RF Solutions Inc.

Sanjay Moghe

“Low Cost RF ICs for OFDM Applications”

Sanjay Moghe is the President and CTO of RF Solutions, which makes advanced ICs for wireless applications. He has 24 Years of management and engineering experience in development of technology and products for wireless and Internet applications with large and small companies. He was director of engineering at ADC Telecom, and was responsible for development of Broadband wireless access systems. He has worked in various engineering management positions at a number of companies including Northrop Grumman, Pacific Monolithics, Avantek and Raytheon. At Northrop Grumman as the Director of advanced microwave technology group he managed a group of more than 37 engineers and technicians working on advanced MMICs and systems. He has published over 32 papers in the areas of wireless telecommunication systems, low-noise and power amplifiers; microwave integrated circuit (MIC) and monolithic microwave integrated circuit (MMIC) design techniques. Served on the technical program Committees of GaAs IC Symposium and International Microwave and Millimeter wave Monolithics Circuit Symposium. His helped develop over 600 MMIC and MIC component and subsystem products for wireless communication and military markets covering 0.1-100 GHz frequency range. He received a Ph. D. in electrical engineering from Troy NY in 1980 and an MS in Physics from IIT Bombay in India in 1974.

Low Cost RFICs for OFDM Applications

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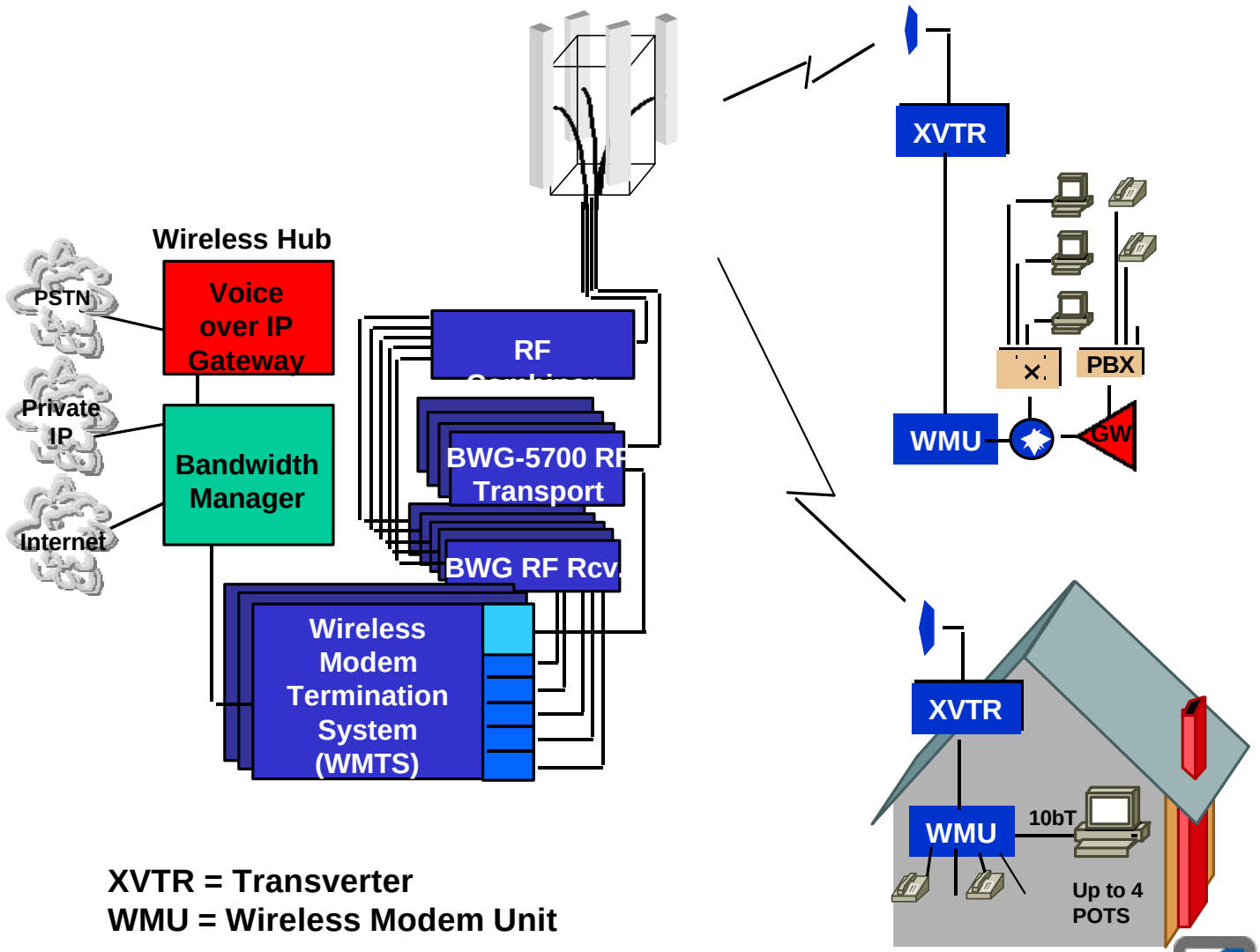
Outline

- Broadband Wireless Access
- Low Cost CPE
- OFDM requirements
- RFICs for MMDS systems
- RF Solutions' RFICs
- Summary

Typical MMDS System Block Diagram



XVTR = Transverter
WMU = Wireless Modem Unit

System Considerations

- Coverage area
- Take rate / applications- data, VOIP, video, video conferencing etc.
- Technology, single vs. multi carrier (OFDM), MIMO,
- FDD vs. TDD
- Interference, neighbors, ITFS channels etc.
- Symmetry u/s, d/s
- Number of cells
- Sectorization
- Frequency planning - u/s, d/s channels, sub channels, frequency reuse
- Headend modem - modulation, FEC, symbol rate etc. Head end - channels, no of receivers, sectorization
- Antenna - headend , transverter, specs.- front to back, side lobes,
- Frequency hopping, space diversity
- Transverter specs.-Po, TR on / off,
- Modem performance - symbol rate, equalizer, FEC,
- Modem transverter integration

CPE Cost Drivers

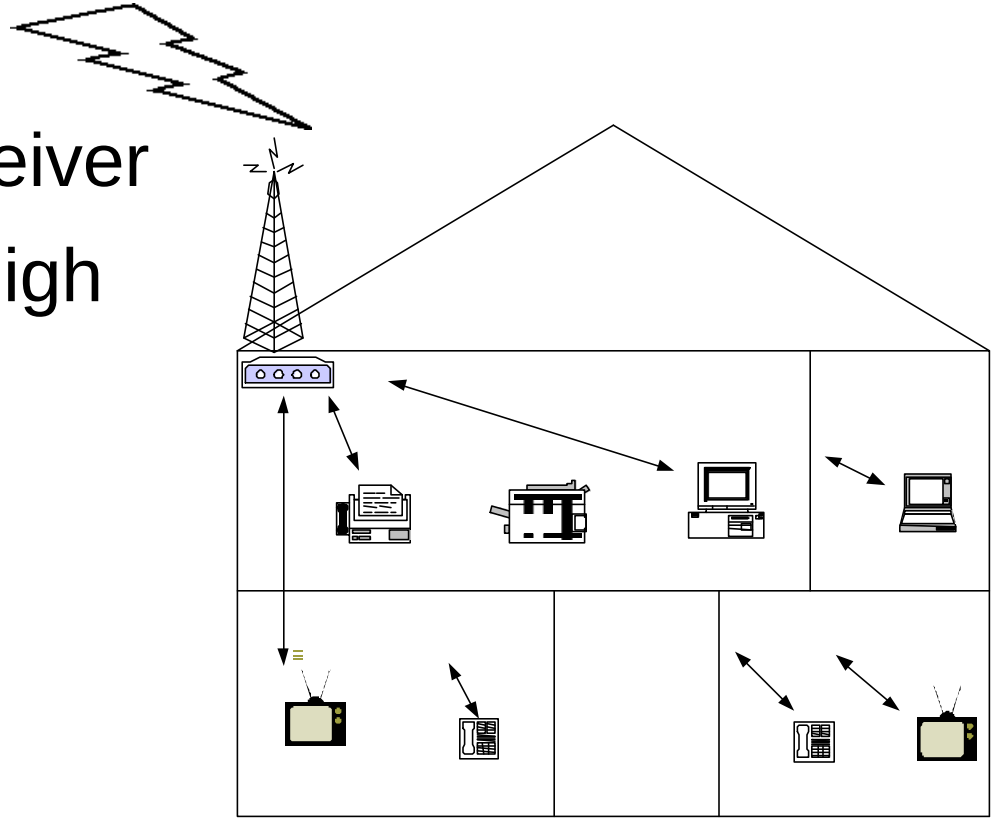
- **System architectures**
  - Large vs. small cells
  - Single vs. multi carrier system
  - Antenna / Transceiver
    - OFDM
    - MIMO
    - RFIC integration
  - Modem
    - Baseband IC integration
    - Modem / transceiver integration

OFDM Requirements

- **Higher Linearity Requirements**
  - 4-8 dB higher P-1 needed than single carrier
  - Transceiver architectures
  - Need for standardization of different OFDM technologies
- **MIMO System Architectures**

Fixed Broadband Access Product

- MMDS Transceiver
- Enables very high speed:
  - voice
  - data
  - video
- Consumer and business customers



Cost Drivers for RFICs

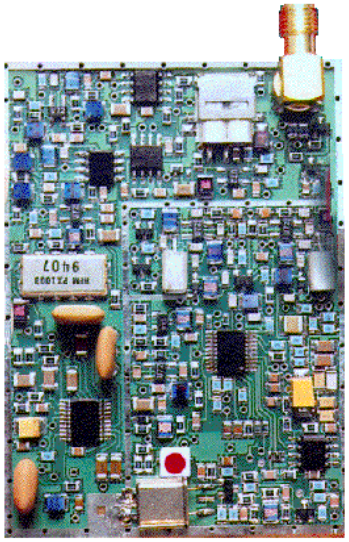
- Process – SiGe vs. GaAs
- Wafer size -- 4” vs. 8”
- Process steps - # of steps, via holes
- System Architecture
- Integration level
- Die size / yield
- Packaging

RF Solutions IC Examples

- MMDS transceiver
- 5 GHz transceivers
- 3.5 GHz transceivers

Conventional Transceiver

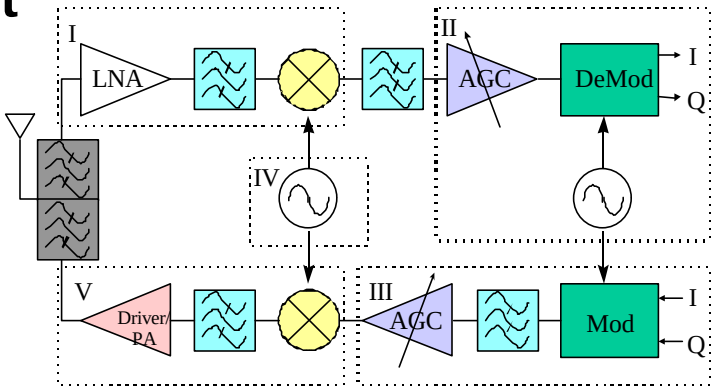
- Approximately 500 total components
- High bill of materials cost
- High cost of manufacturing/part placement
- Difficult to integrate into system
- A complex and cumbersome RF testing process
- High variability in performance (more component variables higher uncertainty)
- Physically large in size

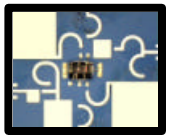


Conventional Transceiver

Why MMICs?

- **Greatly reduced component count** (*approximately 500 to 50*)
- **Lower bill of materials cost**
- **Lower cost of manufacturing/part placement**
- **Easier to integrate into system**
- **Simplified, repeatable RF testing process**
- **Tight performance tolerance (fewer component variables less uncertainty)**
- **Physically smaller in size**
- **Easier to implement advanced architectures**





MMIC Transceiver

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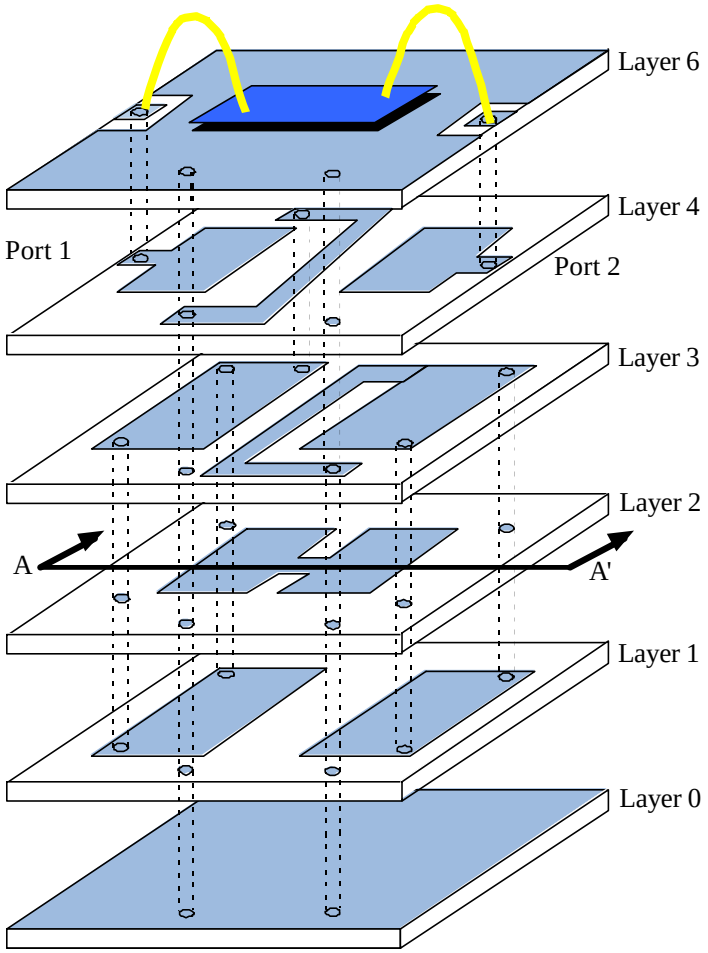
RF Solutions MMIC Technology

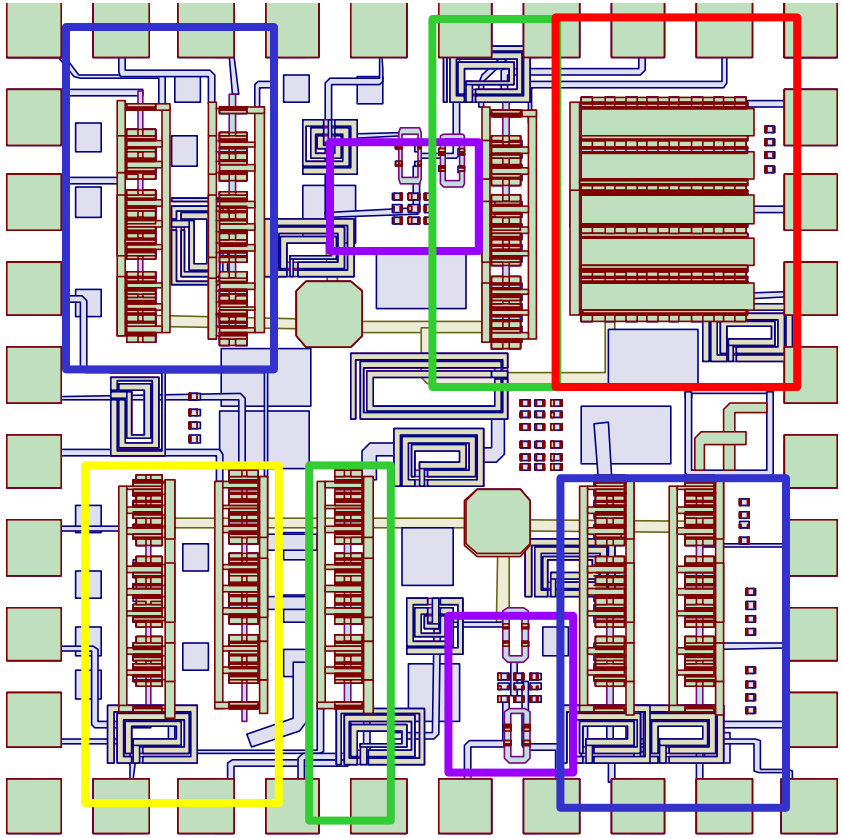
- Benefits
  - High volumes = low cost
  - Highly repeatable performance
  - Integrated active and passives
  - FETs are free
- Processes
  - GaAs, GaAlAs, Si, SiGe, InGaP
- Devices
  - CMOS, BiCMOS, MESFET, HBT, pHEMT

FlexICore Concept

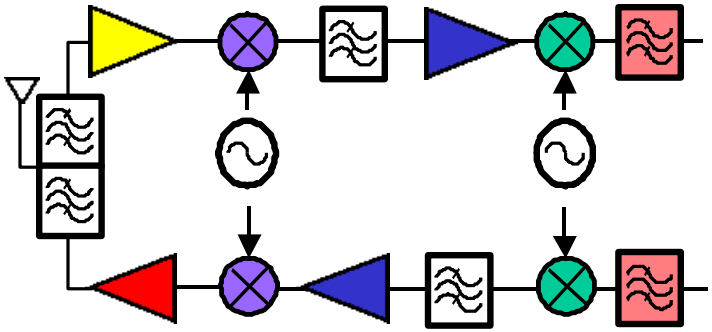
- MMIC active device blocks and LTCC matching
- Flexible Design
- Rapid Prototyping
- Embedded Passives
- Reduction of device count (100+ to 2)



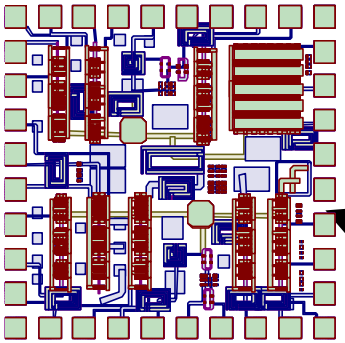
FlexICore Dual Conversion Transceiver



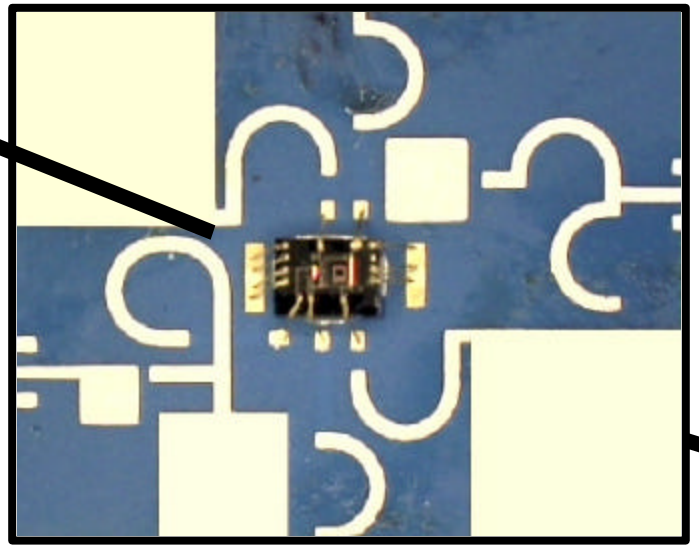
- LNA – 2 FETs
- PA – 3 FETs
- RF Mixer – 4 Diodes
- Amp – 2 FETs
- IF Mixer – 1 FET
- IF Filters –LTCC



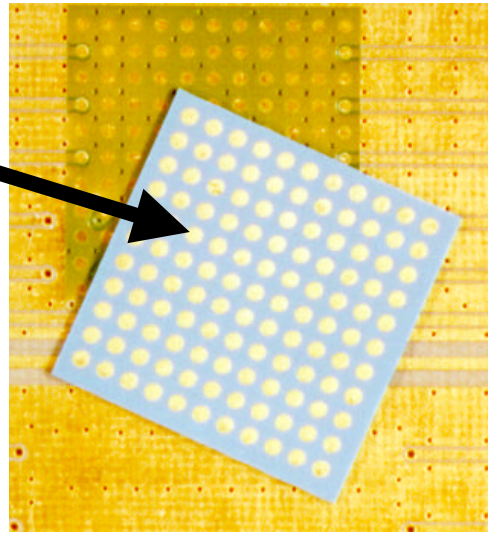
FlexICore



MMIC

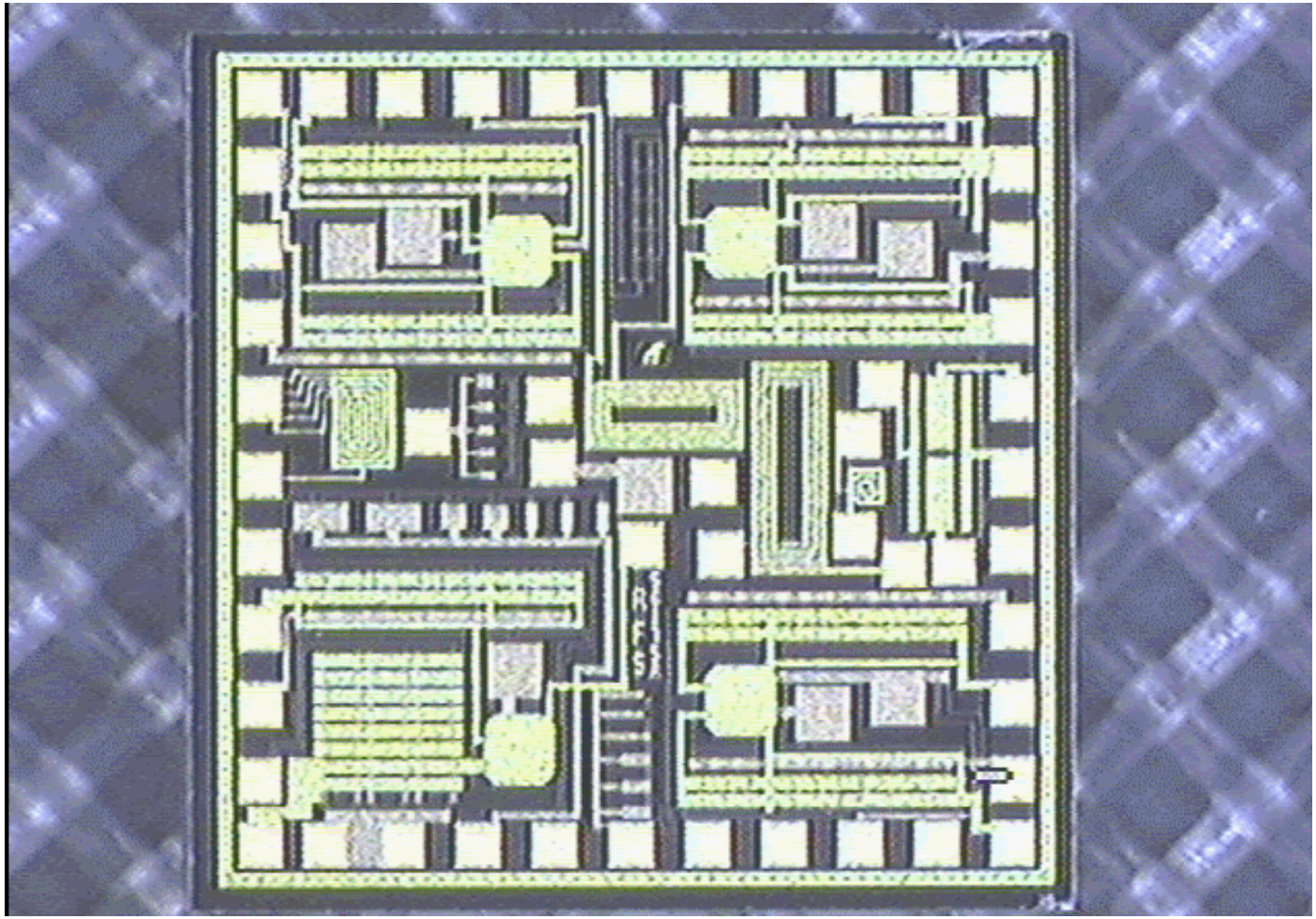


MMIC on LTCC



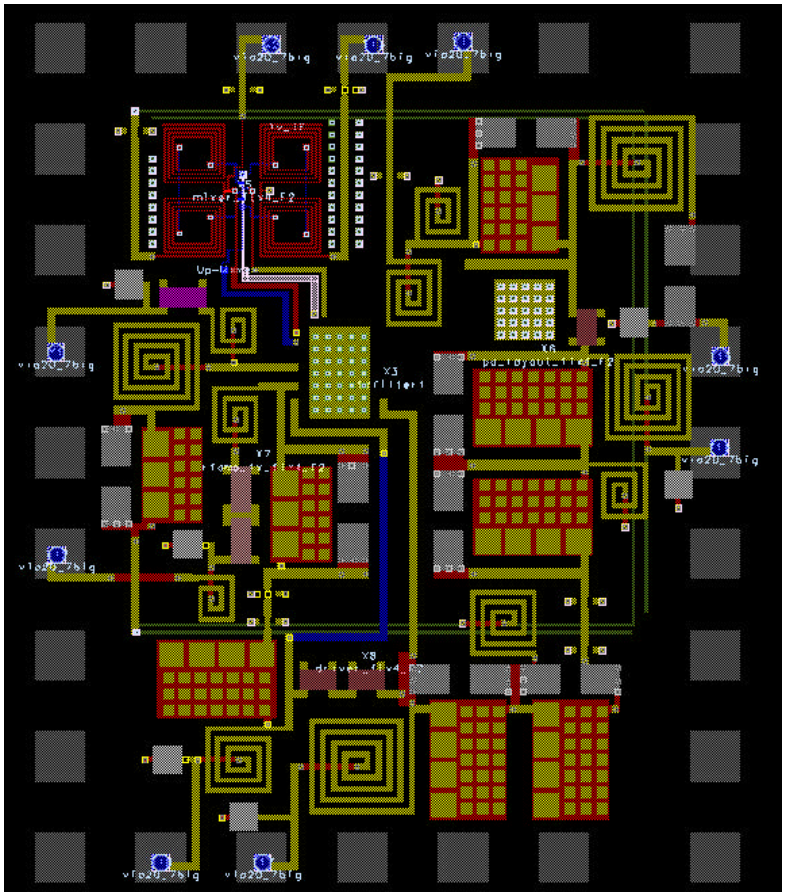
BGA

RFS Transceiver MMIC

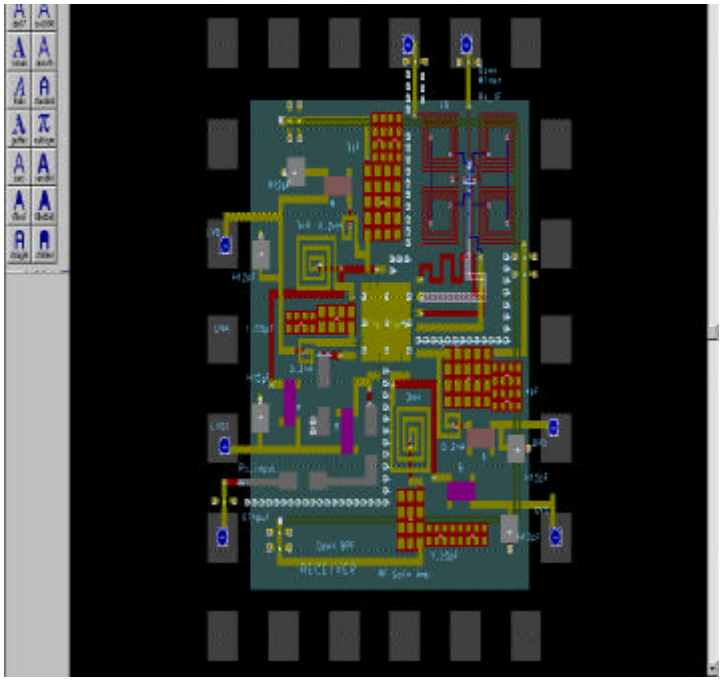


3.5 Rx/Tx

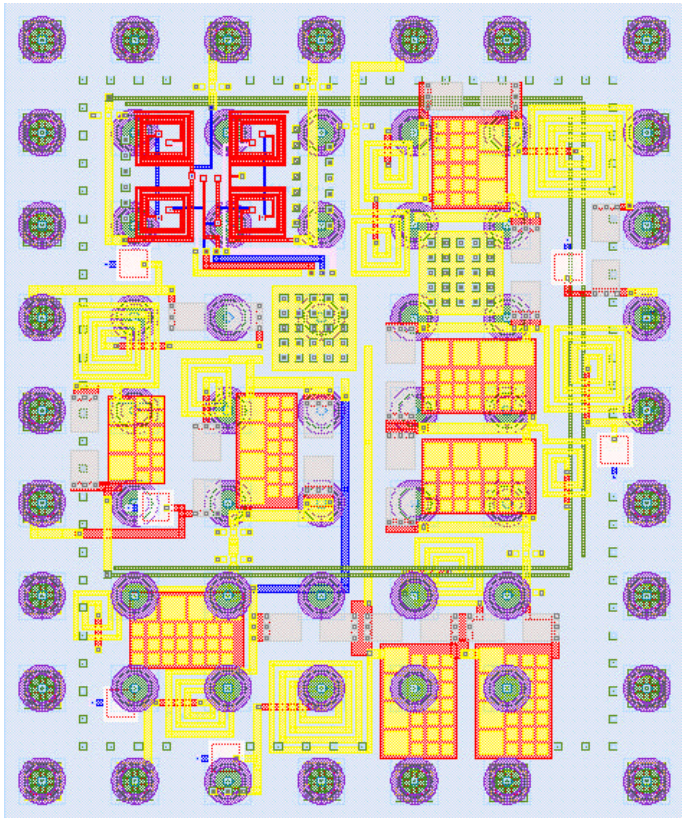
850x700mil



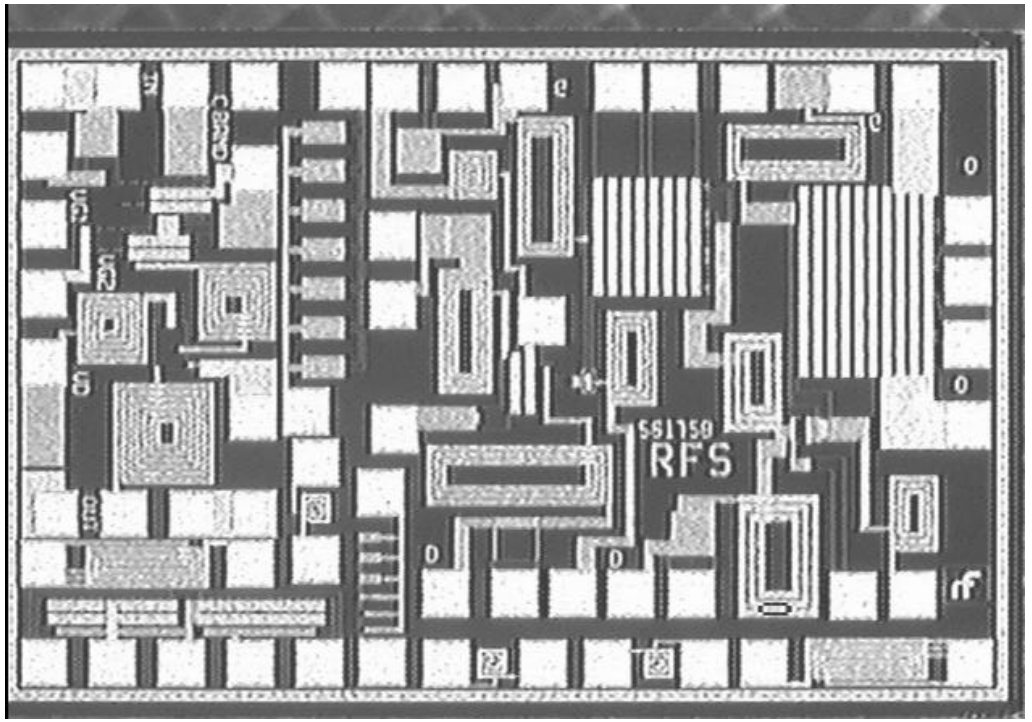
700x700mil



MMDS Transceiver LTCC Substrate with FlexICore IC



RFS LNA and PA



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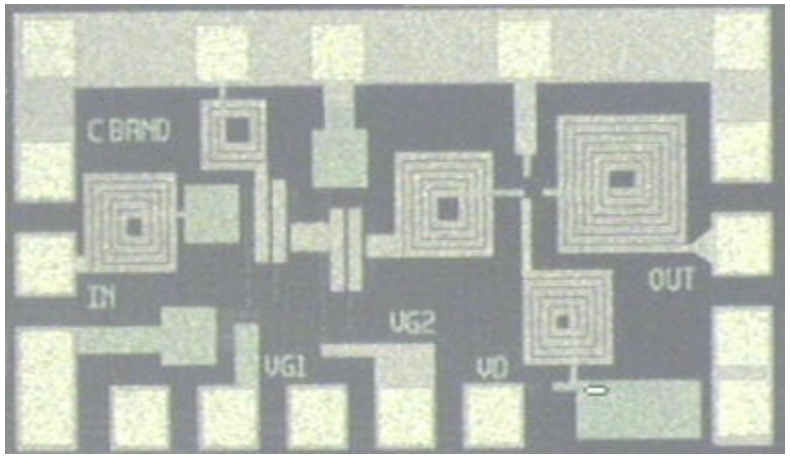
OFDM LNA Summary

- **Linear High IP3 LNA**
- **Low Power Consumption**

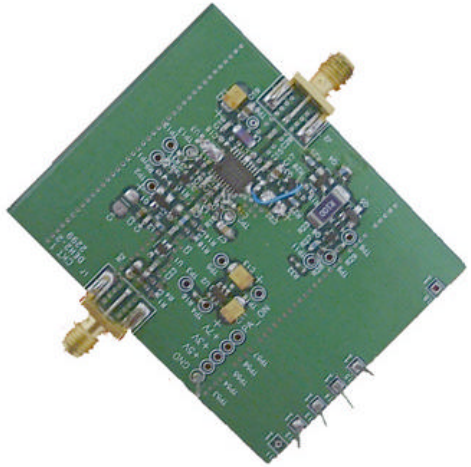
	Measured
Frequency (GHz)	**5.8**
NF (dB)	**2.2**
Gain (dB)	**13**
IIP3 (dBm)	**2.8**
Input Return Loss (dB)	**18**
Output Return Loss (dB)	**12**
Supply Voltage	**3.3**
Current (mA)	**4.5**



Rev A

3.5 GHz Power Amplifier IC

- **Applications**
  - Wireless Local Loop based on Proprietary 3G Wireless Standards
  - Subscriber Unit



- **Features**
  - 30 dBm P1dB at 5V
  - 31.5 dBm P1dB at 7V
  - TSSOP-20 package with backside slug
  - Suitable for W-CDMA

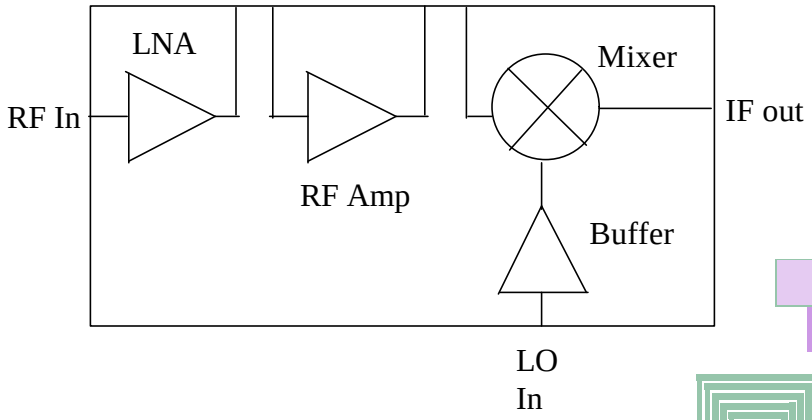
3.5 GHz PA Specs

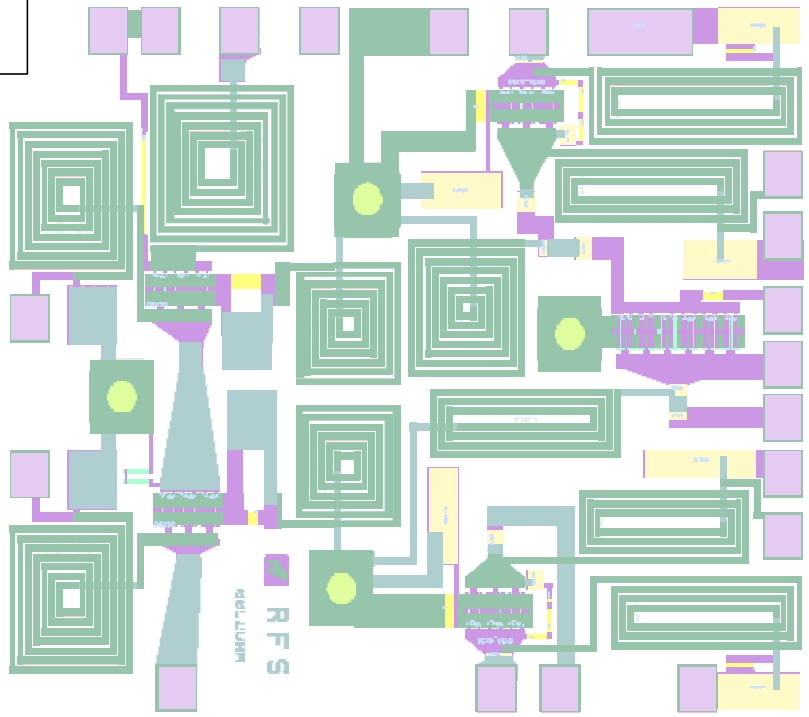
Specifications

Test conditions: room temperature, at Vd = 5 V, Vg = -0.9 V

Parameter	Min	Typical	Max	Units
Frequency	3400		3500	MHz
P1dB	29.5	30		dBm
Gain	23	23.5		dB
DC Supply	4.8	5	5.5	V
Operating Temperature	-40		85	°C

MMDS Receiver Chip





MMDS Receiver IC Specs

LNA

	Min	Typ	Max.	Simulated		
Frequency	2500		2686	2500	2600	2700
NF (dB)		1.7	1.8	1.63	1.62	1.65
Gain (dB)		18		18.8	18.1	17.1
IIP3 (dBm)		0		4	8	5
Gain Flatness (dB)				1.7		
Input RL (dB)		-14		-15	-16	-13
Output RL (dB)		-14		-13	-16	-15
Supply Voltage (V)		5		5		
Current (mA)		10		9		

Buffer Amp

	Typ.	Sim.
Frequency	2278	2278
Gain (dB)	12	12.6
IIP3 (dBm)	17	16
Input RL (dB)	-14	-20
Output RL (dB)	-14	-21
Supply Voltage (V)	5	5
Current (mA)	50	43

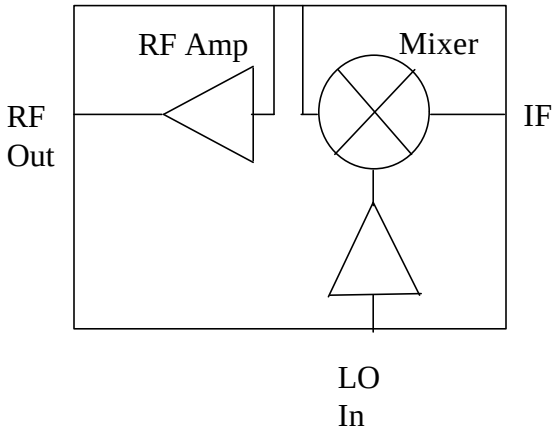
Mixer

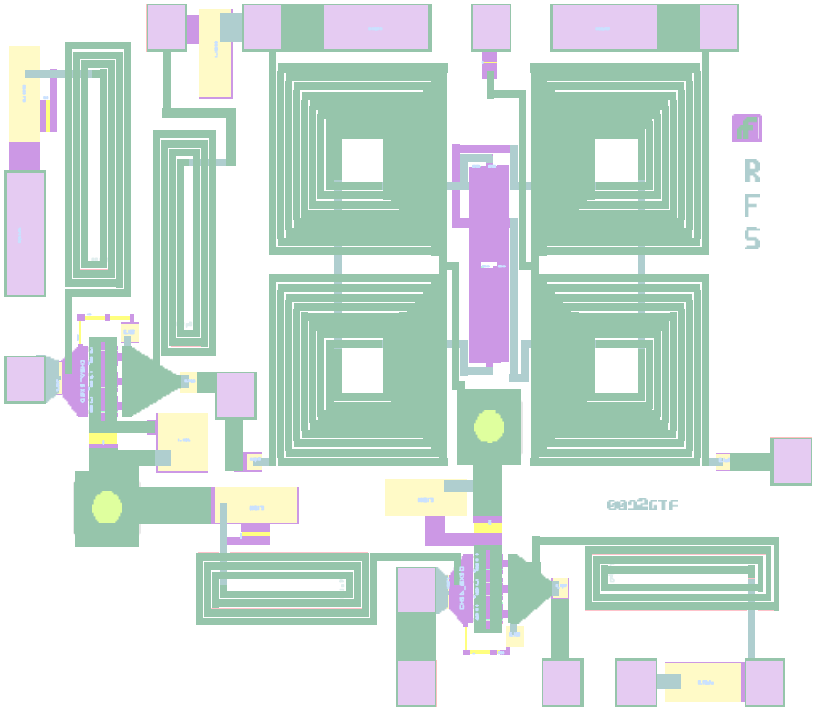
	Min	Typ	Max.	Sim.
RF (MHz)	2500		2686	
IF (MHz)	222		408	
LO (MHz)		2278		2278
LO Power (dBm)		8		12
Conv.Gain (dB)		-6		-6.5
IIP3 (dBm)		26		26
Gain Flatness (dB)				0.06
LO-IF Iso.(dB)		-30		-66
IF RL (dB)		-14		-26
LO RL (dB)		-14		-30
RF RL (dB)		-14		-13.5
Supply Voltage (V)				0.3

RF Amp

	Min	Typ.	Max.	Sim.
Frequency	2500		2686	
NF (dB)		4.5		
Gain (dB)		12		11.5
IIP3 (dBm)		17		16
Input RL (dB)		-14		-15
Output RL (dB)		-14		-18
Supply Voltage (V)		5		5
Current (mA)		50		43

MMDS Transmitter Chip





MMDS Transmitter IC Specs

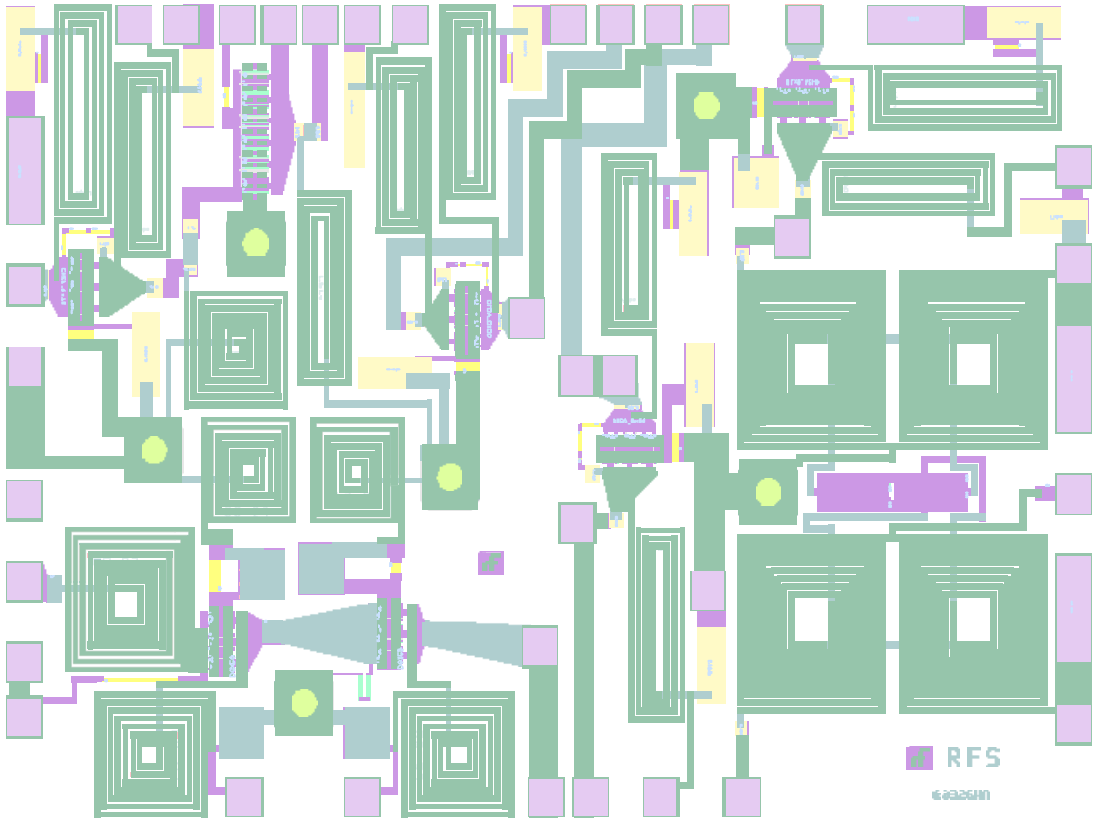
Mixer & Buffer Amp

	Min.	Typ.	Max.	Sim.
RF (MHz)	2500		2686	
IF (MHz)	100		900	
LO (MHz)		2278		
LO Power (dBm)		0		0
Conv. Gain (dB)		-6		-6.5
IIP3 (dBm)		18		17.5
LO-IF Iso. (dB)		-30		-38
IF RL (dB)		-14		-14.5
LO RL (dB)		-14		-14
RF RL (dB)		-14		-26
Supply Voltage (V)		5		5
Current (mA)		40		43

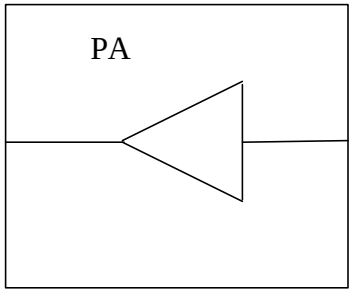
RF Amp

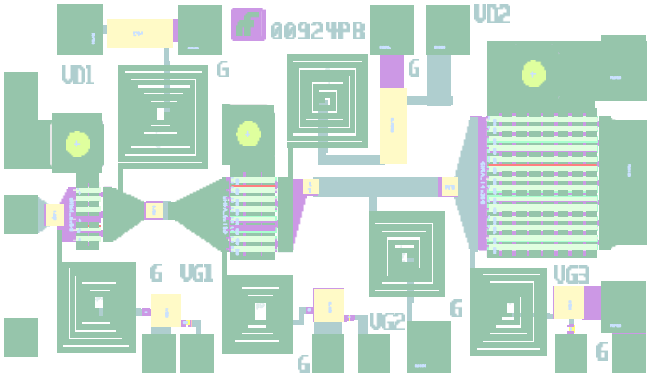
	Min	Typ.	Max.	Sim.
Frequency	2500		2686	
NF (dB)		4.5		
Gain (dB)		12		11.5
IIP3 (dBm)		17		17
Input RL (dB)		-14		-15
Output RL (dB)		-14		-16
Supply Voltage (V)		5		5
Current (mA)		50		43

MMDS Transceiver Chip



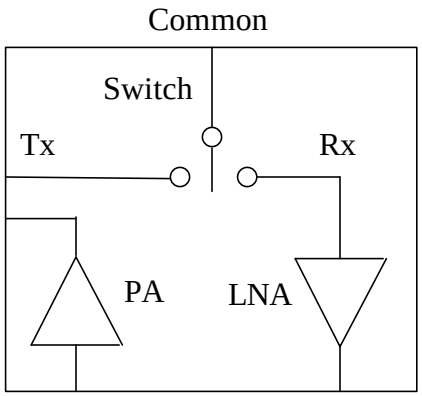
MDS/MMDS PA IC

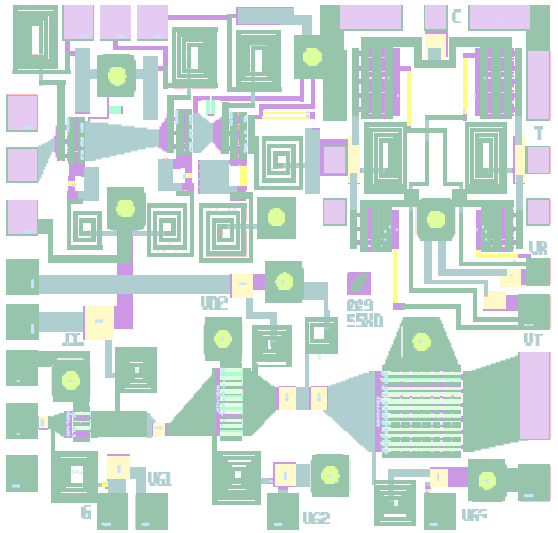




	Min	Typical	Max.	Simulated	
Frequency (MHz)	2150		2686	MDS	MMDS
Gain (dB)		27		29	30
P1dB (dBm)		31.5		32	32.2
Gain Flatness (dB)				< 0.1dB	< 2.3dB
Input RL (dB)		-14		< -15	< -15
Output RL (dB)		-14		< -12	< -15
Supply Voltage (V)		7		7	7
Gate Supply Voltage (V)		-0.9		-0.9	-0.9
Current Consumption (mA)			800	780	720

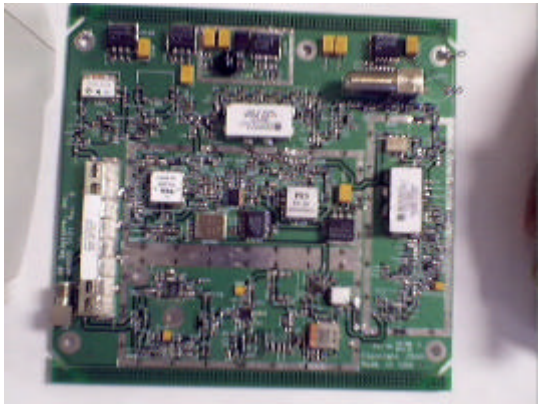
UNII PA/LNA/SW IC





RFS MMDS/MDS transceiver

- Circuit architecture critical to achieving tough specs and low cost
- MMICs and filters play a key role
- Advanced systems concepts can lower cost and improve performance



MDS/MMDS Transceiver

Aergo™ 2121 1-watt
MDS/MMDS Transceiver
2.1 GHz Upstream / 2.5 GHz Downstream

PARAMETER	TYPICAL	COMMENTS
DOWNCONVERTER		
RF Input Frequency	2500-2686 MHz	MMDS Band
Output Frequency	222-408 MHz	
Gain	15 to 30 dB	Factory Adjustable
Gain Variation vs. Temp.	± 2 dB	
Gain Flatness	± 0.25 dB	Per 6-MHz Channel
Noise Figure	5.0 dB	
PCS Rejection	>90 dB	Includes image freq.
WCS Rejection	>100 dB	
ISM Rejection	>40 dB	
Out-of-Band Rejection	>50 dB	(2725 MHz & above)
LO Frequency	2278 MHz	
LO Frequency Stability	± 5 KHz	
LO Phase Noise	-65 dBc/Hz @ 100 Hz -80 dBc/Hz @ 1 KHz -90 dBc/Hz @ 10 KHz -105 dBc/Hz @ 100 KHz	
Group Delay	<10 ns	Per 6-MHz Channel

MDS/MMDS Transceiver

PARAMETER	TYPICAL	COMMENTS
UPCONVERTER		
IF Input Frequency	14.375 - 26.375 MHz	
RF Output Frequency	2150 - 2162 MHz	MDS Band
Gain	15 to 30 dB	Factory Adjustable
Gain Variation vs. Temperature	± 2 dB	
Output Power	+30 dBm	
Output Transmit Noise	-122 dBm/Hz Max	
Output Spurious (+30 dBm Tx Out)	-60 dBc in-band -60 dBc out-of-band	
Threshold IF Input (Power blanking)	-50 dBm min.	
Gain Flatness	± 0.5 dB	Full 12 MHz Band
IP3	40 dBm	
Harmonics	<-60 dBc	
LO Frequency	142.375 MHz (1st) 2278 MHz (2nd)	
GENERAL		
IF Connector (Rx out / Tx In)	F-Type Female, 75 Ohm	
RF Connector (Rx In/Tx out)	N-Type Female, 50 Ohm	
DC Supply	12-24 VDC	Nominally[1]
Current	500 mA	
Operating Temperature	-35°C to +75°C	
Size	6.0” x 7.0” x 2.375”	

Summary

- **RF Solutions has a well planned IC and module development strategy for BWA offering**
  - Higher integration levels with complex MMICs
  - Lower cost
  - Improved CPE performance
  - Advanced CPE architectures
  - Higher reliability