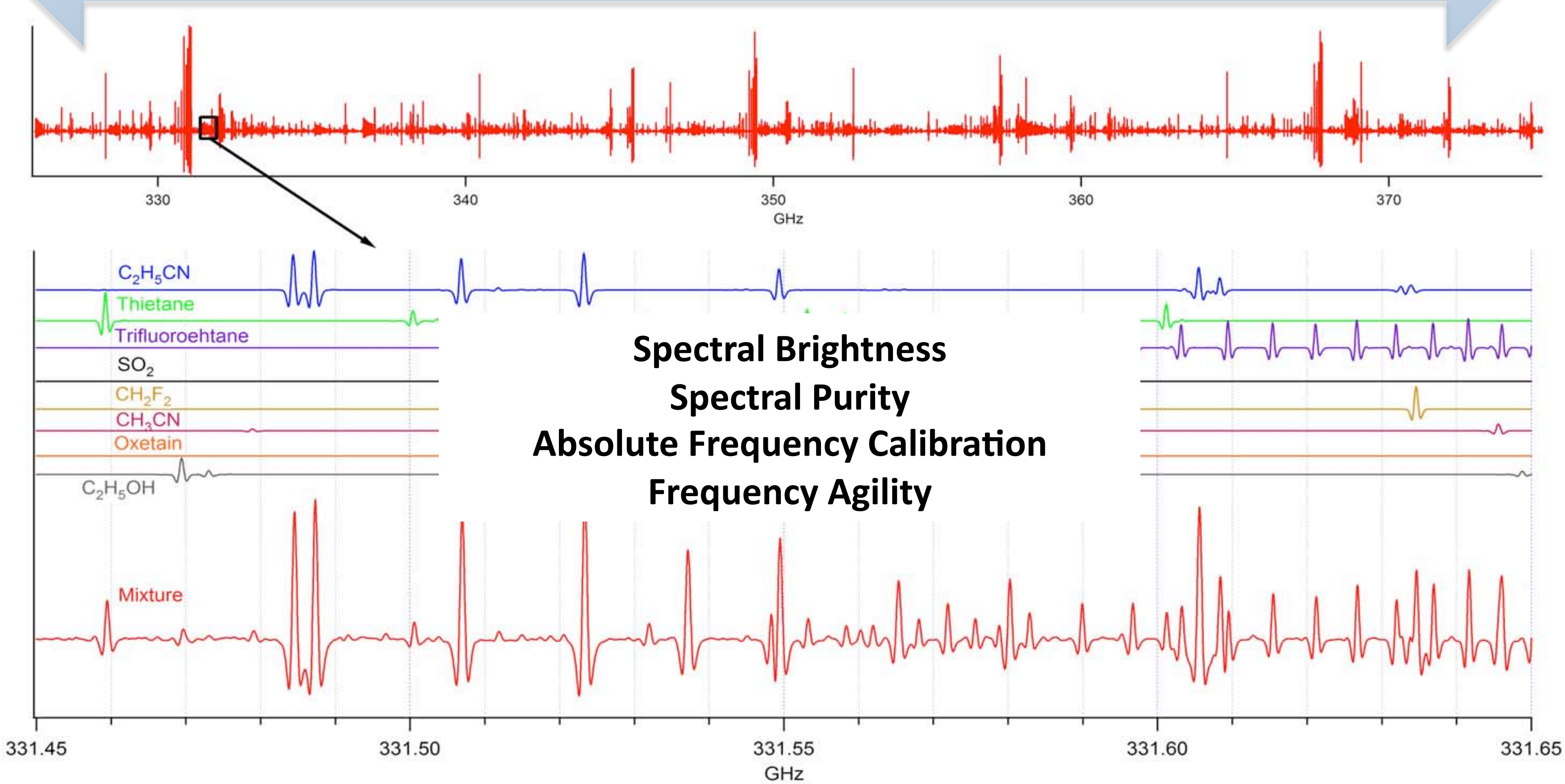
Spectrum of a Mixture of 20 Gases

Three seconds of data acquisition expands to 1 kilometer at scale of lower panel



Consequences of the Physics

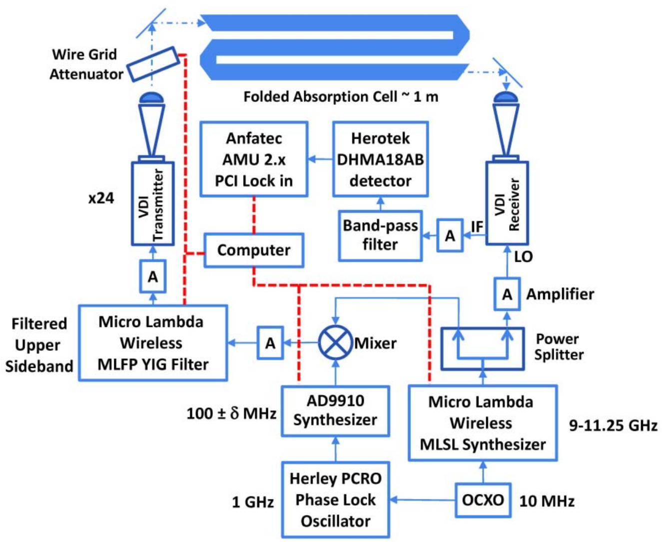
Optimum pressure is ~ 10^{-5} atmospheres (Doppler) and sample is static
=> very small sample requirements
=> sampling volumes for large preconcentration gains are small (1 liter STP gives 10^5 gain)
=> vacuum requirement greater than in IR/Op
=> atmospheric clutter limit ~1 ppt (aided by spectroscopic specifics as well)

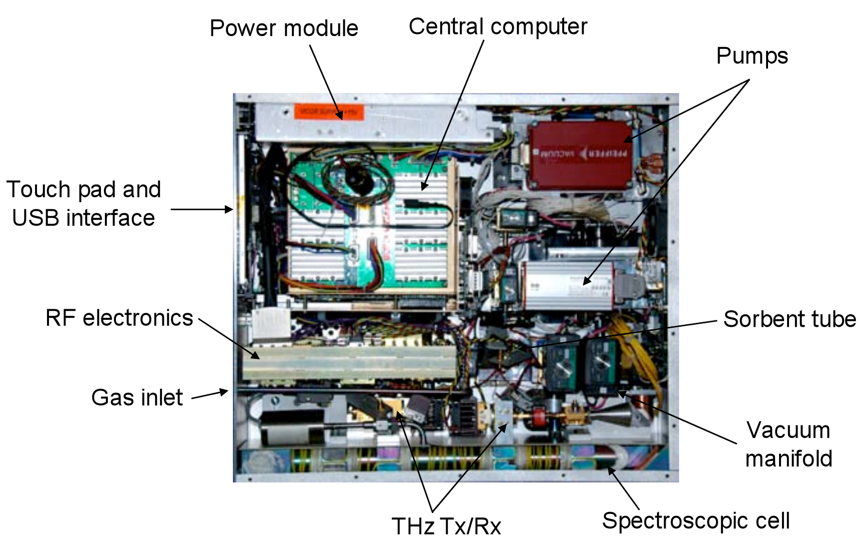
Electronic sources are essentially delta functions, even in Doppler limit

Small Power provides very high brightness (1 mW in 1 MHz corresponds to 10^{14} K)
=> path to very small an inexpensive technology

Spectral density strong function of molecular size
=> large molecule limit

Current System

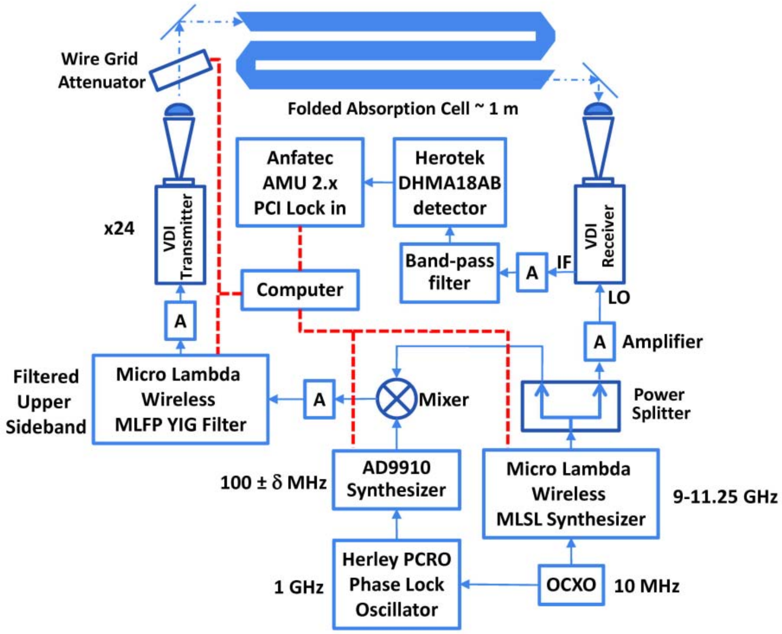




		Power (W)	Cost(parts)	Size (cm^3)
X-band drive/synthesis	COT Synthesis/YIG/SB gen		$25,000	2925
mm-wave system	2-VDI		$50,000	3250
Pumping	Diaphram + turbo 150 W	150	$10,000	8580
Sorbant	tube			5
Computing	PC cage		$1,000	5200
Interface	USB device in cage		$500	
LockIn/Signal Processing	Card in cage		$2,800	
Absorption Cells				
Non-Resonant	1 m, folded	0	$1,000	2600
Cavities	10 cm, 1.5 GHz FSR	0		
Stark				
Power Supply		0	$2,000	2340
Total		150	$92,300	24900

Some power is missing from this roll-up

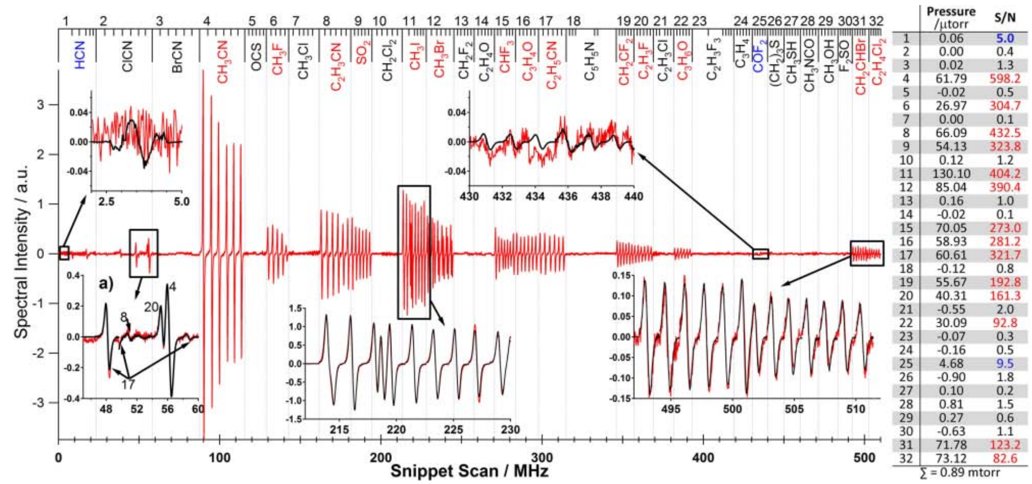
An implementation as a point in trade space



1 Cubic Foot Package

Demonstrated that atmospheric clutter insignificant

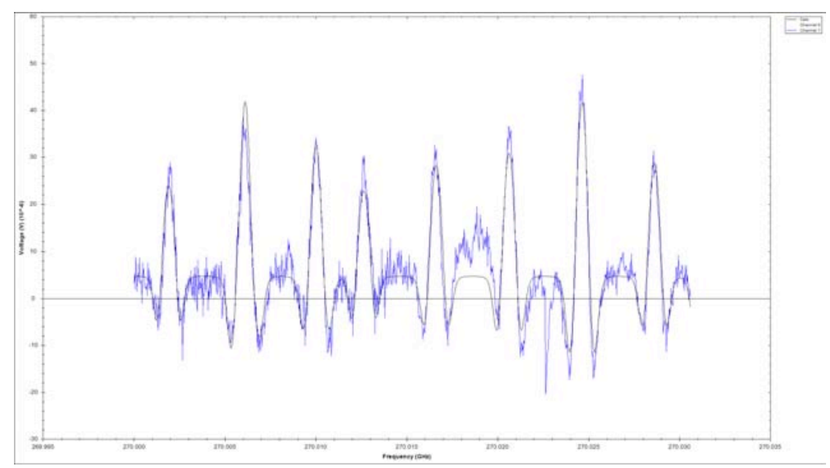
'absolute' specificity on mixture of 32



	Pressure /μtorr	S/N
1	0.06	5.0
2	0.00	0.4
3	0.02	1.3
4	61.79	598.2
5	-0.02	0.5
6	26.97	304.7
7	0.00	0.1
8	66.09	432.5
9	54.13	323.8
10	0.12	1.2
11	130.10	404.2
12	85.04	390.4
13	0.16	1.0
14	-0.02	0.1
15	70.05	273.0
16	58.93	281.2
17	60.61	321.7
18	-0.12	0.8
19	55.67	192.8
20	40.31	161.3
21	-0.55	2.0
22	30.09	92.8
23	-0.07	0.3
24	-0.16	0.5
25	4.68	9.5
26	-0.90	1.8
27	0.10	0.2
28	0.81	1.5
29	0.27	0.6
30	-0.63	1.1
31	71.78	123.2
32	73.12	82.6

∑ = 0.89 mtorr

2 ppt sensitivity demonstrated on one gas



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Results of Numerical Analysis

	Name	Partial Pressure	Uncertainty	σ
1	Hydrogen Cyanide (HCN)	0.00005887	0.00001177	5.0
2	Cyanogen Chloride (ClCN)	0.00000373	0.00000863	0.4
3	Cyanogen Bromide (BrCN)	0.00001529	0.00001190	1.3
4	Acetonitrile (CH_3CN)	0.06179212	0.00010329	598.2
5	Carbonyl Sulfide (OCS)	-0.00002180	0.00004785	0.5
6	Methyl Fluoride (CH_3F)	0.02696802	0.00008850	304.7
7	Methyl Chloride (CH_3Cl)	0.00000402	0.00006642	0.1
8	Acrylonitrile (C_2H_3CN)	0.06608506	0.00015278	432.5
9	Sulfur Dioxide (SO_2)	0.05412899	0.00016715	323.8
10	Dichloromethane (CH_2Cl_2)	0.00011741	0.00009868	1.2
11	Methyl Iodide (CH_3I)	0.13009995	0.00032185	404.2
12	Methyl Bromide (CH_3Br)	0.08504046	0.00021784	390.4
13	Difluoromethane (CH_2F_2)	0.00015923	0.00015236	1.0
14	Ethylene Oxide (C_2H_4O)	-0.00002183	0.00016894	0.1
15	Trifluoromethane (CHF_3)	0.07005161	0.00025661	273.0
16	Acrolein (C_3H_4O)	0.05893068	0.00020953	281.2
17	Propionitrile (C_2H_5CN)	0.06061219	0.00018844	321.7
18	Pyridine (C_5H_5N)	-0.00011725	0.00014392	0.8
19	1,1 Difluoroethene (CH_2CF_2)	0.05567078	0.00028872	192.8
20	Vinyl Fluoride (C_2H_3F)	0.04030862	0.00024987	161.3
21	Vinyl Chloride (C_2H_3Cl)	-0.00055029	0.00027035	2.0
22	Oxetane (C_3H_6O)	0.03009420	0.00032445	92.8
23	1,1,1 Trifluoroethane ($C_2H_3F_3$)	-0.00007049	0.00021531	0.3
24	Propyne (C_3H_4)	-0.00016353	0.00034151	0.5
25	Carbonyl Fluoride (COF_2)	0.00467462	0.00048952	9.5
26	Thietane ($(CH_2)_3S$)	-0.00089690	0.00049489	1.8
27	Methyl mercaptan (CH_3SH)	0.00009574	0.00060512	0.2
28	Methyl isocyanate (CH_3NCO)	0.00080489	0.00052955	1.5
29	Methanol (CH_3OH)	0.00026869	0.00046662	0.6
30	Thionyl fluoride (F_2SO)	-0.00063312	0.00058645	1.1
31	Vinyl bromide (CH_2CHBr)	0.07177855	0.00058255	123.2
32	1,2 dichloroethane ($C_2H_4Cl_2$)	0.07311919	0.00088521	82.6
		∑ = 0.888408		

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Broad Coverage of TIC Gases

USACHPPM Toxic Industrial Chemicals [27] Info Card - Updated last: hauschildvd **PAGE 1 of 2** 11/1/01

HCI

Chemical	Rate of Onset	Persists in Environment	Toxicity Thresholds (ppm/hour) *impairment*	Toxicity Thresholds (ppm/hour) *fatality*	BDO/ Mask Effective	Odor	Related hazards/ Source/ Use	Field Detection: *Sensidyne tube (#)*	Field Detection: *205Aseries Miran SapphiRE*
Allyl alcohol *(colorless liquid)*	Immediate	Days-weeks, +	7.7	22	?	Mustard-like	Rapidly absorbed through skin highly flammmable with caustic fumes; used as contact pesticide, plastic/perfume manufacture	Not available (liquid)	Not available (liquid)
Acrolein *(colorless-yellow liq)*	Immediate	Minutes to hour	0.1	1.4	Poor	1 ppm -sharp, acrid, sweet	Toxic and corrosive fumes; Herbicide	#93 *(BUT high detection)*	Not standard
Acrylonitrile *(clear/pale yellow liq)*	Immediate	Minutes to HOURS	35	75	Poor	17 ppm - unpleasant, sweet (peach)	Flammable gas; used in Plastics, coatings, adhesives industries; dyes; pharmaceuticals;	#191	Standard
Ammonia *(colorless gas)*	Immediate	Minutes	110	1100	Poor	17 ppm - sharp,suffocati ng,dry urine	Explosives manufacture; pesticides; detergents industry	#3M	Standard
Arsine *(colorless gas)*	Immediate to 24 hours	Minutes to hours	0.2	0.5	Good	0.5 ppm - garlic-like	Reacts with H20 (don't use H2O in fire); Used in electronics ind	#19L	Not standard
Chlorine *(greenish-yellow gas)*	Immediate to hours	Minutes to hours	3	22	Good	3.5 ppm- pungent (bleach), suffocating	Irritating corr fumes; heavier than air; Cleaner/disinfectant in many industries; water treatment; WWI war gas;	#80	Not standard
Diborane *(colorless gas)*	Immediate	Minutes to hours	>1	15	Good	2.5 ppm -sickly sweet	Very flammable; Intermediate chemical manufacturing;	#22	Not standard
Ethylene oxide *(colorless gas/liq)*	Immediate	Minutes to hours	45	200	Poor	425 ppm - sweet, ether-like	Very flammable; Rocket propellant; fumigant; sterilization in health care industry;	#163L	Standard
Formaldehyde *(clear- white gas/liq)*	Immediate	Hours	10	25	Poor	1 ppm -pungt suffocating	Flammable,Disinfection/ germicide; fungicide; textile; health care (tissue fixing)	#91D (Dosi)	Standard
Hydrogen bromide *(pale yellow liq)*	Immediate	Minutes to hours	3	30	Good	2 ppm -sharp stinging	Chemical manufacturing industry; very corrosive	#15L	Not standard
Hydrogen chloride (hydrochloric acid) *(pale yellow-colorless liq)*	Immediate	Minutes to hours	22	104	Good	0.77 ppm - pungent, irritating	Corrosive liquid; Ore, other metal refining/ cleaning; food/pickling; petroleum;	#80	Not standard
Hydrogen Cyanide *(colorless-white-pale blue gas; liquid <75F)*	Immediate	MInutes	7.0	15-50	Good	1-5 ppm- bitter/sweet almond-like	Weak acid except in water or mucous membranes – then corrosive/irritating; used as War gas, pesticide, Herbicide; other industries	#12L	Not Standard
Hydrogen fluoride *(colorless gas/fuming liq)*	Immediate & Delayed	Minutes to hours	24	44	Good	0.4 ppm - strong irritating	Corrosive liq; Aluminum and other metal industries; insecticide manufacturing-	#17	Not standard
Hydrogen selenide *(colorless gas)*	Immediate	Minutes - Hour	0.2	1.5+	Poor	0.3 ppm- decayed horseradish	Highly flammable/explosive; can cause burns/frostbite; decomposes rapidly to form elemental selenium Metals &semiconductor prep;	Not available	Not standard
Hydrogen sulfide *(colorless gas)*	Immediate & Delayed	MINUTES to hours	30	100	Good	0.1 ppm -rotten egg	Disinfectant lubricant/oils; interm for HC manufacture; deadens sense of smell	#44	Not standard

Symptoms *(from inhalation and dermal contact)*

General Mild Health Effects:
- Nausea, dizziness; headaches; chills; coughing, choking, throat irritation

Specific and More Severe Effects:

Eyes:
- Irritation; tearing/watering; pain; intolerance to light (e.g. from Hydrogen Sulfide)

Skin (particularly if liquid contact):
- Irritation; burning; blisters (eg with Hydrogen Fluoride); vesiculation (nitric & sulfuric acid); dermatitis; and frostbite (e.g. Acryonitrile)

Respiratory Tract/Lungs:
- Breathing difficulty.respiratory distress; laryngeal spasm (e.g., from hydrogen chloride or hydrogen bromide); **pulmonary edema**

Chest/Heart:
- chest pain; tachardia (rapid heartbeat)

Systemic; Blood
- Cyanotic (blue skin from lack Oxy to blood) (e.g. from SO_2, SO_3, NO_2, ethylene oxide):
- Convulsions/seizures
- Hemolytic anemia; kidney damage (Arsine)

Additional Chemical Specific Symptoms:

pink/froth sputum: Ammonia
mucoid frothy sputum: SO_2,SO_3, NO_2
peculiar taste: Ethylene oxide
asphyxia: Acrylonitrile
metal taste & or garlic breath: Hydrogen Selenide

----------→

Decontamination and Treatment

Decontamination:
- Flush (15 min) eyes & skin with water;
- Soap optional after initial water rinse

Treatment & Diagnostic procedures/ options:

Eye injuries:
- Saline wash
- Antibiotic ointments

Skin burns/blisters/irritation
- topical corticosteroids and/or antihistamines
- Inject $MgSO_4$ at affected site (*Hydrogen fluoride)*

Breathing/respiratory distress:
- Oxygen & ventilation
- Prophylactic antibiotics
- Xrays
- Pulse ox/blood gas

NOTE: **avoid mouth to mouth** to protect against cross contamination

Broncospasm/Pulm Edema
- Inhale corticosteroids
- Beta2 agonist
- Endotracheal intubation

Hemolysis (e.g. Arsine):
- IV, transfusion

Seizures:
- Diazepam

See page 2 ---------→

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Simultaneous Recovery with 'Absolute Specificity' in Mixture

USACHPPM Toxic Industrial Chemicals [27] Info Card - Updated last: hauschildvd **PAGE 2 of 2** 11/1/01

Chemical	Rate of Onset	Persists in Environment	Toxicity Thresholds (ppm/hour) impairment	fatality	BDO/ Mask Effective	Odor	Source/ Use/other hazard	Field Detection: Sensidyne tube (#)	Field Detection: 205Aseries Miran SapphiRE
Methyl hydrazine	Immediate & Delayed (LUNGS)	Hours - days	1.0	3.0	Poor?	1 –10 ppm- ammonia like	Irritating vapors; Flammable- Once ignited continues to burn; Used as solvent, rocket fuel;	#185	Not standard
Hydrazine *Colorless, oil (fuming) liquid/waxy solid or crystals*	Immediate & Delayed (LUNGS)	Hours - days	13	35	Poor?	3-4 ppm- Ammonia -like	Flammable- Once ignited continues to burn; irritating vapors; Used as solvent, rocket fuel;	#3D (Dosi)	Standard
Methyl isocyanate *(colorless liquid)*	Immediate	Minutes to hours	0.5	5	Poor	2.1 ppm -sharp pungent	Intermediate in manufacturing; reacts with H20 (don't use in fire)	Not available (liquid)	Not standard (liquid)
Methyl mercaptan *(colorless gas; liquid <43F)*	Immediate	Minutes to hours	5.0	23	Poor	0.002 ppm- rotten cabbage (1 ppm odor fatigue)	From decayed organic matter – pulp mills, oil refineries; highly flammable; liquid burns/frostbite	#71	Not standard
Nitrogen dioxide *(colorless gas/pale liq)*	Delayed (24-72 hrs)	MINUTES to hours	12	20	Poor	1 ppm - ?	Intermediate for manuf of nitric acid & sulfuric acid; explosives/rocket propellant	#9D (Dosi)	Not standard
Nitric Acid *(colorless, yellow, or red fuming liquid)*	Immediate	Hours- days +	4.0	22+	Poor	~1 ppm- Choking, sweet – acrid	Used in many industries; Very corrosive to skin/mucous membranes as well as metals & other materials;	#80	Not standard
Parathion *(pale yellow to brown liquid)*	Immediate but often Delayed (weeks)	Days to weeks	0.2	0.8	Good	0.04 ppm	Organophosphate (insecticide); similar symptoms (and thus treatment) as nerve gases; penetrates leather/canvas and plastics/rubber coatings	Not Available (liquid)	Not Available (liquid)
Phosgene *(colorless – light yellow gas)*	Immediate & Delayed (LUNGS)	Minutes - HOURS	0.3	0.8-5	Good	0.5ppm- musty hay	Dye, pesticide, and other industries; history as war gas, corrosive/irritating	#16	Standard
Phosphine *(colorless gas)*	Immediate & Delayed (LUNGS)	Minutes- hours	0.3	1.1-30	Good?	0.9 ppm- rotten fish, garlic	Insecticide; used in manufacture of flame retardants and incendiaries;	#7LA	Not Standard
Sulfuric Acid *(clear colorless- brown oily liquid)*	Immediate	Hours, days	2.5	7.5	Good	Odorless (acrid taste)	Toxic fumes when heated Battery/dyes/paper/glue/metals industries; volcanic gas;	Not available (liquid)	Not Available (liquid)
Sulfur dioxide; sulfur trioxide; -form sulfuric acid *(colorless gas)*	Immediate & Delayed	MINUTES to hours	>3	15-100	Good (SO2); Marginal (SO3)	1 ppm; pungent; metallic taste	Disinfectant and preserving in breweries and food/canning; textile industry; batteries	# 5L	Standard
Toluene diisocyanate (2,4) *(water-white to pale yellow liquid, or crystals)*	Immediate	Hours - weeks	0.08	0.51	Good	0.4-2 ppm- sharp pungent	Skin irritant Polyurethane (wood coatings , foam), nylon industries;	Not Available (liquid)	Not Available (liquid)

Symptoms *(from inhalation and dermal contact)*

General Mild Health Effects:
- Nausea, dizziness; headaches; chills; coughing, choking, throat irritation

Specific and More Severe Effects:

Eyes:
- Irritation; tearing/watering; pain; intolerance to light (e.g. from Hydrogen Sulfide)

Skin (particularly if liquid contact):
- Irritation; burning; blisters (eg with Hydrogen Fluoride); vesiculation (nitric & sulfuric acid); dermatitis; and frostbite (e.g. Acryonitrile)

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Systemic; Blood
- Cyanotic (blue skin from lack Oxy to blood) (e.g. from SO2, SO3, NO2, ethylene oxide): Convulsions/seizures
- Hemolytic anemia; kidney damage (Arsine) (sulfuric acid, hyrdazine)

Additional Chemical Specific Symptoms:

pink/froth sputum: Ammonia
mucoid frothy sputum: SO2,SO3, NO2
peculiar taste: Ethylene oxide
asphyxia: Acrylonitrile
metal taste & or garlic breath: Hydrogen Selenide
Miosis, sweating, ⇓ ACHe Parathion
Coffee-ground vomit – sulfur acid

Decontamination and Treatment

Decontamination:
- Flush (15 min) eyes & skin with water;
- Soap optional after initial water rinse

Treatment & Diagnostic procedures/ options:

Eye injuries:
- Saline wash
- Antibiotic ointments

Skin burns/blisters/irritation
- topical corticosteroids and/or antihistamines
- Inject MgSO4 at affected site (*Hydrogen fluoride*)

Breathing/respiratory distress:
- Oxygen & ventilation
- Prophylactic antibiotics
- Xrays
- Pulse ox/blood gas

NOTE: **avoid mouth to mouth** to protect against cross contamination

Broncospasm/Pulm Edema
- Inhale corticosteroids
- Beta2 agonist
- Endotracheal intubation

Hemolysis (e.g. Arsine):
- IV, transfusion

Seizures:
- Diazepam

How are the requirements for an absorption spectrometer different from those of a network analyzer?

Previously discussed:
- frequency agility
- software strategy
- spectral recognition

To follow:
- noise
- dynamic range

Small Absorption vs. Small Signals

Special Considerations for System Design

(How do we differ from a network analyzer?)

1. There are new fundamental noise sources that are typically orders of magnitude greater than the receiver noise (a 10^5 effect).

2. There are systematic non-white noise sources resulting from standing waves that need to be suppressed and signal processing schemes based on the narrowness of the spectral lines implemented (a 10^6 effect).

3. Strategies need to be implemented so that excessive digitization are not required to recover 10^{-7} fractional absorptions.

4. Fundamental misconceptions about white noise in the submillimeter exist (a 10^{10} effect).

Townes Noise in Absorption Spectrometers

Assume that we have a probe power (carrier) of P_p. Then in a waveguide of impedance Z, the voltage associated with this probe power is

$$V = \sqrt{2ZP_p}$$

Similarly, the noise voltage associated with the thermal radiation is

$$\Delta V = \sqrt{4ZkT\Delta\nu}$$

The net power flow is then

Townes Noise

$$\frac{(V \pm \Delta V)^2}{2Z} = P_p \pm 2\sqrt{2kT\Delta\nu P_p} + 2kT\Delta\nu$$

Because P_p is typically many orders of magnitude greater than the thermal power, the cross term dominates the noise in a system designed to observe a small change in P_p.

System Numbers

For a receiver noise temperature T_N = 3000 K and $b = B = 10^6$ Hz, $P_N = 5 \times 10^{-14}$ W.

$$\frac{P_c}{P_N} \sim 10^{10}$$

If we have a carrier power of P_c = 1 mW, we must also consider the noise associated with the adding of the blackbody noise *voltage* with the carrier.
For this case

$$P_n' \approx \sqrt{kT\Delta\nu P_c} = \sqrt{(5 \times 10^{-14})(10^{-3})} \approx 10^{-8} W$$

Five Orders of Magnitude

This is about five orders of magnitude above the receiver noise.

The system S/N is then

$$S/N = \frac{P_c}{P_N'} \sim \frac{10^{-3} W}{10^{-8} W} \sim 10^5$$

This is the impact of the so called 'Townes Noise'.

Impact is only large when we are looking to detect a small change in a large P_c

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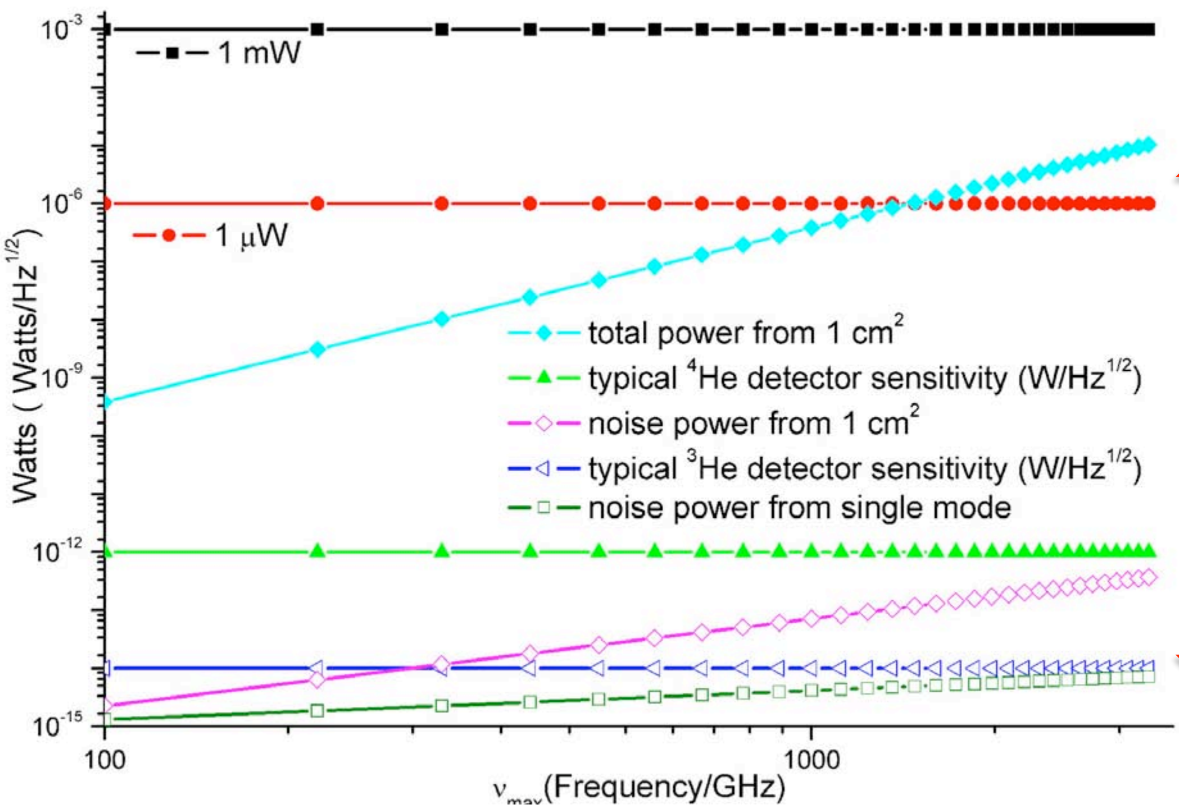
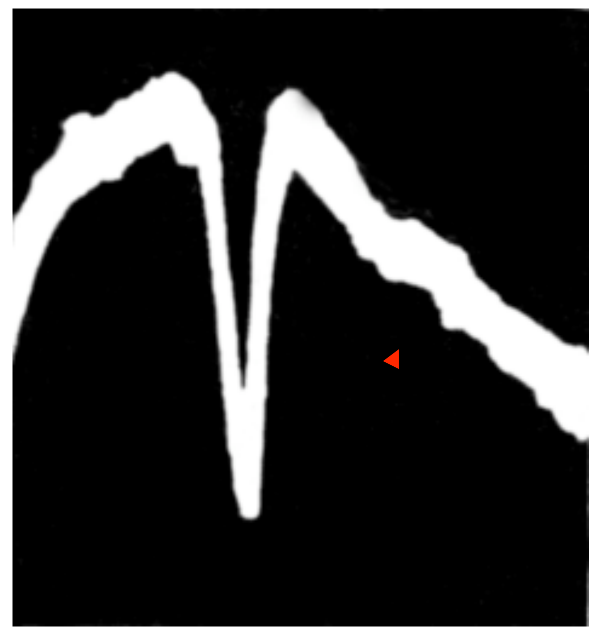
The THz is *VERY* Quiet even for CW Systems in Harsh Environments



10^{10} Misconception

Experiment: SiO *vapor* at ~1700 K



***All* noise from 1.6 K detector systemm**

Noise, detectors, and submillimeter–terahertz system performance in nonambient environments

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Cell Phone Architecture and Gas Sensors

Conceptually Multiply or Up/Down Convert
Cell Phone Technology to 200 – 300 GHz

Synthesizer

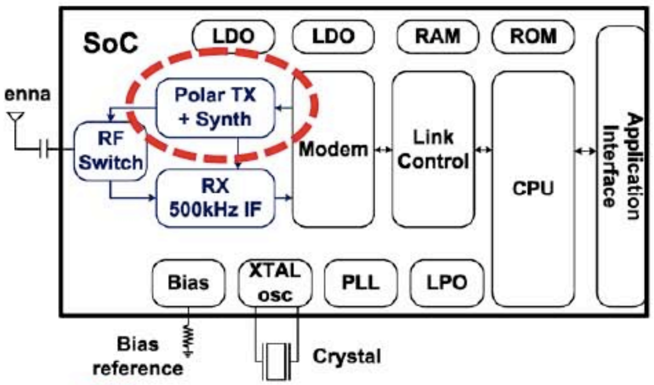
- Spectral Purity
- Frequency Sweep and Agility
- FM modulation

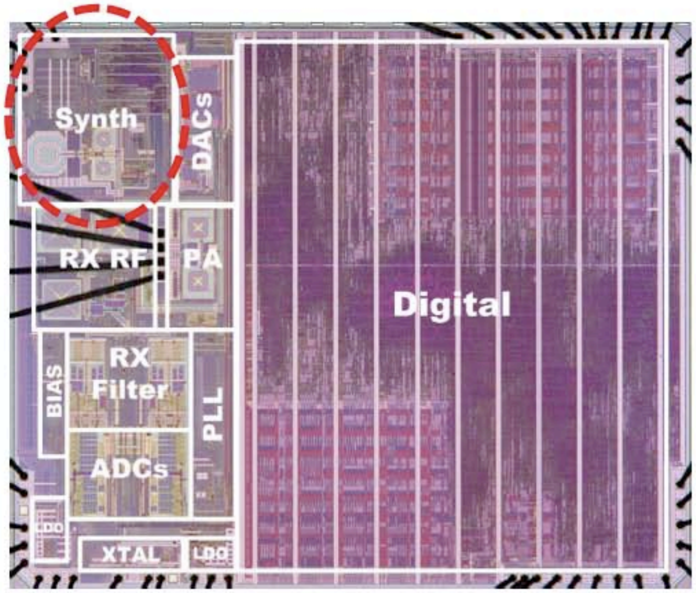
IF amplifier

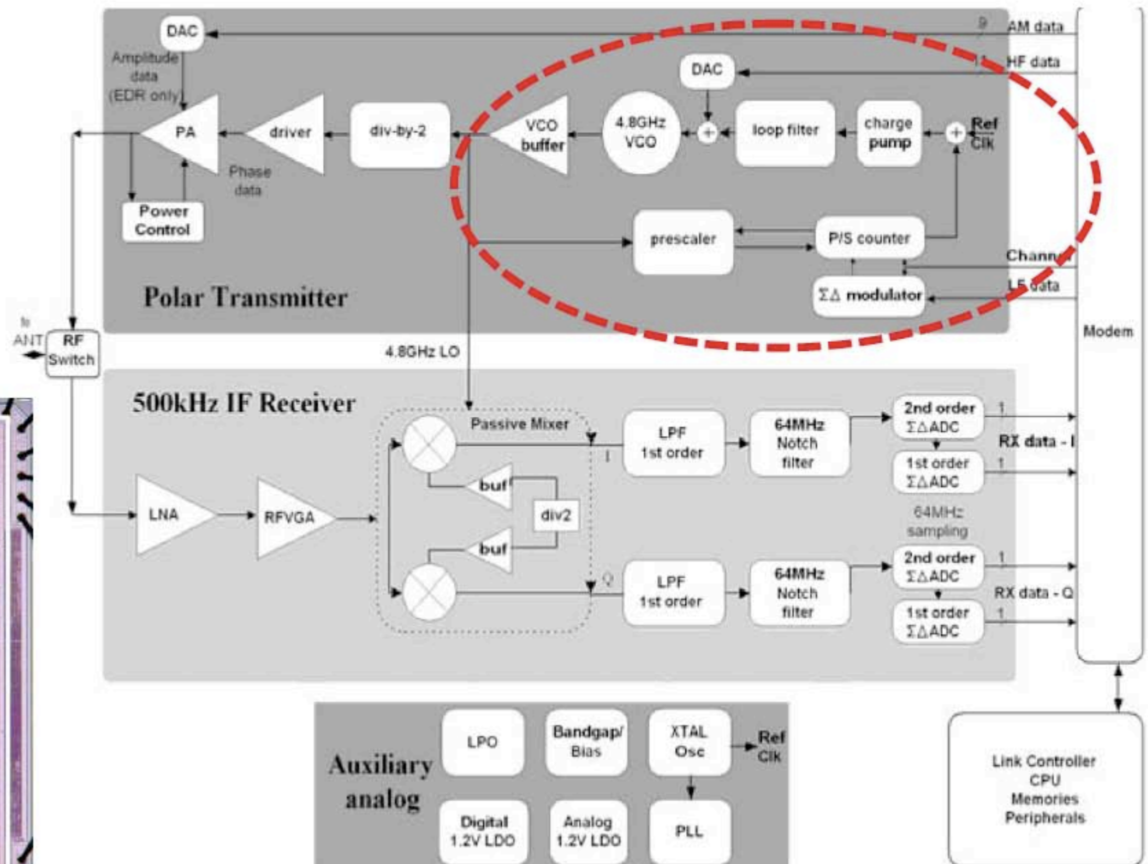
- Bandwidth 1 – 10 MHz
- Phase sensitive demodulation at FM modulation frequency
- Dynamic range

[6] 2008: 130nm 9mm^2 Bluetooth SoC (Atheros)

- Bluetooth v2 (EDR): GFSK (1Mb/s), QPSK (2Mb/s), 8PSK (3Mb/s)
- Calibration needed for the two-point frequency modulator of the analog polar TX







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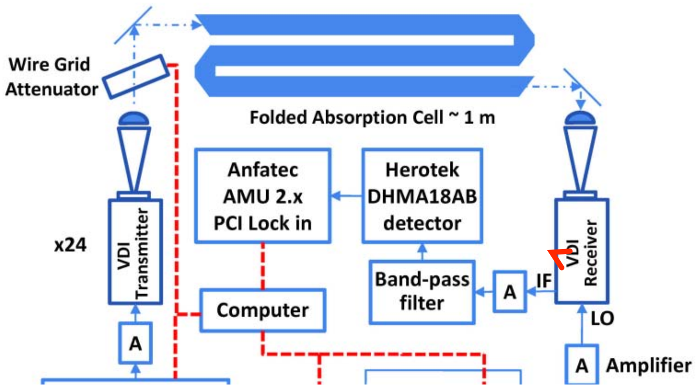
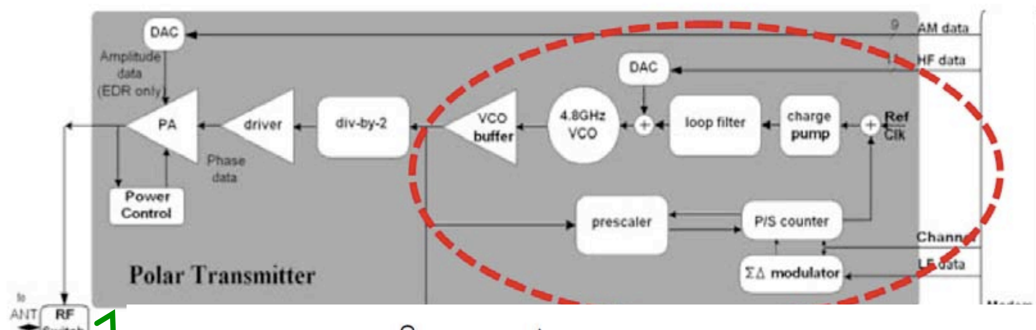
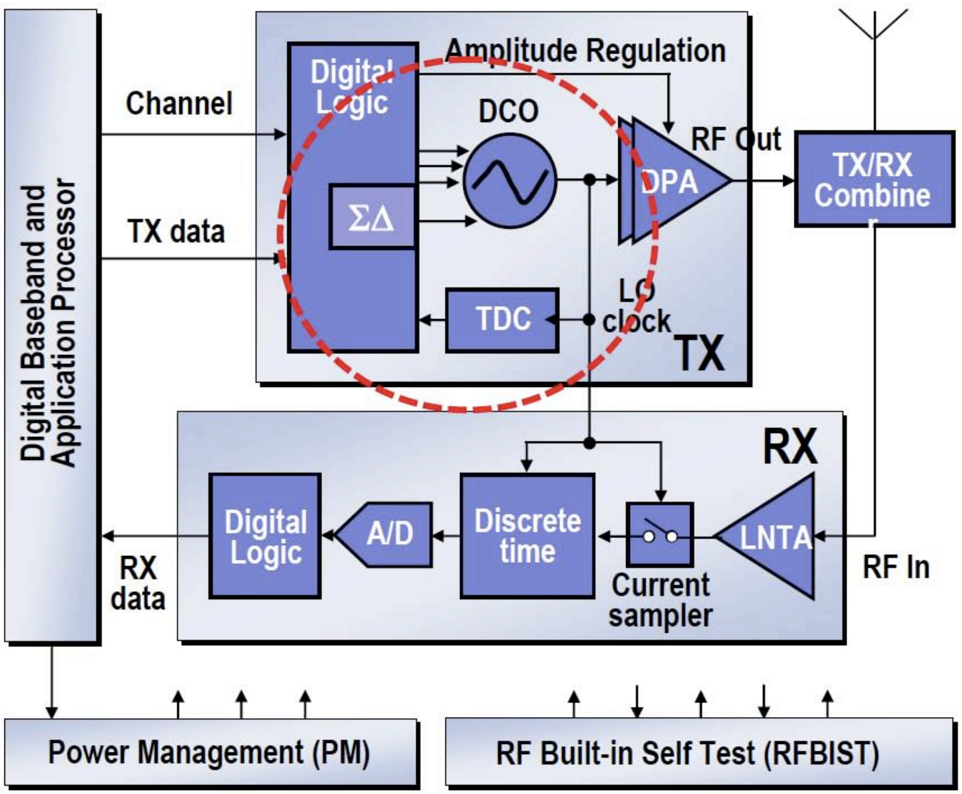
Current System-relation to cell phone







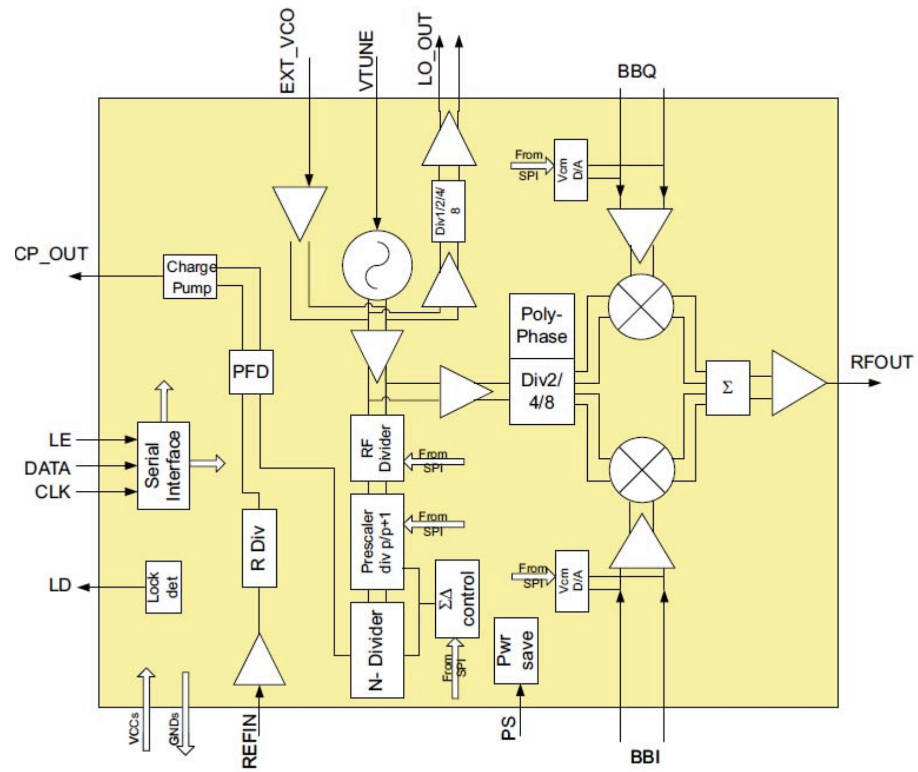


Figure 1. TRF372017 Block Diagram

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Rashaunda Henderson

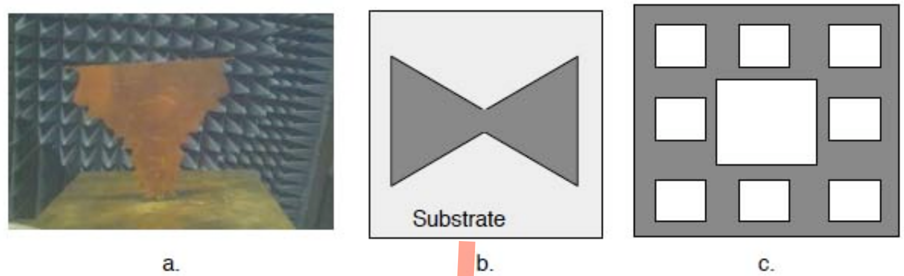
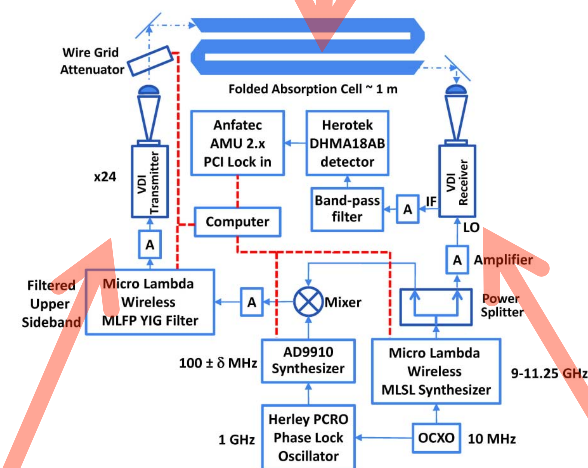


Figure 4: Antennas designs (a) bow-tie antenna with a modified edge (quasi-fractal) design, (b) printed bow-tie, and (c) square patch with fractal components.



Kenneth O

Bhaskar Banerjee

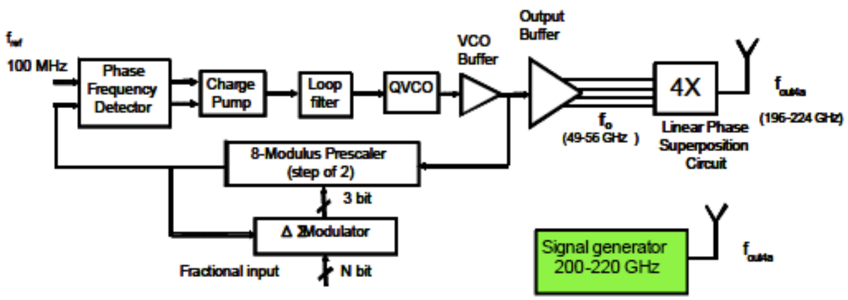


Figure 2, 200-220 GHz frequency generator using a fractional-N synthesizer.

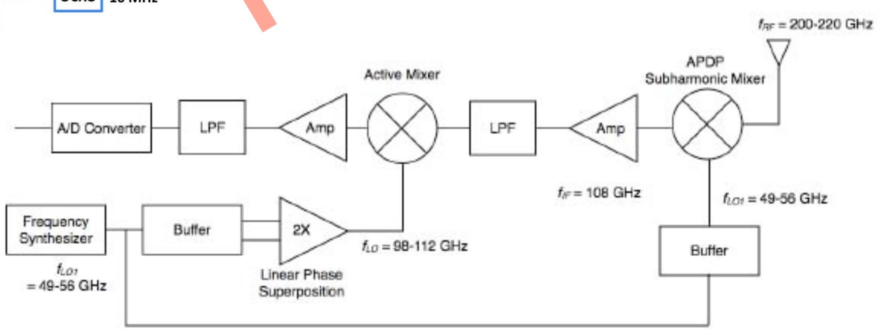
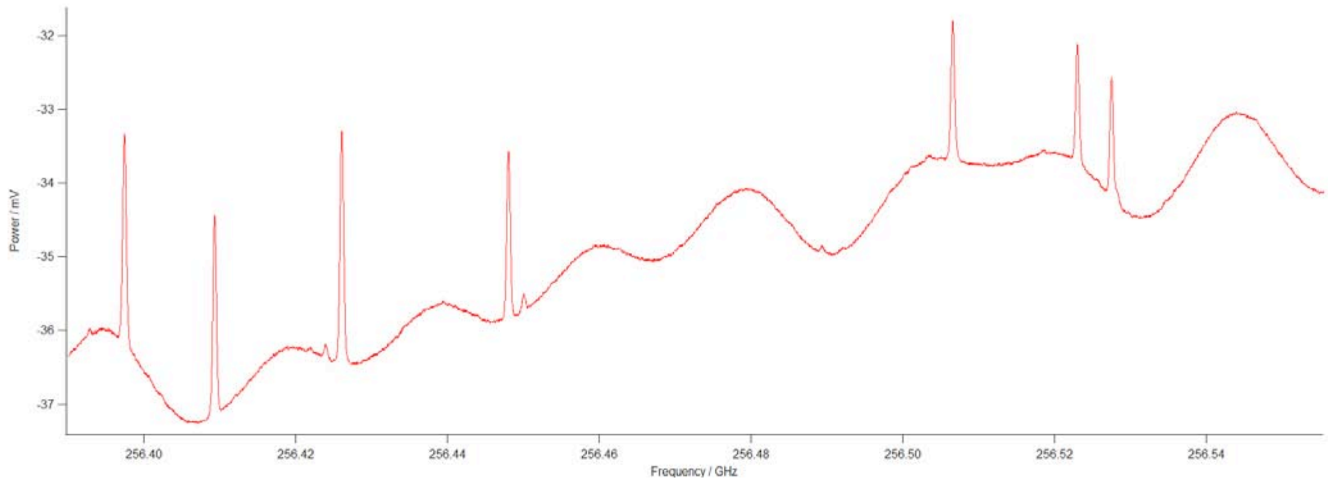


Fig. 5. Two-step heterodyne down conversion architecture for the spectrometer receiver. The first down conversion is performed using an APDP sub-harmonic mixer to an IF of around 100 GHz.

Dynamic Range



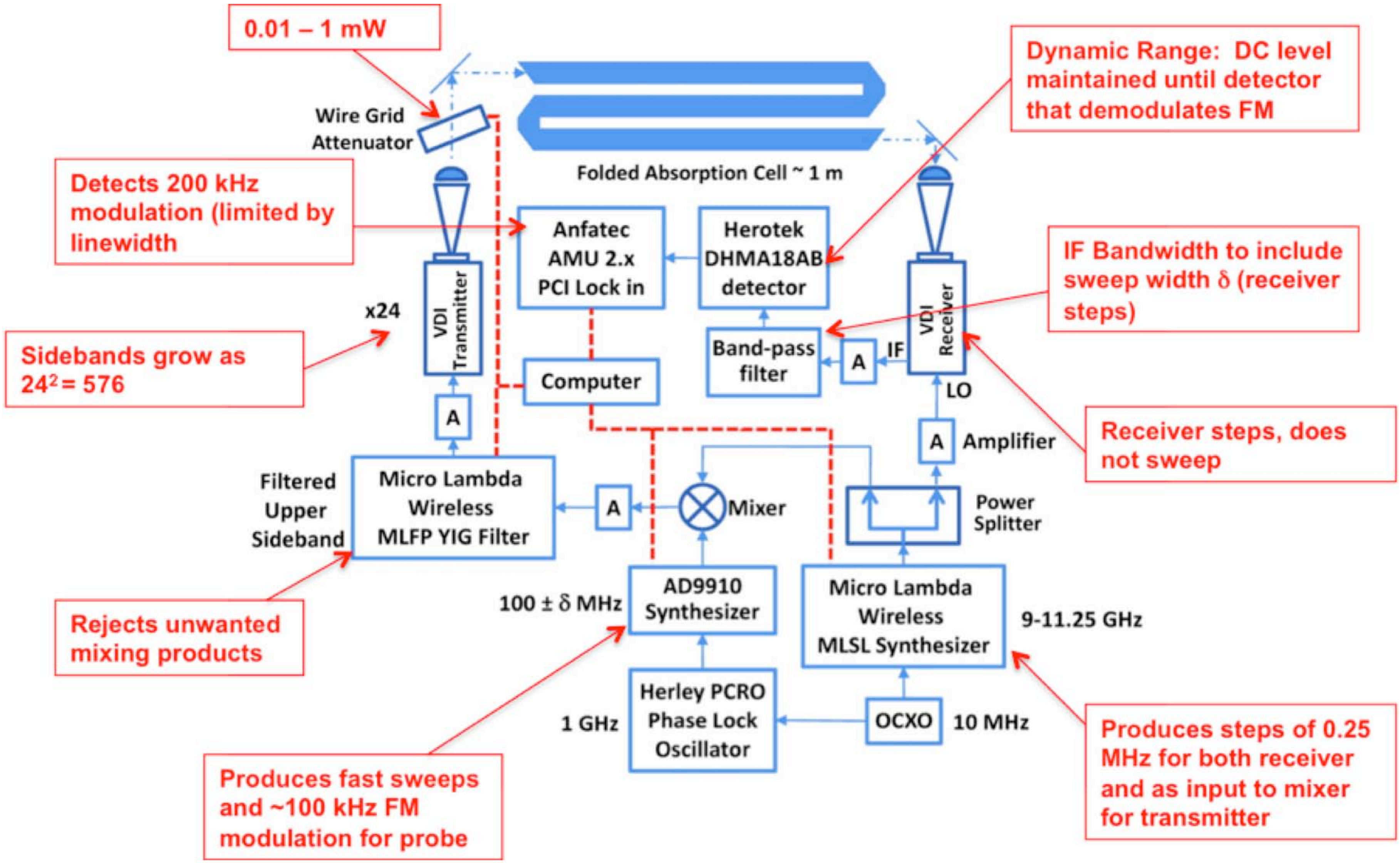
The problem: detect a molecular absorption of width 1 MHz that is 1/10^7 of total power against a baseline that varies by 1/10 over 500 MHz and 1/1.5 over 10 GHz

Strategy 1: Use 'AC' coupling to roll of the more slowly varying baseline.

Strategy 2: Use FM modulation *f* at ~50 kHz with a deviation of ~1 MHz that modulated the narrow line, but not the broader baseline features.

Specific Implementation: Modest IF gain, followed by detector, followed by narrow band amplifier at *f* or 2*f*.

Dynamic Range



Submillimeter Sensors of Static Samples Summary

- Dominates a significant portion of spectroscopic sensor space
  - Absolute specificity
  - Extremely small samples with good sensitivity
  - Favorable trades of sensitivity for speed (agility of electronic synthesis)
- Clear path to small and inexpensive implementations
  - Electronic synthesis
  - Wireless technology and CMOS
  - Small sample requirements allow less elaborate vacuum systems
- Challenges and opportunities
  - Limits on applicability to larger molecules – unclear bounds
  - Vacuum strategies
  - Not a mature technique
  - Significant up side potential – fundamental limits very favorable
  - Still a steep curve between proven capability and research effort (good? bad?)