Emerging RFIC Technologies for WLAN and Mobile Wireless Communications in Asia Pacific Market

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Emerging RFIC Technologies for WLAN and Mobile Wireless Communications

Outlines:

- **Technology Requirements of Wireless Communication Systems**
- **Trends of Key RFIC Technologies**
  - ***Head-On Competition of RF CMOS and SiGe HBT/BiCMOS***
  - ***High-Q Passive Elements***
  - ***Isolation Techniques***
- **Trends of RF Power Amplifiers**
  - ***Niche & Volume Applications of III-V PA's***
  - ***Market Place Snapshots***
- **Summary**
  - ***Challenges and Opportunities***

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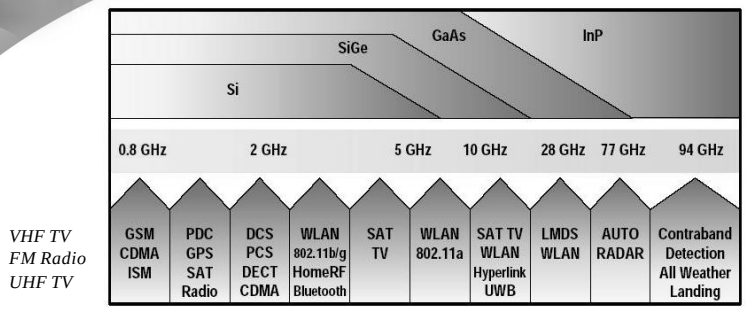
Evolution of Wireless Communication Systems

- Higher Frequencies, Higher Bit Rates, More Sophisticated Modulation Schemes



VHF TV
FM Radio
UHF TV

Radio Frequencies — **Micro Wave Frequencies** — **MilliMeter Waves Frequencies**

Cordless

PAN ***Bluetooth:*** *2.4 GHz*

WLAN ***802.11b/g:*** *2.4 GHz*
802.11a: *5.2 GHz*
802.11n: *2.4/5.2 GHz*
Hyperlink: *17 GHz*

Cellular
1G: *voice only, 0.8-0.9 GHz*
2G: *voice & message, 0.8-1.9 GHz*
2.5G: *voice & data, 0.8-1.9 GHz*
3G: *voice, data & medium, 0.9-2.6 GHz*

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Representative Wireless Communications Systems

❑ **Specifications:**

System	Standard	Freq (GHz)	Data Rate (Mb/sec)	Max Transmit Power (dBm)	Min Receive Sens. (dBm)
Cellular	GSM	0.9	0.014	33	-102
	CDMA	0.9/1.9	0.014	23	-104
	WCDMA	2.0	2	27	-117
PAN	Bluetooth	2.4	0.723	0	-70
WLAN	802.11b	2.4	11	20	-80
	802.11a	5.2	54	23	-82
	802.11n	2.4/5.2	108/320	-	-

❑ **Technology Requirements:**

- ***Very low noise***
- ***High fiedelity***
- ***Wide dynamic range RF/Analog***
- ***Very low power consumption***
- ***High-quality passive elements***
- ***Multi-mode & multi-band capabilities***
- ***Very low cost***
- ***High-level integration digital***

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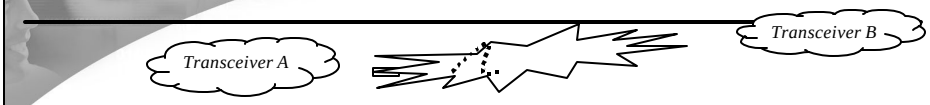
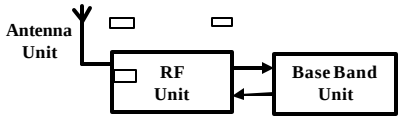
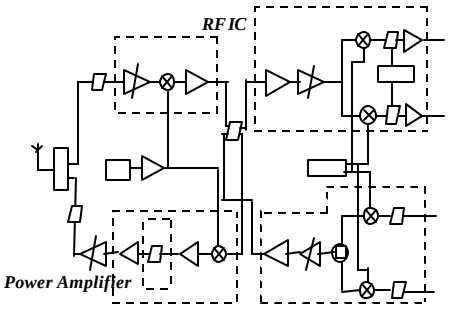
RF Integrated Circuits
Key Enabler of Wireless Communication Systems





- **Major RF IC Architectures :**
  - **Heterodyne – widely used and most developed**
  - **Zero IF – fewer external components needed**
  - **Low IF – almost like ZIF**



- **Key Building Blocks : High Operating Frequency, High Operating Range, High Linearity, Low Noise, Low Loss, Low Power**
  - **Low Noise Amplifers**
  - **Mixers**
  - **Voltage Controlled Oscillators**
  - **Phase Locked Loop**
  - **Power Amplifers**
  - **Inductors**
  - **Varactors**
  - **Capacitors**

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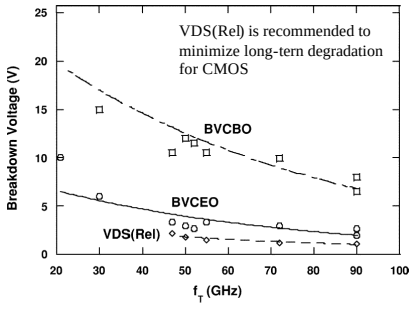
Fundamental Limits of
RF/Analog Technology Scaling

Tech	E Gap (ev)	e (e_o)	m (cm2/Vsec)	BV (V/cm)	Nmax (cm-2)
Si	1.1	11.8	1450	$4x10^5$	$2.6x10^{12}$
Ge	0.66	15.8	3900	$\sim 1x10^5$	-
GaAs	1.4	12.8	8500	$5x10^5$	$3.5x10^{12}$
InGaAs/ InP	1.35	12.4	10000	$>4x10^5$	$\sim 3.0x10^{12}$



- **Lower Limits of Voltage Dynamic Range:**
  - **Noise level > sqrt (kTB)**
  - **Thermal engergy sets minimum noise energy level**
- **Upper Limits of Voltage Dynamic Range:**
  - **Product of Breakdown Voltage (BV) and Band Width (BW)**
    [or product of BV and max Drift Velocity (m)]
  - **A trade off between Dynamic Range and Speed**
- **Si, SiGe RF IC's dominate up to 10 GHz**
- **III-V compound devices dominate Power Amplifiers and applications requiring ultra low noise and high power**

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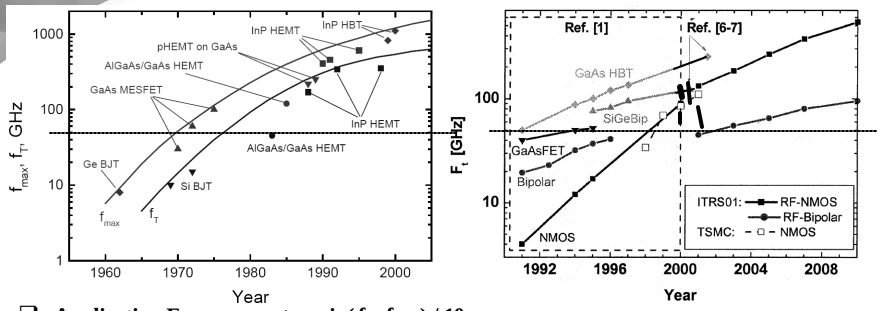
Trends of RF Transistors



- **Application Frequency <= min(f_T, f_{max}) / 10**
  - **f_T Cut-Off Frequency: Unit Current/Voltage Gain frequency**
  - **f_{max} Max Power Frequency: Unit Power Gain frequency**
- **HBT/BJT Technologies:**
  - **for a given material, higher frequencies than RF CMOS**
  - **for a give base thickness, III-V devices has higher freq**
- **RF CMOS Technologies:**
  - **frequencies increase with scaling**
  - **ratio of f_{max}/f_T decreases with scaling**

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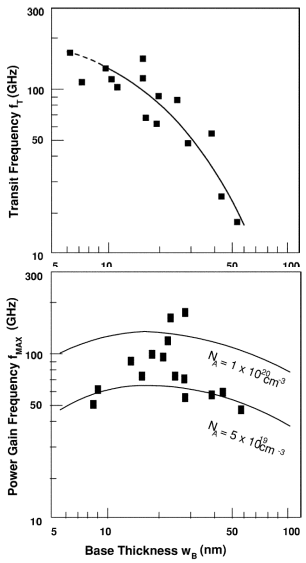
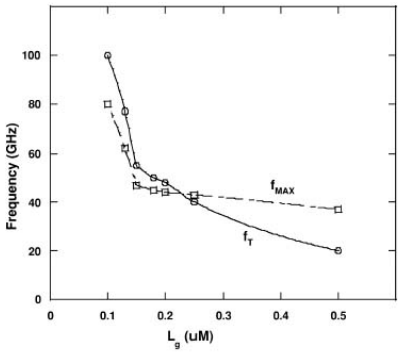
Speed as Function of Feature Length

SiGe HBT NPN





Si nMOS

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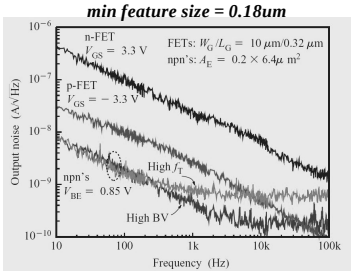
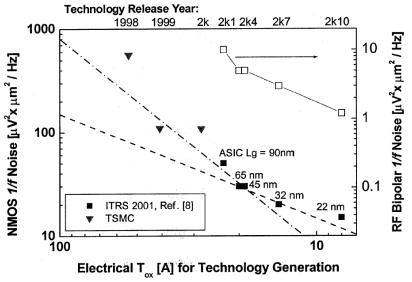
1/f Noise of Transistors

1/f Noise is high near dc and tapers off at a corner frequency

- *caused by interface traps*
- *This noise could be straddled to higher frequency, potentially causing jitter and channel interference*
- *MOSFET has high 1/f noise*

min feature size = 0.18um





1/f Noise in MOS improves as scaling down

- *~ $T_{ox}^{\ 2}$ at low bias*
- *~ T_{ox} at high bias*
- *Noise sensitivity to bias increases as scaling down because slower scaling pace of E fields*
- *Nitrogen in gate dielectric in deep submicron also contributes to 1/f noise.*

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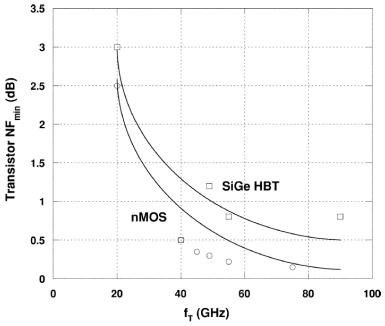
Noise Figures of Transistors

Noise Figure (NF) is a measure of the output SNR referenced to the input SNR

- *For an equivalent intrinsic device speed, the MOSFET typically has an about 0.5dB advantage because of high base resistance of the HBT*
- *However, the optimum source impedance for MOSFET is much higher than that of the HBT*
- *Large MOSFET normally are used to minimize mismatch in source resistance and lead to higher power consumption*



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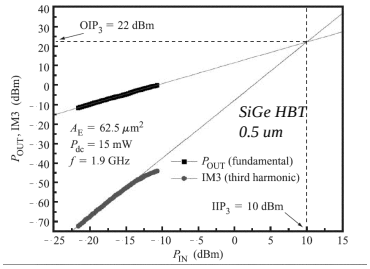
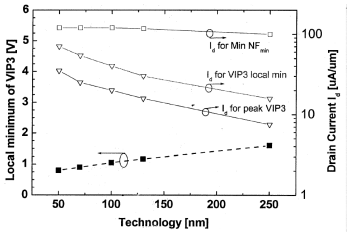
Linearity of Transistors

***Linearity** is the ability of a transistor to amplify the fundamental frequency of an input signal while minimizing the generation of undesirable harmonics due to inter-modulation*

- *OIP3 is the point at which the amplified signal power at its fundamental frequency equals that of the 3rd-order harmonic generated by nonlinear effects*
- *small signal linearity is key to RF receiver input stage*
- *large signal linearity is key to RF transmitter output stage*





- *MOS exhibits better linearity than HBT/BJT*
- *MOS's linearity degrades slightly as scaling down, provided the drain current density per unit width is increased.*

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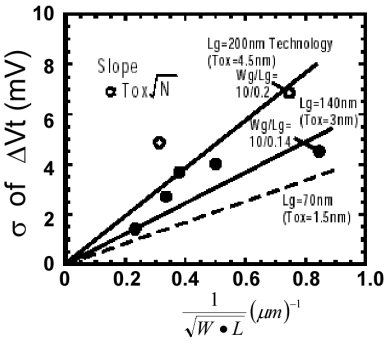
Mismatch Considerations

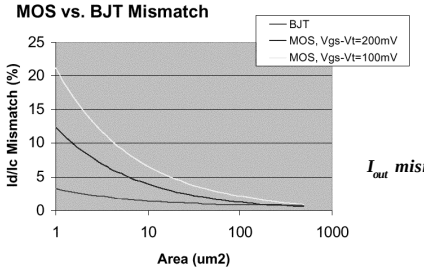
- **CMOS requires larger area for a given offset requirement**
- **CMOS V_{th} mismatch improves as scaling down**

$$s_{th} \sim q\,T_{inv} / e_{ox} * (2\,N\,T_{depl} / [W*L])^{1/2}$$

$$= A / (W * L)^{1/2}$$

- *Careful layout practice must be followed to minimize mismatch*





I_{out} mismatch in a differential pair

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High-Quality RF Passive Elements

Passive elements mostly created from existing process flows

- **Passive devices takes ~ 30-50% chip area**
- **Must be low parasitic, low TC, low VC, low mismatch**
- **Additional masks are needed to achieve better Q factors**

❑ **Resistors**

- **High R poly, N+/P+ poly, N+/P+ diffusion, N-well, metal (TaN)**

❑ **Capacitors**

- **MIM, PIP, MOS,… MOM**
- **Stacked capacitors doubles capacitance density**

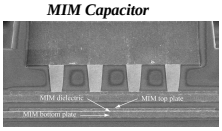
❑ **Varactors**

- **Junction varactors, MOS varactors**
- **Additional FOM's:** ***Tunability, linearity and capacitance density***

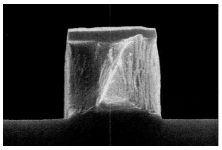
❑ **Inductors**

- **Thick metallization is necessary to increase Q of inductors**
- **Copper is better than Aluminum**
- **Differential inductors, balun's and transformers can be realized**

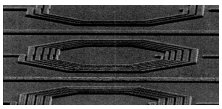
MIM Capacitor



3m m thick top metal



On-chip spiral inductor



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Isolation Techniques

- ***Necessary for single-chip transceivers and RF-SOC integrations***

❑ **Lightly doped substrates** ***(8-10 Ohm-cm)***

❑ **Grounded Guard ring using P+ diffusions**

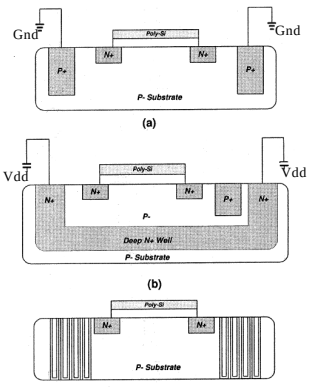
- *isolation improves with spacing,, guard-ring width, substrate resistivity*

❑ **Deep low-resistivity n-well** ***(tied to a low impedance and low-noise potential)***

- ***"tripple-well"*** now is a standard offering in RF CMOS, *roughly 20db at 2 GHz*

❑ **Deep trench**

- ***"deep-trench"*** now is a standard offering in BiCMOS
- *Not as effective as the above two methods*



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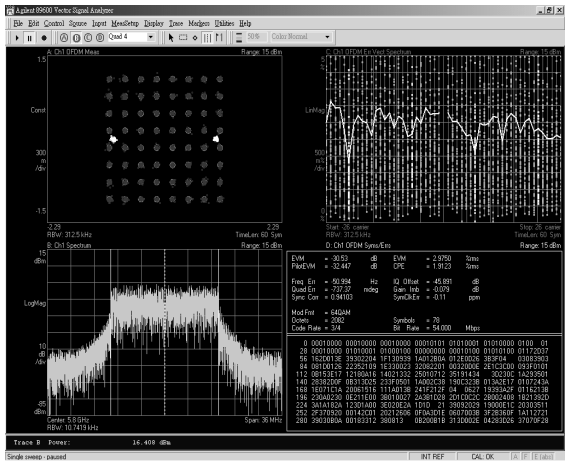
III-V Compound Semiconductors for Power Amplifiers and MMIC

- **Switches:**
  - ***MESFET, PHEMT***
- **Linear Power Amplifiers for GSM/GPRS, WCDMA, High Power WLAN**
  - ***GaAs HBT, EPHEMT***
- **High performance Gain Blocks for Wireless Infrastructures**
  - ***GaAs HBT***
- **Niche Applications in High Power Modules**
  - ***Linear Efficient Driver Amplifiers for Base Station (high breakdown, high linear power)***
- **World Leading GSM/GPRS GaAs HBT Suppliers in 2003**
  - ***RFMD***
  - ***Skyworks Solutions***
  - ***Anadigic***
  - ***Triquent***
  - ***ADI***

InGaP HBT Linear Amplifier

802.11a applications: CF=5.8 GHz, EVM ~3%, 64 QAM, 54 Mbps

OFDM Output Power @ 5.8 GHz



Vcc=3.3V

Vb=2.8V

I_{total} ~270mA

Input Power ~ -15.5dBm

Output Power ~ +17.5dBm

Cable loss ~ 1.1dB

Summary

- **RF CMOS has coming of age for RF IC implemetations**
  - ***Offering competitive performance for below 10 GHz applications***
  - ***Superior in circuit linearity***
  - ***Driven by needs in low-cost solutions and high-level SOC MS integrations***
- **SiGe HBT/BiCMOS also has coming of age**
  - ***Offering III-V performance with Si fabrication yield and cost***
  - ***Superior in mismatch handling, high gm, low noise***
  - ***Very low power dissipation at NFmin***
- **Multi-Chip Modules being replaced with " highly integrated Si solutions**
  (linear PA+ control circuit + transceiver)
  - ***SiGe HBT linear PA used as a reference for Broadcom 802.11b/g chip set***
  - ***Silicon Lab (Si4300) and Axiom(AX501) are promoting "Fully integrated GSM/GPRS Power Amplifier with CMOS technology***
- **GaAs HBT will continue to serve for GSM/GPRS**
  - ***SiGe HBT is limited by its breakdown voltage for GSM/GPRS***
- **Integration in RF modules is a major technology barrier for Asian Vendors**

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