ACADEMIA SINICA
Institute of Astronomy and Astrophysics

HARVARD-SMITHSONIAN
Center for Astrophysics

SMA Interferometry School

Basics of Analog Signal Processing & Transmission

March 15-19, 2021

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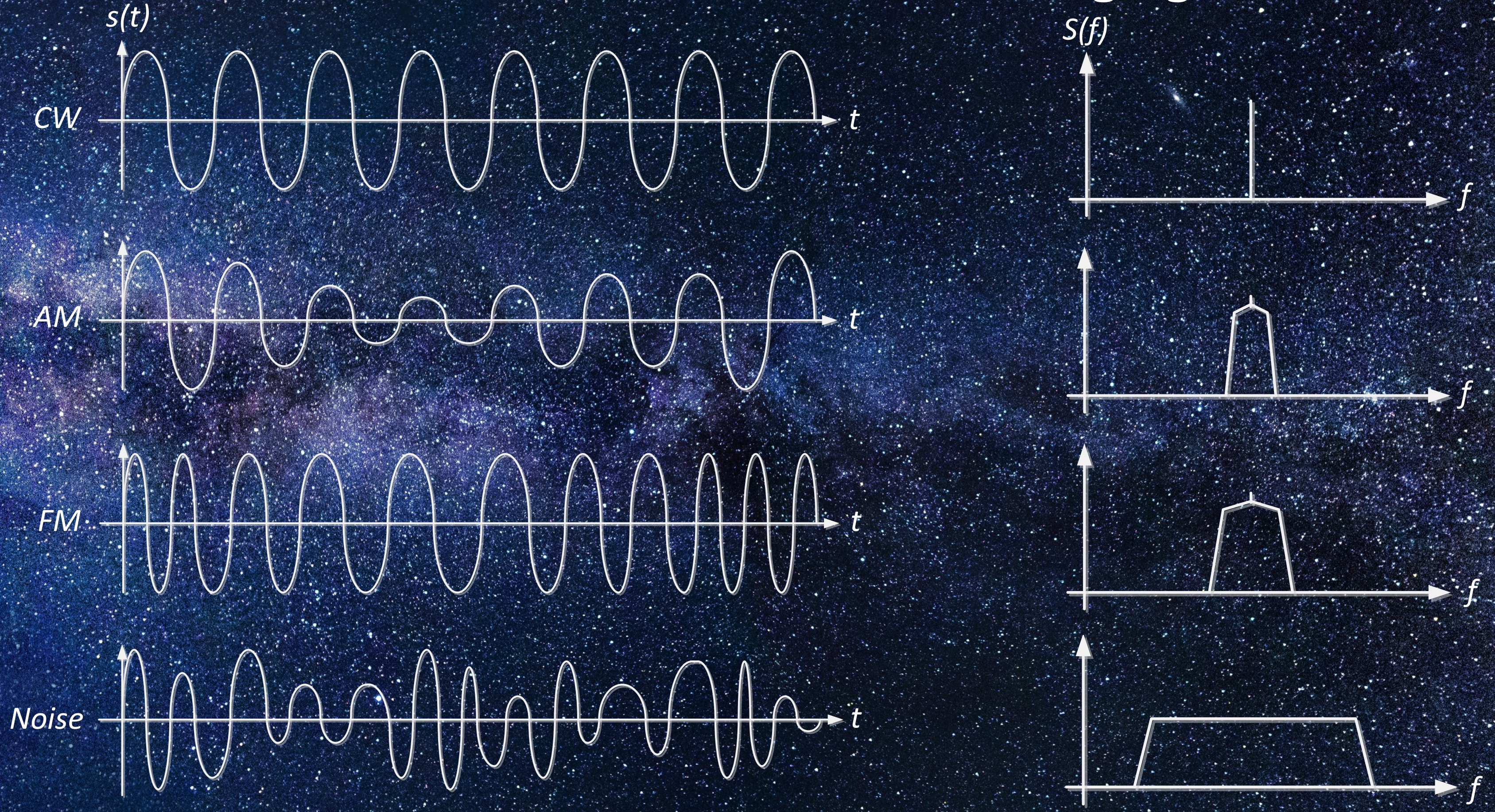
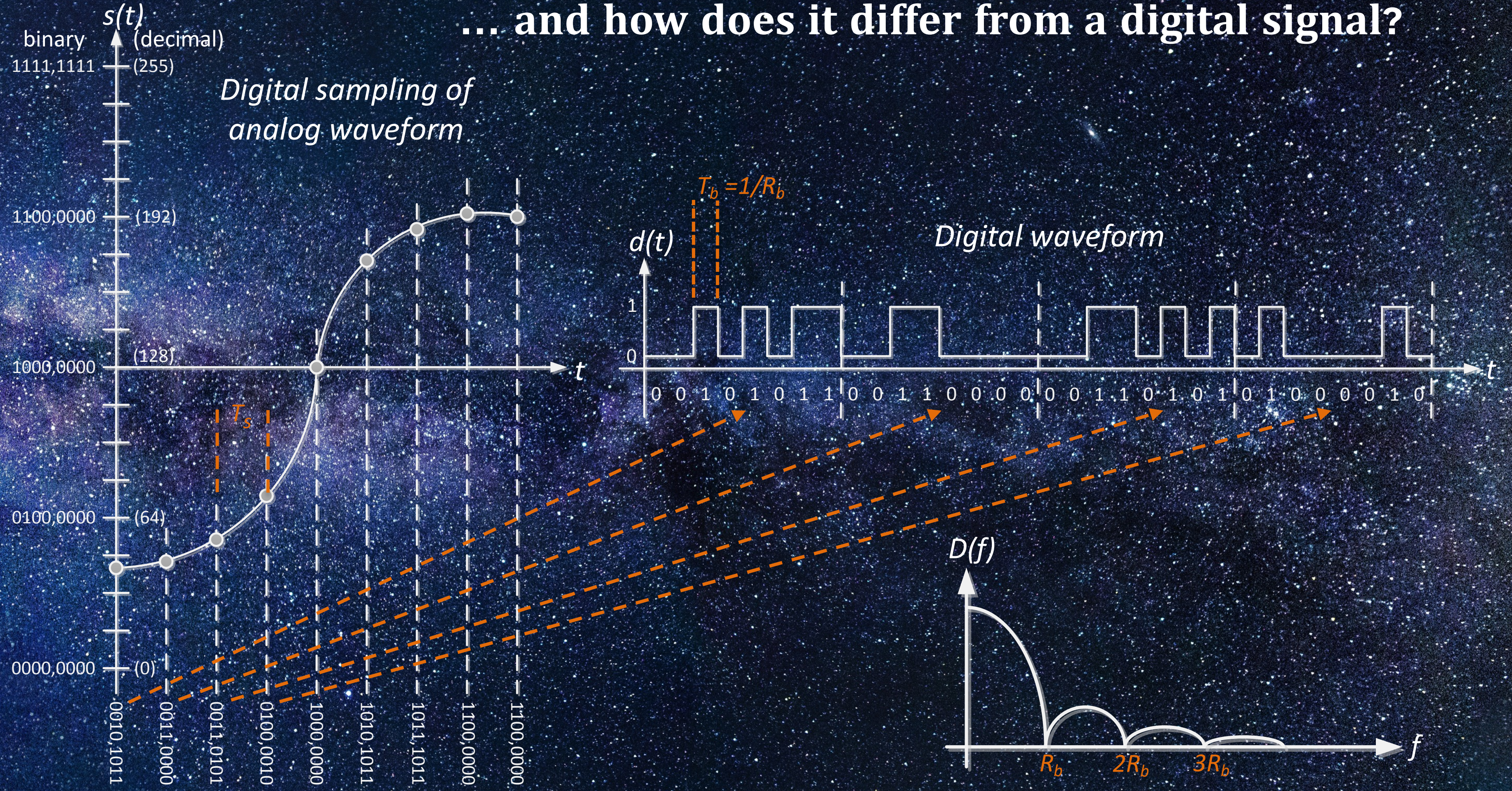
What is an analog signal?



… and how does it differ from a digital signal?



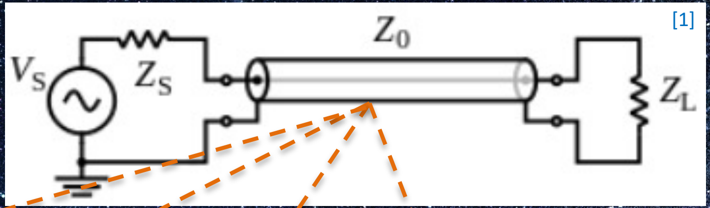
Why do we still use analog signal processing?

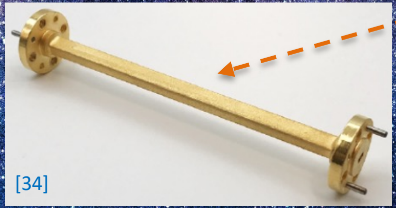
- The front-end of radio receivers utilize analog signal processing
  - Receiving antenna is usually followed by a combination of Low Noise Amplifier (LNA) and/or detector
  - Analog filtering and heterodyne frequency conversion to a common Intermediate Frequency (IF)
- Digitization is generally implemented as early as possible
  - Typically performed at IF but sometimes it is performed at RF for low frequency applications
- Radio Interferometer telescopes require the generation and distribution of a pure Local Oscillator (LO) from a central location to all of the antennas

Basic analog building blocks

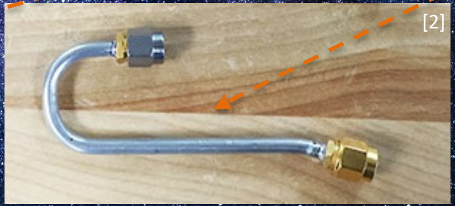
- ***Transmission line***
  - Characteristic impedance standardized to 50 Ohms
  - Waveguide
  - Coaxial cables

Source *Load*



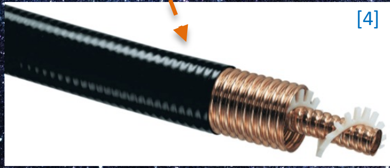


Straight waveguide
(75-110 GHz)



Semirigid coaxial cable
(0-18 GHz)

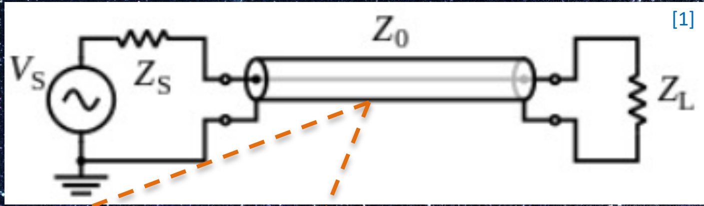
Flexible coaxial cable
(0-18 GHz)

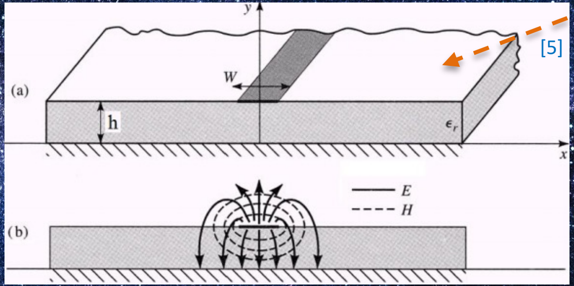


Heliax coaxial cable
(0-1 GHz)

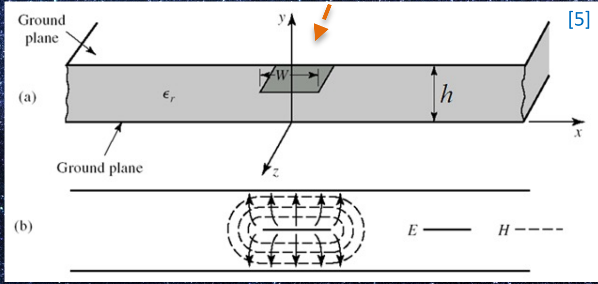
Basic analog building blocks

- ***Transmission line***
  - Circuit board transmission lines





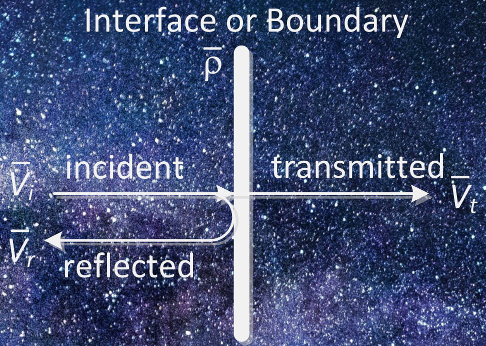
Microstrip

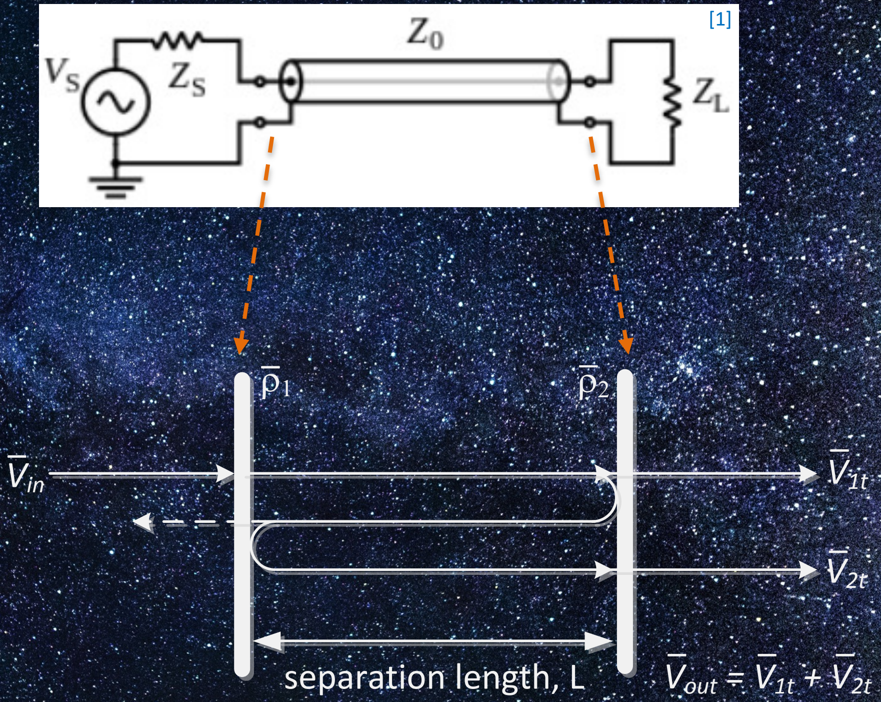


Stripline

Basic analog building blocks

- ***Transmission line and VSWR***





Voltage reflection coefficient $\rho = V_r/V_i$

Return Loss in dB = $20 * \mathrm{Log}_{10}(\rho)$

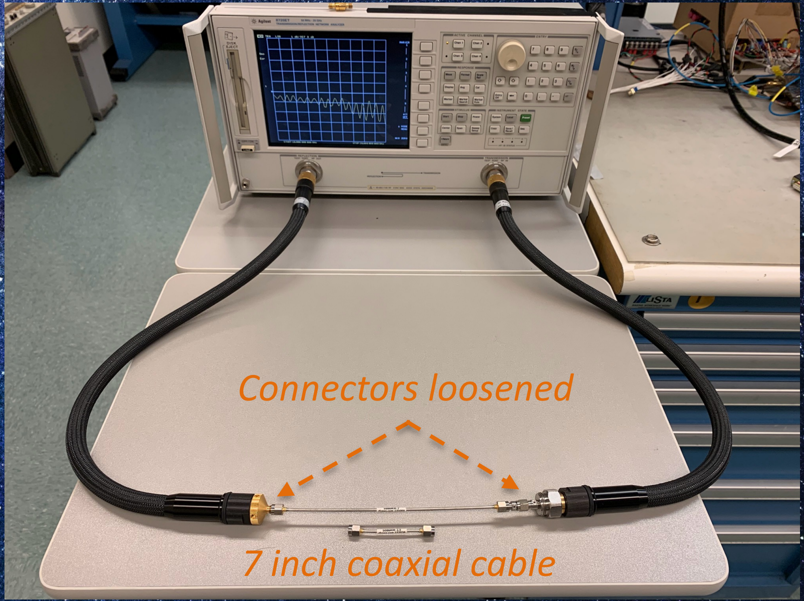
Voltage Standing Wave Ratio = $(1 + \rho)/(1 - \rho)$

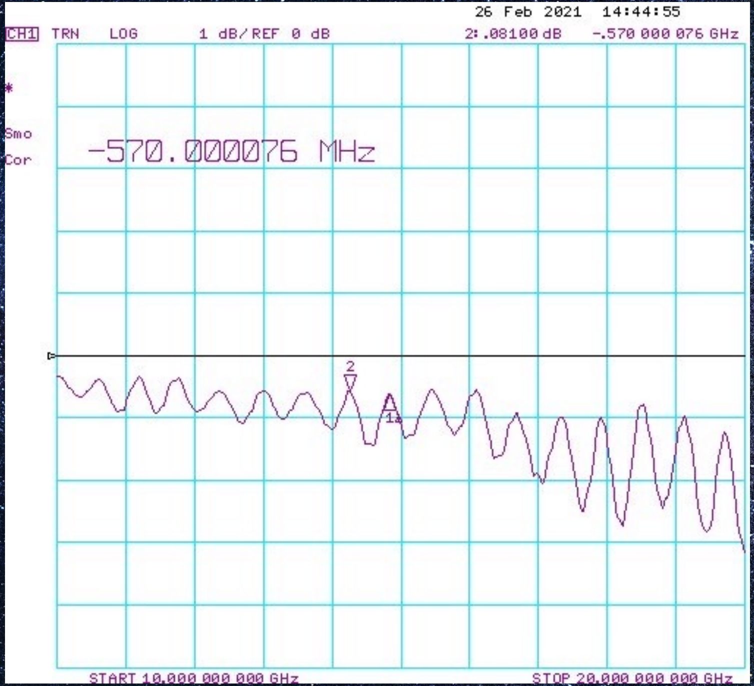
Basic analog building blocks

- ***Transmission line and VSWR***

Interference pattern $f_{ripple} = \frac{c/\sqrt{\varepsilon_r}}{2L}$

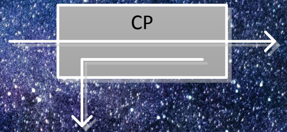
$$F_{ripple} = \frac{(3e8m/s)(0.674)}{2*(0.178m)} = 568\ MHz$$

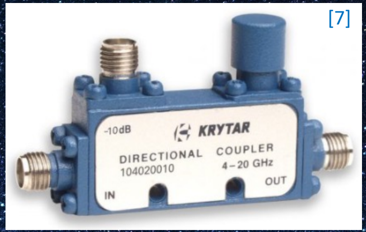




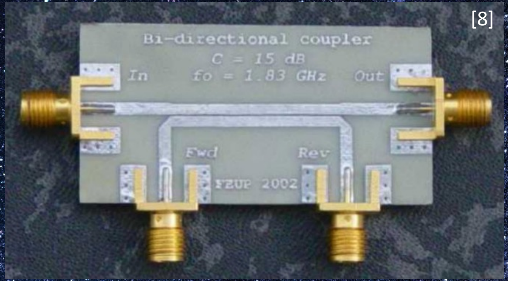
Basic analog building blocks

- ***Directional coupler***
  - Sample fractional portion of a signal

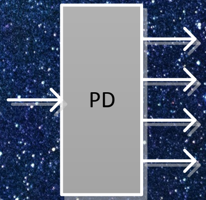




10 dB coupler
(4 - 20 GHz)



- ***Power divider***
  - Divide signal N-ways
  - Input to output loss 10*log(N)

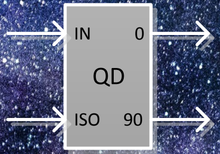


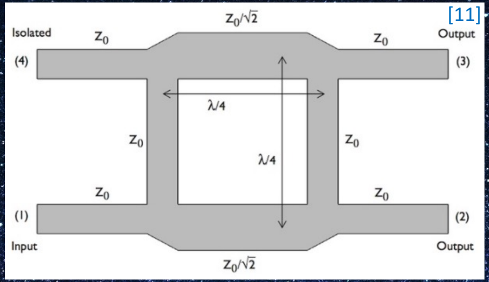
2-way power divider
(1.7 - 9 GHz)

2-way power divider

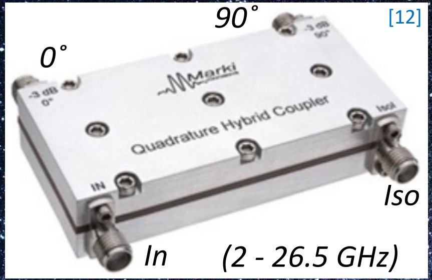
Basic analog building blocks

- ***90˚ hybrid coupler***
  - Divide signal into 0˚ and 90˚
  - I/Q modulator/demodulator
  - I/Q down converter

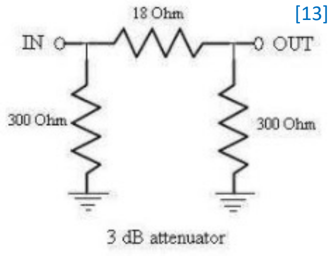




Microstrip arrangement



- ***Fixed attenuator***
  - Signal level control
  - Impedance matching

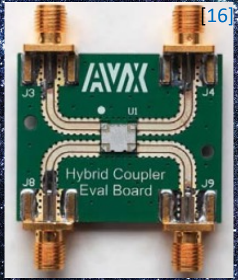


Resistive Pi circuit

(0 – 18 GHz)

(0 – 18 GHz)

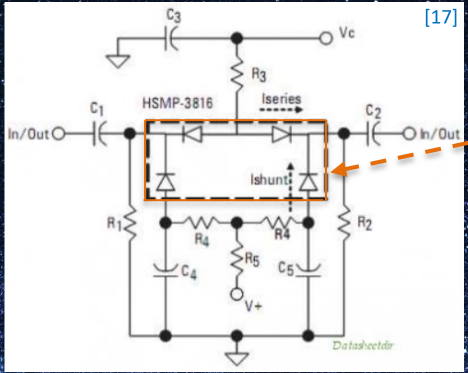
Chip 3.12 x 3.73 mm



Chip mounted on Evaluation board (1.5 – 2.1 GHz)

Basic analog building blocks

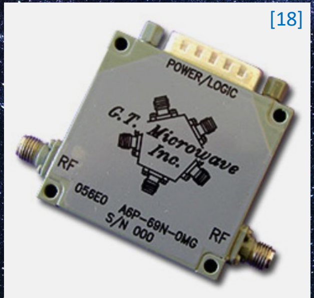
- ***Variable attenuator***
  - Variable signal power control
  - Automatic level control (ALC)
  - Amplitude/pulse modulation



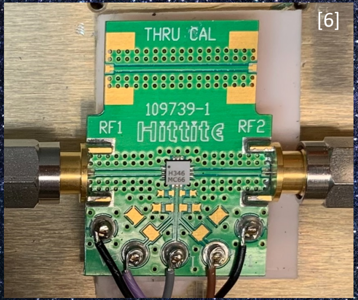
PIN diode attenuator

PIN diodes (0 – 4 GHz)

Manually controlled W/G attenuator (50-75 GHz)



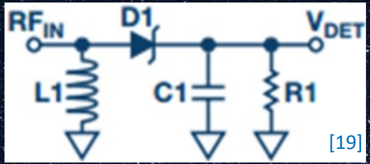
Digitally controlled attenuator (2 - 18 GHz)



GaAs MMIC (0 – 18 GHz) chip attenuator

Basic analog building blocks

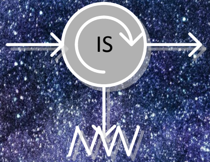
- ***Power detector***
  - Convert power to voltage for signal level measurement
  - AM/pulse detector



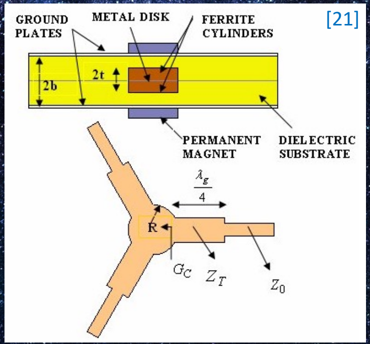
Zero bias Schottky

DC Out

RF In *(0.01 – 26.5 GHz)*



- ***Circulator***
  - Port-1 → Port-2, Port-2 → Port-3, Port-3 → Port-1
  - Low loss & high reverse isolation
  - Isolate mismatches between components
  - Separation of bidirectional signals

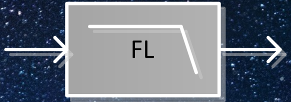


Internal configuration

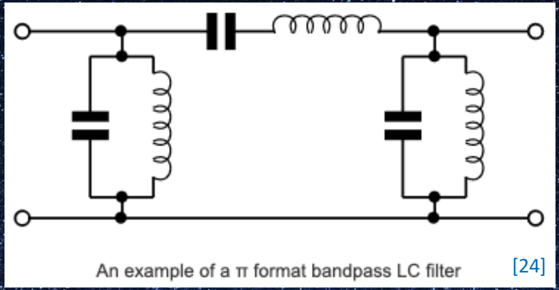
Surface mount

(6 – 18 GHz)

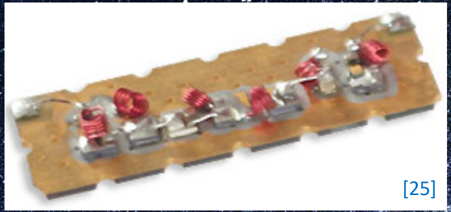
Basic analog building blocks



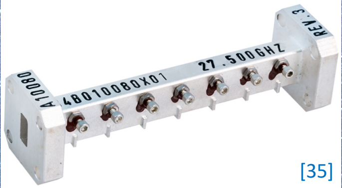
- ***Filter***
  - Low-pass, high-pass, band-pass
  - Band-stop, notch



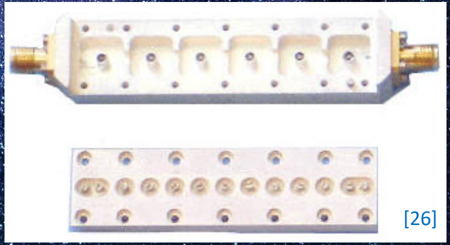
Schematic of 3rd order BPF



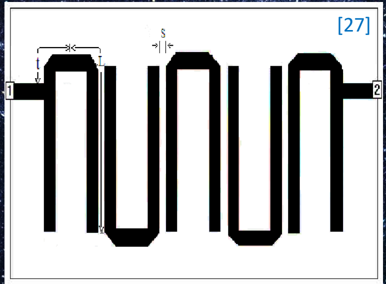
Lumped Element



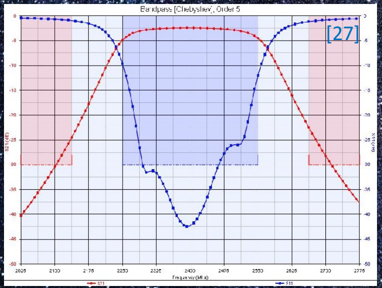
W/G cavity
(27.325 – 27.675 GHz)



Cavity



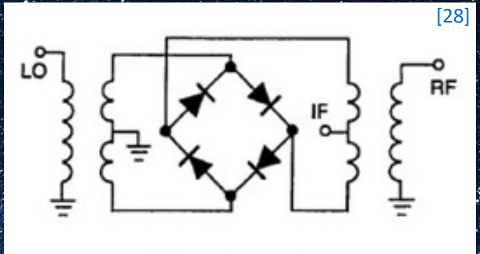
Coupled line hairpin



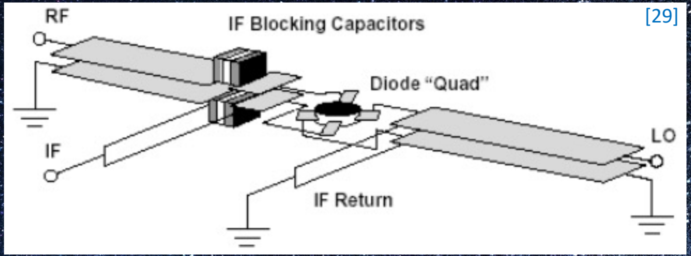
Filter response
(-3 dB at 2250 and 2550)

Basic analog building blocks

- ***Mixer***
  - Frequency translation, up or down conversion
  - Data modulation, demodulation
  - Frequency multiplication



Schematic of double balanced mixer



Typical layout of double balanced mixer

W/G mixer

(RF/LO 75 – 110 GHz, IF 0.1 – 35 GHz)

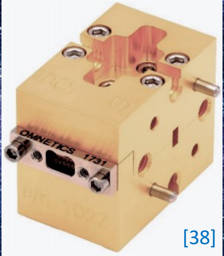
Packaged mixer

Active GaAs MMIC mixer

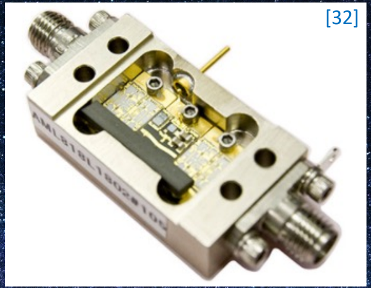
(RF/LO 2 – 12 GHz, IF 0 – 3 GHz)

Basic analog building blocks

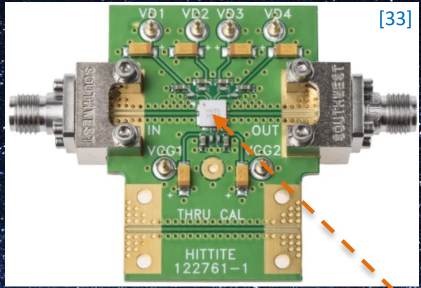
- ***Amplifier***
  - Frequency
  - Gain and flatness
  - Noise figure
  - Linearity
  - Match


[38]

65 – 115 GHz
gain 23 dB
flatness +/- 3 dB
NF 0.4 dB
P1dBc - dBm
VSWR 3.6:1, 2.5:1

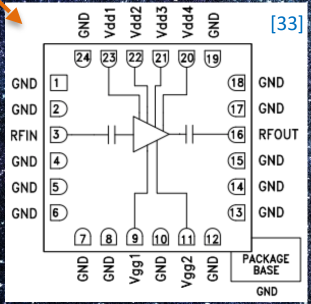

[32]

1 – 8 GHz
gain 30 dB
flatness +/- 2 dB
NF 1.8 dB
P1dBc +13 dBm
VSWR 1.8:1



[33]

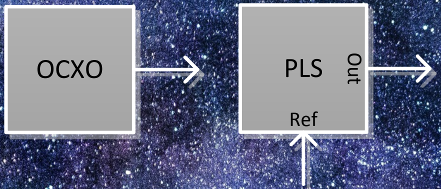
18 - 36 GHz
gain 18 dB
flatness +/- 1 dB
NF 7 dB
P1dBc +22 dBm
VSWR 1.6:1, 1.9:1

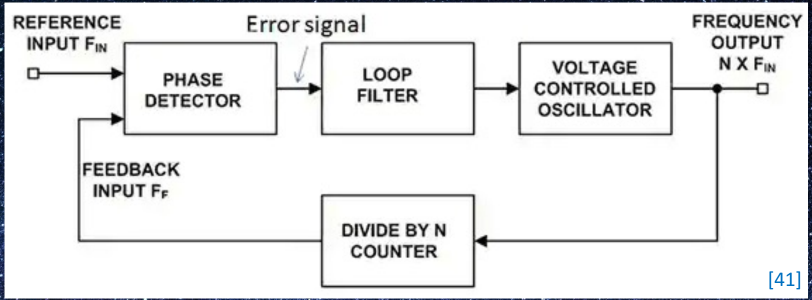


[33]

Basic analog building blocks

- ***Local Oscillator***
  - Synthesize sinusoid waveform
  - Phase lock loop (PLL)





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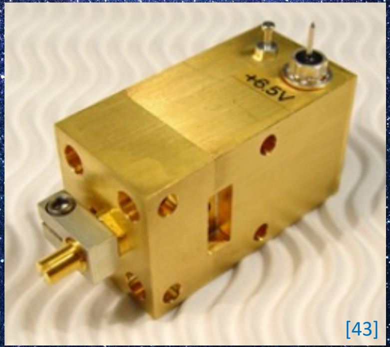

[43]

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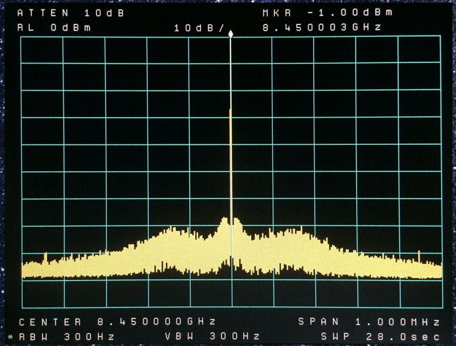
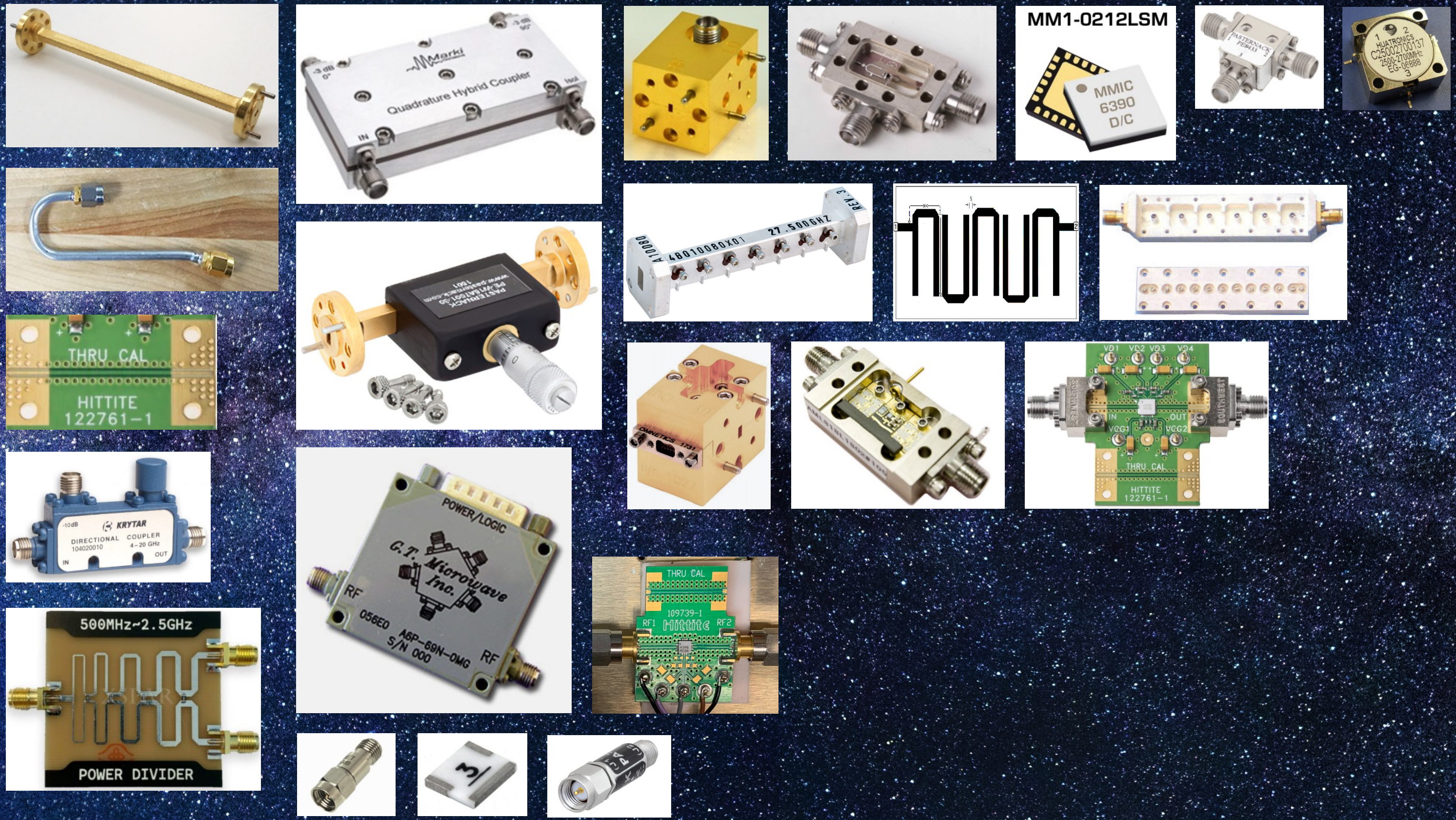
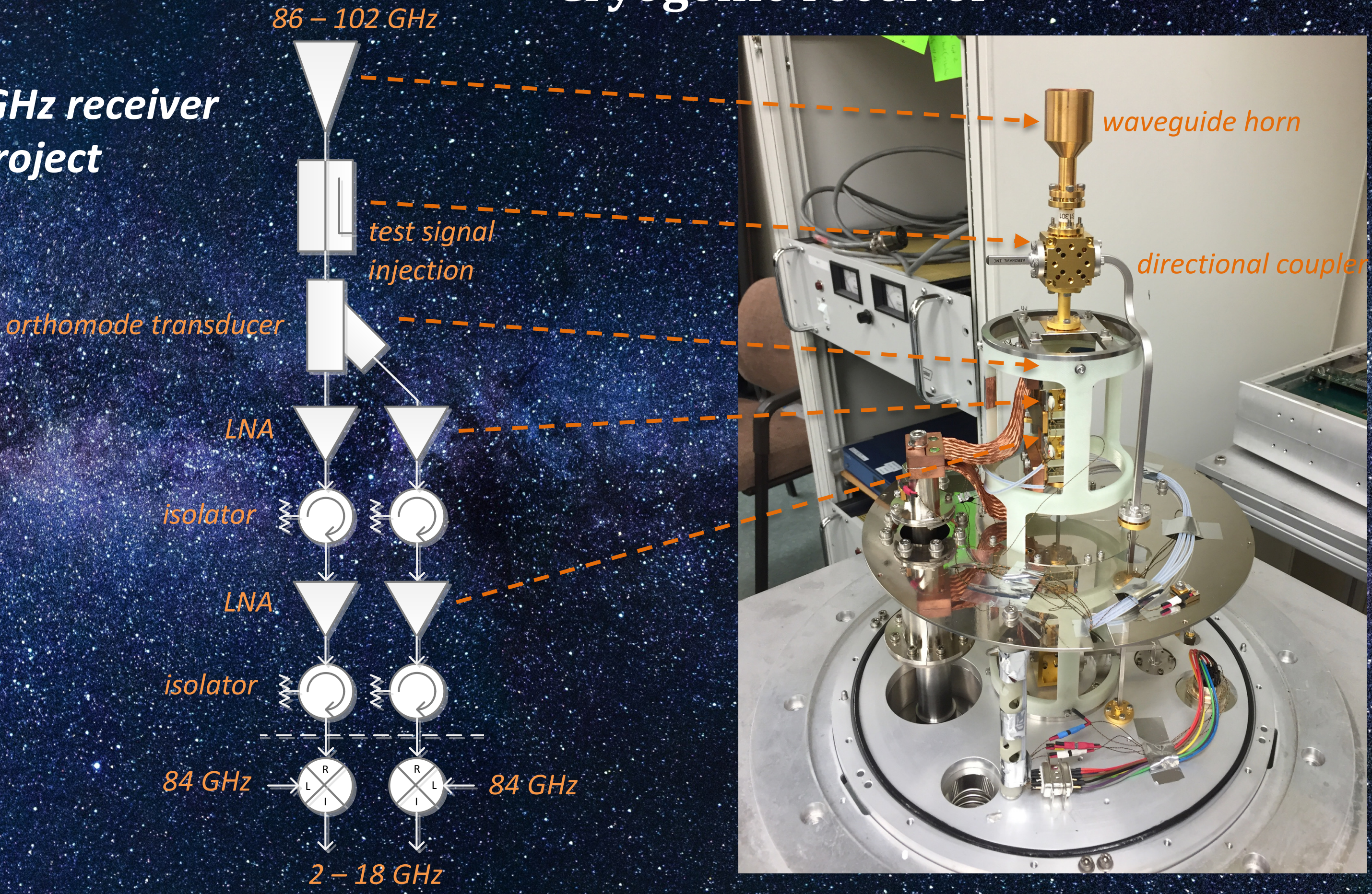


Basic analog building blocks



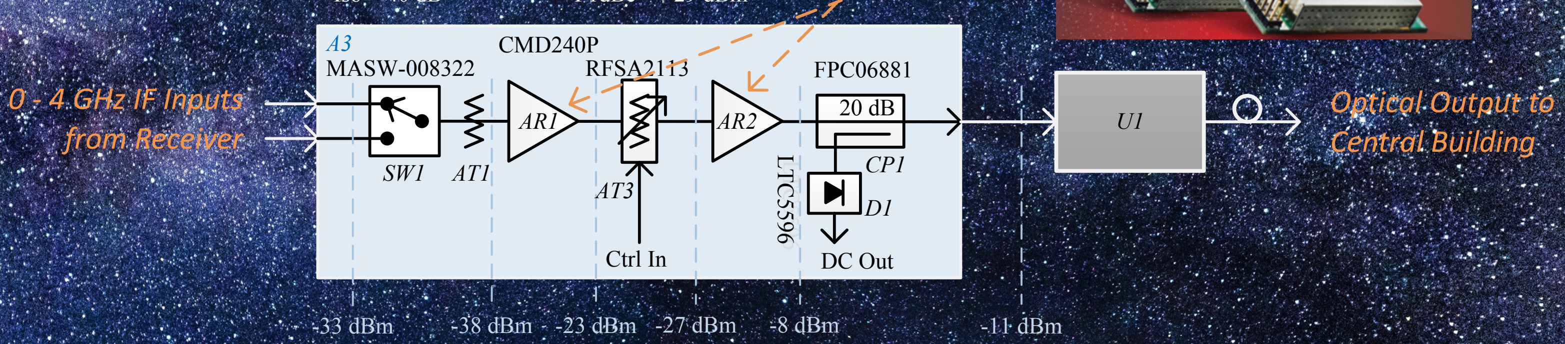
Cryogenic receiver

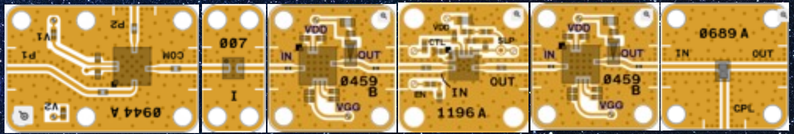
- ***86 – 102 GHz receiver for YTLA project***



Transmission of IF signal from antenna

- ***SMA design concept for transmission of 0 – 4 GHz IF Signal from antenna to central building***

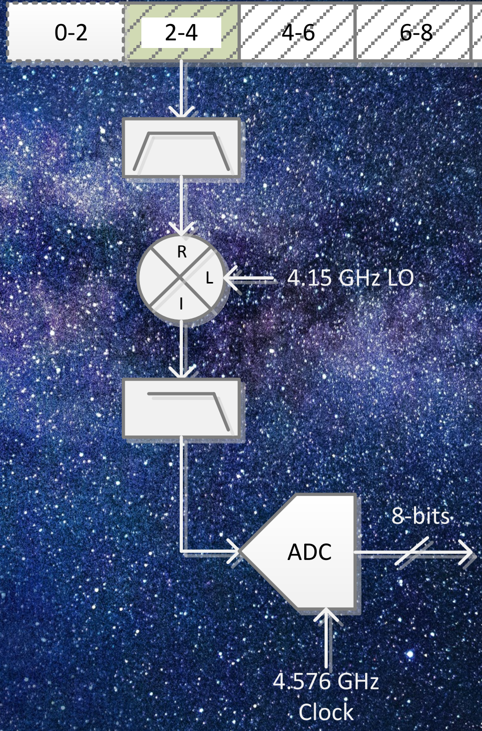


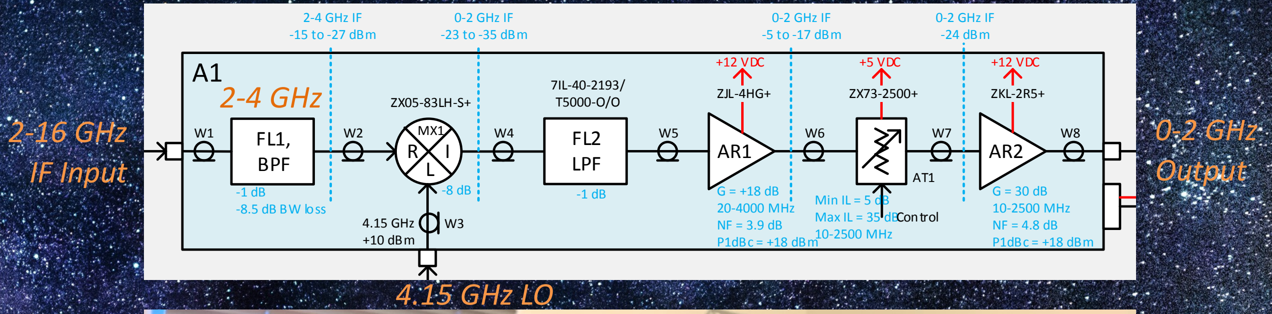


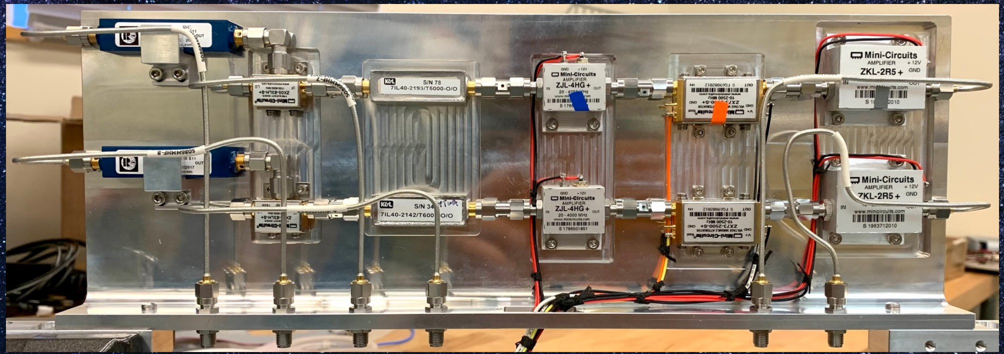
Individual microwave drop-in components

Frequency translation from IF to baseband

- ***Block Down Converter for SMA project***

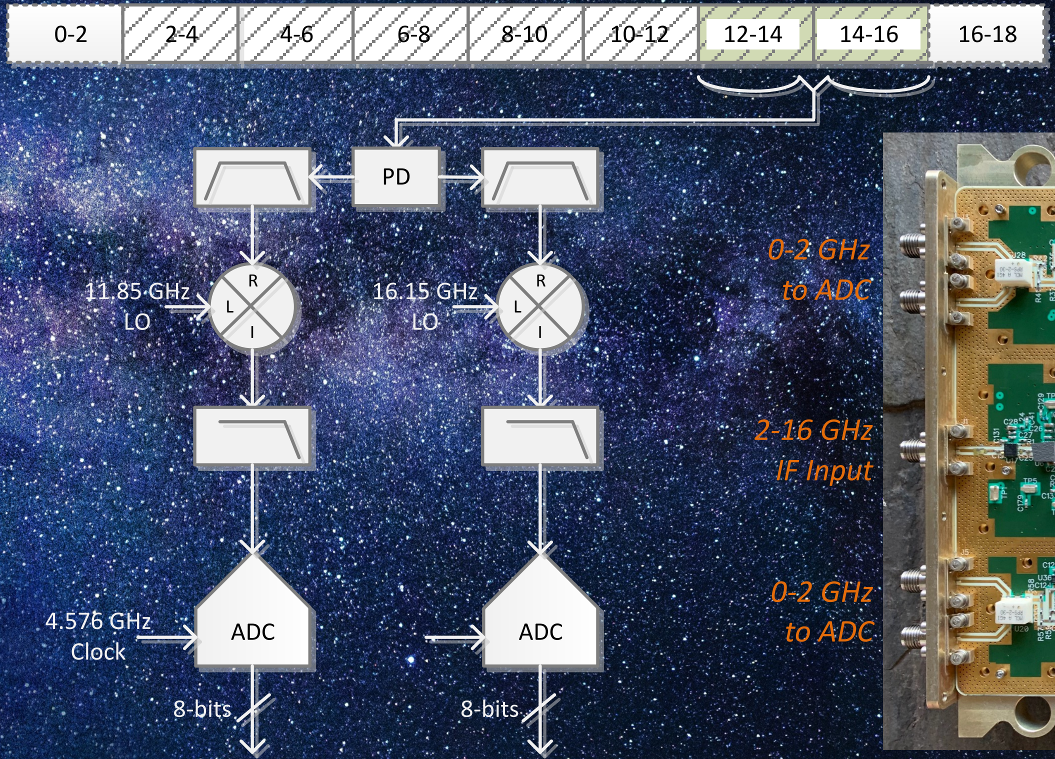


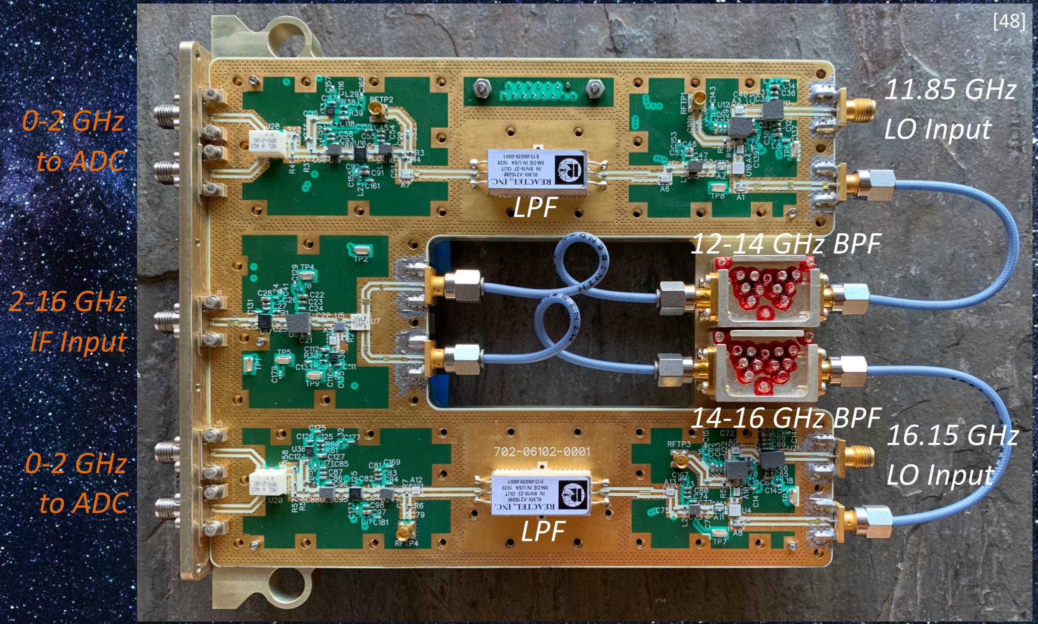




Frequency translation from IF to baseband

- ***Block Down Converter***





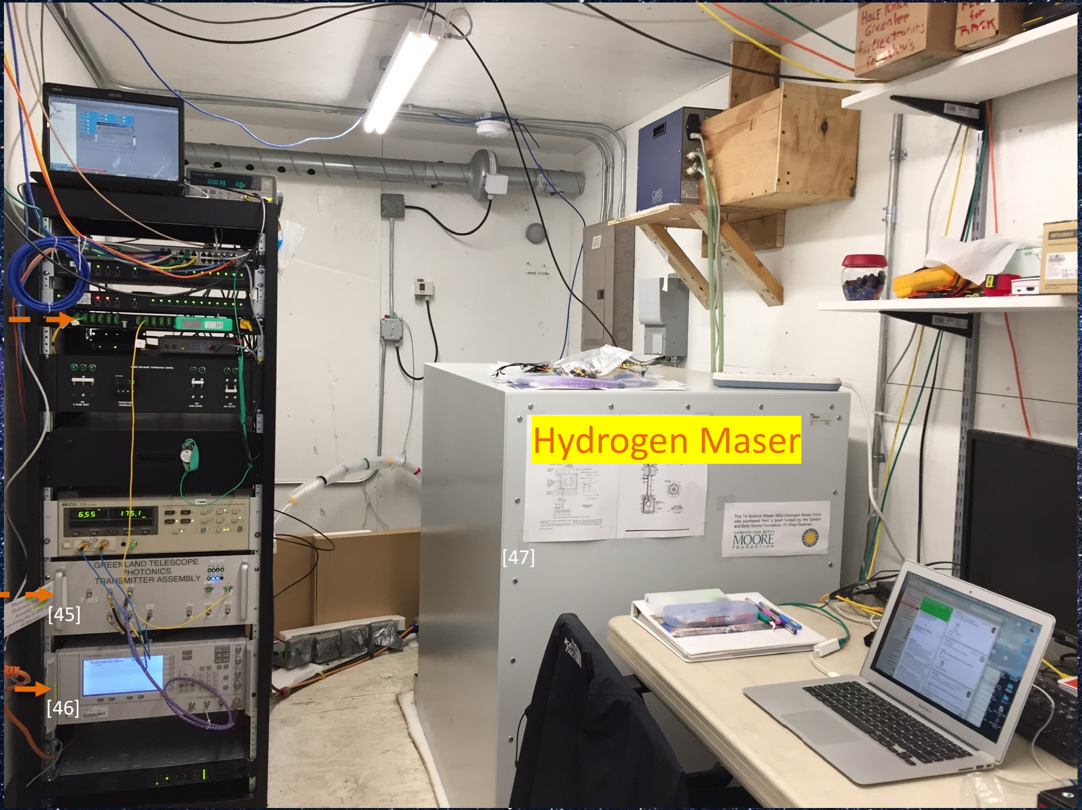
Transmission of LO to antenna

- *Transmission of 18 – 32 GHz LO Signal from central building to antenna, GLT project*

Fiber optics to antenna

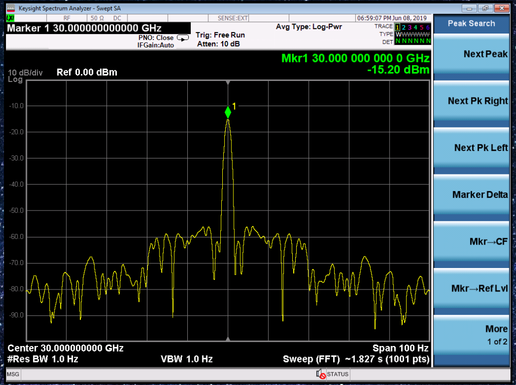
Optical LO transmitter

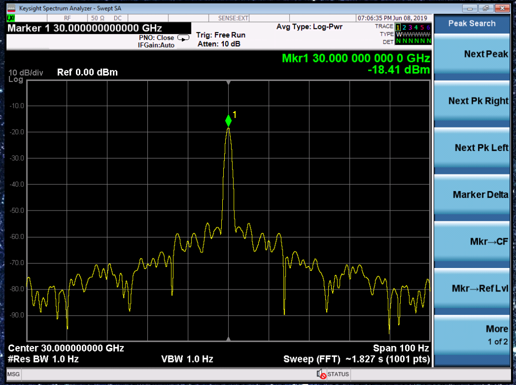
Low phase noise synthesizer

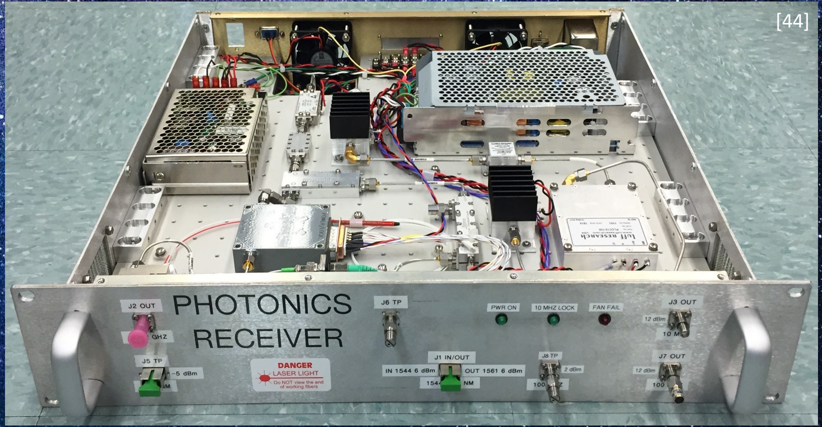


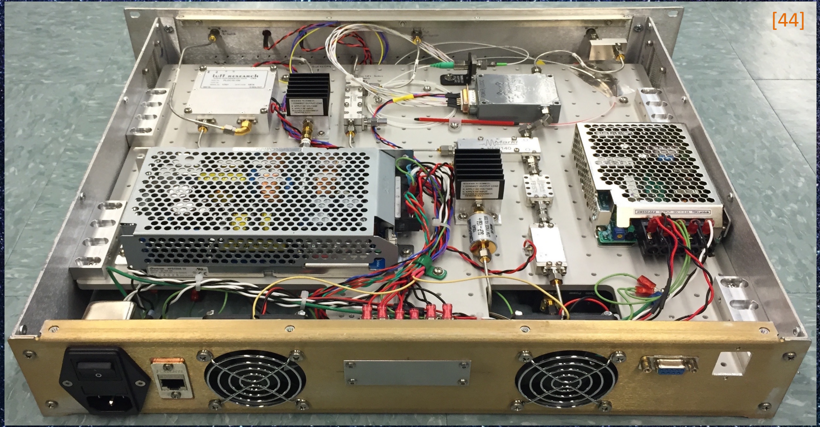
Reception of LO in antenna

- ***Reception of 18 – 32 GHz LO signal in antenna, GLT project***









References

Image sources and references:

[1] https://www.pngegg.com/en/png-pbilr
[2] https://www.santron.com/blog/index.cfm/2015/3/26/SemiRigid-Cable-Assemblies-Still-Alive-and-Well
[3] https://www.centricrf.com/cable-assemblies/sma-cable-assemblies/
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[5] Skaik, Talal, EELE 3332 lecture, 2013, http://site.iugaza.edu.ps/tskaik/files/Microstrip.pdf
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[8] http://www.ittc.ku.edu/~jstiles/723/handouts/The%20Directional%20Coupler.pdf
[9] https://www.osbaytech.com/product-catagory/power-splitter-divider/
[10] https://www.ebay.com/itm/283986682223
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