

Appendix RF Manual

5th edition

Product and design manual for RF Products

October 2004

Semiconductors



PHILIPS

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Appendix A: BGA2715-17 general purpose wideband amplifiers, 50 Ohm Gain Blocks

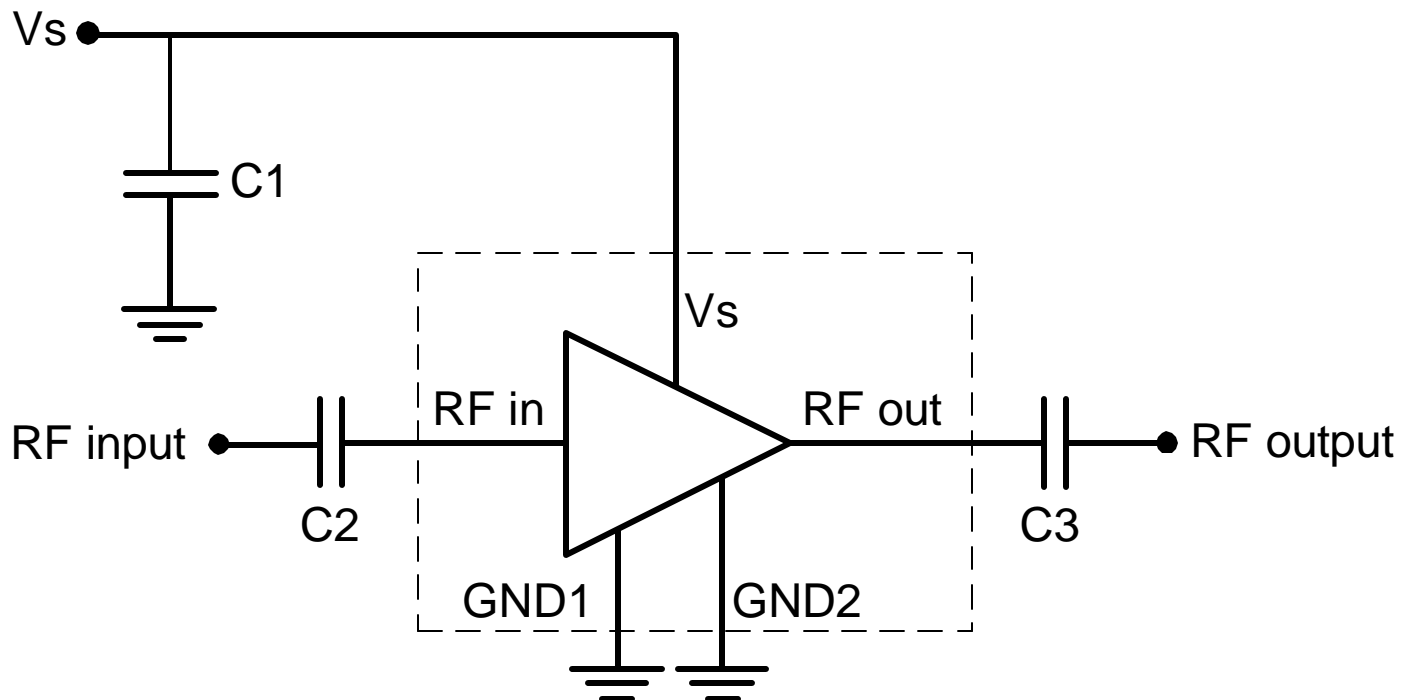
APPLICATION INFORMATION BGA2715-17

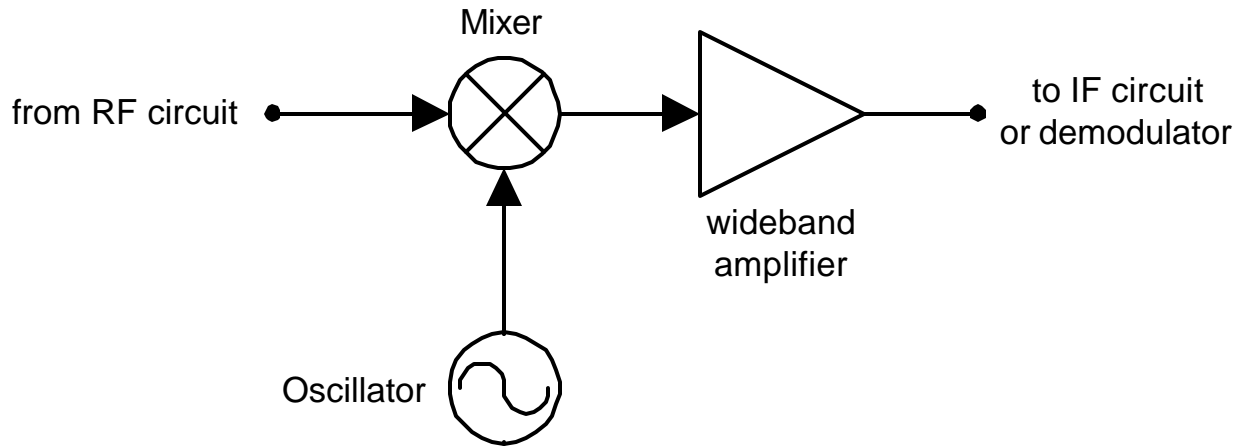
Figure 2 shows a typical application circuit for the BGA2715-17 MMIC. The device is internally matched to 50 Ω , and therefore does not need any external matching. The value of the input and output DC blocking capacitors C2 and C3 should not be more than 100 pF for applications above 100 MHz. However, when the device is operated below 100 MHz, the capacitor value should be increased.

The 22 nF supply decoupling capacitor C1 should be located as close as possible to the MMIC.

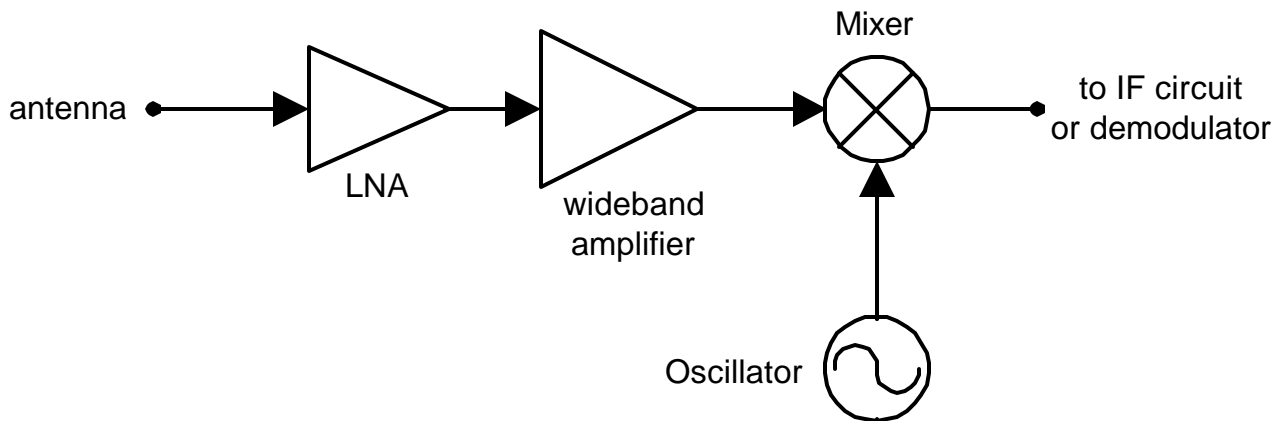
The PCB top ground plane, connected to the pins 2, 4 and 5 must be as close as possible to the MMIC, preferably also below the MMIC. When using via holes, use multiple via holes, as close as possible to the MMIC.

Application examples





The MMIC is very suitable as IF amplifier in e.g. LNB's. The excellent wideband characteristics make it an easy building block.



As second amplifier after an LNA, the MMIC offers an easy matching, low noise solution.

MMIC wideband amplifier

BGA2715

FEATURES

- Internally matched to 50 Ohms
- Wide frequency range, 3 dB bandwidth = 3.3 GHz
- Flat 22 dB gain, ± 1 dB up to 2.8 GHz
- -8 dBm output power at 1 dB compression point
- Good linearity for low current, OIP3 = 2 dBm
- Low second harmonic, -30 dBc at $P_{\text{Drive}} = -40$ dBm
- Unconditionally stable, K

APPLICATIONS

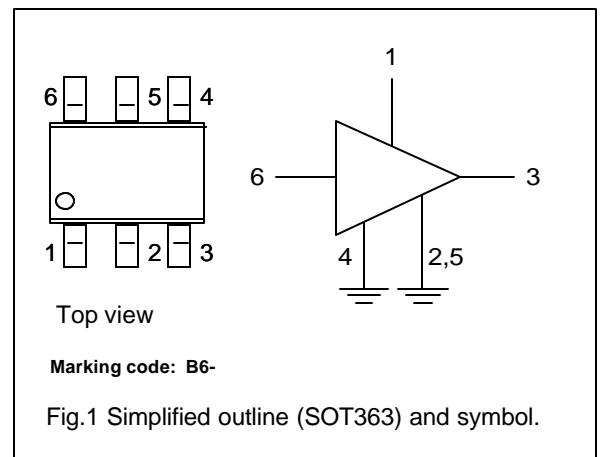
- LNB IF amplifiers
- Cable systems
- ISM
- General purpose

DESCRIPTION

Silicon Monolithic Microwave Integrated Circuit (MMIC) wideband amplifier with internal matching circuit in a 6-pin SOT363 plastic SMD package.

PINNING

PIN	DESCRIPTION
1	V_S
2,5	GND 2
3	RF out
4	GND 1
6	RF in



QUICK REFERENCE DATA

SYMBOL	PARAMETER	CONDITIONS	TYP.	MAX.	UNIT
V_S	DC supply voltage		5	6	V
I_S	DC supply current		4.3	-	mA
$ S_{21} ^2$	insertion power gain	$f = 1$ GHz	22	-	dB
NF	noise figure	$f = 1$ GHz	2.6	-	dB
$P_{L \text{ sat}}$	saturated load power	$f = 1$ GHz	-4	-	dBm

MMIC wideband amplifier

BGA2716

FEATURES

- Internally matched to 50 Ohms
- Wide frequency range, 3 dB bandwidth = 3.2 GHz
- Flat 23 dB gain, ± 1 dB up to 2.7 GHz
- 9 dBm output power at 1 dB compression point
- Good linearity for low current, OIP3 = 22 dBm
- Low second harmonic, -38 dBc at $P_{Load} = -5$ dBm
- Unconditionally stable, $K > 1.2$

APPLICATIONS

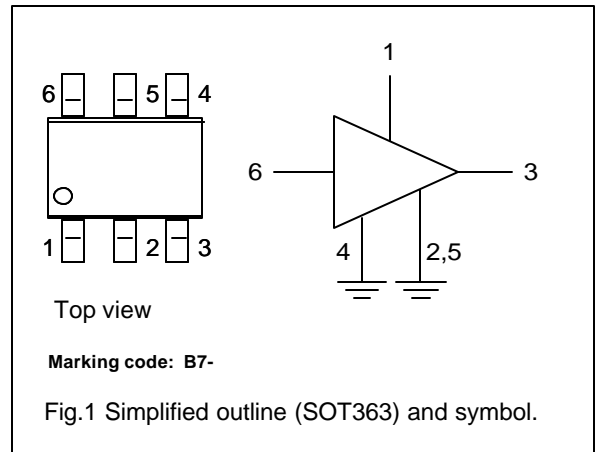
- LNB IF amplifiers
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DESCRIPTION

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PINNING

PIN	DESCRIPTION
1	V_s
2,5	GND 2
3	RF out
4	GND 1
6	RF in



QUICK REFERENCE DATA

SYMBOL	PARAMETER	CONDITIONS	TYP.	MAX.	UNIT
V_s	DC supply voltage		5	6	V
I_s	DC supply current		15.9	-	mA
$ S_{21} ^2$	insertion power gain	$f = 1$ GHz	22.9	-	dB
NF	noise figure	$f = 1$ GHz	5.3	-	dB
$P_{L\ sat}$	saturated load power	$f = 1$ GHz	11.6	-	dBm

MMIC wideband amplifier

BGA2717

FEATURES

- Internally matched to 50 Ohms
- Wide frequency range, 3 dB bandwidth = 3.2 GHz
- Flat 24 dB gain, ± 1 dB up to 2.8 GHz
- -2.5 dBm output power at 1 dB compression point
- Good linearity for low current, OIP3 = 10 dBm
- Low second harmonic, -38 dBc at $P_{Drive} = -40$ dBm
- Low noise figure, 2.3 dB at 1 GHz.
- Unconditionally stable, $K > 1.5$

APPLICATIONS

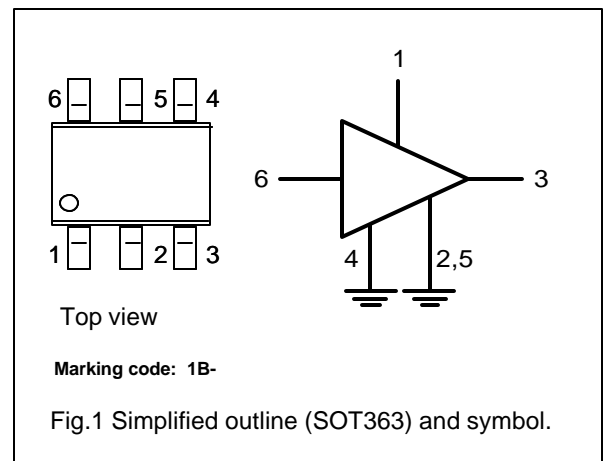
- LNB IF amplifiers
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- General purpose

DESCRIPTION

Silicon Monolithic Microwave Integrated Circuit (MMIC) wideband amplifier with internal matching circuit in a 6-pin SOT363 plastic SMD package.

PINNING

PIN	DESCRIPTION
1	V_S
2,5	GND 2
3	RF out
4	GND 1
6	RF in

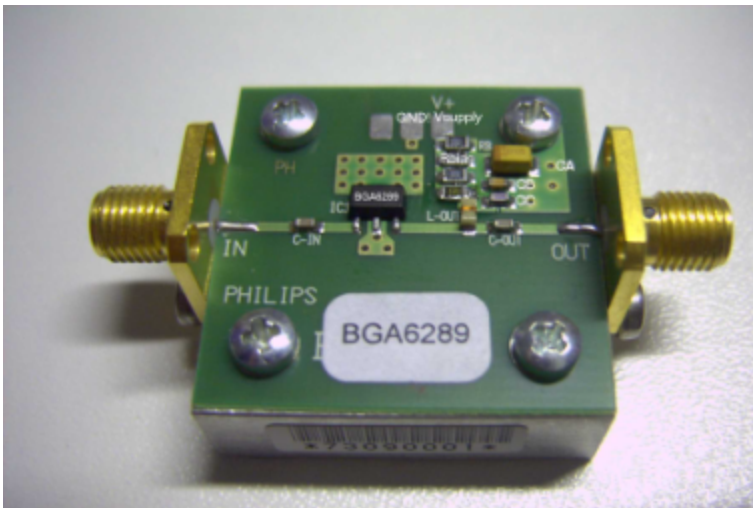


QUICK REFERENCE DATA

SYMBOL	PARAMETER	CONDITIONS	TYP.	MAX.	UNIT
V_S	DC supply voltage		5	6	V
I_S	DC supply current		8.0	-	mA
$ S_{21} ^2$	insertion power gain	$f = 1$ GHz	24	-	dB
NF	noise figure	$f = 1$ GHz	2.3	-	dB
$P_{L\ sat}$	saturated load power	$f = 1$ GHz	1	-	dBm

Appendix B: BGA6x89 general purpose medium power ampl., 50 Ohm Gain Blocks

Application note for the BGA6289



Application note for the BGA6289.
 (See also the objective datasheet BGA6289)

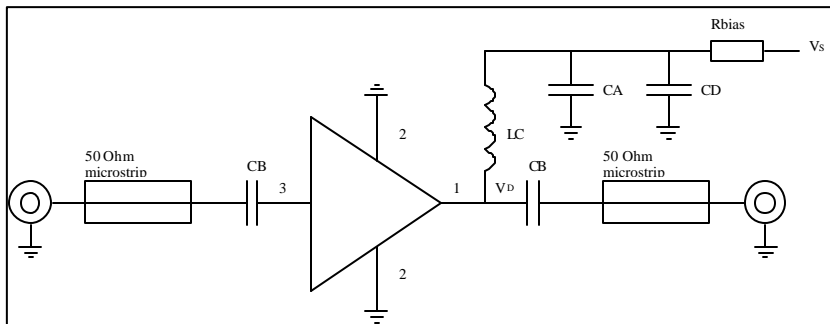


Figure 1 Application circuit.

COMPONENT	DESCRIPTION	VALUE	DIMENSIONS
C _{in} C _{out}	multilayer ceramic chip capacitor	68 pF	0603
C _A	Capacitor	1 μF	0603
C _B	multilayer ceramic chip capacitor	1 nF	0603
C _C	multilayer ceramic chip capacitor	22 pF	0603
L _{out}	SMD inductor	22 nH	0603
V _{supply}	Supply voltage	6 V	
R _{bias} =RB	SMD resistor 0.5W	27 Ohm	----

Table 1 component values placed on the demo board.

C_A is needed for optimal supply decoupling .

Depending on frequency of operation the values of C_{in} C_{out} and L_{out} can be changed (see table 2).

COMPONENT	Frequency (MHz)				
	500	800	1950	2400	3500
C _{in} C _{out}	220 pF	100 pF	68 pF	56 pF	39 pF
C _A	1 μF	1 μF	1 μF	1 μF	1 μF
C _B	1 nF	1 nF	1 nF	1 nF	1 nF
C _C	100 pF	68 pF	22 pF	22 pF	15 pF
L _{out}	68 nH	33 nH	22 nH	18 nH	15 nH

Table 2 component selection for different frequencies.

V_{supply} depends on R_{bias} used. Device voltage must be approximately 4 V (i.e. device current = 80mA).

With formula 1 it is possible to operate the device under different supply voltages. If the temperature raises the device will draw more current, the voltage drop over R_{bias} will increase and the device voltage decrease, this mechanism provides DC stability.

Measured small signal performance.

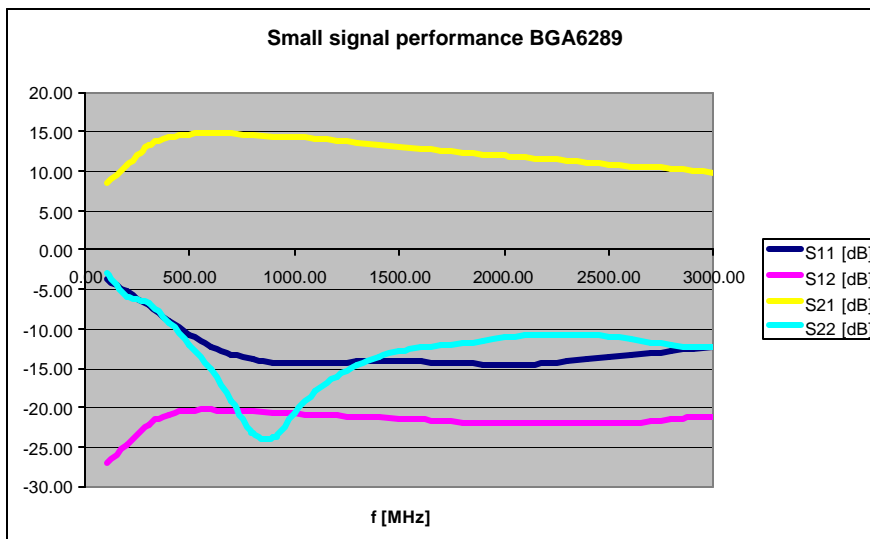


Figure 2 Small signal performance.

Measured large signal performance.

f	850 MHz	2500 MHz
IP3 _{out}	31 dBm	25 dBm
PL _{1dB}	18 dBm	16 dBm
NF	3.8	4.1

Table 3 Large signal performance and noise figure.

Application note for the BGA6489



Application note for the BGA6489.
 (See also the objective datasheet BGA6489)

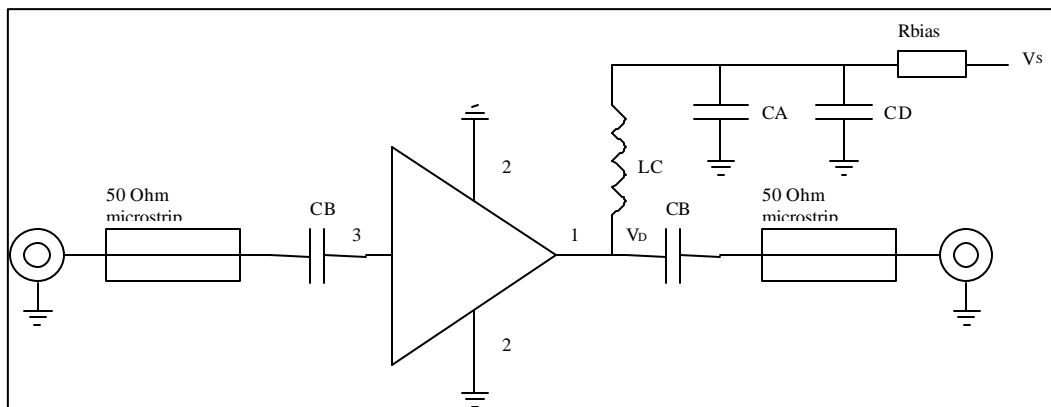


Figure 1 Application circuit.

COMPONENT	DESCRIPTION	VALUE	DIMENSIONS
C _{in} C _{out}	multilayer ceramic chip capacitor	68 pF	0603
C _A	Capacitor	1 μF	0603
C _B	multilayer ceramic chip capacitor	1 nF	0603
C _C	multilayer ceramic chip capacitor	22 pF	0603
L _{out}	SMD inductor	22 nH	0603
V _{supply}	Supply voltage	8 V	
R _{bias} =R _B	SMD resistor 0.5W	33 Ohm	----

Table 1 component values placed on the demo board.

C_A is needed for optimal supply decoupling .

Depending on frequency of operation the values of C_{in} C_{out} and L_{out} can be changed (see table 2).

COMPONENT	Frequency (MHz)				
	500	800	1950	2400	3500
C _{in} C _{out}	220 pF	100 pF	68 pF	56 pF	39 pF
C _A	1 μF	1 μF	1 μF	1 μF	1 μF
C _B	1 nF	1 nF	1 nF	1 nF	1 nF
C _C	100 pF	68 pF	22 pF	22 pF	15 pF
L _{out}	68 nH	33 nH	22 nH	18 nH	15 nH

Table 2 component selection for different frequencies.

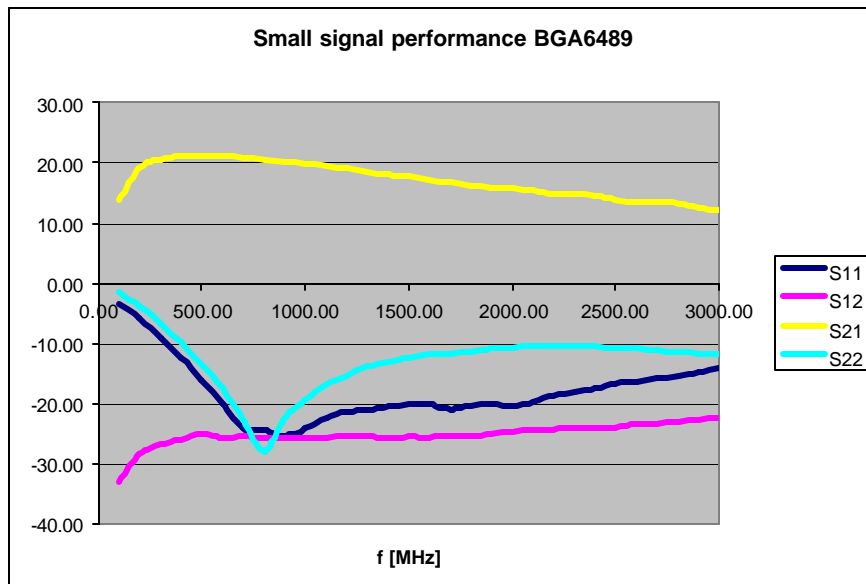
V_{supply} depends on R_{bias} used. Device voltage must be approximately 5.1 V (i.e. device current = 80mA).

With formula 1 it is possible to operate the device under different supply voltages.

If the temperature raises the device will draw more current, the voltage drop over R_{bias} will increase and the device voltage decrease, this mechanism provides DC stability.

Measured small signal performance.

Figure 2 Small signal performance.



Measured large signal performance.

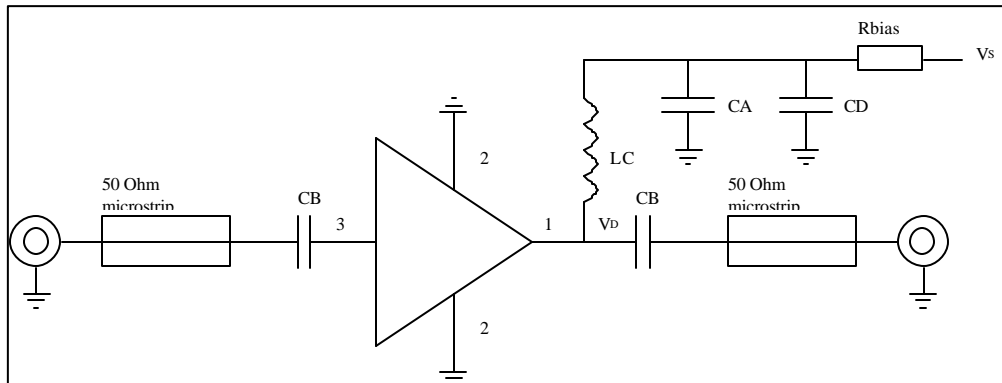
f	850 MHz	2500 MHz
IP _{3out}	33 dBm	27 dBm
PL _{1dB}	20 dBm	17 dBm
NF	3.1 dB	3.4 dB

Table 3 Large signal performance and noise figure.

Application note for the BGA6589



The Demo Board with medium power wide-band gainblock BGA6589. (See also the objective datasheet BGA6589)



Application circuit.

COMPONENT	DESCRIPTION	VALUE	DIMENSIONS
C_{in} C_{out}	multilayer ceramic chip capacitor	68 pF	0603
CA	Capacitor	1 μ F	
C_B	multilayer ceramic chip capacitor	1 nF	0603
C_C	multilayer ceramic chip capacitor	22 pF	0603
L_C	SMD inductor	22 nH	0603
V_{supply}	Supply voltage	7.5 V	
$R_{bias}=R_B$	SMD resistor 0.5W	33 Ohm	----

Table 1 component values placed on the demo board.

C_A is needed for optimal supply decoupling .

Depending on frequency of operation the values of C_{in} C_{out} and L_{out} can be changed (see table 2).

COMPONENT	Frequency (MHz)				
	500	800	1950	2400	3500
C_{in} C_{out}	220 pF	100 pF	68 pF	56 pF	39 pF
C_A	1 μ F	1 μ F	1 μ F	1 μ F	1 μ F
C_B	1 nF	1 nF	1 nF	1 nF	1 nF
C_C	100 pF	68 pF	22 pF	22 pF	15 pF
L_{out}	68 nH	33 nH	22 nH	18 nH	15 nH

Table 2 component selection for different frequencies.

V_{supply} depends on R_{bias} used. Device voltage must be approximately 4.8 V (i.e. device current = 83mA).

With formula 1 it is possible to operate the device under different supply voltages. If the temperature raises the device will draw more current, the voltage drop over R_{bias} will increase and the device voltage decrease, this mechanism provides DC stability. Measured small signal performance.

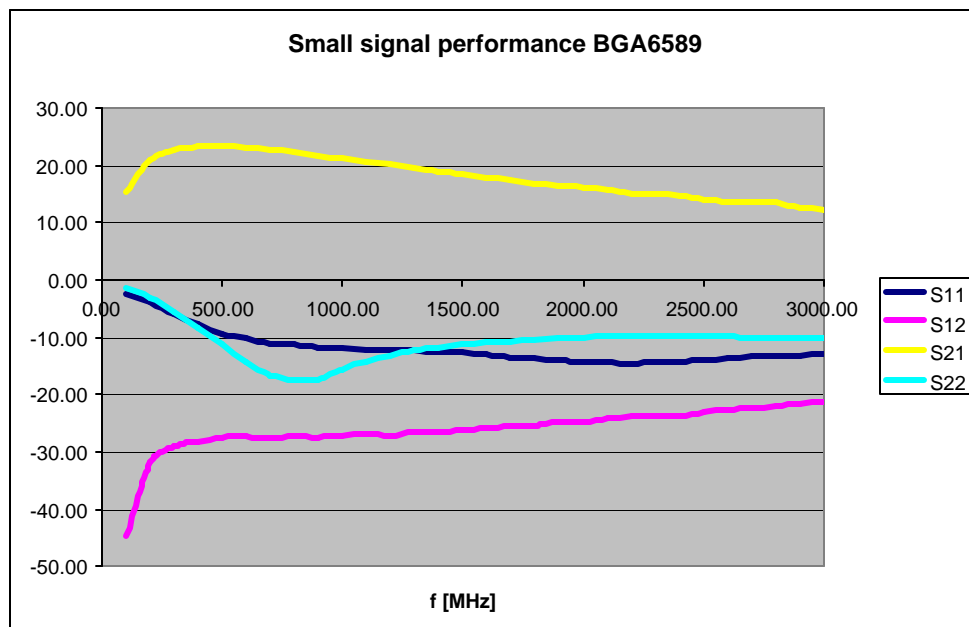


Figure 2 Small signal performance.

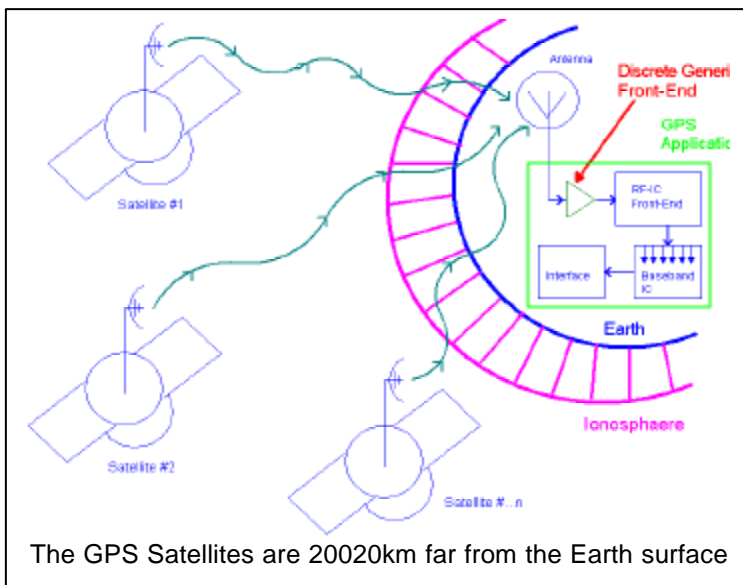
Measured large signal performance.

f	850 MHz	2500 MHz
$IP3_{out}$	33 dBm	32 dBm
PL_{1dB}	21 dBm	19 dBm
NF	3.1 dB	3.4 dB

Table 3 Large signal performance and noise figure.

Appendix C: Introduction GPS Front-End

Due to shrinking of the mechanical dimensions and attractive pricing of the semiconductors, GPS applications got very popular in the last years. A GPS navigation system is based on measuring and evaluating RF signals transmitted by the GPS satellites. There are at least 24 active satellites necessary in a distance of 20200km above the Earth surface. All sat's transmits their civil useable L1 signal at the same time down to the user on 1575.42MHz in the so-called microwave L-band. Each satellite have it's own C/A code (Coarse Acquisition).



This satellite identifier C/A code is Pseudo Randomly and appears like Noise in the frequency spectrum (=PRN C/A code). The L1 carrier is BPSK (Binary Phase Shift Keying) modulated by the C/A data code, by the navigation data message and the encrypted P(Y)-code. Due to C/A's PRN modulation, the carrier is DSSS modulated (Direct Sequence Spread Spectrum modulation). This DSSS spreads the former bandwidth signal to a satellite internal limited width of 30MHz. A GPS receiver must know the C/A code of each satellite for selecting it out of the antennas kept RF spectrum. Because a satellite is selected out of the data stream by the use of an identification code, GPS is a CDMA-System (Code Division Multiplex Access). This RF signal is transmitted with enough power to ensure a minimum signal

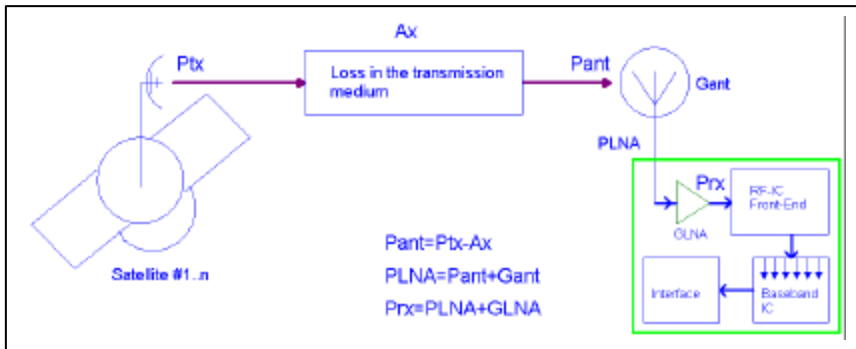
The L1 carrier based GPS system does use : CDMA - DSSS - BPSK modulation

Available GPS carrier frequencies		
L1	Link 1 carrier frequency	1575.42 MHz
L2	Link 2 carrier frequency	1227.6 MHz
L3	Link 3 carrier frequency	1381.05 MHz
L4	Link 4 carrier frequency	1379.913 MHz
L5	Link 5 carrier frequency	1176.45 MHz

The U.S. navigation system GPS was originally started by the U.S. military in 1979. It will be updated in order to supply the carriers L2 & L5 for increasing civil performances together with the standard L1 RF carrier. GPS uses BPSK modulation on the L1 carrier and, beginning with launch of the modernized Block IIR the L2 carrier. The L5 signal that will appear with the Block IIF satellites in 2006 will have use of the QPSK modulation (Quadrature Phase Shift Keying).

The performances overview of the actual and the next up-coming GPS system:

Topic	Used Codes	Need of a second reference base station	Resolution	Comments
Today basic positioning	C/A Code on L1	No	Before May 2000: 25-100m Today 6-10m (resolution controlled by US)	---
Tomorrow basic positioning	C/A Code on L1 L2C Code on L2 New Code on L5	No	1-5m	Eliminates need for costly DGPS in many non-safety applications.
Today advance positioning	L1 Code and Carrier L2 Carrier Data Link	Yes	2cm	max. distance too reference 10km
Tomorrow advanced positioning	L1 Code and Carrier L2 Code and Carrier L5 Code and Carrier Data Link	Yes	2cm	max. distance too reference 100km; faster recovery following signal interruption



The spread spectrum modulated signals field strength is very weak and cause a negative SNR in the receiver input circuit caused by the Nyquist Noise determined by the Analog Front-End IF bandwidth:

Satellite Generation	Channel	C/A Loop peek
II/IIA/IIR	L1	-158.5dBW
	L2	-164.5dBW
IIR-M/IIF	L1	-158.5dBW
	L2	-160.0dBW

$$dBW = 10 \log \left(\frac{P}{1W} \right)$$

Competition Satellite based navigation systems:

In 2004 will be start the European navigation system EGNOS. News forecasted the European system Galileo for 2008. GLONASS is a Russian Navigation System.

Comparison of the front-ends used in a GPS and in a GLONASS receiver:

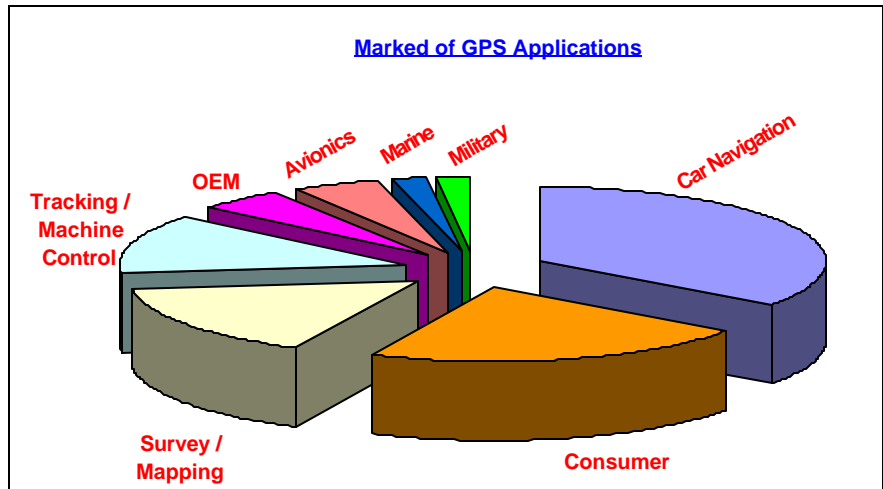
All GPS satellites use the same L1 frequency of 1575.42MHz, but different C/A codes, so a single front-end may be used. To achieve better sky coverage and accelerated operation, more than one antenna can be used. In this case, separate front-ends can be used. Using switches based on Philips' PIN-diodes makes it possible to select the antenna with the best signal in e.g. automotive applications for operation in a city.

Each GLONASS satellite will use a different carrier frequency in the range of 1602.5625MHz to 1615.5MHz, with 562.5KHz spacing, but all with the same spreading code. The normal method for receiving these signals uses of several parallel working front-ends, perhaps with a common first LNA and mixer, but certainly with different final local oscillators and IF mixer.

Application examples:

- Personal Navigations
- Railroads
- Recreation, walking-tour
- Off shore Drilling
- Satellite Ops. Ephemeris Timing
- Surveying & Mapping
- Network Timing, Synchronization
- Fishing & Boat
- Arm Clocks
- Laptops and Palms
- Mobiles
- Child safety
- Car navigation systems
- Fleet management systems
- Telecom Time reference
- High way toll system
- First-Aid call via mobiles

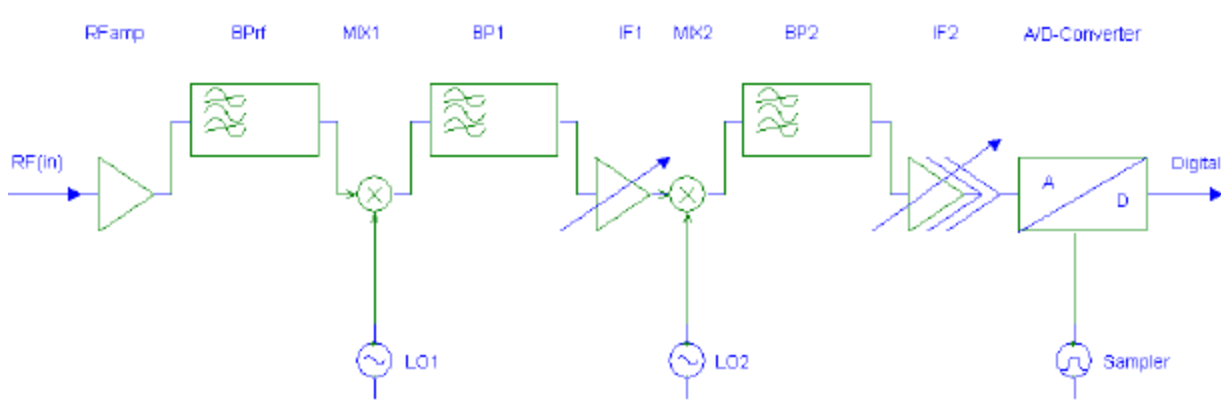
GPS Marked & Applications



References:

- Office of Space Commercialization, United States Department of Commerce
- U.S. Coast Guard Navigation Center of Excellence
- NAVSTAR Global Positioning System
- NAVSTAR GPS USER EQUIPMENT INTRODUCTION
- Royal school of Artillery, Basic science & technology section, BST, gunnery careers courses, the NAVSTAR Global Positioning System
- , ...

Simplified block diagram of a typically GPS receiver analog front-end IC



Typically, an integrated double superheat-receiver technology is used in the analog rail. The under sampling analog to digital converter (ADC) is integrated in the analog front-end IC with a resolution of 1 to 2bit. Due to under sampling, it acts as the third mixer for down converting into to the digital stream IF band. Behind this ADC, the digital Baseband Processor is located. Till this location, the SNR of the received satellite signals is negative. In the Baseband Processor, the digital IF signal is parallel processed in several C/A correlators and NAV-data code discriminators. During this processing, the effective Nyquist Bandwidth is shrink down to few Hertz, dispreading and decoding of the GPS signal is made causing a positive SNR. Because typically front-end ICs are designed in a high-integrated low

power relative noisy semiconductor process, there is a need of an external Low-Noise-Amplifier (LNA) combined with band pass-filters. Because the available GPS IC chipsets on the market differ in their electrically performances like, Gain, Noise Figure (NF), linearity and sensitivity, therefore one and two-stage discrete front-end amplifiers are used. The numbers of filters in the front-end vary with the needs on the applications target environment, costs and sizes. The processed number of GPS carriers as well as the navigation accuracy does determine the min. allowed bandwidth of the analog-front end rail.

Philips Semiconductors offer MMICs with internal 50Ω matches at the input and output (I/O) and without internal matching. The internal matched broadband MMICs typically need an output inductor for DC biasing and DC decoupling capacitors at the amplifier I/O. The internal non-matched devices need I/O matching network typically made by lumped LC circuits in a L-arrangement. This gives additionally selectivity. Another advantage of this MMIC is the integrated temperature compensation in contrast to a transistor. In a system, typically the first amplifier's noise figure is very important. E.g. the BGU2003 SiGe MMIC offers both (NF+IP3) with a good quality. It's Si made brother BGA2003 come with lower amount of IP3 and NF. IC chip-sets with a need of high front-end gain made by one MMIC may be able to use BGM1011 or BGM1013. Two-stage design e.g. will use BGA2001, BGA2011 eventually combined with BGA2748 or BGA2715 or BGA2717. Some examples of configuration for an L1-carrier LNA are shown in the next two tables.

Single Front-End amplifier:

Amplifier	BFG 325W	BFU 540	BGU 2003	BGM 1013	BGM 1011	BFG 410W	BGA 2011	BGA 2001	BGA 2003	BGA 2715	BGA 2748
Gain	14dB	20dB	14dB	34dB	35dB	18dB	12dB	14dB	14dB	23.2dB	21dB
NF	1dB	0.9dB	1.1dB	4.7dB	4.7dB	1.1dB	1.5dB	1.3dB	1.8dB	2.7dB	2dB
IP3o(out)	+24dBm	+21dBm	+21dBm	+21dBm	+20dBm	+15dBm	+10dBm	+9.5dBm	+9.2dBm	+1dBm	-1.6dBm
Matching	External	External	External	Internal	Internal	External	External	External	External	Internal	Internal

Two-cascaded circuit Front-End amplifier:

1 st Stage	BFG325W	BFG410W	BFG410W	BFU540	BFG325W	BGA2011	BGU2003	BGA2011	BGA2003	BGA2011
2 nd Stage	BFU540	BFU540	BGU2003	BFG410W	BFG410W	BGA2011	BGA2001	BGA2715	BGA2715	BGA2748
Cascaded Gain	31dB	35dB	29dB	35dB	29dB	21dB	25dB	32.2dB	34dB	30dB
Cascaded NF	1.19dB	1.25dB	1.32dB	1.11dB	1.28dB	2dB	1.5dB	2.5dB	2.6dB	2.2dB
Cascaded IP3o	+21dBm	+21dBm	+21dBm	+15dBm	+15dBm	+10dBm	+9.5dBm	+1dBm	+1dBm	-1.6dBm

- Note:**
- [1] Gain=|S21|²; data @ 1.8GHz or the next one / approximated, found in the data sheet / diagrams
 - [2] For cascaded amplifier equations referee to e.g. 4th Edition RF Manual Appendix, 2.4GHz Generic Front-End reference design
 - [3] The evaluated cascaded amplifier includes an example interstage filter with 3dB insertion loss (NF=+3dB; IP3=+40dBm).
 - [4] MMICs: BGAxxxx, BGMxxxx, BGUxxxx Transistors: BFGxxx, BFUxxx

Appendix D: 2.4GHz Generic Front-End Reference design

Complete design description in previous RF Manual (4th edition), including datasheet. Downloadable via RF Manual website: http://www.philips.semiconductors.com/markets/mms/products/discretes/documentation/rf_manual

Description of the generic Front-End

This note describes the design and realization of a 2.4GHz ISM front end (Industrial-Scientific-Medical). Useful for wireless communication applications, LAN and e.g. Video/TV signal transmission. It covers power amplifier (PA) design in the Tx path, Low Noise Amplifier (LNA) design in the Rx path and RF multiplexing towards the antenna.

Though actual IC processes enable front-end integration to a certain extend, situations do exist where dedicated discrete design is required, e.g. to realize specific output power. On top of the factual design, attention is paid to interfacing the front end to existing Philips IC. More than trying to fit a target application, our intention here is to illustrate generic discrete Front end design methodology.

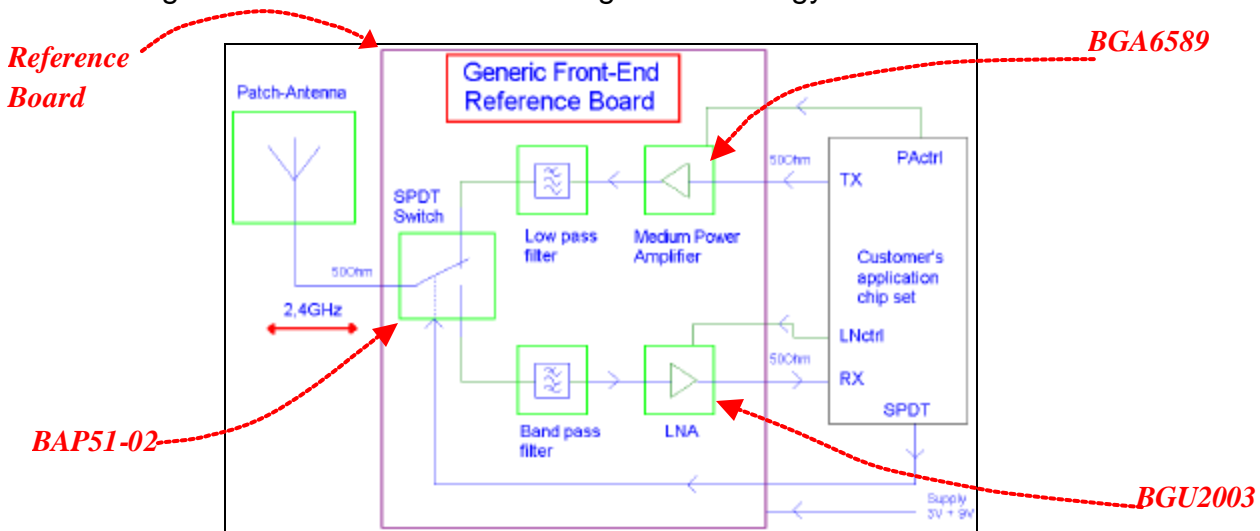


Figure1: The position of the LNA inside the 2.4GHz Generic Front-End

- **The job of the Front-End in an application**

The board supports half duplex operation. This means the TX and RX operation are not possible at the same time. The time during TX and RX activity are so called **time slots** or just **slots**. The order of the TX and RX slots is specific for the selected standard. Special handshaking activities consist of several TX and RX slots put together in to the so-called **time-frame** or just **frame**. The **user points / access points** linked in this

wireless application must follow the same functionality of slots, same order of frames and timing procedure (**synchronization**). These kind of issues must be under the control of specific rules (standard) normally defined by **Institutes** or **Organization** like ETSI, IEEE, NIST, FCC, CEPT, and so on.

Applications for the Reference Board

Some application ideas for the use of the Generic Front-End Reference Board

- 2.4GHz WLAN
- Wireless video, TV and remote control signal transmission
- PC to PC data connection
- PC headsets
- PC wireless mouse, key board, and printer
- Palm to PC, Keyboard, Printer connectivity
- Supervision TV camera signal transmission
- Wireless loudspeakers
- Robotics
- Short range underground walky-talky
- Short range snow and stone avalanche person detector
- Key less entry
- Identification
- Tire pressure systems
- Garage door opener
- Remote control for alarm-systems
- Intelligent kitchen (cooking place, Microwave cooker and washing machine operator reminder)
- Bluetooth
- DSSS 2.4GHz WLAN (IEEE802.11b)
- OFDM
- 2.4GHz WLAN (IEEE802.11g)
- Access Points
- PCMCIA
- PC Cards
- 2.4GHz Cordless telephones
- Wireless pencil as an input for Palms and PCs
- Wireless hand scanner for a Palm
- Identification for starting the car engine
- Wireless reading of gas counters
- Wireless control of soft-drink /cigarette/snag - SB machine
- Communication between bus/taxi and the stop lights
- Panel for ware house stock counting
- Printers
- Mobiles
- Wireless LCD Display
- Remote control
- Cordless Mouse
- Automotive, Consumer, Communication

Please note:

The used MMICs and PIN diodes can be used in other frequency ranges e.g. 300MHz to 3GHz for applications like communication, networking and ISM too.

Selection of Applications in the 2.4GHz environment

Application	Standardization name/issue	Start frequency	Stop Frequency	Centre frequency	Bandwidth-MHz/Channel Spacing-MHz
Bluetooth; 1Mbps	IEEE802.15.1	NUS/EU=2402MHz (All)=2402MHz	NUS/EU=2480MHz (All)=2495MHz	2442.5MHz	NUS/EU=78/1MHz (All)=93/1MHz
WiMedia , (802.15.3a@3.1-10.6GHz)	IEEE802.15.3 (camera, video)	2.4GHz	2.49GHz	2.45GHz	
ZigBee; 1000kbps@2450MHz Other Frequency(868; 915)MHz	IEEE802.15.4	US=2402MHz EU=2412MHz	US=2480MHz EU=2472MHz	2441MHz	US=83/4MHz EU=60/4
DECT@ISM	ETSI	2400 MHz	2483MHz	2441.5MHz	83/
IMT-2000 =3G; acc., ITU, CEPT, ERC ERC/DEC/(97)07; ERC/DEC/(99)25 (=UMTS, CDMA2000, UWC-136, UTRA-FDD, UTRA-TDD)	FDD Uplink (D)	=1920	=1980	Exact Frequency range depending on country & system supplier	(TDD, FDD; WCDMA, TD-CDMA); paired 2x60MHz (D) non paired 25MHz (D)
	FDD Downlink (D)	=2110	=2170		
	TDD (D)	=1900	=2024		
USA - ISM		2400MHz	2483.5MHz	2441.75MHz	83.5/
Wireless LAN; Ethernet; (5.2; 5.7)GHz	IEEE802.11; (a, b, ...)	2400MHz	2483MHz	2441.5MHz	83/FHSS=1MHz; DSSS=25MHz
Wi-Fi; 11-54Mbps; (4.9-5.9)GHz	IEEE802.11b; (g, a)	2400MHz	2483MHz	2441.5MHz	
RFID	ECC/SE24	2446MHz	2454MHz	2.45GHz	
Wireless LAN; 11Mbps	IEEE802.11b	2412MHz	2462MHz	2437MHz	56/
Wireless LAN; 54Mbps	IEEE802.11g				
WPLAN	NIST	2400MHz			
HomeRF; SWAP/CA, 0.8-1.6Mbps		NUS/EU=2402MHz (All)=2402	NUS/EU=2480MHz (All)=2495		78/1MHz, 3.5MHz 93/1MHz, 3.5MHz
Fixed Mobile; Amateur Satellite; ISM, SRD, RLAN, RFID	ERC, CEPT Band Plan	2400MHz	2450MHz	2425MHz	50/
Fixed RF transmission	acc. CEPT Austria regulation	2400MHz	2450MHz	2425MHz	50/
MOBIL RF; SRD	acc. CEPT Austria regulation	2400MHz	2450MHz	2425MHz	50/
Amateur Radio	FCC	2390MHz	2450MHz		60/
UoSAT-OSCAR 11, Telemetry	Amateur Radio Satellite UO-11			2401.5MHz	
AMSAT-OSCAR 16	Amateur Radio Satellite AO-16			2401.1428MHz	
DOVE-OSCAR 17	Amateur Radio Satellite DO-17			2401.2205MHz	
Globalstar, (Mobile Downlink)	Loral, Qualcomm	2483.5MHz	2500MHz	S-Band	
Ellipso, (Mobile Downlink)	Satellite; Supplier Ellipsat	2483.5MHz	2500MHz		
Aries, (Mobile Downlink) (now Globalstar?)	Satellite; Supplier Constellation	2483.5MHz	2500MHz		
Odyssey, (Mobile Downlink)	Satellite; Supplier TRW	2483.5MHz	2500MHz		
Orbcomm Satellite (LEO) eg. GPSS-GSM	Satellite			2250,5MHz	
Ariane 4 and Ariane 5 (ESA, Arianespace)	tracking data link for rocket			2206MHz	
Atlas Centaur eg. carrier for Intelsat IVA F4	tracking data link for rocket			2210,5MHz	
J.S. Marshall Radar Observatory	700KW Klystron TX			S-Band	
Raytheon ASR -10SS Mk2 Series S-Band Solid-State Primary Surveillance Radar	US FAA/DoD ASR -11 used in U.S. DASR program	2700	2900	S-Band Radar ≈2400MHz	
Phase 3D; Amateur Radio Satellite; 146MHz, 436MHz, 2400MHz	AMSAT; 250Wpwp TX			S-Band	2.4KHz, SSB
Apollo 14-17; NASA space mission	transponder experiments			S-Band	
ISS; (internal Intercom System of the ISS station)	Space			2.4GHz	
MSS Downlink	UMTS	2170	2200		

Abbreviations: European Radio communication Committee ([ERC](#)) within the European Conference of Postal and Telecommunication Administration ([CEPT](#))

NIST	=	National Institute of Standards and Technology	RFID	=	Radio Frequency Identification
WPLAN	=	Wireless Personal Area Networks	OSCAR	=	Orbit Satellite Carry Amateur Radio
WLAN	=	Wireless Local Area Networks	FHSS	=	Frequency Hopping Spread Spectrum
ISM	=	Industrial Scientific Medical	DSSS	=	Direct Sequence Spread Spectrum
LAN	=	Local Area Network	DECT	=	Digital Enhanced Cordless Telecommunications
IEEE	=	Institute of Electrical and Electronic Engineers	NUS	=	North America
SRD	=	Short Range Device	EU	=	Europe
RLAN	=	Radio Local Area Network	ITU	=	International Telecommunications Union
ISS	=	International Space Station	ITU-R	=	ITU Radio communication sector
IMT	=	International mobile Telecommunications at 2000MHz	(D)	=	Germany
MSS	=	Mobile Satellite Service	TDD	=	Time Division Multiplex
W-CDMA	=	Wideband-CDMA	FDD	=	Frequency Division Multiplex
GMSK	=	Gaussian Minimum Shift Keying	TDMA	=	Time Division Multiplex Access
UMTS	=	Universal Mobile Telecommunication System	CDMA	=	Code Division Multiplex Access
UWC	=	Universal Wireless Communication	2G	=	Mobile Systems GSM, DCS
MSS Downlink	=	Mobile Satellite Service of UMTS	3G	=	IMT-2000

Schematic

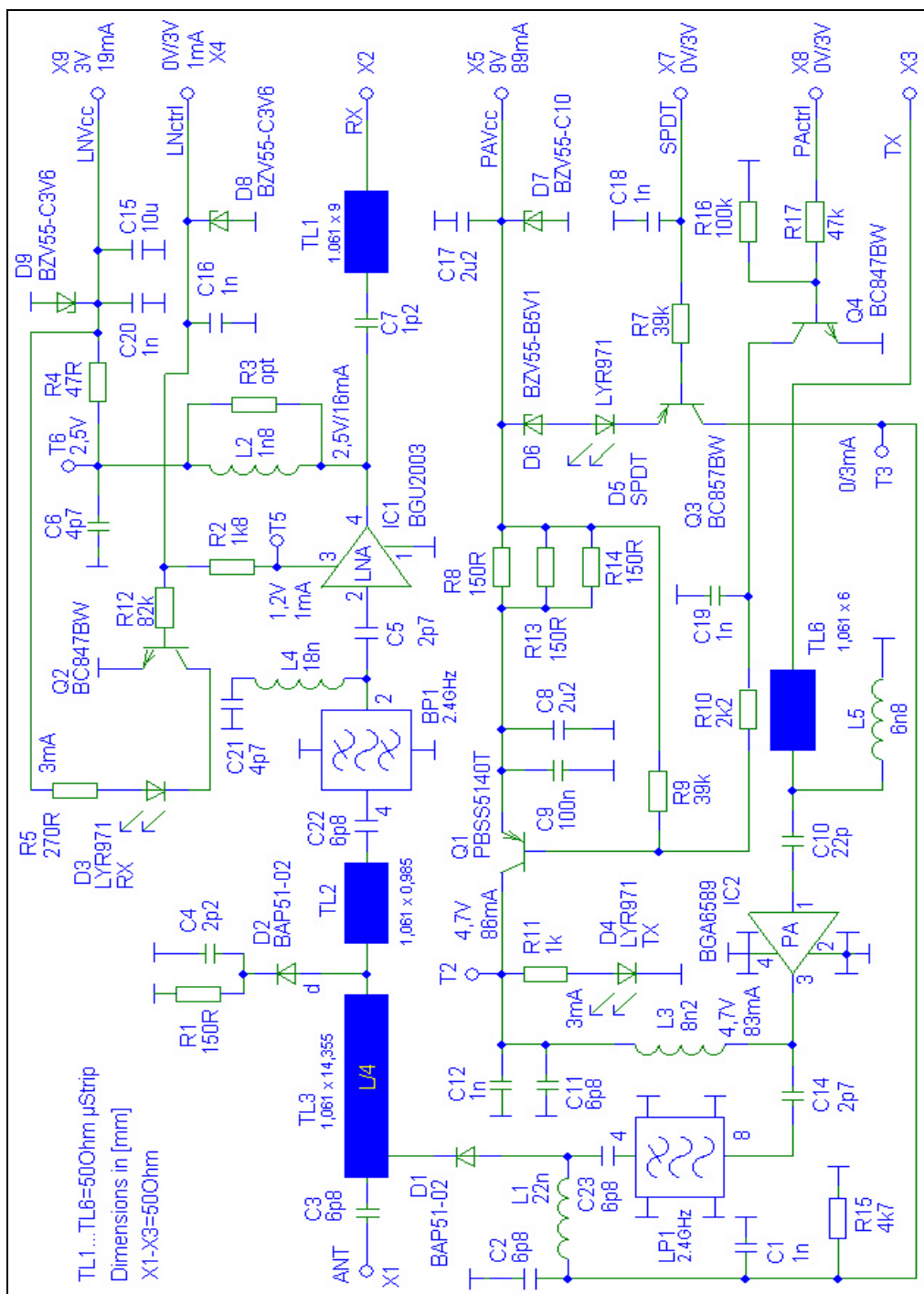


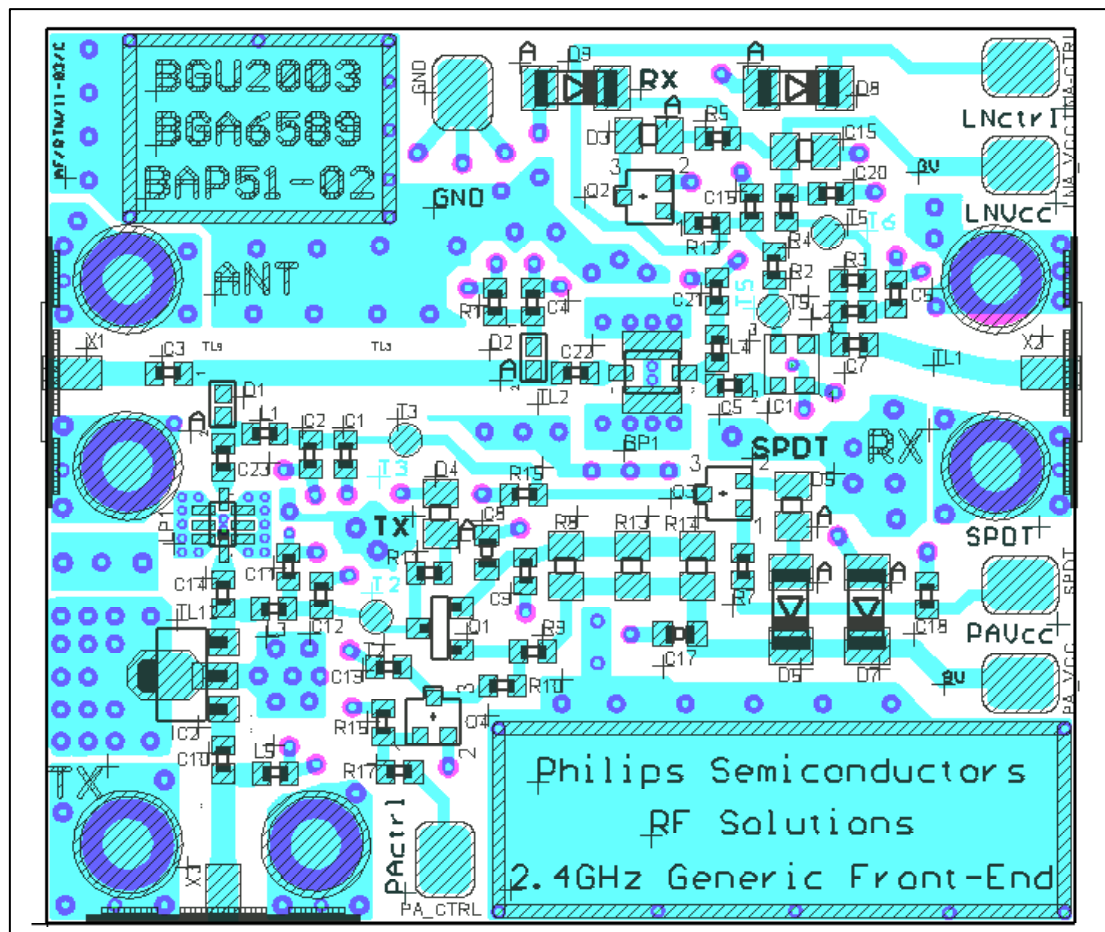
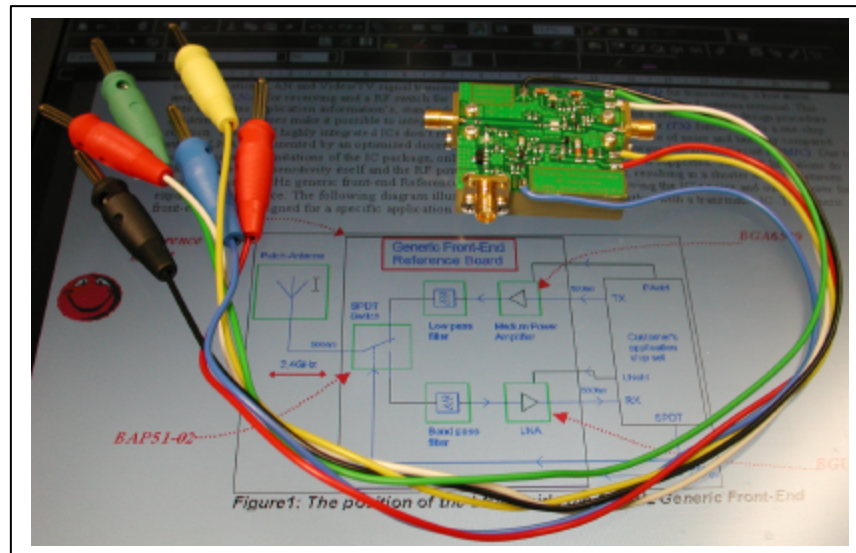
Figure 4: Schematic of the Reference Board

Part List

Part Number	Value	Size	Function / Short explanation	Manufacturer	Order Code	Order source
IC1	BGU2003	SOT363	LNA-MMIC	Philips Semiconductors	BGU2003	PHL
IC2	BGA6589	SOT89	TX-PA-MMIC	Philips Semiconductors	BGA6589	PHL
Q1	PBSS5140T	SOT23	TX PA-standby control	Philips Semiconductors	PBSS5140T	PHL
Q2	BC847BW	SOT323	Drive of D3	Philips Semiconductors	BC847BW	PHL
Q3	BC857BW	SOT323	SPDT switching	Philips Semiconductors	BC857BW	PHL
Q4	BC847BW	SOT323	PA logic level compatibility	Philips Semiconductors	BC847BW	PHL
D1	BAP51-02	SOD523	SPDT-TX; series part of the PIN diode switch	Philips Semiconductors	BAP51-02	PHL
D2	BAP51-02	SOD523	SPDT-RX; shunt part of the PIN diode switch	Philips Semiconductors	BAP51-02	PHL
D3	LYR971	0805	LED, yellow, RX and bias current control of IC1	OSRAM	67S5126	Bürklin
D4	LYR971	0805	LED, yellow; TX	OSRAM	67S5126	Bürklin
D5	LYR971	0805	LED, yellow; SPDT; voltage level shifter	OSRAM	67S5126	Bürklin
D6	BZV55-B5V1	SOD80C	Level shifting for being 3V/5V tolerant	Philips Semiconductors	BZV55-B5V1	PHL
D7	BZV55-C10	SOD80C	Board DC polarity & over voltage protection	Philips Semiconductors	BZV55-C10	PHL
D8	BZV55-C3V6	SOD80C	Board DC polarity & over voltage protection	Philips Semiconductors	BZV55-C3V6	PHL
D9	BZV55-C3V6	SOD80C	Board DC polarity & over voltage protection	Philips Semiconductors	BZV55-C3V6	PHL
R1	150Ω	0402	SPDT bias	Yageo RC0402 Vitrohm512	26E558	Bürklin
R2	1k8	0402	LNA MMIC current CTRL	Yageo RC0402 Vitrohm512	26E584	Bürklin
R3	optional	0402	L2 resonance damping; optional	---	optional	
R4	47Ω	0402	LNA MMIC collector bias	Yageo RC0402 Vitrohm512	26E546	Bürklin
R5	270Ω	0402	RX LED current adj.	Yageo RC0402 Vitrohm512	26E564	Bürklin
R7	39k	0402	Q3 bias SPDT	Yageo RC0402 Vitrohm512	26E616	Bürklin
R8	150Ω	0805	PA-MMIC collector current adjust and temperature compensation	Yageo RC0805 Vitrohm503	11E156	Bürklin
R9	39k	0402	Helps switch off of Q1	Yageo RC0402 Vitrohm512	26E616	Bürklin
R10	2k2	0402	Q1 bias PActrl	Yageo RC0402 Vitrohm512	26E586	Bürklin
R11	1kΩ	0402	LED current adjust; TX-PA	Yageo RC0402 Vitrohm512	26E578	Bürklin
R12	82k	0402	Q2 drive	Yageo RC0402 Vitrohm512	26E624	Bürklin
R13	150Ω	0805	PA-MMIC collector current adjust	Yageo RC0805 Vitrohm503	11E156	Bürklin
R14	150Ω	0805	PA-MMIC collector current adjust	Yageo RC0805 Vitrohm503	11E156	Bürklin
R15	4k7	0402	Improvement of SPDT-Off	Yageo RC0402 Vitrohm512	26E594	Bürklin
R16	100k	0402	PActrl; logic level conversion	Yageo RC0402 Vitrohm512	26E626	Bürklin
R17	47k	0402	PActrl; logic level conversion	Yageo RC0402 Vitrohm512	26E618	Bürklin
L1	22nH	0402	SPDT RF blocking for biasing	Würth Elektronik, WE-MK	744 784 22	WE
L2	1n8	0402	LNA output matching	Würth Elektronik, WE-MK	744 784 018	WE
L3	8n2	0402	PAout Matching	Würth Elektronik, WE-MK	744 784 082	WE
L4	18nH	0402	LNA input match	Würth Elektronik, WE-MK	744 784 18	WE
L5	6n8	0402	PA input matching	Würth Elektronik, WE-MK	744 784 068	WE
C1	1nF	0402	medium RF short for SPDT bias	Murata, X7R	GRP155 R71H 102 KA01E	Murata
C2	6p8	0402	medium RF short for SPDT bias	Murata, C0G	GRP1555 C1H 6R8 DZ01E	Murata
C3	6p8	0402	Antenna DC decoupling	Murata, C0G	GRP1555 C1H 6R8 DZ01E	Murata
C4	2p2	0402	RF short SPDT shunt PIN	Murata, C0G	GRP1555 C1H 2R2 CZ01E	Murata
C5	2p7	0402	DC decoupling LNA input + match	Murata, C0G	GRP1555 C1H 2R7 CZ01E	Murata
C6	4p7	0402	RF short output match	Murata, C0G	GRP1555 C1H 4R7 CZ01E	Murata
C7	1p2	0402	LNA output matching	Murata, C0G	GRP1555 C1H 1R2 CZ0E	Murata
C8	2u2/10V	0603	Removes the line ripple together with R8-R14 from PA supply rail	Murata, X5R	GRM188 R61A 225 KE19D	Murata
C9	100nF/16V	0402	Ripple rejection PA	Murata, Y5V	GRM155 F51C 104 ZA01D	Murata
C10	22pF	0402	DC decoupling PA input	Murata, C0G	GRP1555 C1H 220 JZ01E	Murata
C11	6p8	0402	RF short-bias PA	Murata, C0G	GRP1555 C1H 6R8 DZ01E	Murata
C12	1nF	0402	PA, Supply RF short	Murata, X7R	GRP155 R71H 102 KA01E	Murata

Part Number	Value	Size	Function / short explanation	Manufacturer	Order Code	Order source
C14	2p7	0402	TX-PAout DC decoupling + matching	Murata, C0G	GRP1555 C1H 2R7 CZ01E	Murata
C15	10u/6.3V	0805	dc rail LNVcc	Murata, X5R	GRM21 BR60J 106 KE19B	Murata
C16	1nF	0402	dc noise LNctrl	Murata, X7R	GRP155 R71H 102 KA01E	Murata
C17	2u2/10V	0603	PA dc rail	Murata, X5R	GRM188 R61A 225 KE34B	Murata
C18	1nF	0402	dc noise SPDT control	Murata, X7R	GRP155 R71H 102 KA01E	Murata
C19	1nF	0402	dc noise PActrl	Murata, X7R	GRP155 R71H 102 KA01E	Murata
C20	1nF	0402	dc noise LNVcc	Murata, X7R	GRP155 R71H 102 KA01E	Murata
C21	4p7	0402	RF short for optional LNA input match	Murata, C0G	GRP1555 C1H 4R7 CZ01E	Murata
C22	6p8	0402	dc removal of RX-BP filter and matching	Murata, C0G	GRP1555 C1H 6R8 DZ01E	Murata
C23	6p8	0402	dc removal of TX-LP filter and matching	Murata, C0G	GRP1555 C1H 6R8 DZ01E	Murata
BP1	fo=2.4GHz	1008	RX band pass input filtering	Würth Elektronik	748 351 024	WE
LP1	fc=2.4GHz	0805	TX low pass spurious filtering	Würth Elektronik	748 125 024	WE
X1	SMA, female µStrip tab pin	12.7mm flange 1.3mm tab	Antenna connector, SMA, panel launcher, female, bulkhead receptacle with flange, PTFE, CuBe, CuNiAu	Telegärtner	J01 151 A08 51	Telegärtner
X2	SMA, female µStrip tab pin	12.7mm flange 1.3mm tab	RX-Out connector, SMA, panel launcher, female, bulkhead receptacle with flange, PTFE, CuBe, CuNiAu	Telegärtner	J01 151 A08 51	Telegärtner
X3	SMA, female µStrip tab pin	12.7mm flange 1.3mm tab	TX-IN connector, SMA, panel launcher, female, bulkhead receptacle with flange, PTFE, CuBe, CuNiAu	Telegärtner	J01 151 A08 51	Telegärtner
X4	BÜLA30K	green	LNctrl, BULA30K, Multiple spring wire plugs, Solder terminal	Hirschmann	15F260	Bürklin
X5	BÜLA30K	red	PAVcc, BULA30K, Multiple spring wire plugs, Solder terminal	Hirschmann	15F240	Bürklin
X6	BÜLA30K	black	GND, BULA30K, Multiple spring wire plugs, Solder terminal	Hirschmann	15F230	Bürklin
X7	BÜLA30K	yellow	SPDT, BULA30K, Multiple spring wire plugs, Solder terminal	Hirschmann	15F250	Bürklin
X8	BÜLA30K	blue	PActrl, BULA30K, Multiple spring wire plugs, Solder terminal	Hirschmann	15F270	Bürklin
X9	BÜLA30K	red	LNVcc, BULA30K, Multiple spring wire plugs, Solder terminal	Hirschmann	15F240	Bürklin
Y1	blue { PActrl }	40cm, 0.5qmm	Insulated stranded hook-up PVC wire, LiYv, blue, CuSn	VDE0812/9.72	92F566	Bürklin
Y2	red { PAVcc }	40cm, 0.5qmm	Insulated stranded hook-up PVC wire, LiYv, red, CuSn	VDE0812/9.72	92F565	Bürklin
Y3	green { LNctrl }	40cm, 0.5qmm	Insulated stranded hook-up PVC wire, LiYv, green, CuSn	VDE0812/9.72	92F567	Bürklin
Y4	black { GND }	40cm, 0.5qmm	Insulated stranded hook-up PVC wire, LiYv, black, CuSn	VDE0812/9.72	92F564	Bürklin
Y5	yellow { SPDT }	40cm, 0.5qmm	Insulated stranded hook-up PVC wire, LiYv, yellow, CuSn	VDE0812/9.72	92F568	Bürklin
Y6	white { LNVcc }	40cm, 0.5qmm	Insulated stranded hook-up PVC wire, LiYv, white, CuSn	VDE0812/9.72	92F569	Bürklin
Z1 - Z6	M2	M2 x 3mm	Screw for PCB mounting	Paul-Korth GmbH	NIRO A2 DIN7985-H	Paul-Korth
Z7 - Z12	M2,5	M2,5 x 4mm	Screw for SMA launcher mounting	Paul-Korth GmbH	NIRO A2 DIN7985-H	Paul-Korth
W1	FR4 compatible	47,5mm X 41,5mm	Epoxy 560µm; Cu=17.5µm; Ni=5µm; Au=0.3µm two layer double side	www.isola.de www.haeefe- leiterplatten.de	DURAVER®-E-Cu, Qualität 104 MLB-DE 104 ML/2	Häfele Leiterplat- tenttechnik
W2	Aluminum metal finished yellow Aludine	47,5mm X 41,5mm X 10mm	Base metal caring the pcb and SMA connectors	---	---	---

The PCB



Appendix E: RF Application-basics

Complete RF Application-basics in previous RF Manual (4th edition) which is downloadable via RF Manual website:
http://www.philips.semiconductors.com/markets/mms/products/discretes/documentation/rf_manual

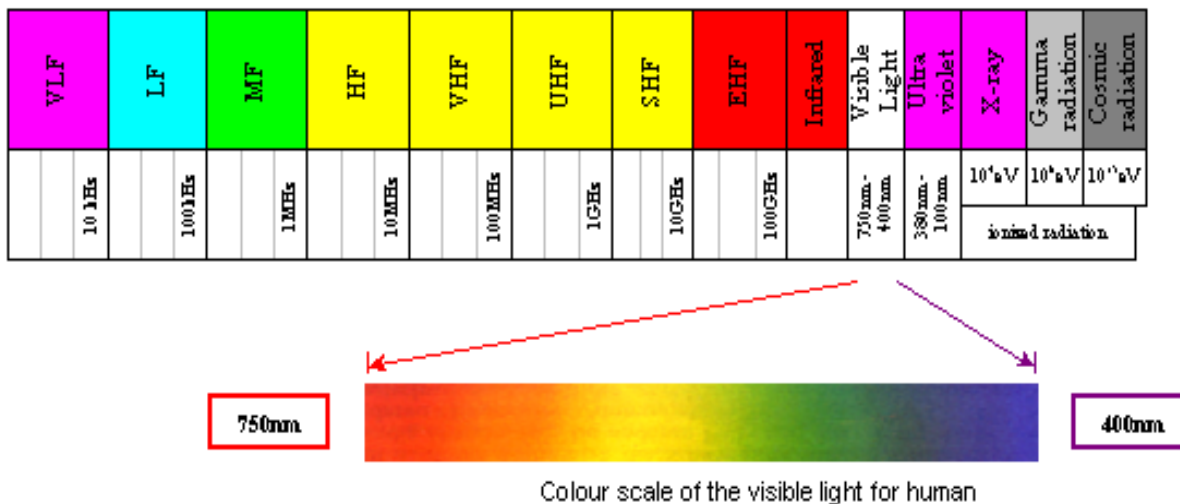
- 1.1 Frequency spectrum
- 1.2 RF transmission system
- 1.3 RF Front-End

For: Function of an antenna, examples of PCB design, Transistor Semiconductor Process, see RF Manual 4th edition on the RF Manual website.

1.1 Frequency spectrum

Radio spectrum and wavelengths

Each material's composition creates a unique pattern in the radiation emitted. This can be classified in the "frequency" and "wavelength" of the emitted radiation. As electro-magnetic (EM) signals travel with the speed of light, they do have the character of propagation waves.



A survey of the frequency bands and related wavelengths:

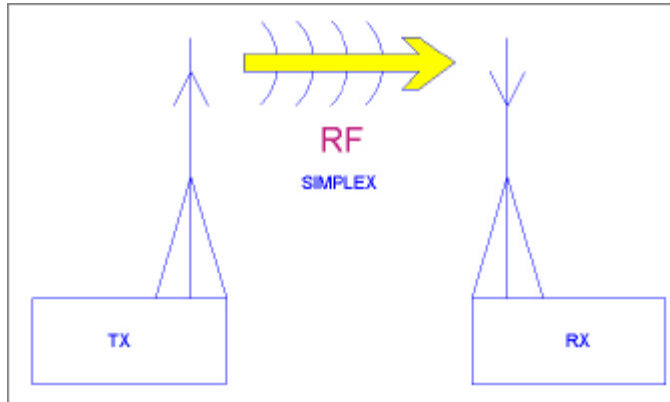
Band	Frequency	Definition (English)	Definition (German)	Wavelength - l acc. DIN40015	CCIR Band
VLF	3kHz to 30kHz	Very Low Frequency	Längswellen (Myriameterwellen)	100km to 10km	4
LF	30kHz to 300kHz	Low Frequency	Langwelle (Kilometerwellen)	10km to 1km	5
MF	300kHz to 1650kHz	Medium Frequency	Mittelwelle (Hektometerwellen)	1km to 100m	6
	1605KHz to 4000KHz	Boundary Wave	Grenzwellen		
HF	3MHz to 30MHz	High Frequency	Kurzwelle (Dekameterwellen)	100m to 10m	7
VHF	30MHz to 300MHz	Very High Frequency	Ultrakurzwellen (Meterwellen)	10m to 1m	8
UHF	300MHz to 3GHz	Ultra High Frequency	Dezimeterwellen	1m to 10cm	9
SHF	3GHz to 30GHz	Super High Frequency	Zentimeterwellen	10cm to 1cm	10
EHF	30GHz to 300GHz	Extremely High Frequency	Millimeterwellen	1cm to 1mm	11
---	300GHz to 3THz	---	Dezimillimeterwellen	1mm-100µm	12

Literature researches according to the Microwave's sub-bands showed a lot of different definitions with very few or none description of the area of validity. Due to it, the following table will try to give an overview but can't act as a reference.

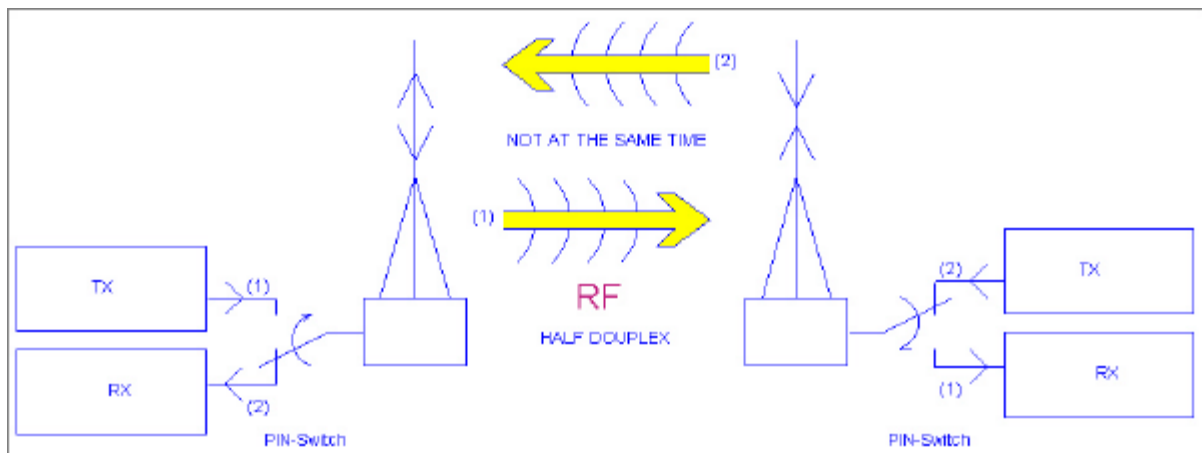
Source	Nührmann	Nührmann	www.wer-weiss-was.de	www.atcnea.de	Siemens Online Lexicon	Siemens Online Lexicon	ARRL Book No. 3126	Wikipedia
Validity	IEEE Radar Standard 521	US Military Band	Satellite Uplink	Primary Radar	Frequency bands in the GHz Area	Microwave bands	---	Dividing of Sat and Radar techniques
Band	GHz	GHz	GHz	GHz	GHz	GHz		GHz
A						0,1-0,225		
C	4-8		3,95-5,8	5-6	4-8	4-8	4-8	3,95-5,8
D		1-3						
E		2-3					60-90	60-90
F		2-4					90-140	
G		4-6					140-220	
H		6-8						
I		8-10						
J		10-20	5,85-8,2					5,85-8,2
K	18-27	20-40	18,0-26,5		18-26,5	10,9-36	18-26,5	18-26,5
Ka	27-40				26,5-40	17-31	26,5-40	26,5-40
Ku	12-18			≈16	12,6-18	15,3-17,2	12,4-18	12,4-18
L	1-3	40-60	1,0-2,6	≈1,3	1-2	0,39-1,55	1-2	1-2,6
M		60-100						
mm	40-100							
P			12,4-18,0			0,225-0,39	110-170	0,22-0,3
R			26,5-40,0					
Q						36-46	33-50	33-50
S	3-4		2,6-3,95	≈3	2-4	1,55-3,9	2-4	2,6-3,95
U			40,0-60,0				40-60	40-60
V						46-56	50-75	50-75
W							75-110	75-110
X	8-12		8,2-12,4	≈10	8-12,5	6,2-10,9	8-12,4	8,2-12,4

1.2 RF transmission system

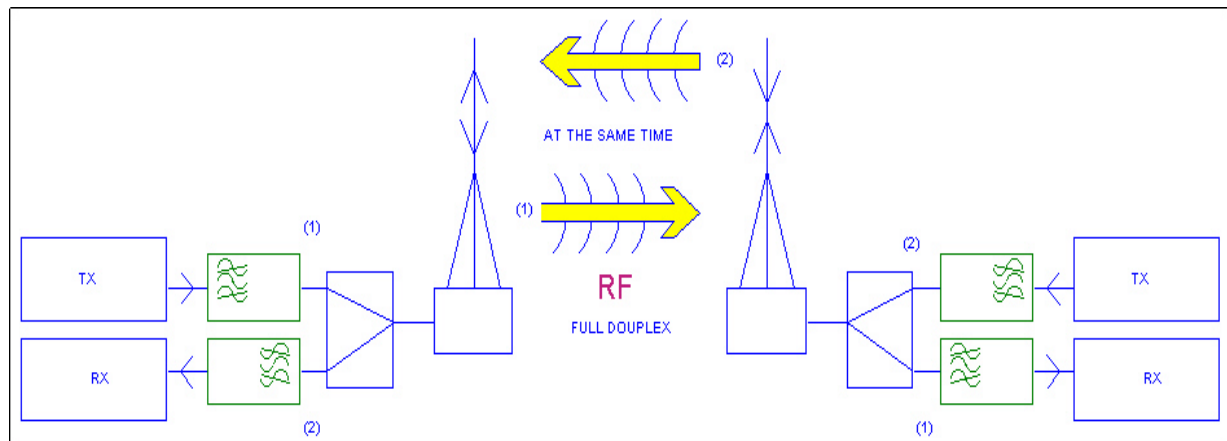
Simplex



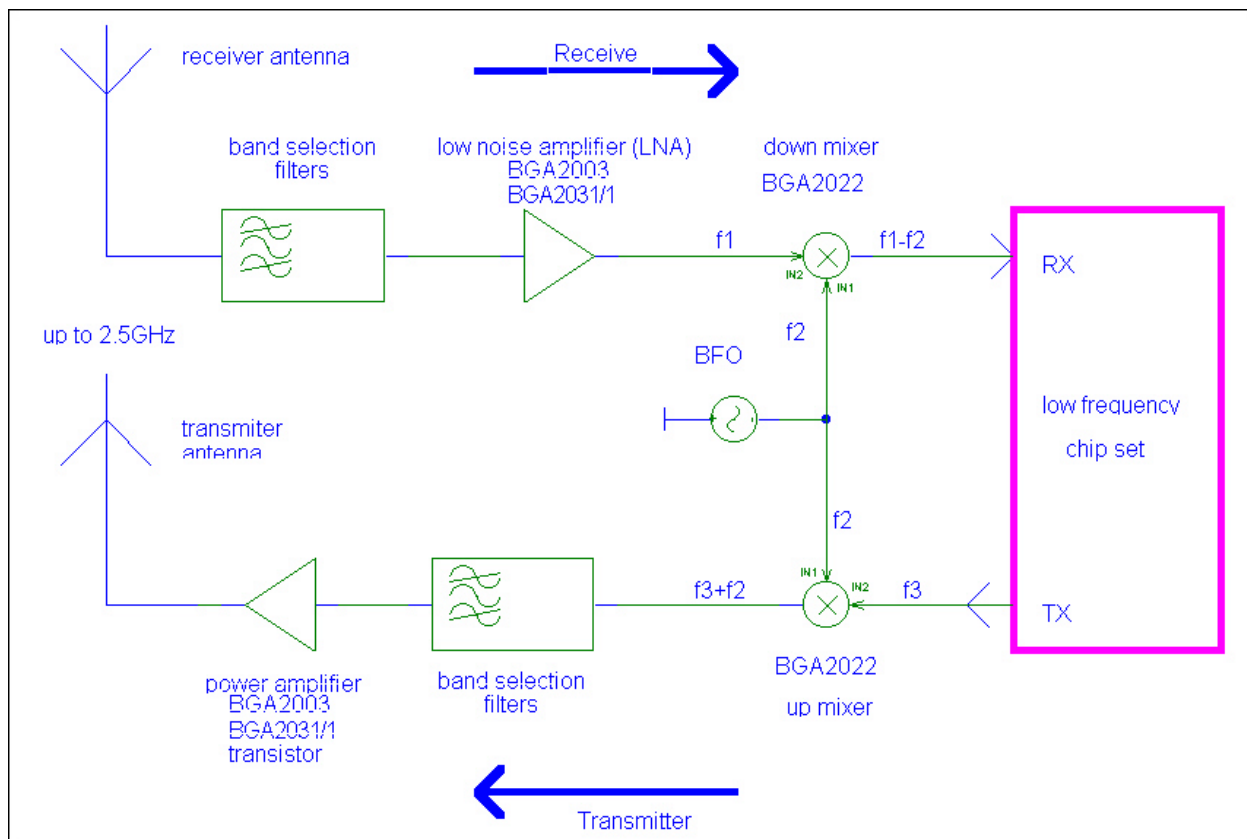
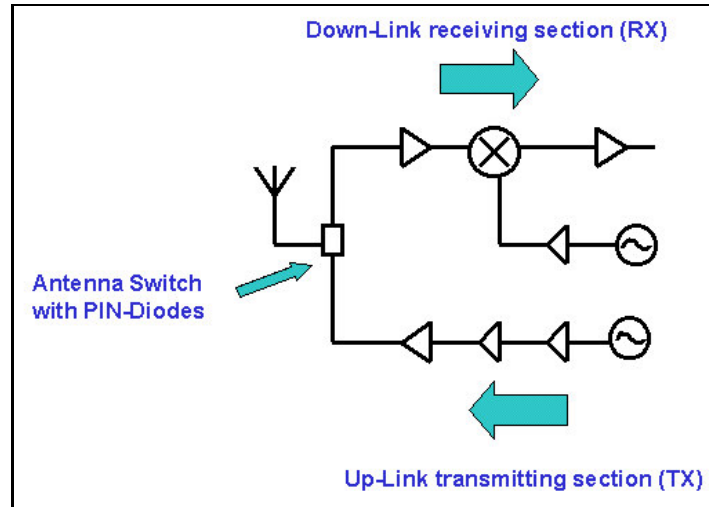
Half duplex



Full duplex



1.3 RF Front-End



Appendix F: RF Design-basics

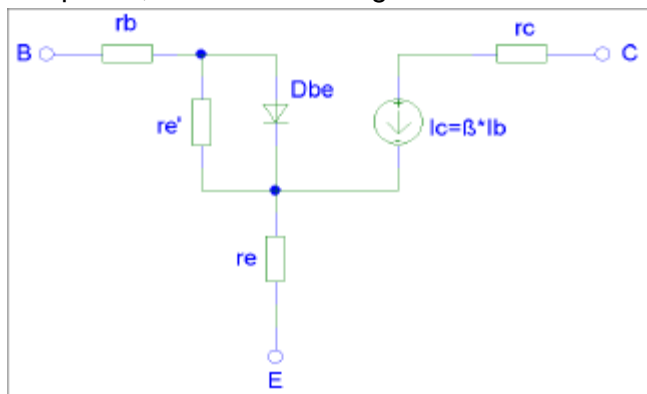
Complete RF Design-basics in previous RF Manual (4th edition). RF Manual 4th edition downloadable via RF Manual website:
http://www.philips.semiconductors.com/markets/mms/products/discretes/documentation/rf_manual

For: Fundamentals and RF Amplifier design Fundamentals, download RF Manual 4th edition on the RF Manual website.

Small signal RF amplifier parameters

1. Transistor parameters, DC to microwave

At low DC currents and voltages, one can assume a transistor acts like a voltage-controlled current source with diode clamping action in the *base-emitter* input circuit. In this *model*, the transistor is specified by its large signal DC-parameters, i.e., DC-current gain (β , β , h_{fe}), maximum power dissipation, breakdown voltages and so forth.



$$I_C = I_{CO} \cdot e^{\frac{U_{BE}}{V_T}} \quad r_e' = \frac{V_T}{I_E}$$

Thermal Voltage: $V_T = kT/q \approx 26\text{mV} @ 25^\circ\text{C}$
 I_{CO} = Collector reverse saturation current

Low frequency voltage gain: $V_u \approx \frac{R_C}{r_e'}$

Current gain $\beta = \frac{I_C}{I_B}$

Increasing the frequency to the audio frequency range, the transistor's parameters get frequency-dependent phase shift and parasitic capacitance effects. For characterization of these effects, small signal *h-parameters* are used. These hybrid parameters are determined by measuring voltage and current at one terminal and by the use of open or short (standards) at the other port.

The *h-parameter* matrix is shown below.

h-Parameter Matrix:
$$\begin{pmatrix} u_1 \\ i_2 \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} * \begin{pmatrix} i_1 \\ u_2 \end{pmatrix}$$

Increasing the frequency to the HF and VHF ranges, open ports become inaccurate due to electrically stray field radiation. This results in unacceptable errors. Due to this phenomenon *y-parameters* were developed. They again measure voltage and current, but use of only a "short" standard. This "short" approach yields more accurate results in this frequency region. The *y-parameter* matrix is shown below.

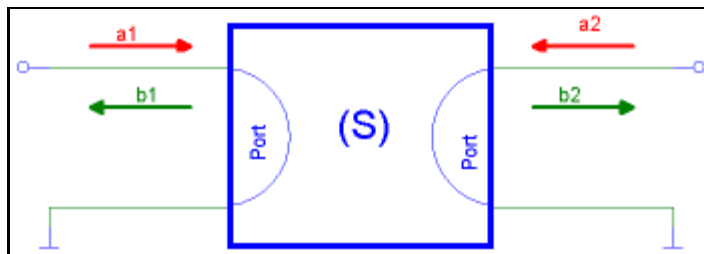
y-Parameter Matrix:
$$\begin{pmatrix} i_1 \\ i_2 \end{pmatrix} = \begin{pmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{pmatrix} * \begin{pmatrix} u_1 \\ u_2 \end{pmatrix}$$

Further increasing the frequency, the parasitic inductance of a “short” causes problem due to mechanical depending parasitic. Additionally, measuring voltage, current and it’s phase is quite tricky. The scattering parameters, or **S-parameters**, were developed based on the measurement of the forward and backward traveling waves to determine the reflection coefficients on a transistor’s terminals (or ports). The **S-parameter** matrix is shown below.

S-Parameter Matrix:
$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} * \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

2. Definition of the S-Parameters

Every amplifier has an input port and an output port (a 2-port network). Typically the input port is labeled Port-1 and the output is labeled Port-2.



Matrix:
$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} * \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

Equation:
$$b_1 = S_{11} \cdot a_1 + S_{12} \cdot a_2$$

$$b_2 = S_{21} \cdot a_1 + S_{22} \cdot a_2$$

Figure 10: Two-port Network’s (a) and (b) waves

The forward-traveling waves (a) are traveling into the DUT’s (input or output) ports. The backward-traveling waves (b) are reflected back from the DUT’s ports. The expression “port Z₀ terminate” means the use of a 50Ω-standard. This is not a conjugate complex power match! In the previous chapter the reflection coefficient was defined as:

Reflection coefficient:
$$r = \frac{\text{back running wave}}{\text{forward running wave}}$$

Calculating the **input reflection factor** on port 1:
$$S_{11} = \left. \frac{b_1}{a_1} \right|_{a_2=0}$$
 with the output terminated in Z₀.

That means the source injects a forward-traveling wave (a1) into Port-1. No forward-traveling power (a2) injected into Port-2. The same procedure can be done at Port-2 with the

Output reflection factor:
$$S_{22} = \left. \frac{b_2}{a_2} \right|_{a_1=0}$$
 with the input terminated in Z₀.

Gain is defined by:
$$\text{gain} = \frac{\text{output wave}}{\text{input wave}}$$

The **forward-traveling wave gain** is calculated by the wave (b2) traveling out off Port-2 divided by the wave (a1) injected into Port-1.

$$S_{21} = \left. \frac{b_2}{a_1} \right|_{a_2=0}$$

The **backward traveling wave gain** is calculated by the wave (b1) traveling out off Port-1 divided by the wave (a2) injected into Port-2.

$$S_{12} = \left. \frac{b_1}{a_2} \right|_{a_1=0}$$

The normalized waves (a) and (b) are defined as:

$$a_1 = \frac{1}{2\sqrt{Z_o}}(V_1 + Z_o \cdot i_1) = \text{signal into Port-1}$$

$$a_2 = \frac{1}{2\sqrt{Z_o}}(V_2 + Z_o \cdot i_2) = \text{signal into Port-2}$$

$$b_1 = \frac{1}{2\sqrt{Z_o}}(V_1 - Z_o \cdot i_1) = \text{signal out of Port-1}$$

$$b_2 = \frac{1}{2\sqrt{Z_o}}(V_2 - Z_o \cdot i_2) = \text{signal out of Port-2}$$

The normalized waves have units of $\sqrt{\text{Watt}}$ and are referenced to the system impedance Z_o . It is shown by the following mathematical analyses:

The relationship between U, P and Z_o can be written as:

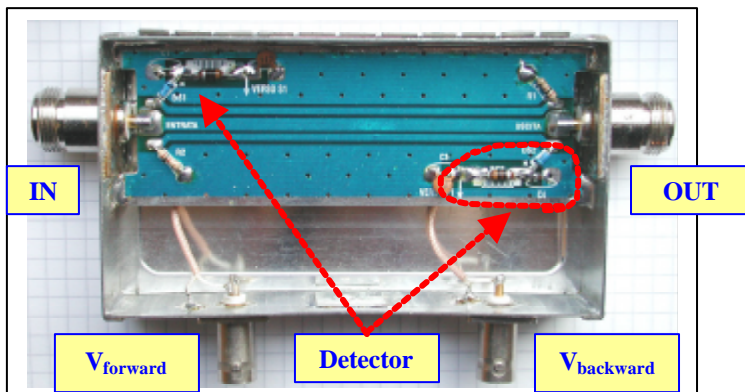
$$\frac{u}{\sqrt{Z_o}} = \sqrt{P} = i \cdot \sqrt{Z_o} \quad \text{Substituting: } \frac{Z_o}{\sqrt{Z_o}} = \sqrt{Z_o}$$

$$a_1 = \frac{V_1}{2\sqrt{Z_o}} + \frac{Z_o \cdot i_1}{2\sqrt{Z_o}} = \frac{\sqrt{P_1}}{2} + \frac{Z_o \cdot i_1}{2\sqrt{Z_o}}$$

$$a_1 = \frac{\sqrt{P_1}}{2} + \frac{\sqrt{Z_o} \cdot i_1}{2} = \frac{\sqrt{P_1}}{2} + \frac{\sqrt{P_1}}{2} \rightarrow a_1 = \sqrt{P_1} \quad (\rightarrow \text{Unit} = \sqrt{\text{Watt}} = \frac{\text{Volt}}{\sqrt{\text{Ohm}}})$$

Because $a_1 = \frac{V_{\text{forward}}}{\sqrt{Z_o}}$, the normalized waves can be determined the measuring the voltage of a

forward-traveling wave referenced to the system impedance constant $\sqrt{Z_o}$. Directional couplers or VSWR bridges can divide the standing waves into the forward- and backward-traveling voltage wave. (Diode) Detectors convert these waves to the V_{forward} and V_{backward} DC voltage. After an easy processing of both DC voltages, the VSWR can be read.



50Ω VHF-SWR-Meter built from a kit (Nuova Elettronica). It consists of three strip-lines. The middle line passes the main signal from the input to the output. The upper and lower strip-lines select a part of the forward and backward traveling waves by special electrical and magnetic cross-coupling. Diode detectors at each coupled strip-line-end rectify the power to a DC voltage, which is passed to an external analog circuit for processing and monitoring of the VSWR. Applications: Power antenna match control, PA output power detector, vector voltmeter, vector network analysis, AGC, etc. These kinds of circuit's kits are published in amateur radio literature and in several RF magazines.

Forward transmission:
 $FT = 20\log(S_{21})\text{dB}$

Isolation:
 $S_{12}(\text{dB}) = -20\log(S_{12})\text{dB}$

Input Return Loss:
 $RL_{\text{in}} = -20\log(S_{11})\text{dB}$

Output Return Loss:
 $RL_{\text{out}} = -20\log(S_{22})\text{dB}$

Insertion Loss:
 $IL = -20\log(S_{21})\text{dB}$

Rem:

$$\frac{Z_o}{\sqrt{Z_o}} = \frac{Z_o \cdot \sqrt{Z_o}}{\sqrt{Z_o} \cdot \sqrt{Z_o}} = \frac{Z_o \cdot \sqrt{Z_o}}{Z_o} = \sqrt{Z_o}$$

$$P = U \cdot I = \frac{U^2}{R} \rightarrow \sqrt{P} = \frac{U}{\sqrt{R}} = I \cdot \sqrt{R}$$

2-Port Network definition

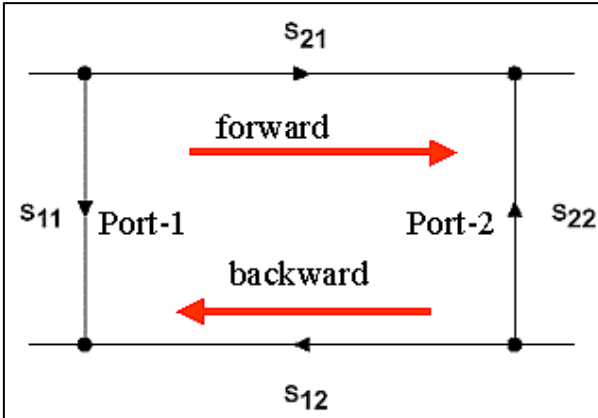


Figure 11: S-Parameters in the Two-port Network

Input return loss

$$S_{11} = \sqrt{\frac{\text{Power reflected from input port}}{\text{Power available from generator at input port}}}$$

Output return loss

$$S_{22} = \sqrt{\frac{\text{Power reflected from output port}}{\text{Power available from generator at output port}}}$$

Forward transmission loss (insertion loss)

$$S_{21} = \sqrt{\text{Transducer power gain}}$$

Reverse transmission loss (isolation)

$$S_{12} = \sqrt{\text{Reverse transducer power gain}}$$

Philips' data sheet parameter **Insertion power gain** $|S_{21}|^2$: $10dB \cdot \log|S_{21}|^2 = 20dB \cdot \log|S_{21}|$

Example: Calculate the insertion power gain for the [BGA2003](#) at 100MHz, 450MHz, 1800MHz, and 2400MHz for the bias set-up $V_{VS-OUT}=2.5V$, $I_{VS-OUT}=10mA$.
 Calculation: Download the S-Parameter data file [2_510A3.S2P] from the Philips' website page for the Silicon MMIC amplifier BGA2003.

This is a section of the file:

#	MHz	S	MA	R	50				
!	Freq	S11		S21		S12		S22 :	
100	0.58765	-9.43	21.85015	163.96	0.00555	83.961	0.9525	-7.204	
400	0.43912	-28.73	16.09626	130.48	0.019843	79.704	0.80026	-22.43	
500	0.39966	-32.38	14.27094	123.44	0.023928	79.598	0.75616	-25.24	
1800	0.21647	-47.97	4.96451	85.877	0.07832	82.488	0.52249	-46.31	
2400	0.18255	-69.08	3.89514	76.801	0.11188	80.224	0.48091	-64	

Results:

100MHz → $20 \cdot \log(21.85015) = 26.8 \text{ dB}$

450MHz → $20dB \log \left| \frac{16.09626e^{130.48^\circ} + 14.27094e^{123.44^\circ}}{2} \right| = 23.6dB$

1800MHz → $20 \cdot \log(4.96451) = 13.9 \text{ dB}$

2400MHz → $20 \cdot \log(3.89514) = 11.8 \text{ dB}$

3-Port Network definition

Typical vehicles for 3-port s-parameters are: Directional couplers, power splitters, combiners, and phase splitters.

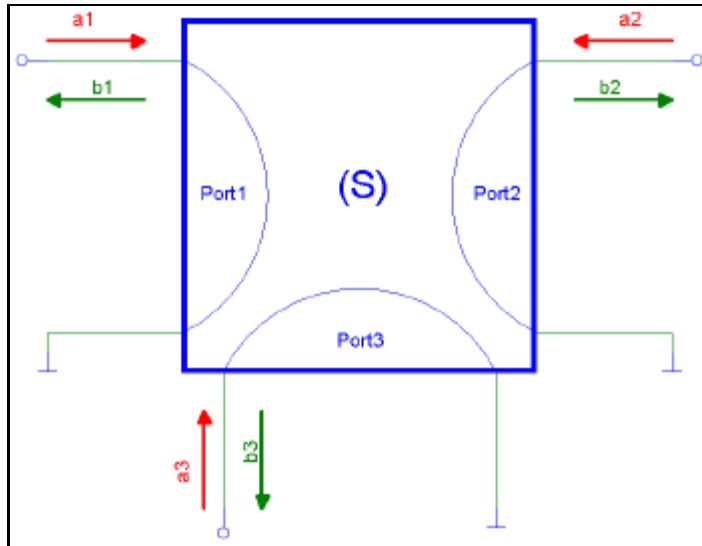


Figure 12: Three-port Network's (a) and (b) waves

3-Port s-parameter definition:

- Port reflection coefficient / return loss:

Port 1 → $S_{11} = \frac{b_1}{a_1} |_{(a_2=0; a_3=0)}$

Port 2 → $S_{22} = \frac{b_2}{a_2} |_{(a_1=0; a_3=0)}$

Port 3 → $S_{33} = \frac{b_3}{a_3} |_{(a_1=0; a_2=0)}$

- Transmission gain:

Port 1=>2 → $S_{21} = \frac{b_2}{a_1} |_{(a_3=0)}$

Port 1=>3 → $S_{31} = \frac{b_3}{a_1} |_{(a_2=0)}$

Port 2=>3 → $S_{32} = \frac{b_3}{a_2} |_{(a_1=0)}$

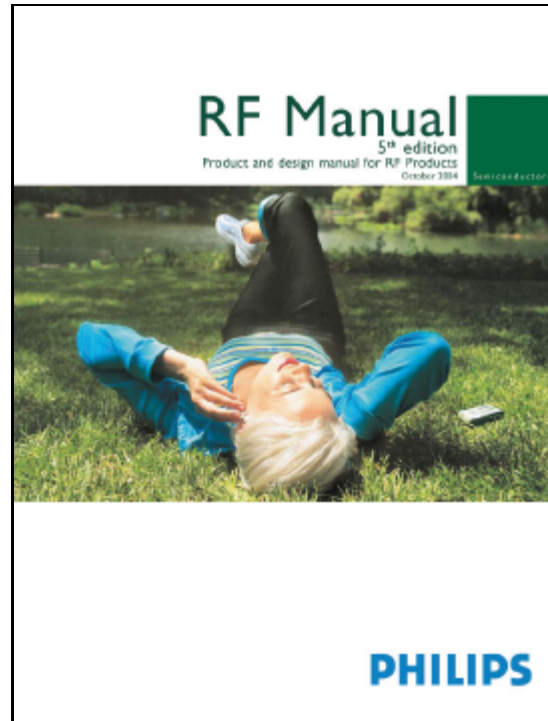
Port 2=>1 → $S_{12} = \frac{b_1}{a_2} |_{(a_3=0)}$

Port 3=>1 → $S_{31} = \frac{b_1}{a_3} |_{(a_2=0)}$

Port 3=>2 → $S_{23} = \frac{b_3}{a_2} |_{(a_1=0)}$

MAIN FILE RF Manual

In separate file !



Download main RF Manual from internet:

http://www.philips.semiconductors.com/markets/mms/products/discretes/documentation/rf_manual



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