IEEE MTT Short Course
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Microwave and Millimeter wave Technology and Applications for Short Haul Digital Radios

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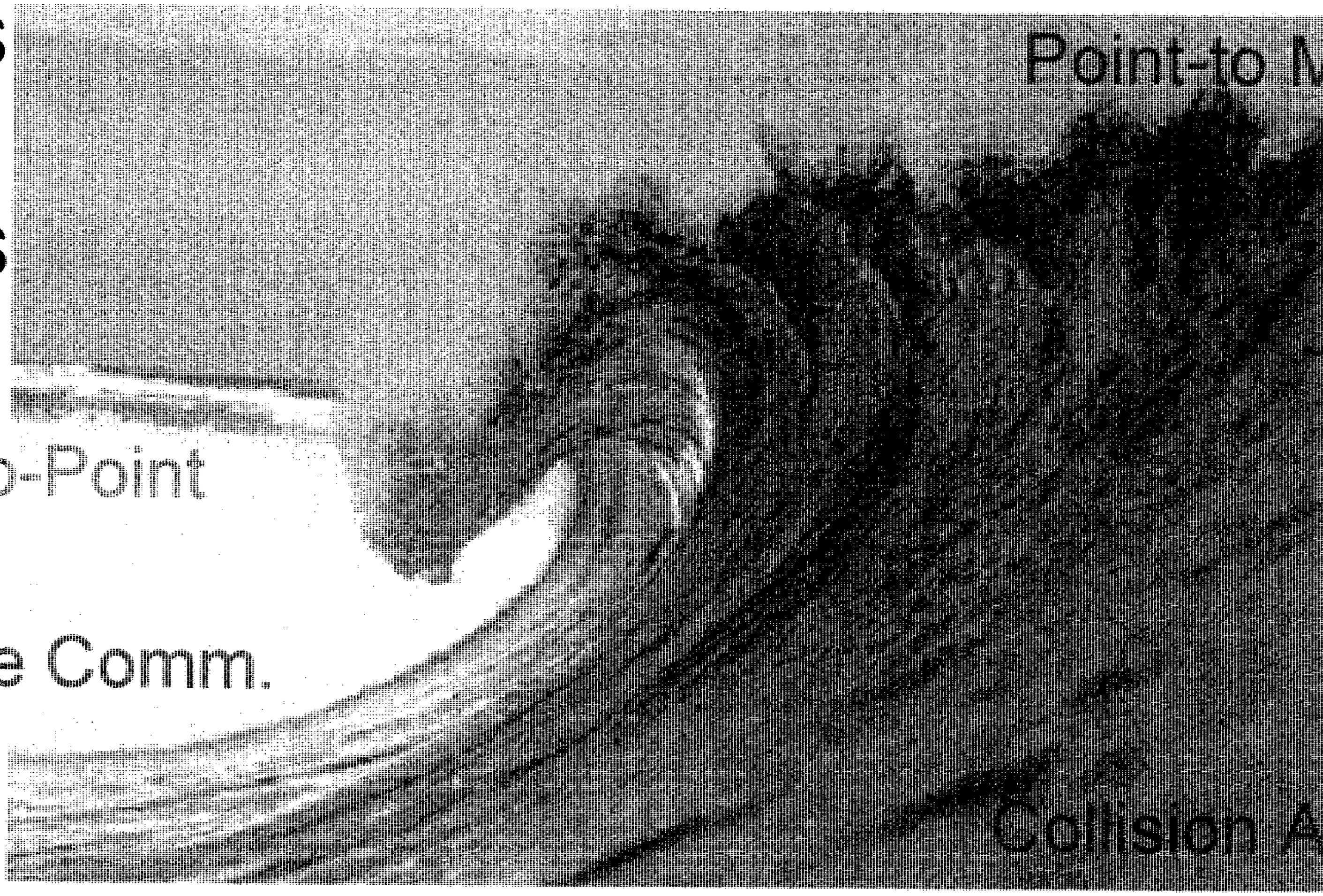
Millimeter Wave - Wave of the ~~Future~~ Present

Communications Infrastructure



LMDS

Point-to Multipoint

LMCS

DEMS

Point-to-Point

WLAN

Satellite Comm.

Collision Avoidance

(20 - 80 GHz)

Contents

- Applications and Markets
- RadioTransceivers Architectures
- Components & Device Technology
- Manufacturing Technology
- Challenges & Conclusion

Short Haul vs. Long Haul Pt.-to-Pt. Radios

	Long Haul	Short Haul
Distance	up to 40 miles	up to 10 miles
Power Output	up to 10 W	up to 200 mw
Frequency Range	7 to 18 GHz	13 to 40 GHz
Data Rates	up to 155 Mbits/s	up to 45 Mbits/s
Tx/Rx Location	On Ground/Tower Top	On Tower Top
Antenna Size	2 to 8 feet dia.	1 to 2 feet dia.
Selling Price	>$25K	<$10K
Microwave Content	20 to 30 %	30 to 50 %

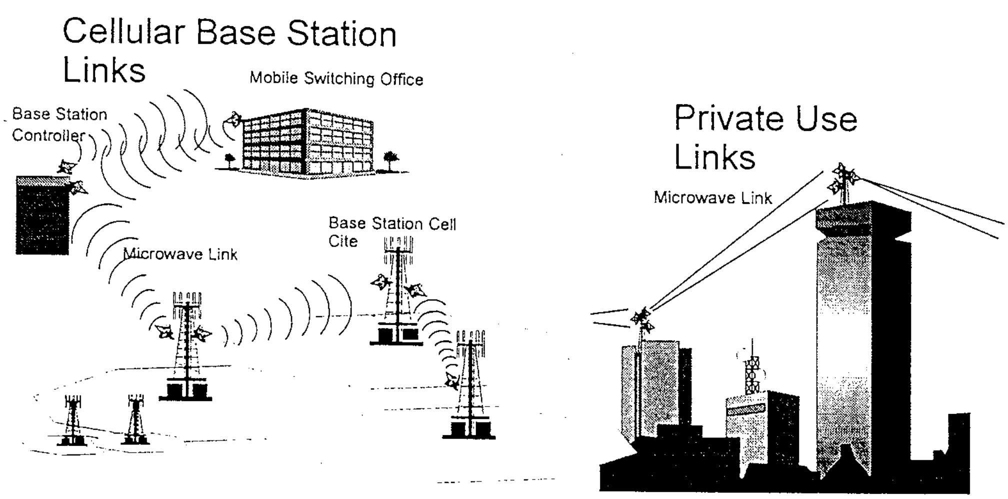
Applications of Short Haul Digital Radios

Communications Infrastructure

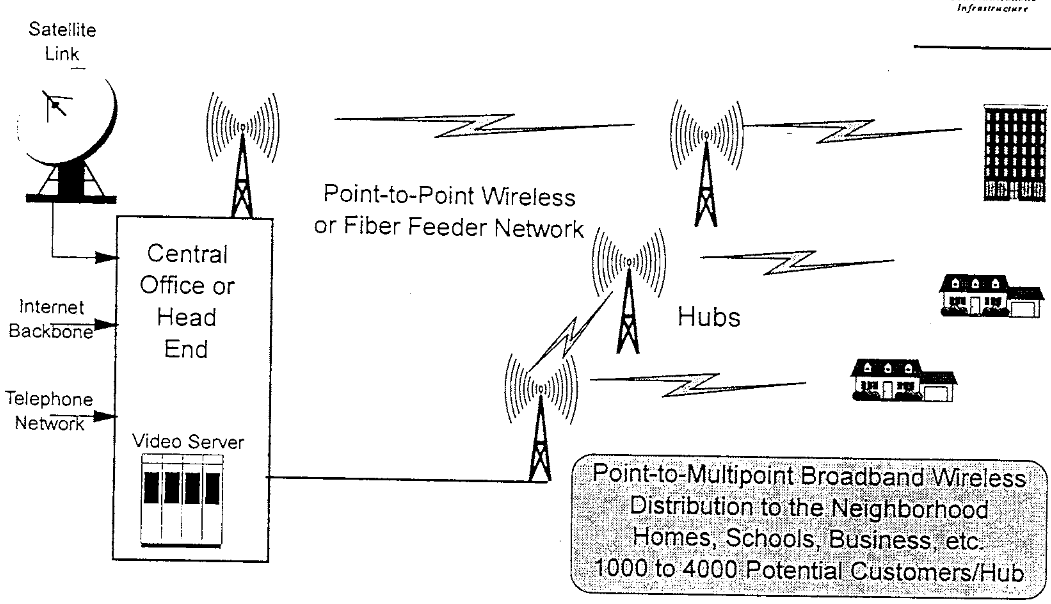
- Wireless Infrastructure:
  - Cellular and PCS backbone
  - Wireless Access
  - PTT fixed network applications
  - Private network applications
  - WLL, MMDS infrastructure
- Broadband Wireless Access:
  - Point-Multi Point:
    - *LMDS*
    - *DEMS*
    - *BB@38*
  - BBWA infrastructure

Integrated Microwave Modules for the Communication Data Link Market

Communications Infrastructure

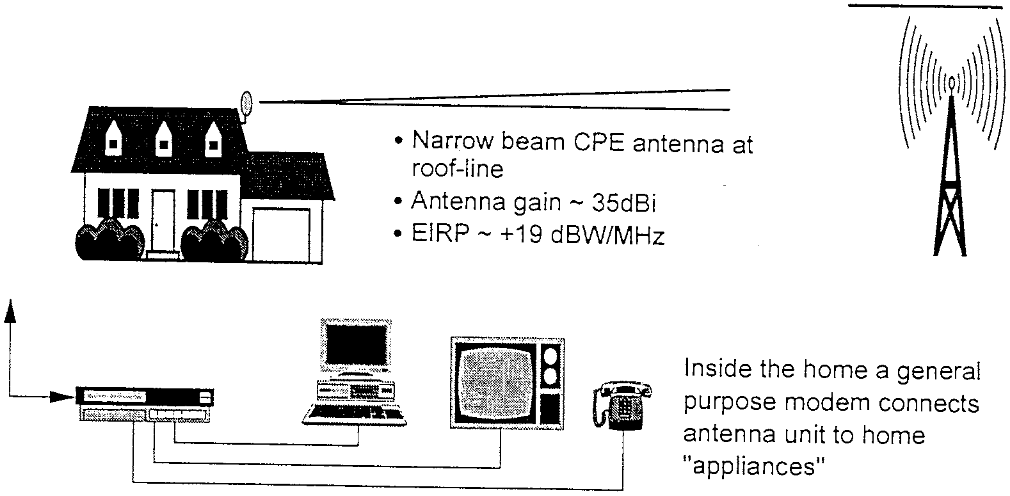


Local Multipoint Distribution Service



LMDS System Architecture

Customer Premises Equipment



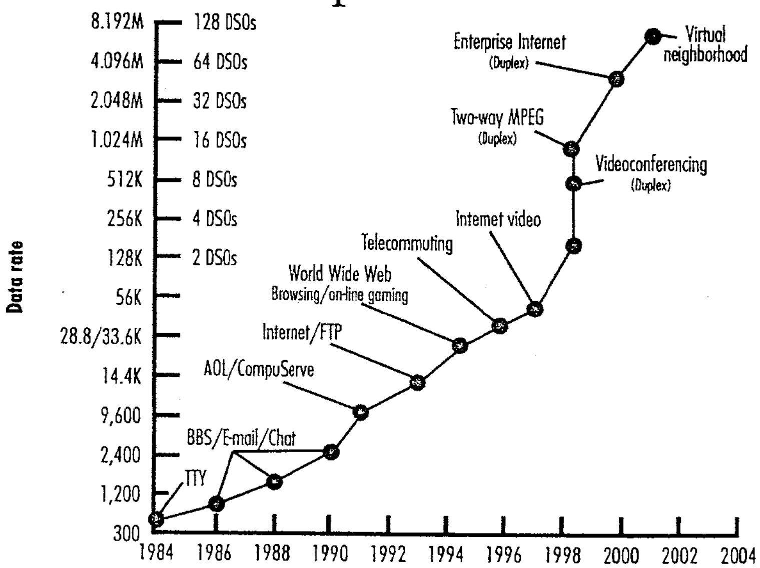
- Narrow beam CPE antenna at roof-line
- Antenna gain ~ 35dBi
- EIRP ~ +19 dBW/MHz

Inside the home a general purpose modem connects antenna unit to home "appliances"

Why Microwave Radios ?

- Who is the competition ?
  - Wireline .... fiber, copper, coax ...
- Radio Advantages:
  - Time to install
  - No right of way issues
  - Reliability / Availability
  - Economical
  - Flexibility
  - Control and Ownership
- Issues:
  - Masts
  - Capacity limitaion

Need For Speed ...



Source: Communications Technology, January 1998 pg.66

Data Rates

Communications Infrastructure

North America

T1	DS-1	1.544 Mbits/s
T2	DS-2	6.312 Mbits/s
T3	DS-3	44.736 Mbits/s
	DS-4	274.176 Mbits/s

DS- 0 = 1 Channel = 64 kbits/s
T1 represents 24 channels
= (24 X 8 bits/sample +1) x 8000 samples/sec
= 1.544 Mbits/sec

(Framing bit/group of channels)

&

E1= 30 channels
= (30 X 8 bits/sample +2) x 8000 samples/sec
= 2.048 Mbits/sec

Europe & ROW

E1	2.048 Mbits/s
E2	8.448 Mbits/s
E3	34.368 Mbits/s

Sonnet Standards

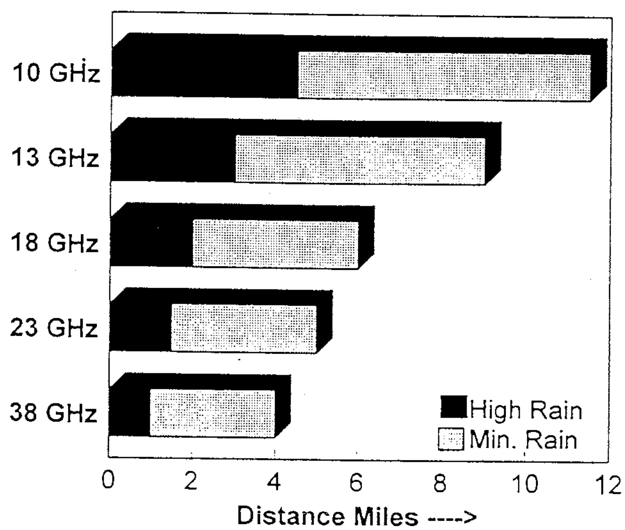
OC1		51.84 Mbits/s
OC3	STM-1	155 Mbits/s
OC12	STM-4	622 Mbits/s
OC48	STM-16	2.488 Gbits/s

Microwave How far can you go ?
(with 50 mwatt of power)

Communications Infrastructure

Frequency Selection

- Regulations
- Climate
- Why Higher Frequencies:
  - *Congestion at lower frequencies*
  - *Improves Frequency Reuse*
  - *Reduced Multipath fading*
  - *Smaller size ODU*
  - *Wider Bandwidth*



Regulatory Agencies

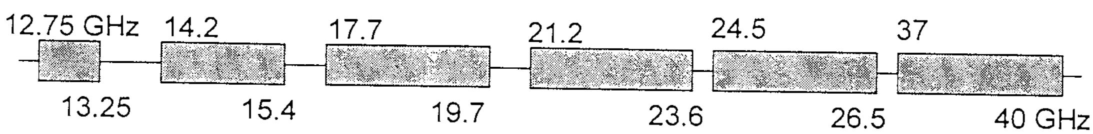
Communications Infrastructure

- International :
  - International Telecommunications Union (ITU) **www.itu.int**
  - International Radio Consultative Committee(CCIR)
- USA:
  - Federal Communications Commission (FCC) **www.fcc.gov**
- Europe:
  - Central European Post and Telecommunications (CEPT)
  - European Telecommunications Standards Institute (ETSI) **www.etsi.fr**
  - Department of Transport and Industry (DTI), UK
- Japan:
  - Ministry of Post and Telecommunications (MPT)

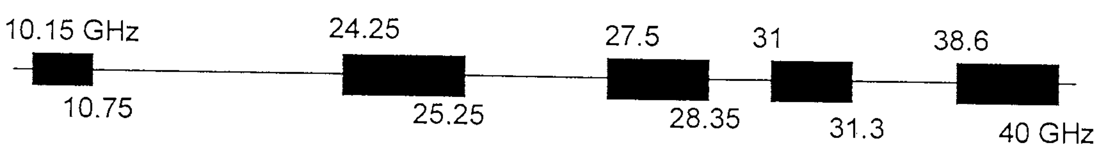
Frequency Band Allocations (GHz)

Communications Infrastructure

Point-to-Point



Broadband Access

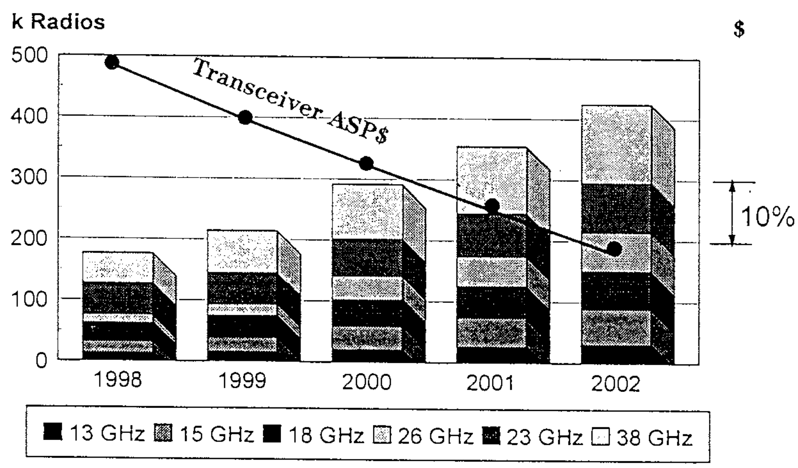


P-P & P-MP

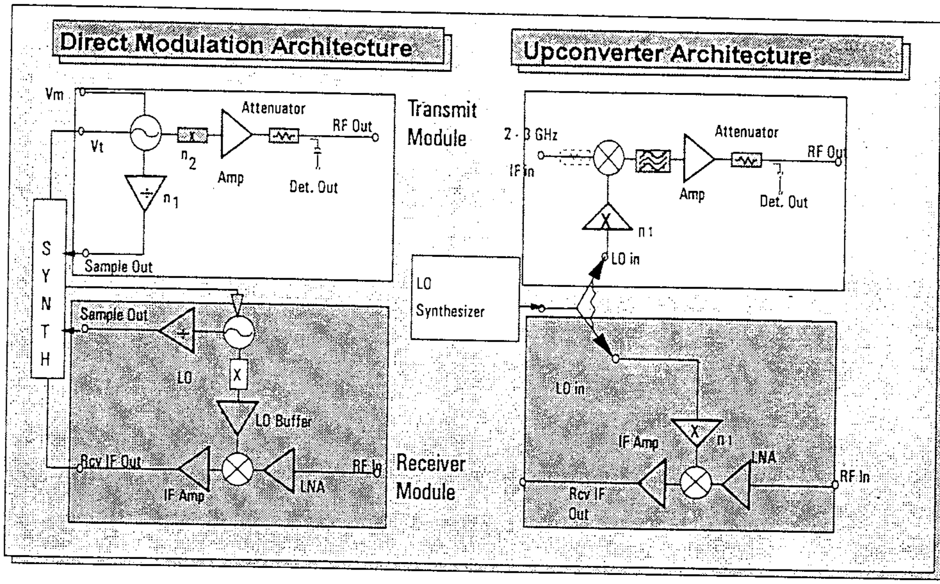
Worldwide Utilization of Point-to-Point Radios

	ASIA	Europe	South & Cent. America	USA & Canada
13GHz	X	X		
15GHz	X	X	X	
18GHz	X	X	X	X
23GHz		X	X	X
26 GHz		X		
38 GHz		X	X	X
>40 GHz		X		

Estimated Total Available Market for Short Haul P-to-P Digital Radios.



Radio Architectures



Direct Modulation vs. Upconverter Architecture

Direct Modulation

- Simpler Architecture
- Used for FSK only
- Easier phase noise
- Saturated Power Amp.
- Lower Cost

Upconverter

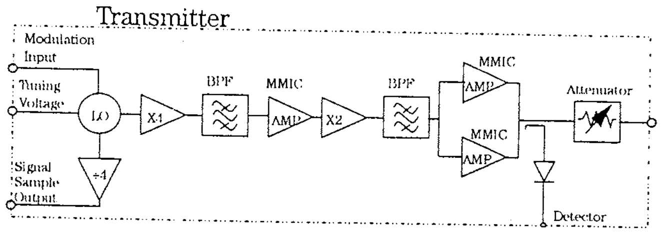
- Flexible Architecture
- Higher spectral efficiencies with QPSK & QAM
- Linear Power
- Lower Phase Noise

	Phase Noise	Amplifier Linearity
FSK Systems	-80 dBc/Hz @ 100 KHz	Saturated Output Power
QPSK Systems	-95 dBc/Hz @ 100 KHz	3 dB back off from P-1
QAM Systems	-90 to -105 dBc/Hz @ 10 KHz	up to 10 dB back off from P-1

Direct Modulation Transmitters

Transmitter Functions

- Integrated Transmit Functions
  - Signal source (Oscillator)
  - Multipliers to raise the source frequency to the final output frequency
  - A Divide function to provide a low frequency output used for phase locking
  - Filters to filter out unwanted spurious and harmonics
  - Amplifiers to provide the final frequency at the required power output
  - Detector and Attenuator to provide power detection and control.



Key Transmitter Module Specifications

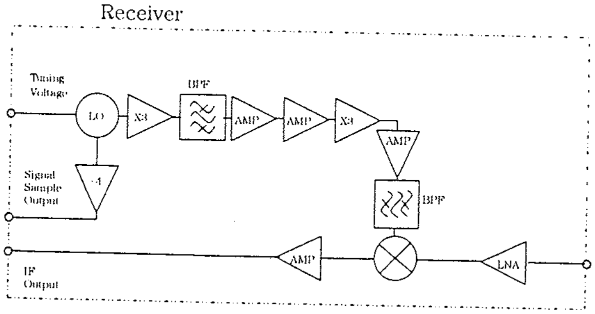
Parameters	Units	38 GHz	26 GHz	23 GHz	18 GHz	15 GHz	13 GHz
Frequency Range	GHz	37.0-40.0	24.5-26.5	21.2-23.6	17.7-19.7	14.5-15.35	12.75-13.25
Operating Temperature Range	°C	-30 to +70	-30 to +70	-30 to +70	-30 to +70	-30 to +70	-30 to +70
RF Power Output	dBm	19	20	20	20	20	20
Detected Out	V	0.4 - 2.0	0.4 - 2.0	0.4 - 2.0	0.4 - 2.0	0.4 - 2.0	0.4 - 2.0
Harmonics and Sub-harmonics	dBc	-30	-30	-30	-30	-30	-30
Spurious Output	dBc	-50	-50	-50	-50	-50	-50
Phase Noise @ 100 KHz	cBc	-82	-85	-85	-85	-92	-92
Tuning Voltage VDC Fl to Fh	VDC	1 - 16	1 - 16	1 - 16	1 - 16	1 - 16	1 - 16
Main Tuning Sensitivity	MHz/V	200 - 400	175 - 350	260 - 310	100 - 200	150 - 300	80 - 160
MainTuning Sensitivity Variation		1.5 : 1	1.5 : 1	1.5 : 1	1.5 : 1	1.5 : 1	1.5 : 1
Modulation Bandwidth	MHz	20	20	20	20	20	20
Attenuator Range	dB	30	30	30	30	30	30
Mute Control	dBc	-50	-50	-50	-50	-50	-50
DC Circuit Power 10 Volts +5 Volts -5 Volts	 mA mA mA	 200 975 50	 200 975 50	 200 900 50	 175 500 50	 175 500 50	 175 500 50
Case Size	inches	3.5 x 1.25 x 0.40	3.5 x 1.25 x 0.40	3.5 x 1.25 x 0.40	2.69 x1.25 x 0.40	2.69 x1.25 x 0.40	2.69 x1.25 x 0.40

Direct Modulation Receivers

Communications Infrastructure

Receiver Functions

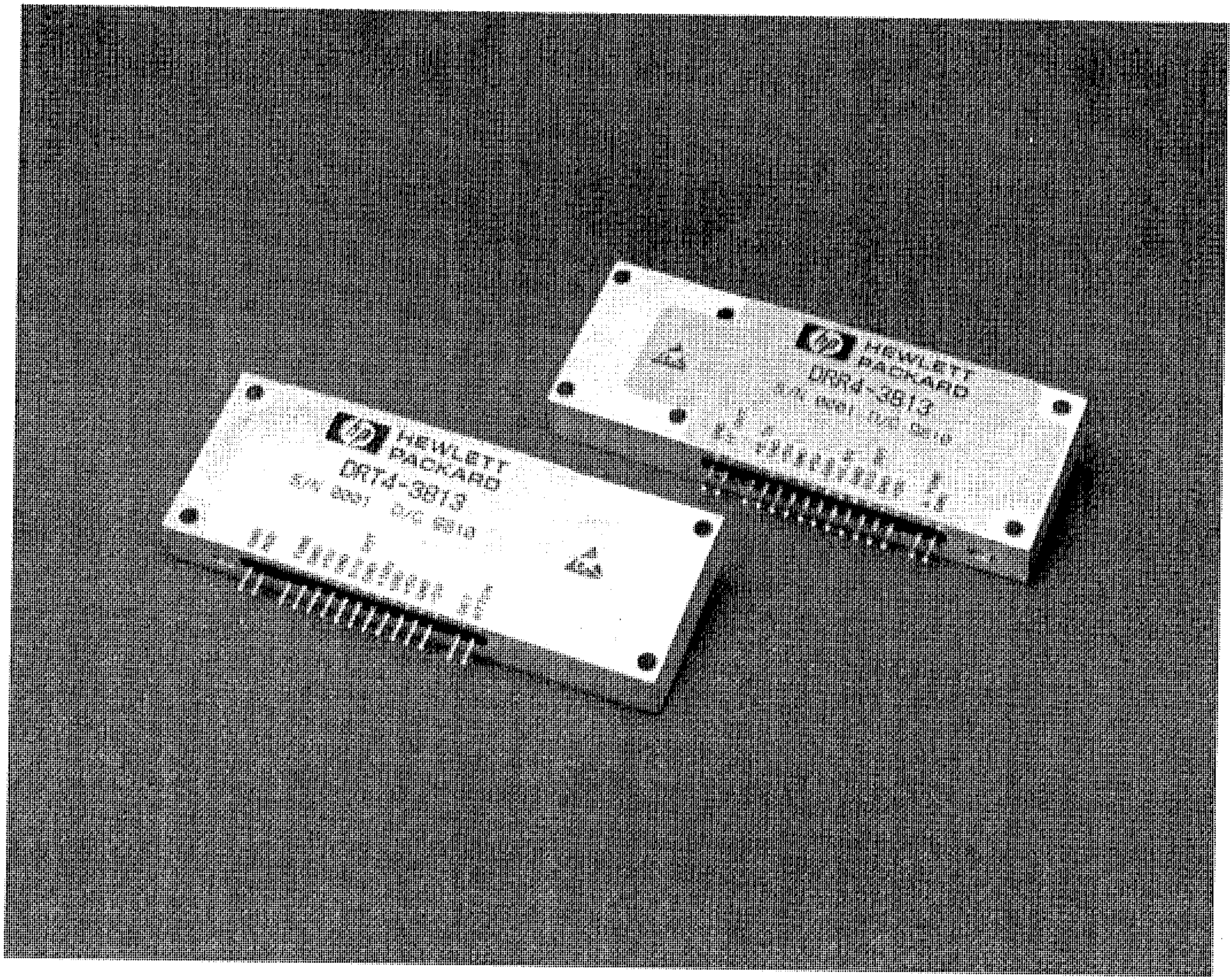
- Integrated Receiver Functions
  - Local Oscillator Signal Source
  - Multipliers to raise the source frequency to the final LO frequency
  - A Divide function to provide a low frequency output used for phase locking
  - Low Noise Amplifier to provide increased sensitivity.
  - Image Reject Mixer mixes the Local Oscillator Signal with the output of the LNA and provides a down converted IF.
  - IF Amplifier to raise the down converted signal level



Key Receiver Module Specifications

Communications Infrastructure

Parameters	Units	38 GHz	26 GHz	23 GHz	18 GHz	15 GHz	13 GHz
Frequency Range	GHz	37.0-40.0	24.5-26.5	21.2-23.6	17.7-19.7	14.5-15.35	12.75-13.25
Operating Temperature	°C	-30 to +70	-30 to +70	-30 to +70	-30 to +70	-30 to +70	-30 to +70
IF Frequency	MHz	630 or 1260	630 or 1260	630 or 1260	630 or 1260	630 or 1260	630 or 1260
IF Bandwidth	MHz	±20	±20	±20	±20	±20	±20
Noise Figure	dB	7.0	4.5	5.5	5.5	5.5	5.5
RF Power Input @ P-1 dB	dBm	-17	-17	-17	-17	-17	-17
Sample Out = RFout - IF +N	GHz	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5
Gain	dB	18 to 27	16 to 24	18 to 26	18 to 26	18 to 26	18 to 26
Gain Flatness over 300 MHz	dB	±1.0	±1.0	±1.0	±0.75	±0.75	±0.75
Harmonics and Sub Harm.	dBc	-30	-30	-30	-30	-30	-30
Spurious Output	dBc	-50	-50	-50	-50	-50	-50
Phase Noise @ 100 KHz	cBc	-82	-85	-85	-85	-92	-92
Tuning Voltage VDC Fl toFh	VDC	1 - 12	1 - 12	1 - 12	1 - 12	1 - 12	1 - 12
Main Tuning Sensitivity	MHz/V	200 - 400	175 - 350	260 - 310	100 - 200	150 - 300	95 - 190
MainTuning Sens. Variation		1.5 : 1	1.5 : 1	1.5 : 1	1.5 : 1	1.5 : 1	1.5 : 1
Image Rejection	dB	15	15	15	15	15	15
DC Circuit Power 8.5Volts +5 Volts -5 Volts	 mA mA mA	 350 600 50	 350 600 50	 350 600 50	 350 600 50	 350 300 50	 350 300 50
Case Size	inches	3.5 x 1.25 x 0.40	3.5 x 1.25 x 0.40	3.5 x 1.25 x 0.40	2.69 x 1.25 x 0.40	2.69 x 1.25 x 0.40	2.69 x 1.25 x 0.40



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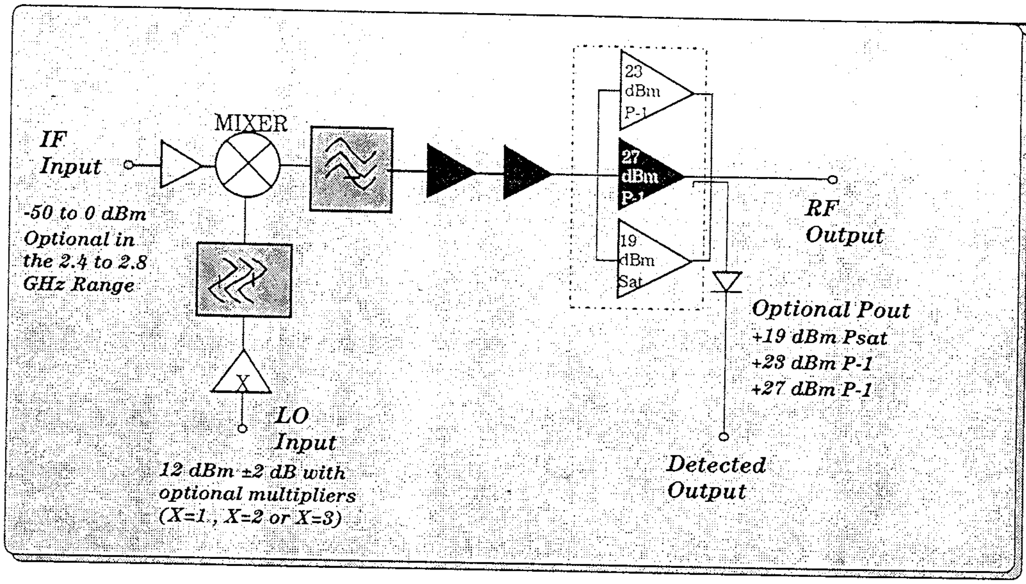
Upconverter Transmitter Module

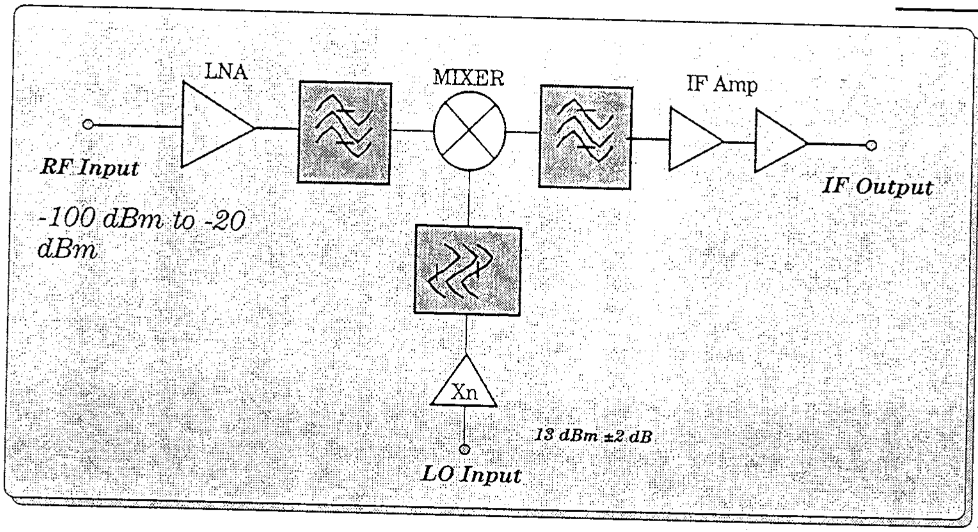


Typical Upconverter Requirements

Operating Temp. -30 to 70 deg. C

Parameter	Unit	38GHz	26GHz	23GHz	18GHz	15GHz	13GHz
RF Frequency in	GHz	37-40	24.5-26.5	21.2-23.6	17.7-19.7	14.2-15.4	12.7-13.3
Conversion Gain	dB	22	22	22	22	22	22
Gain Variation	dB	±3	±3	±3	±3	±3	±3
P-1 dB	dBm	15,23,27	15,23,27	15,23,27	15,23,27	15,23,27	15,23,27
Spurious Output	dBm	-50	-50	-50	-50	-50	-50
IF Input Range	GHz	2-3	2-3	2-3	2-3	2-3	2-3
IF Bandwidth	MHz	+/- 50	+/- 50	+/- 50	+/- 50	+/- 50	+/- 50
LO Multiplier		2,3	2,3	2,3	2,3	2,3	2,3
RF Output RL min.		10 dB	12 dB	12 dB	14 dB	14 dB	14 dB
DC Power: .							
+5.0 +/- 0.1V	Amp	1.5 A	1.5 A	1.5 A	1 A	1 A	1 A
-5.0 +/- 0.1 V	mA	50	50	50	50	50	50
Output Conn.		WR-28	WR-42	WR-42	Coax	Coax	Coax

Receiver Down Converter Block Diagram



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WID

Typical Downconverter Requirements

Operating Temp. -30 to 70 deg. C

Parameter	Unit	38GHz	26GHz	23GHz	18GHz	15GHz	13 GHz
RF Frequency in	GHz	37-40	24.5-26.5	21.2-23.6	17.7-19.7	14.2-15.4	12.7-13.3
Conversion Gain	dB	22	22	22	14/ 22	14/ 22	14/ 22
Gain Variation	dB	±3	±3	±3	±3	±3	±3
Noise Figure	dB	6.5	5	5	4	4	4
Image Rejection	dB	12	15	15	15	15	15
Spurious Output	dBm	-50	-50	-50	-50	-50	-50
IF Output Range	GHz	1.25 - 2.5	1.25 - 2.5	1.25 - 2.5	1.25 - 2.5	1.25 - 2.5	1.25 - 2.5
IF Bandwidth	MHz	+/- 50	+/- 50	+/- 50	+/- 50	+/- 50	+/- 50
LO Multiplier		2 or 3	2 or 3	2 or 3	2 or 3	2 or 3	2 or 3
RF Output RL min.		10 dB	12 dB	12 dB	14 dB	14 dB	14 dB
DC Power:							
+5.0 +/- 0.1 V	Amp	500 mA	500 mA	500 mA	400 mA	400 mA	400 mA
-5.0 +/- 0.1 V	mA	50	50	50	50	50	50
Output Conn.		WR-28	WR-42	WR-42	Coax	Coax	Coax

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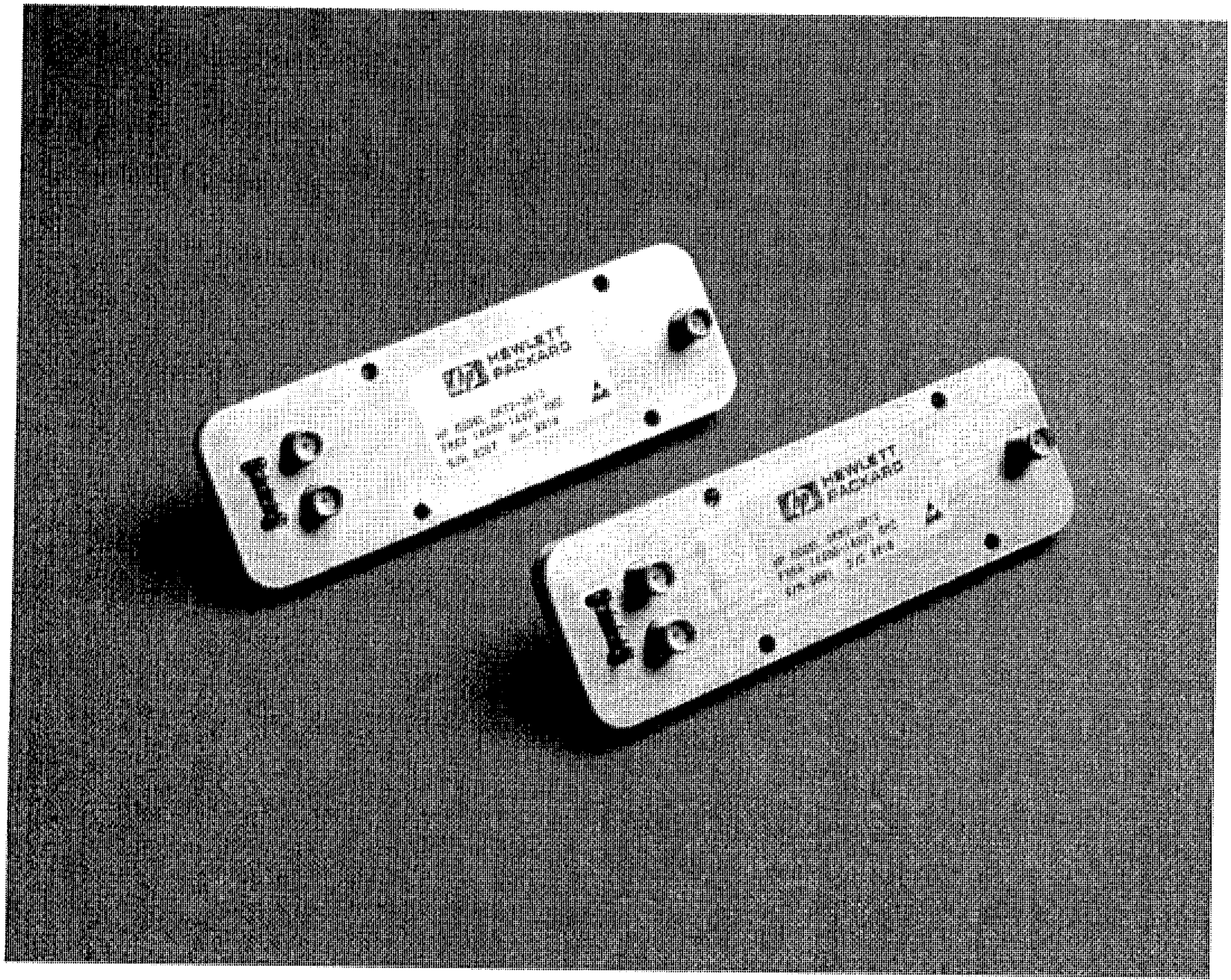
WID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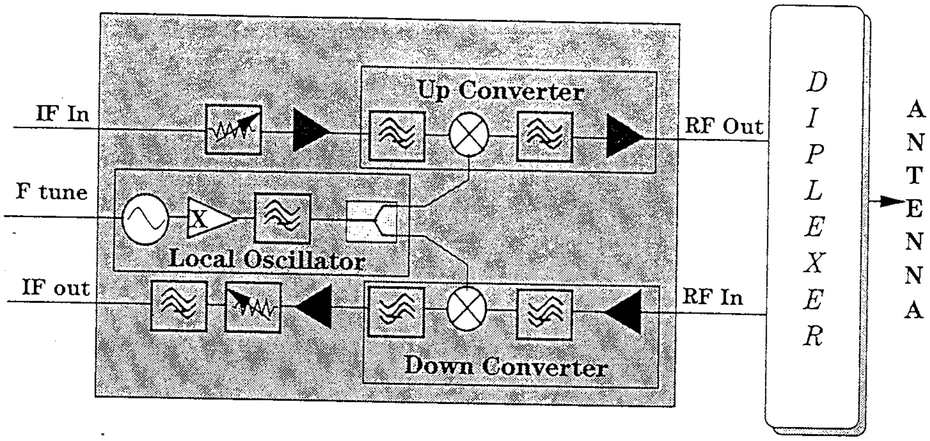
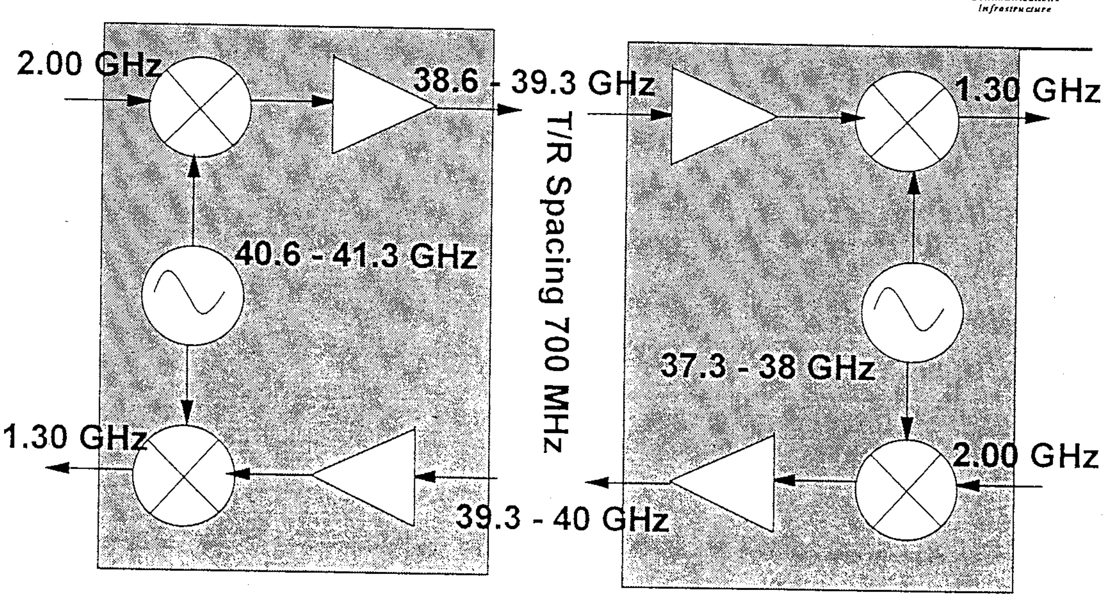
38 GHz Transceiver Block Diagram



38 GHz Tx/Rx Link Example



Point-to-Point vs. BBW Access

Communications Infrastructure

	Point-to-Point	BB Access
Frequencies GHz	13,15,18,23,26,38	10,24,28,38
Power Output	17-23 dBm P-1	30 dBm Down S 23 dBm Up S
Modulation	2L FSK, 4LFSK, QPSK,OQPSK,QAM	QPSK, 16 QAM
Data Rates	2 - 45 Mbits/sec	51 Mbits/s Down S 1-10 Mbits/s Up S
Transceiver Architecture	Direct Mod. or Up Converter, Swept LO	Upconverter Fixed LO
Data Transport	Continuous Stream	Packetized,ATM,FR..
Applications	Cellular Backhaul, Private Links	Broadband 2 way data, video,voice

Key Component Requirements

Communications Infrastructure

- **Antennas**
- **Filters**
- **Attenuators**
- ***Low Noise Amplifiers***
- ***Mixers***
- ***Power Amplifiers***
- ***Oscillators***

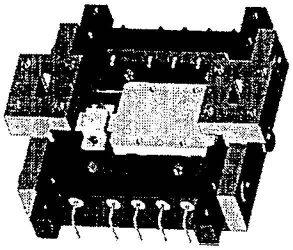
Oscillator Performance Comparison

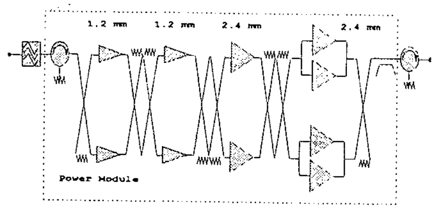
Type	Phase Noise at 38 GHz	Comments
Fundamental Cavity Gunn	-90 dBc/Hz @ 100 KHz	Reliability,Microphonics, Narrowband
Fundamental MMIC / FET	-75 dBc/Hz@ 100 KHz	Marginal Phase Noise for FSK
Multiplied BJT	-85 dBc/Hz@ 100 KHz	Practical Solution for 4LFSK.
Multiplied Permanent Magnet YIG	-85 dBc/Hz @ 10 KHz	Tunable Low Noise. Suits QAM applications
Phase Locked DRO	-80 dBc/Hz @ 10 KHz	Fixed Tuned

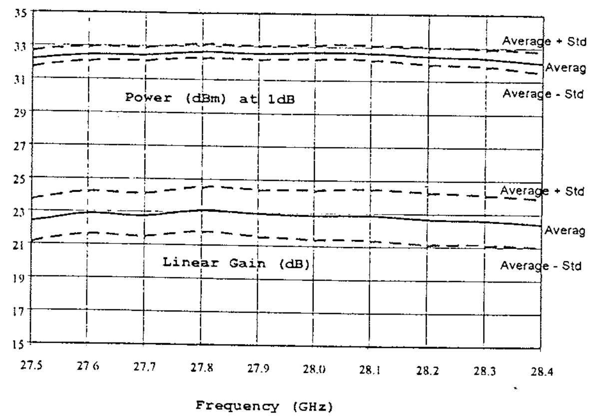
Amplifier Performance Comparison

Frequency	LNA	Pt-to-Pt P-1	BBA P-1
13/15/18 GHz	<3 dB	18-23 dBm	
23/26 GHz	<3.5 dB	18 -23 dBm	
38 GHz HUB	<4 dB	20 dBm	21 - 25 dBm 27 - 30 dBm
28 GHz CPE HUB	<4 dB		21-25 dBm 27-30 dBm
25 GHz CPE HUB	<4 dB		21-25 dBm 27-30 dBm

2 Watt Power Amplifier for LMDS







Technology Issues ....

- Discrete vs. MMICs : why and when ?
- Circuit Board: Thin Film, Thick Film or Softboard
- Chip & wire vs. Flip Chip
- Microstrip vs. CPW
- Chips vs. packaged devices

Technology Comparison

Communications Infrastructure

	0.25um PHEMT	0.12 um PHEMT	GaAs HBT	Si / Si-Ge Bipolar
Freq. of Operati	50 GHz	80 GHz	40 GHz	40 GHz
Ft / Fmax GHz	60 / 100	120 / 150	60 / 75	50
Power Capability	400mw / mm	250mw /mm	2 mW/um^2	1 mW/um^2
N.Fig. @18GHz Gain at 40 GHz	1 dB 6 dB	.7 dB 8 dB	2 dB 6 dB	4 dB 4 dB
Phase Noise 38GHz@100KHz	-75 dBc/Hz	-75 dBc/Hz	-80 dBc/Hz	-80 dBc/Hz
Level of Integratio (No.of Transistors)	medium (10-100)	medium (10-100)	high (100-1000)	high 1,000-10,000)
Applications	All Purpose	Med. Power	Amp.,Osc.,Div Multi,digital Ckt	Amp,Osc,Div,PLL Multi,digital Ckt

Key MMICs Requirements

Communications Infrastructure

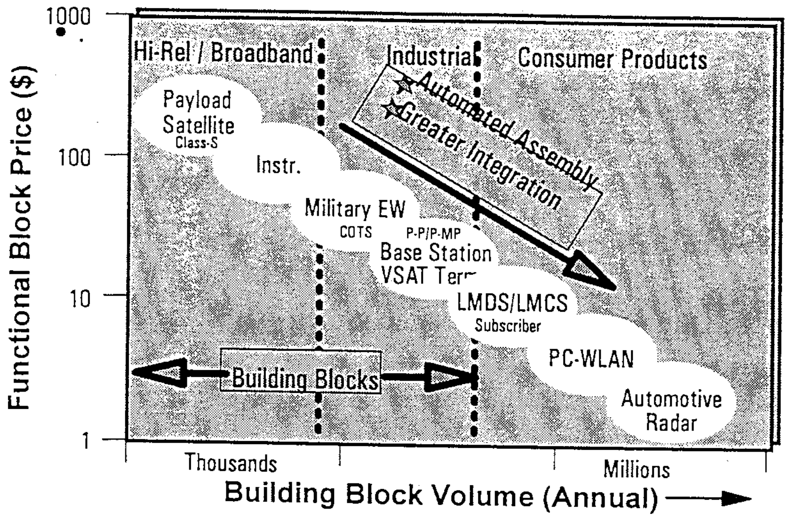
- Power Amplifiers:
  - >30 dBm at 1 dB gain compression
  - >20 dBm at 1 dB gain compression
- Mixers/Buffers:
  - Up and down converters
- Low Noise Amplifiers:
- 3 to 5 dB Noise Figure
- Oscillators:
  - -80 dBc/Hz @ 100 KHz
  - -90 dBc/Hz @ 10 KHz

- Cost
  - $20 - 50 / basic building block needs to come down.
- Packages
  - Low Cost
  - High Performance
- Standardisation:
  - Specification
  - Outline / Packages

MW/MMW GaAs ICs (> 5 GHz)

Communications Infrastructure

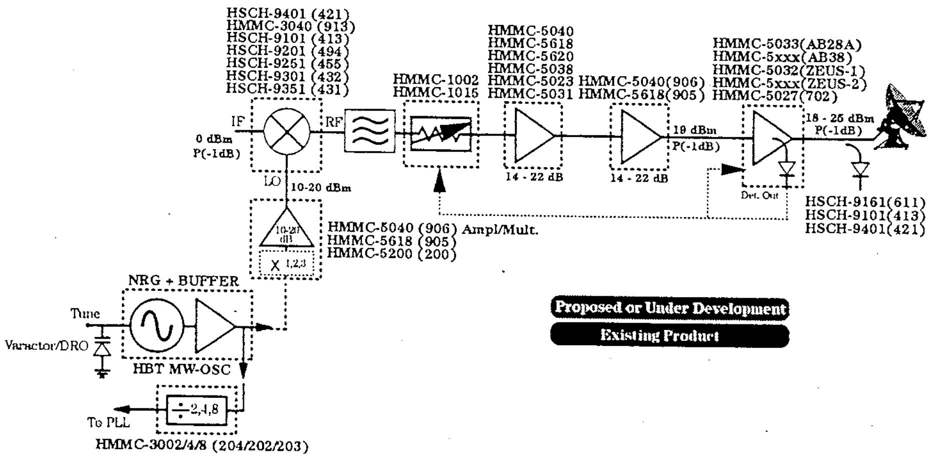
Outlook for Building Block Price by Volume



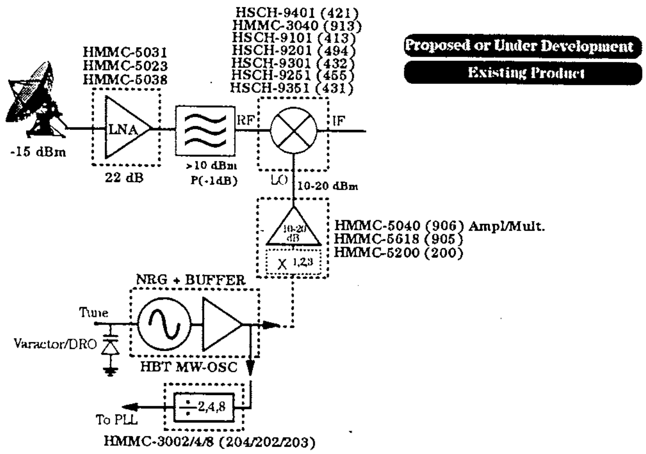
MW/MMW GaAs ICs

Upconverter Transmitter (6-43 GHz) Building Blocks

Communications Infrastructure



MW/MMW GaAs ICs
Receiver (6-43 GHz) Building Blocks



Manufacturing Technology and Challenges

- What is critical to the radio manufacturer ?
  - Reliability
  - Time to volume
    - Reduce development cycle
    - Simplify and standardize transceiver architectures
    - Assembly and test Automation
  - Cost
    - Focus on assembly and test automation
    - Increase capacity to Increase Volumes
    - New technologies
  - Power Consumption & Size

Future Direction

Communications Infrastructure

- Innovation
  - Flip integrated chip & CPW at millimeter waves
  - Higher integration at chip level for BB Access
- New ways to succeed
  - Alliances
  - Competition or Partner ?
- Technology and Applications at 60 GHz (59-64 GHz)
- Improved millimeter wave packaging
- ***Standardization***

Acknowledgements

Communications Infrastructure

- R&D / Marketing Team
  Wireless Infrastructure Division, HP
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- Pat McDonald, Innova Corp.