Software Defined Radio Forum

Base Station Working Group

Base Station System Structure

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1 Introduction

This document is a compilation of documents developed in the Base Station Working Group. It describes the structure of base station systems with a convergent top-down and bottom-up framework. The BSWG has now moved beyond detailed consideration of these specific contributions. As they represent a valuable structuring of information relevant to base stations, they are presented here as a means of capturing the information, preserving it in a formal manner, and making it available as a citation for future work.

2 Base Station Background

The intent of this section is to explore the role of base stations in communications systems, and to develop a reference model that can be used to describe and compare base station software architectures. It is hoped that the model can also be the basis for standardization of base station components. The paper will focus on cellular base stations for two reasons. One is the importance of base stations in making possible the system capabilities that users want to use and that network operators want to offer. The other is the size of the market that they represent. To develop a base station reference model we will take a top-down approach that explores the system context from which the cellular service has evolved and toward which it is migrating. Then we will narrow the focus to those system segments where SDR technology has a significant impact.

The evolution of telephony over many years has developed to provide the ubiquitous service called the public service telephone network (PSTN). In the US it provides instantaneous high quality voice connections between any two of the millions of subscribers at modes cost. It was originally developed to enable people to talk to each other over telephone instruments hard-wired at fixed locations, the service now known as "plain old telephone service," or POTS. That service offered pay phone and phone booths for people away from their home or office, but made little provision for mobile telephone calls.

At the same time, two-way radios were used in a limited market called Mobile Radios, characterized by tactical military radios, aeronautical and maritime service, Fire, Police, and other emergency services, taxis, and Public Works departments. Those radios were normally mounted in a vehicle because of their weight and power consumption. Infrastructure for the Mobile Radio Service was high-powered equipment, at a fixed central location, that permitted a dispatcher to control radio traffic and manage operation of the remote mobile stations. That central location was called a "base station." Users of mobile services had no access to the telephone system except for an occasional "telephone patch" capability in a base station. Use of the patch facility was limited because it tied up a frequency, and made no provisions for privacy.

A third major development in the middle decades of the twentieth century was the introduction of the digital computer. Initially used in businesses to automate routine bookkeeping, its use became much more common as developments in semiconductor technology brought the price point down to make possible the introduction of the personal computer (PC). By the end of the century those PCs became the access points for universal digital connectivity, and enabled emergence of the Internet and the World Wide Web.

Cellular technology was developed as a way to provide telephone connectivity without the tether of the local loop by developing mobile base station technology. As cellular phones have grown in popularity for voice, users have asked that their web access also be extended to mobile terminals. One key to providing the personal connectivity of the future is the needed infrastructure, and in particular base station functionality.

In the SDR Forum Base Station Working Group we intend to define a reference model for base stations to facilitate their evolution.. Our approach will be to take communications systems and Internet access before the introduction of wireless mobility as a baseline. Then we will investigate the enhancements necessary to support the user connected by an RF link as a means of identifying requirements for base station functionality.

3 Communications Systems for Personal Use

A large number of communications systems are currently in use. Many of them are involved with transfer of data from one computer system to another. Within the SDR Forum Base Station Working Group, we are primarily interested in considering communications systems that have a wireless connection from a network to a person at a remote terminal. That individual typically wants to talk from their personal device to another person, or wants to see information on a screen in their hand.

The two communications systems we take as a baseline are the telephone system and the Internet. The two networks share physical links, but could scarcely be more different. The telephone system operates on the basis of fixed path connections set up as part of call initiation. It provides two-way voice communication of high quality. The Internet operates on a connectionless best effort basis, with some recovery facilities when things go wrong. In the following sections we will explore the characteristics of each.

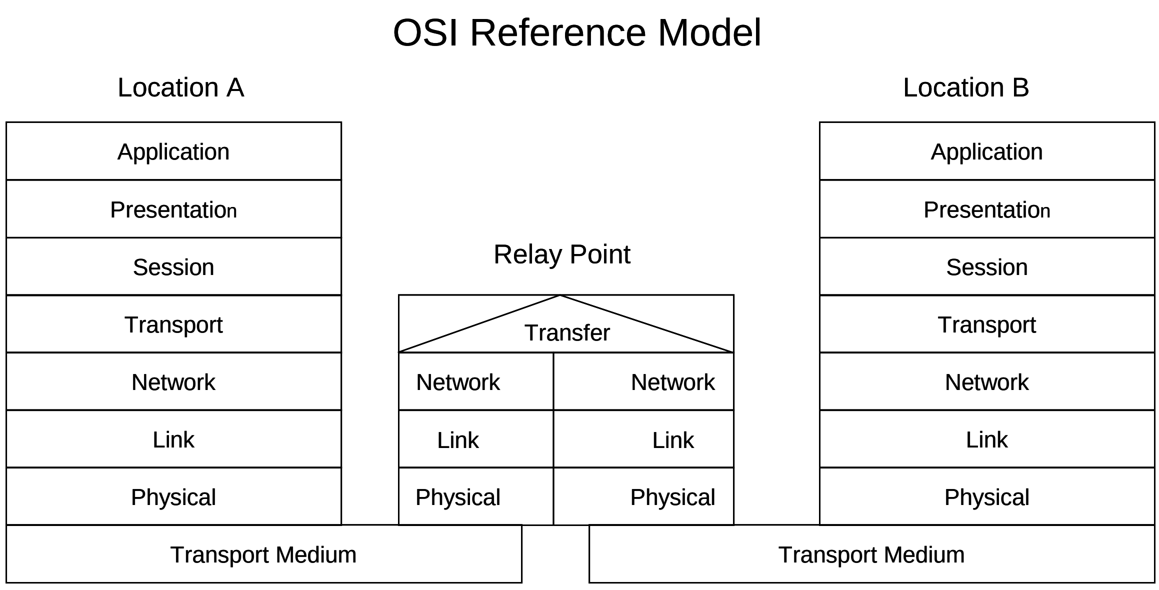


Figure 1. The OSI Reference Model

Figure 1 shows the layered structure of the OSI Reference Model. Information from an application at location A is fed down through a number of layers that perform prescribed tasks, resulting in data transfer over the transport medium, cable or optical fiber, in the form of bits. It goes through a relay point (which may be one of many) where it may be changed to a completely different protocol in the stacks there. Finally it arrives at its destination, where it is reassembled into the record format expected by the application at location B.

The information is presented for two reasons. One is that it is a good example of a reference model we can look at it, point, and say, "I am talking about that." The other reason is, although the OSI model is rarely implemented as defined, it is a good yardstick with which to measure other systems.

3.1 The Telephone System

The telephone system in the United States is based on a great clock, ticking 8,000 times a second. Every 125 milliseconds all the active elements in the entire telephone system go through a process to service the millions of active calls.

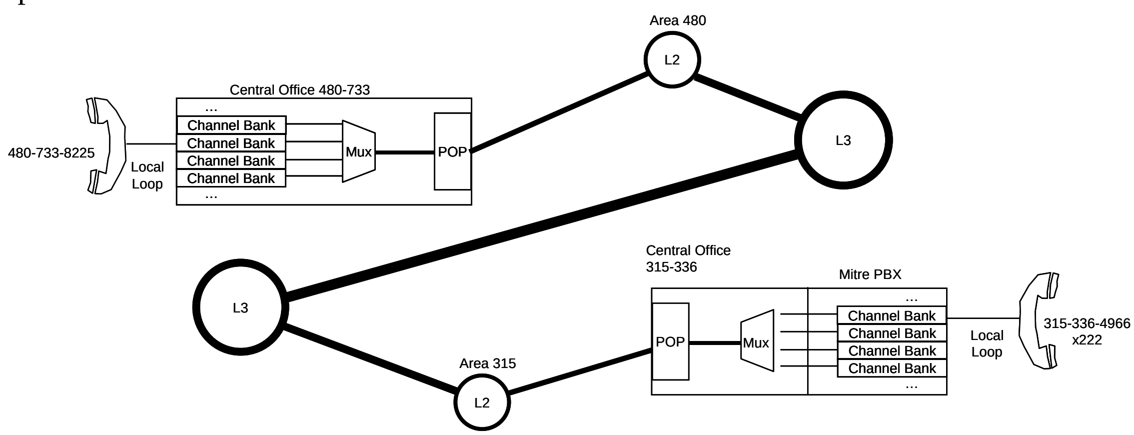


Figure 2. A typical POTS phone call

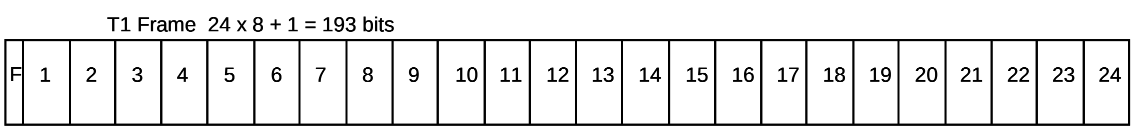


Figure 3. The T1 Frame structure.

Figure 2 is a very high-level representation of a call from Pete Cook in Mesa, Arizona to Al Margulies in Rome, New York. At each clock tick the channel bank in my local central office samples the analog voltage level in the copper pair of my local loop. (The 8,000 samples per second is derived from the Nyquist theoretical value needed to properly handle the 4KHz design frequency limit of the circuit.) It digitizes the voltage level into an 8 bit value. Then my octet is placed in the specified slot of the outgoing T1 frame in the multiplexer, and is sent on. On subsequent clock cycles that octet moves through exactly the same process as all of the other samples for the duration of the call. It advances step by step through the route set up by the switching software when I dialed the call. After multiplexing and buffering in the local office, it is turned over to the long distance carrier at the point of presence (POP). There is no telling what chain of long distance centers or exchanges will be used, or what level of multiplexing will be experienced by the octets of our conversation. At each step of the way a different slot in a designated T1 frame is assigned, and waiting for the octet to arrive. The octets flow along the assigned route, and no one else has access to that time slot.

The route is shown symbolically as going from the 733 local office in area 480 to a Level 2 center, then through two level 3 centers, until it arrives at another level 2 in area 315. From there it goes to the 336 exchange serving the former Griffiss AFB, and through the remote POP, through demultiplexing, into the Mitre PBX, and into the vocoder serving Al's phone. There the analog voltage of my voice is reproduced for him to hear. Probably 30 ticks have gone by, representing an imperceptible delay of about 4 milliseconds.

3.2 The Internet

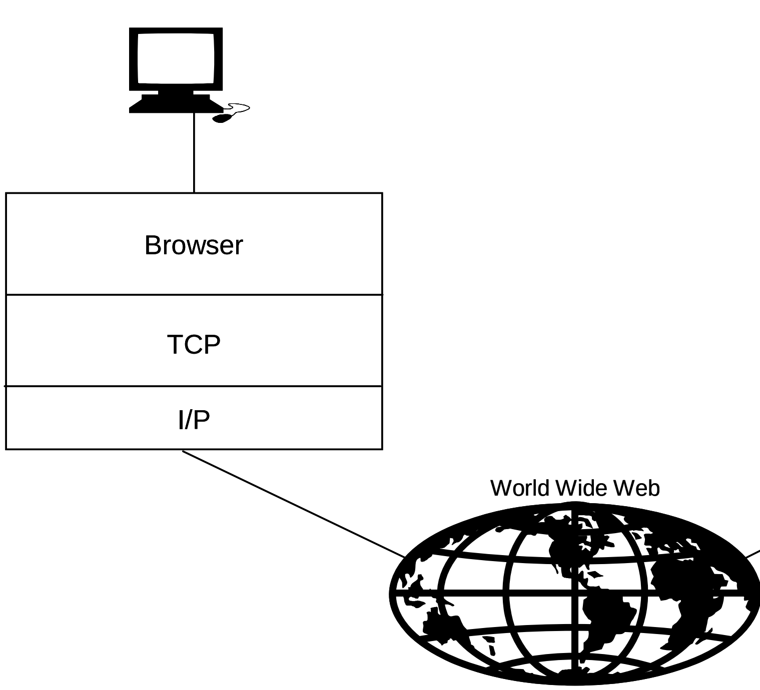


Figure 4. Internet Connectivity to a Web Site

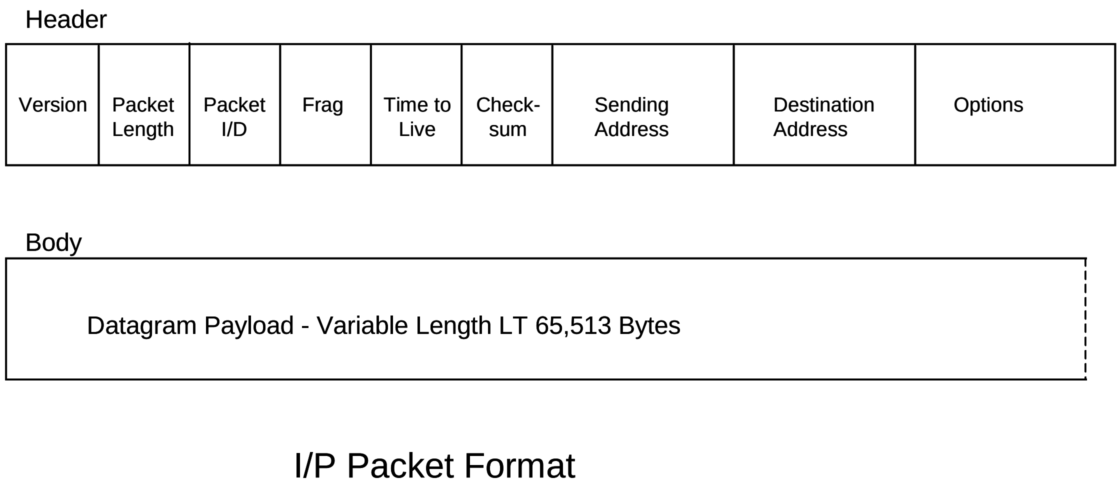


Figure 5. The Internet Protocol Frame Structure

The PSTN is highly structured, and has been carefully engineered over the years for voice quality and reliability. Like Ethernet, which also has a non-deterministic performance characteristic, the current trend seems to be in favor of the ad hoc network structure characterized by the Internet. Even voice over IP is becoming a strong contender for new installations due to its flexibility, reasonable performance, and significantly lower cost. Of course the bits have to be transmitted somehow, and the PSTN and Internet share a substantial number of transmission facilities.

4 A Base station System Model

4.1 The Base Station SDRF Reference Model

Figure 7 is a version of the SDRF reference model with some changes made to reflect terminology common in base station applications. It is presented in this form to emphasize that the base station model is in concert with the overall views of the SDR Forum models.

4.1.1 The Reference Model Diagram

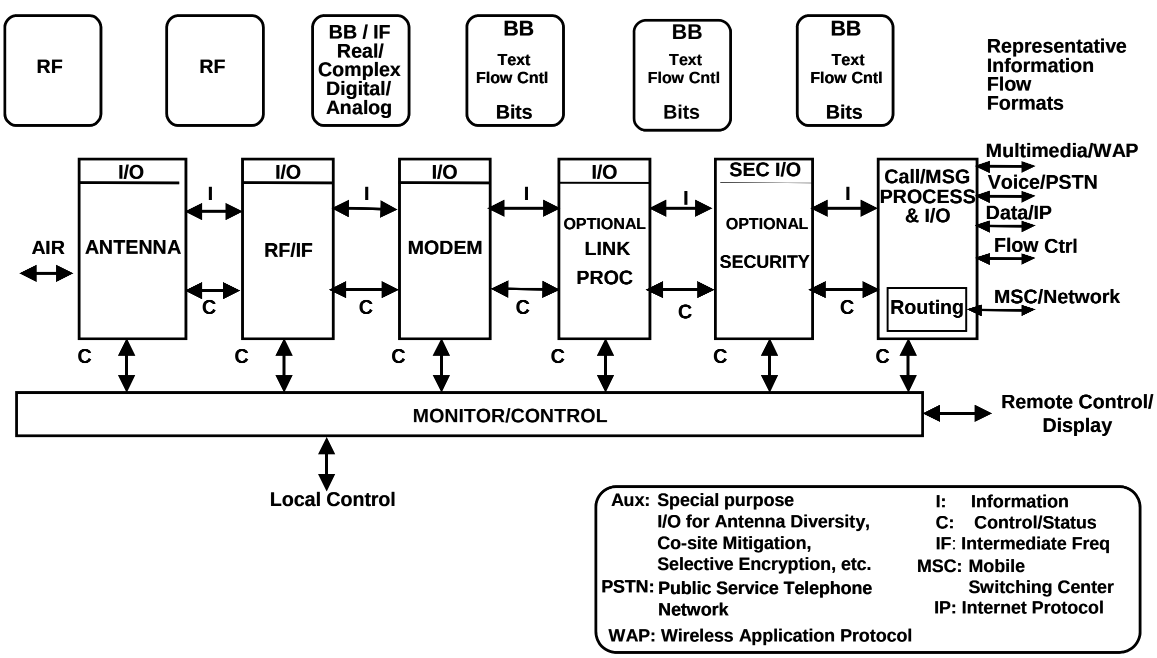


Figure 6. A Generalized Modular SDR Architecture

4.1.2 Reference Model Elements

We will describe the functions of the receive path, from left to right. The transmit path is similar, but flows from right to left. Functions of the elements in this diagram are as follows:

Antenna. This element may be a simple dipole or a complex phased array. It delivers energy as an RF emf into the system.

RF/IF. This element is where the necessary analog processing takes place. Preselectors limit the input energy to frequencies of interest. Cosite mitigators feedback known local interference signals inverted to suppress them. A local oscillator reduces the signal to an intermediate frequency. The wiring and capacitance and inductance components needed in this stage add cost, introduce artifacts into the signal, and reduce the flexibility of the equipment. It is desirable to reduce it as much as possible.

Modem. Analog to digital conversion takes place either at the output of the RF/IF element or the input of this element. Here is where digital signal processing is done to extract the desired signal from the digitized representation of the original signal. Unwanted signals are discarded, and the baseband bits are demodulated from the signal by applying the inverse of the modulation transform.

Link Processor. This element is responsible for operations to enhance the link based on control and data information from the modem. Signal strength measurement, power control, need or ability to handoff, frequency hopping, antenna control, and TOA data are processed here.

Security. If link encryption is in operation the decryption takes place here. Any information in the system that needs to be protected for security purposes is handled in this module.

Call/message processing & I/O. This element delivers traffic to the rest of the system. Rate conversion or translation from one vocoding scheme to another is done. This function provides access to different networks and varying protocols according to the application type designated for the specific session.

For transmission the conceptual flow is from right to left. The primary difference between transmit and receive is the introduction of power amplifiers in the RF/IF section to drive the antenna.

The further to the left of this diagram the Analog/digital boundary is located, and the better the performance of the A to D converters, the more flexible will the equipment be. In the limit any new performance or functionality needed, even to the point of changing air interfaces, can be accommodated by software changes.

4.1.3 Functional Receive Reference Model

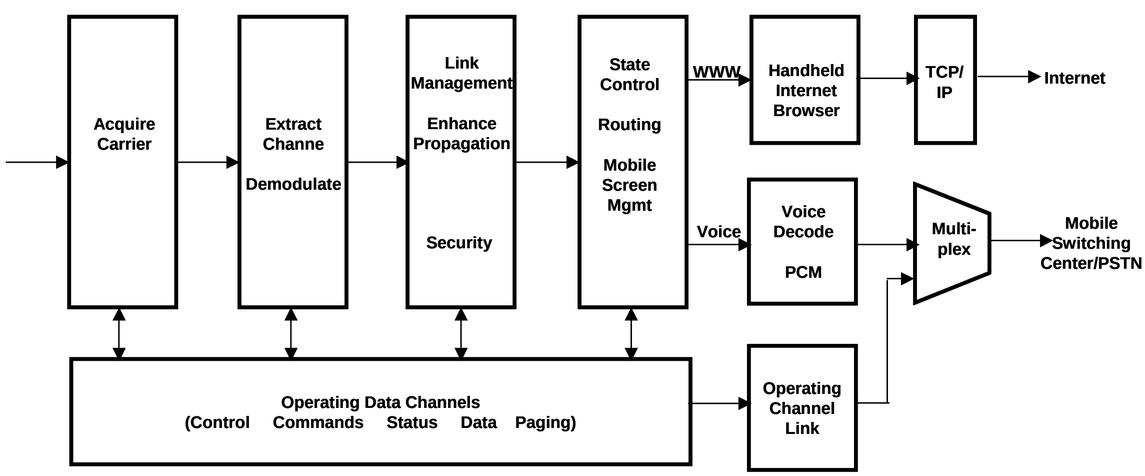


Figure 7. Base Station Functional Reference Model

Figure 7 presents the same information in the form of a functional reference model, representing the processing that takes place for the base station to maintain the loop and act al a wireless local loop. Again we will concentrate on the receive function, with transmission being a logical converse.

Acquisition. The first task is to acquire the carrier. That is a frequency band that carries the signals of interest. In analog cellular system there is one channel per carrier. In multiple access schemes the carrier will carry a number of channels.

Data Extraction. Once the carrier signal is received, the channel information must be extracted. That involves either decoding (CDMA) or demultiplexing (TDMA). Then the channel data, such as a voice call or web session, is extracted for processing.

Link Management. The next block indicates the housekeeping functions associated with the wireless link.

Session Control. The focus of base station control of the session is located in the next functional grouping. It keeps state information on the mobile and on the call. It routes information either through the internet connection, or the PSTN interconnect point in the MSC. Control of the mobile screen here involves filtering information so the mobile capabilities are not over-run.

Data. Information for an Internet link is routed to the handheld browser, and out over the TCP/IP link.

Voice. Information relating to a voice call in converted to PCM modulation for transmission on a T1, and shipped out.

Signaling. The operating data channel handles the non-information data, including command and control, paging the mobile to indicate an outgoing call, and tracking system status and error messages.

4.1.4 Summary

These two models describe the functioning of a base station in the context of the SDR Forum model for a software defined radio. We have also explored the context in which it operates. It is the intention of this exercise to provide a context for the more detailed bottoms-up look at base station components.

5 Base Station Use Cases

5.1 I - Introductory notes

With the name "Download" we denote a set of services (more in the sense of capabilities) for transferring data into an SDR (enabled) device. This data corresponds to reconfiguration information needed in order to change more or less profoundly (depending on the case) the operation (personality/behavior) of an SDR enabled device.

The distinction between information data and reconfiguration data needs to be underlined. The downloading facilities addressed here concern only reconfiguration data. Such information can be:

- a piece of software: DSP algorithm, OS device driver, application sw
- parameters: UI stuff, DSP processing parameters etc.
- an FPGA configuration bitstream
- parameter values for parametrized ASICs
- ...

The download may modify things at any layer (application down to hardware) including application sw, system sw (middleware, OS, etc.), firmware and radioware (air intf. related stuff). For regulation reasons some things may happen earlier than others. For instance modifications at the application layer have been already thoroughly considered by WAP and MexE and are more likely to be seen before modifications of the air interface.

The purpose of download can be things like:

- bug fixes and system upgrades,
- new service offers,
- change of air interface (for multi-standard support, G transition purposes etc.)
- ...

To be able to download (transfer) the needed data and reconfigure an SDR device, the SDR device's design of software and hardware architectures, has to support these features.

These issues are graphically summarized in Fig. 8.

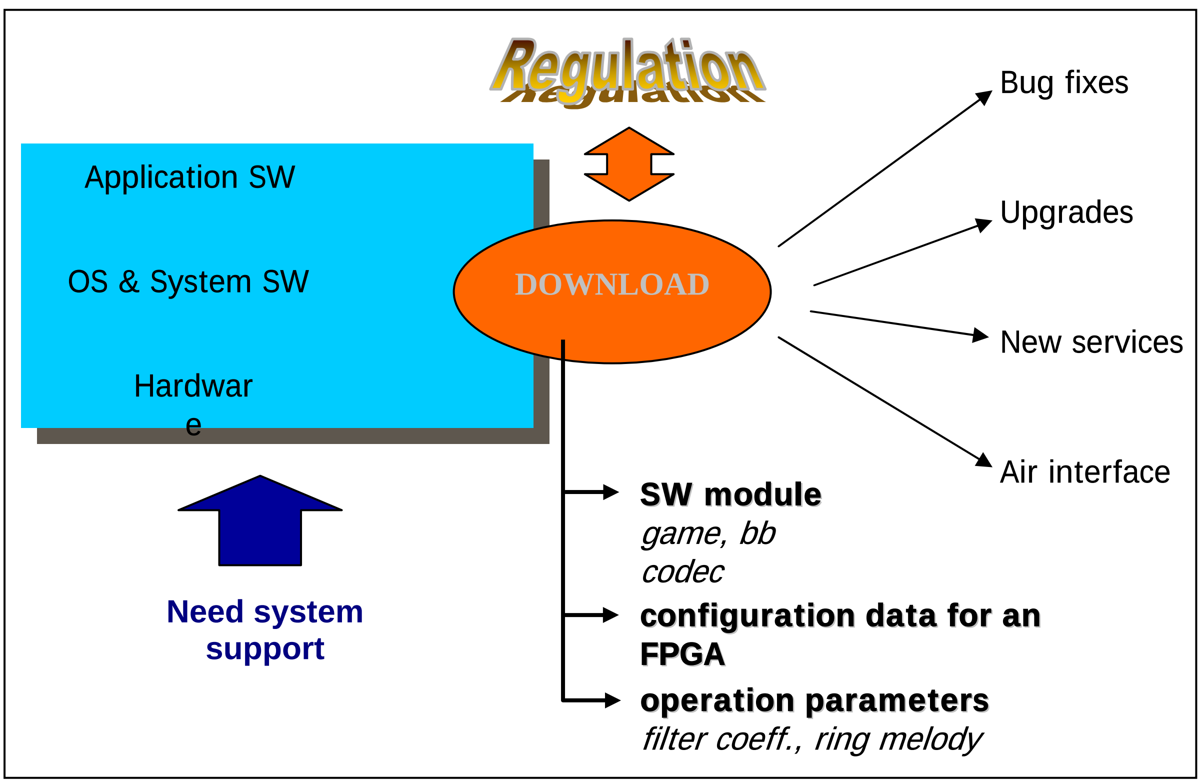


Fig. 8: Download considerations

Some things that need to be considered:

- Download purpose (changes at the application or lower layers for bug fixes, updates, change of air interface etc.)
- Download sources and destinations (point to point, broadcasting)
- Download physical communication link (local connection, network connection, smartcard/disk etc., OTAR, PoS, ...)
- Role of the user in the process. In some cases the user is the initiator of a download transaction; in other cases the user needs to accept billing and licensing conditions; finally, there are cases where the whole process may be transparent for the user (are there any ethical problems with this?)
- Initiator of the download process: e.g. user asks for a service, Network asks SDRF device to reconfigure for capacity or QoS vs. cost optimization, SDRF device wants to adapt to operation environment (e.g. switch between standards, algorithm change)
- R/T requirements. In some cases the download is offline (its effects become visible at a later time) and in other cases it happens online (i.e. during the normal operation of the SDRF device) and as such it may be necessary to make it seamless and thus respect harder R/T constraints.

Downloading involves the network and one or many SDR enabled devices (e.g. handhelds, BTS). The "many" case corresponds to broadcasting scenarios. So as a handheld device may be reconfigured, via downloading, for some reasons, a BTS may as well reconfigure for some other reasons.

5.1.1 I.1 - The switcher issue

Switcher is a particular case of download since it may correspond in:

- either downloading a control command requesting switching from a mode of operation to another (in velcro'd multimode set ups)
- or downloading first the mode reconfiguration data (software, hw parameters, FPGA configuration bitstreams etc.) and then, after installation, switching to the new mode of operation.

5.1.2 I.2 - BTS specificities

From the discussion above it is evident that the BTS implication in download scenarios may vary depending on the particular scenario. The BTS is an SDR enabled device by itself so it may need to be reconfigured by the network entity. Nevertheless, it is quite different from SDR handhelds in many aspects.
The list below identifies some of these points.

- As the operation environment may change (number of users etc.) the BTS may need to reconfigure itself to maintain a certain capacity and quality of service; in such cases it may ask the network to provide the necessary configuration info.
- In an OTAR context the BTS serves as the front end of the network entity to the air that serves as the physical medium for the information transfer. In some cases the BTS has a passive role, meaning that it just relays the exchanged messages between the download source and destination (client and server) entities. In other cases the BTS role is more active

since the purpose and the content of a download transaction may require its adaptation to a new operating context.

- Finally, there may be cases that the BTS involvement in a download process may need to be registered for accounting, administration, security or other reasons.

It becomes clear that a "Download" capability depends on a lot of parameters. These parameters define the particular download context or even a particular scenario within a context. These parameters define also the complexity of the download process in each case. To clarify some of these issues studying relevant use cases and their typical scenarios is useful.

5.2 II Use case study: "Switcher/Download operation on a handheld, from the base station point of view"

This paragraph is focusing on the role of the base station during a download operation on a handheld. In other words only OTA downloading to a SDR handheld device is considered here (even if, in some case, the remarks here could be relevant in the case of the use of any other downloading medium). We also make the assumption that the whole operation takes place in the same cell (no intercell handover).

Actually, in certain cases of downloading, the base station is passive in the sense that it only transmits the information it is ordered to. This is the case for instance, when the module downloaded on the handheld concerns only the application layer (refer to fig. 3), or when the installation of the downloaded module is planned for a later time.

However if the downloaded function requires right away any inherent base station function change (for example the air interface that links the handheld and the base station) the base station needs to be aware of this change, and also must itself configure to conform to its new link with the handheld (refer to fig. 4). We may also imagine that the base station plays a completely passive role but keeps in memory, or sends to any entity, a trace of the route of the downloading message.

For these reasons such use cases must be taken under consideration by the base station working group.

5.2.1 II.1 - Use case diagram

Use case diagram consists in an easy way of describing a system at any level of abstraction. Such a diagram may be refined as long as the designing process goes on. **Figure 2** describes the use case diagram that could be studied here.

The two main actors under consideration are the network and the handheld. The user is merged to the handheld for simplicity. Indeed, the network will take or not the decision of making a downloading operation on the handheld. In many cases the base station is most of the time only an intermediate component between the network and the handheld. However, in certain cases the downloading operation itself may have an influence on the way the base station has to work and so the base station is an important actor.

We may first consider separately "*switch"* and "*download"* operations in order to see the differences it will involve in respect to the base station behavior.

A *"switch"* use case describes the operation that aims in adapting a handheld standard to one of the supported standards of a cell. This assumes that the chosen new air interface will be matched to the base station one (assuming some previous knowledge of the base station configuration).

We make the distinction between two variants. First, *"switch velcro'd"* is the particular case of a multi-band, or multi-standard handheld where duplicated hardware is present. Second, we may have *"switch by download"* where switching from one band or one standard to another needs re-configuring only a few modules which have to be downloaded.

In the same way, *"download"* use case may be refined following specific considerations imposed by things such as:

- the nature of the physical medium of the download transmission: OTA, smart card, ethernet, point of sale…
- the nature of downloaded module (application or air interface module)…

This imposes that such issues need to be separately addressed. That's why several sub-use cases of download are represented here.

Note also that if this download is done via a smart card or any other device, no base station is effectively concerned. At this point, the base station may be involved since the initiative of activating this use case may be taken by the user or the network, without having a previous knowledge of the base station configuration.

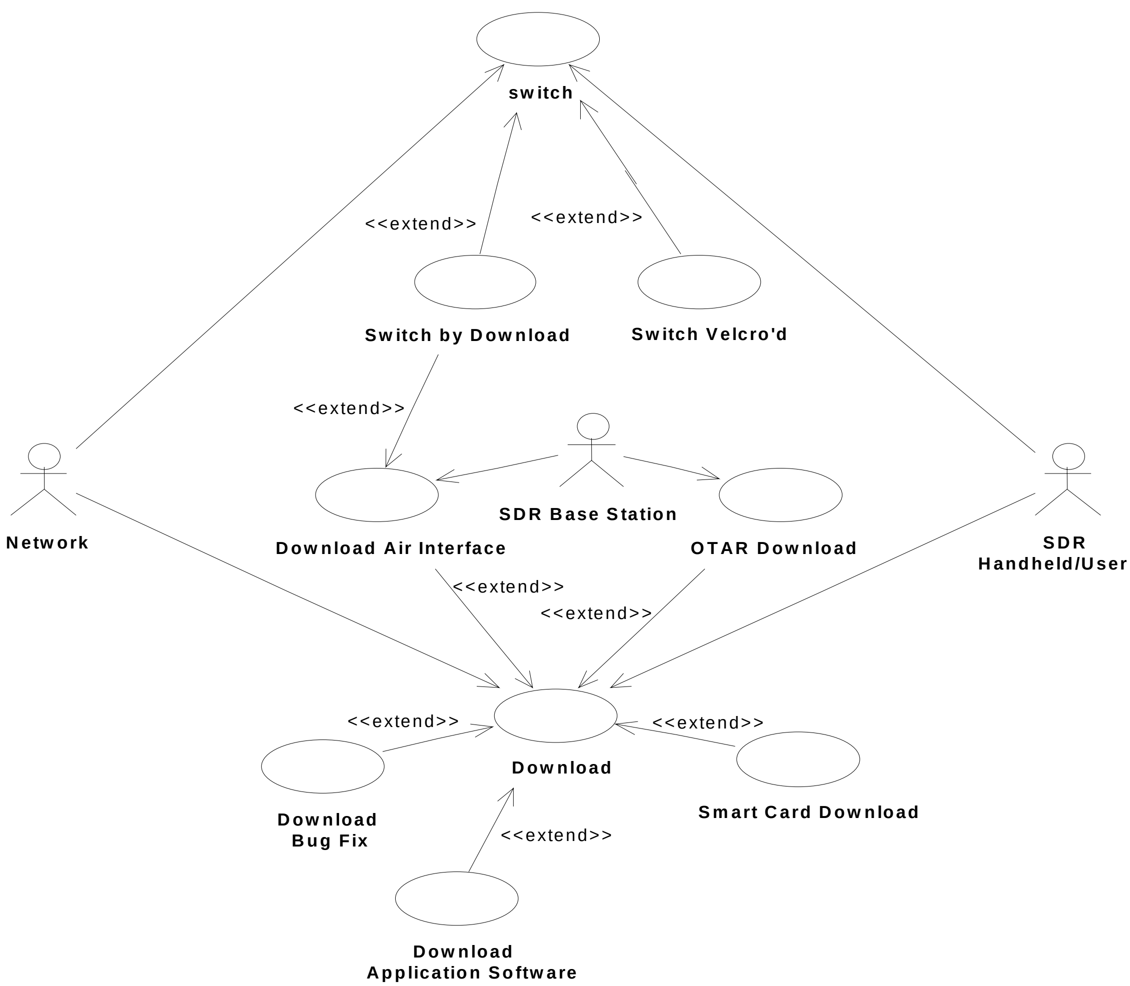


Fig 9: Simplified use case diagram

In the following, we propose to develop several interesting scenarios, that should help to precise the behavior of a SDR base station.

5.2.2 II.2 - Scenario #1: Successful download operation of an application module initiated by the network

Figure 10 details the "conversation" between the Network and the SDR Handheld/User in the context of:

- a successful downloading operation,
- initiated by the network,
- concerning an application module.

The base station is completely passive and so it does not appear in the MSC diagram.

Sum-up:
The network first sends a download request to the SDR handheld that answers if it’s ready or not. After a mutual authentication that may be defined later, the network verifies if the handheld capabilities are compatible with those required by the downloaded module, before executing the downloading operation. No billing or licensing is introduced here. The network itself would support this service. The base station in clearly not involved at all in this procedure; it just serves to relay messages between Network and Handheld.

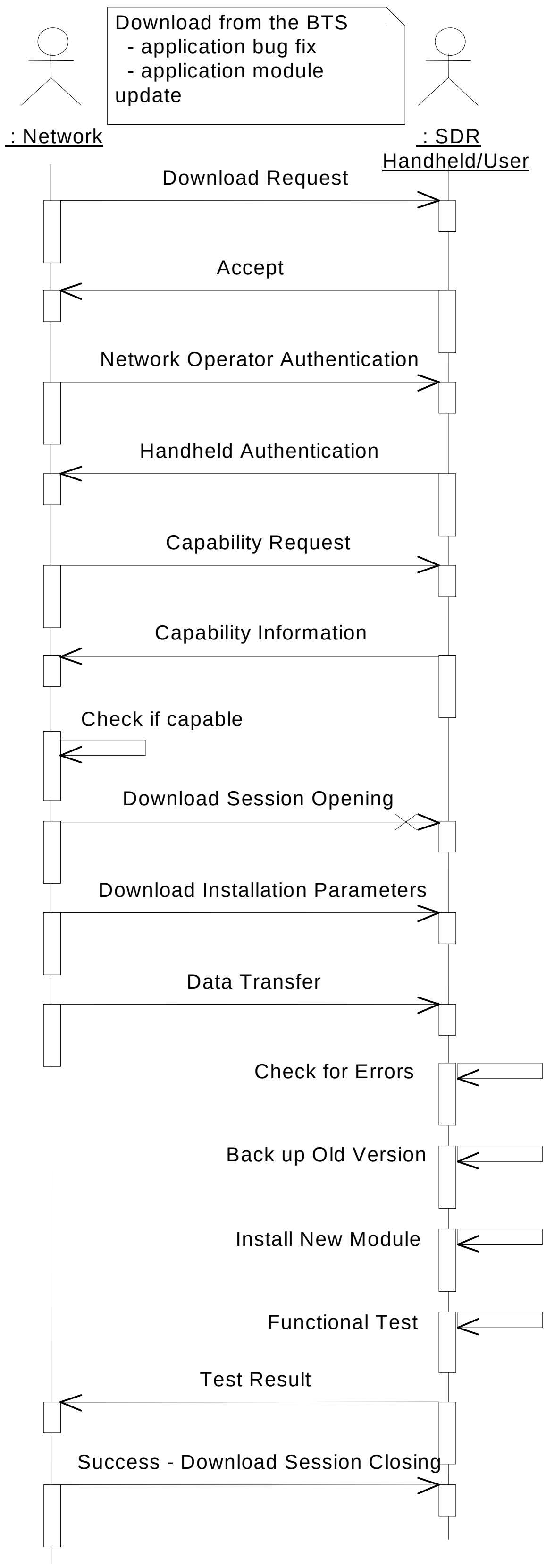


Fig 10: Successful download operation of an application module initiated by the network

We can distinguish the following steps in the process:

- *Initiation*,
- *Mutual Authentication*: to ensure the identity of communicating parties,

- *Capability Exchange*: to see if the handheld is capable to support the downloaded entity,
- *Data transfer*: data transfer and error checking,
- *Installation/Testing*: transformation of data into their executable form, linking with the rest of the system and testing to verify correct functionality,
- *Closing*.

5.2.3 II.3 - Scenario #2: Successful download operation of an air interface module initiated by the network

Figure 11 details the conversation between the Network and the SDR Handheld/User in the context of:

- a successful download operation of a module or a part of the system that induces a base station reconfiguration, for example a change of air interface,
- the operation is initiated by the network,
- the module is immediately installed on the handheld.

Since the installation (reconfiguration) is immediate (right after the data transfer) the BTS must be aware of the whole process. Note the assumption that the operation takes place in a single cell to avoid having to consider details of downloading with intercell handover.

We could also imagine other scenarios where the installation is delayed. For example we could re-configure a handset before taking a plane in order to adapt it to the foreign country standard. In such a case, the base station would be totally "transparent".

Sum-up:
The network first offers to download through the air a new module to the SDR handheld that answers if it’s ready or not. After a mutual authentication that may be defined later, the network verifies if the handheld capabilities are compatible with the new module requirements, and properties of the current cell base station (availability request), before executing the downloading operation. A backup of the former version of the module may be necessary in case of transfer failure. A reason for installing the new capability at once could be to benefit from a functional test in situ.

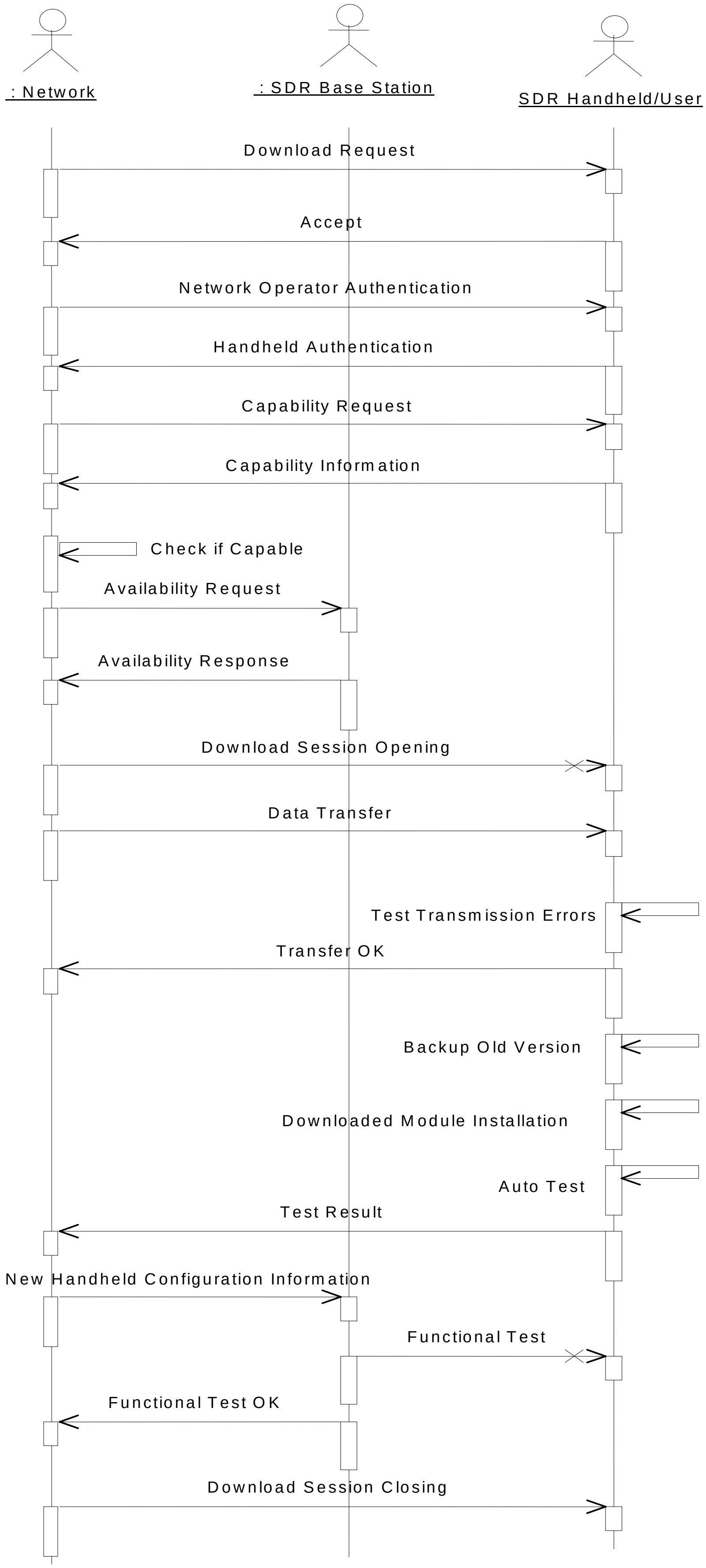


Fig 11: Successful download operation of an air interface module initiated by the network

We can distinguish the following steps in the process:

- *Initiation*,
- *Mutual Authentication*: to ensure the identity of communicating parties,
- *Capability Exchange*: to see if the handheld is capable to support the downloaded entity, to see if the base station support to communicate with the "new reconfigured handheld".
- *Data transfer*: data transfer and error checking,
- *Installation/Testing*: transformation of data into their executable form, linking with the rest of the system and testing to verify correct functionality, handheld - base station link functional verification.
- *Closing*.

[[
Comments from the Mobile working group, after a verification of the compliance of this scenario with their framework architecture: OK but need a precision at Auto Test point.

AutoTest needs previous operations:

to be compatible with mobile framework, we need first
LOAD
EXECUTE
READY either AUTOTEST
or RUN
READY to be able to communicate later with the BTS

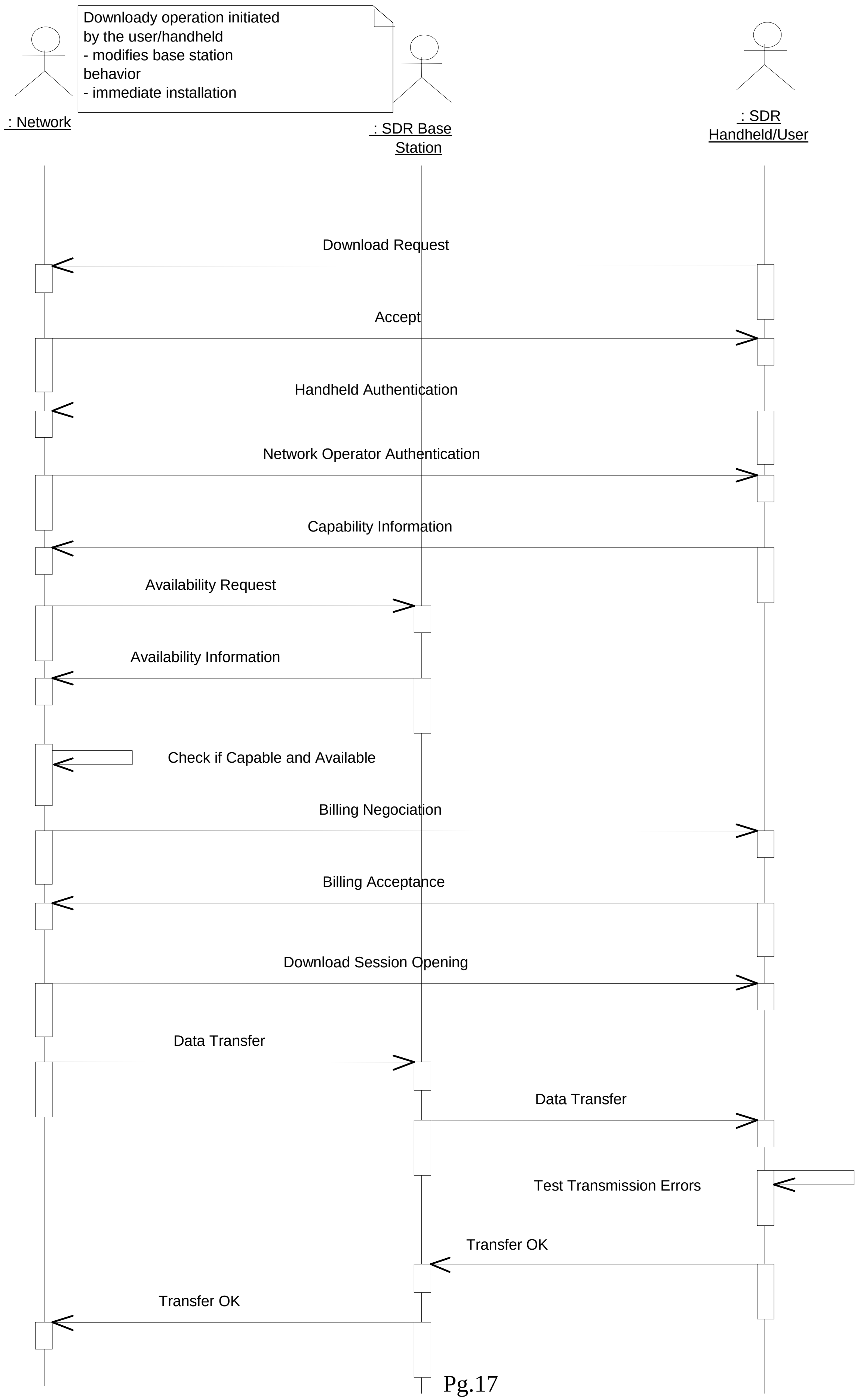
All this can be considered inside the Auto Test procedure.]]

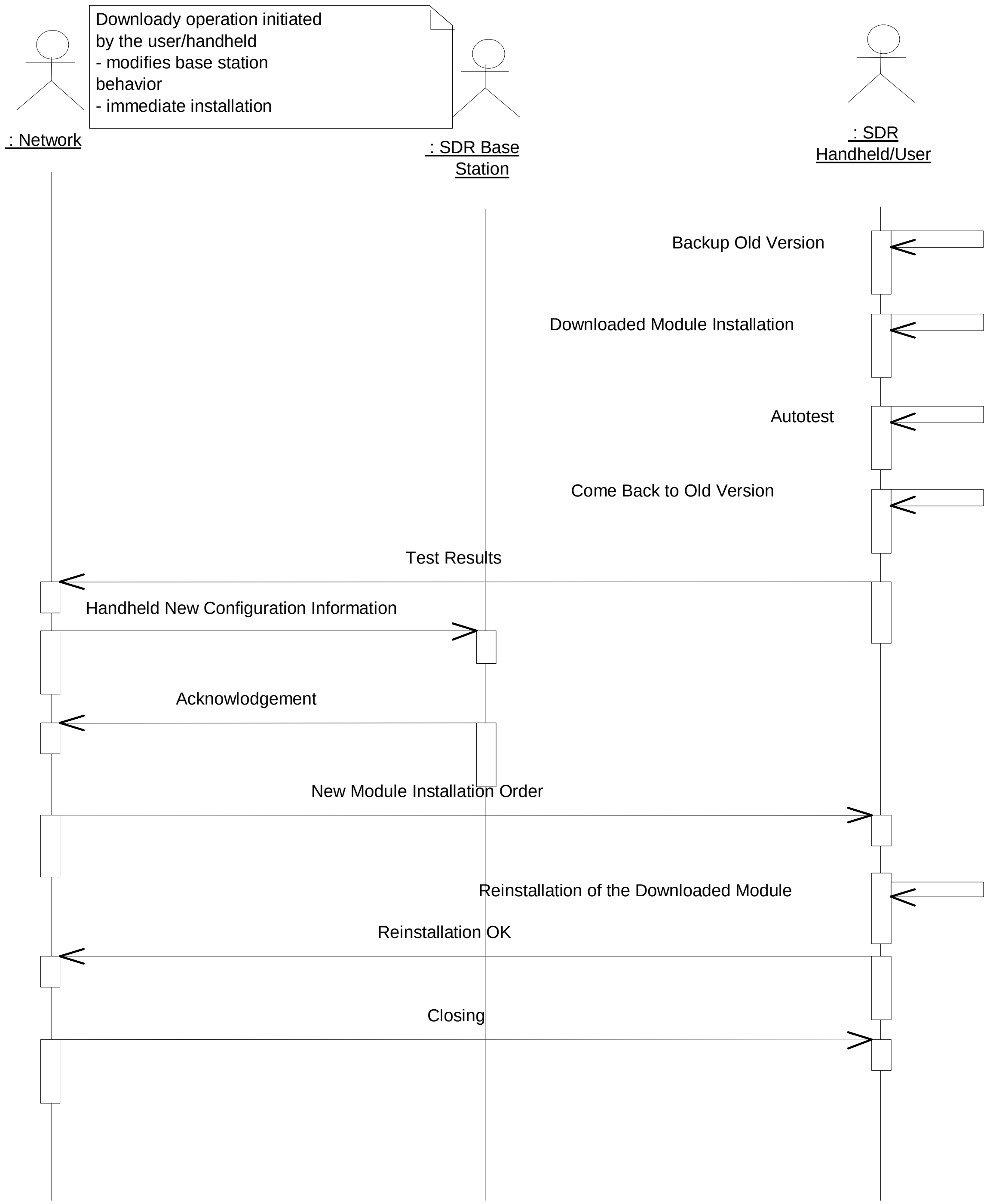
5.2.4 II.4 - Scenario #3: Successful download operation of an air interface module initiated by the user

Figure 12 details the conversation between the Network and the SDR Handheld/User in the context of:

- a successful download operation of a module or a part of the system that induces a base station reconfiguration, for example a change of air interface.
- the operation is initiated by the user
- the module is immediately installed on the handheld.

Since the installation (reconfiguration) is immediate (right after the data transfer) the BTS must be aware of the whole process. Note the assumption that the operation takes place in a single cell to avoid having to consider details of downloading with intercell handover.


Downloady operation initiated
by the user/handheld
- modifies base station
behavior
- immediate installation
: Network
: SDR Base Station
: SDR Handheld/User
Download Request
Accept
Handheld Authentication
Network Operator Authentication
Capability Information
Availability Request
Availability Information
Check if Capable and Available
Billing Negociation
Billing Acceptance
Download Session Opening
Data Transfer
Data Transfer
Test Transmission Errors
Transfer OK
Transfer OK



5.2.4.1.1.1.1 Fig 12: Successful download operation of an air interface module initiated by the user

5.3 III - Use case study: “Base station maintenance: base station upgrade”

5.3.1 III.1 – Use case diagram

While considering an upgrade of a base station, we may consider both software and combined hardware-software upgrades.
In order to refine the analysis, we may consider that making a software upgrade will probably won't follow the same manner if this upgrade is done remotely or locally. We may also imagine that sub-cases of a remote upgrade would consist in the medium used to download the necessary information. Further discussions should tell if a more precise refinement is needed, or inversely, the use case diagram should be simplified.

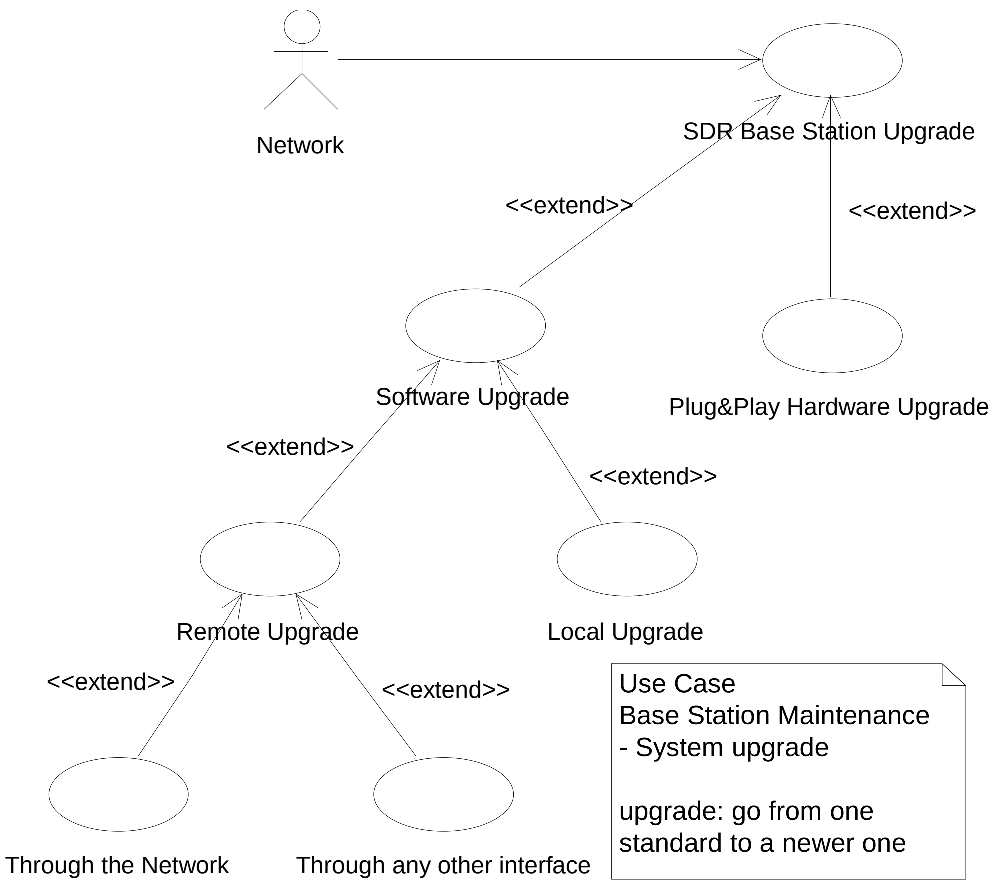


Fig 13: Simplified use case diagram

5.3.2 III.2 - Scenario #1: Success installation of a new hardware module in a SDR base station

Some restriction has to be made first. In fact we limit here such capabilities to a hardware module provided by the same manufacturer of the rest of the base station. This could be generalize to any other hardware board of any kind and manufacturer if an exhaustive data base could be available.

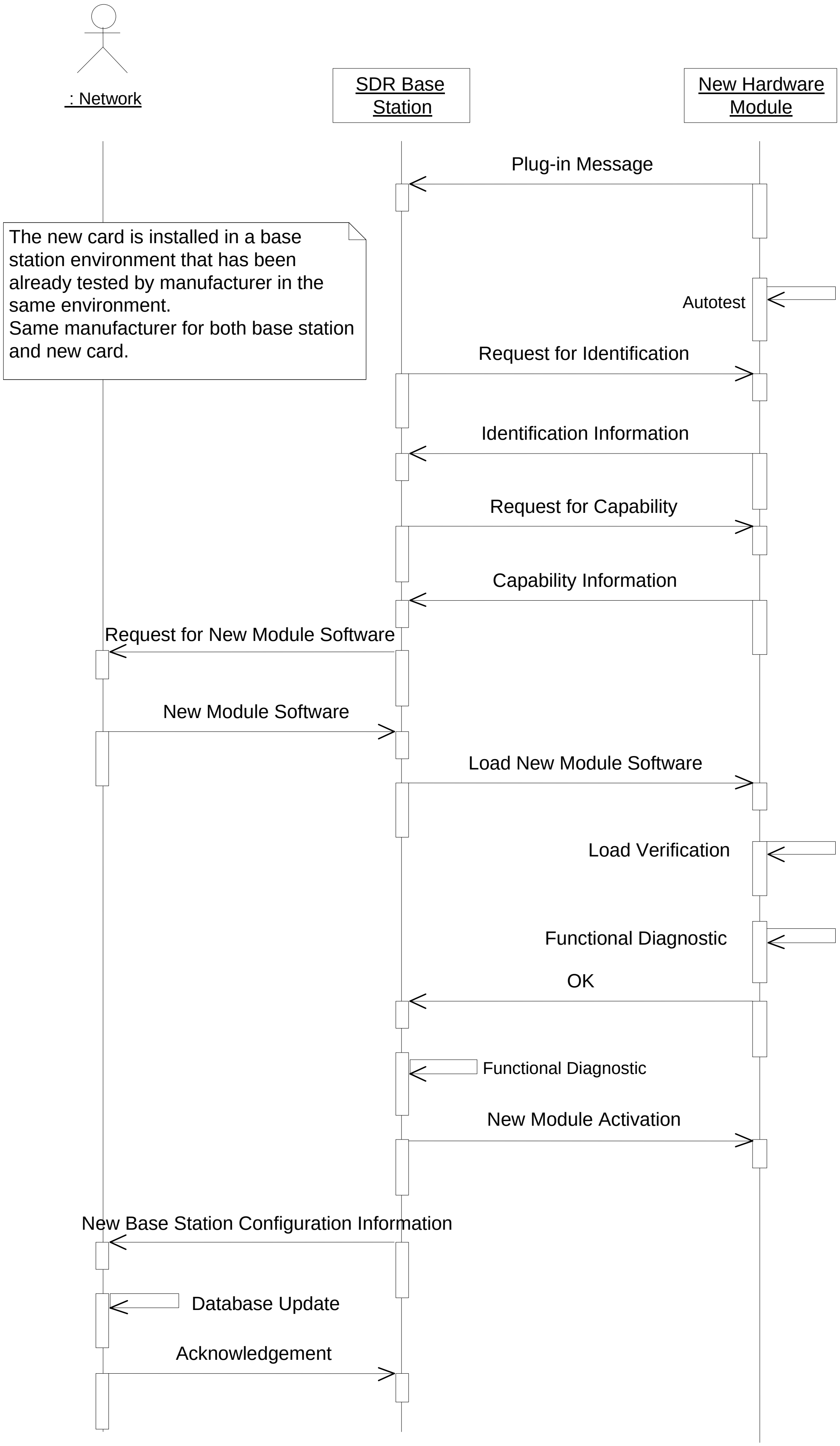
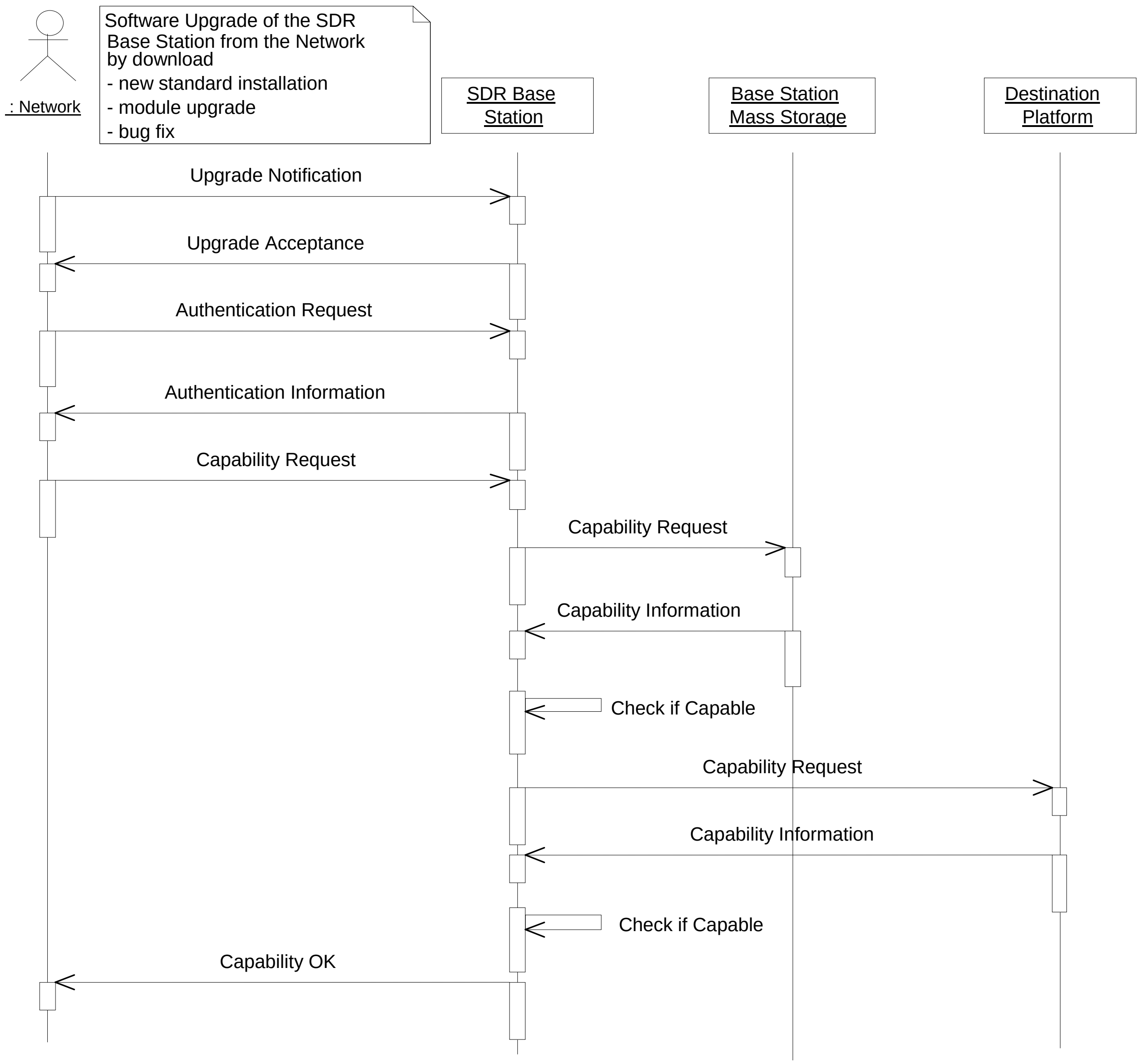

: Network
SDR Base Station
New Hardware Module
Plug-in Message
The new card is installed in a base station environment that has been already tested by manufacturer in the same environment.
Same manufacturer for both base station and new card.
Autotest
Request for Identification
Identification Information
Request for Capability
Capability Information
Request for New Module Software
New Module Software
Load New Module Software
Load Verification
Functional Diagnostic
OK
Functional Diagnostic
New Module Activation
New Base Station Configuration Information
Database Update
Acknowledgement

Fig 14:Successful installation of a plug & play new hardware module in the base station

5.3.3 III.2 - Scenario #2: Software upgrade of a SDR base station by software download from the network

The SDR base station is separated into several functional pieces: intelligent part, mass storage part, the re-configured hardware part.



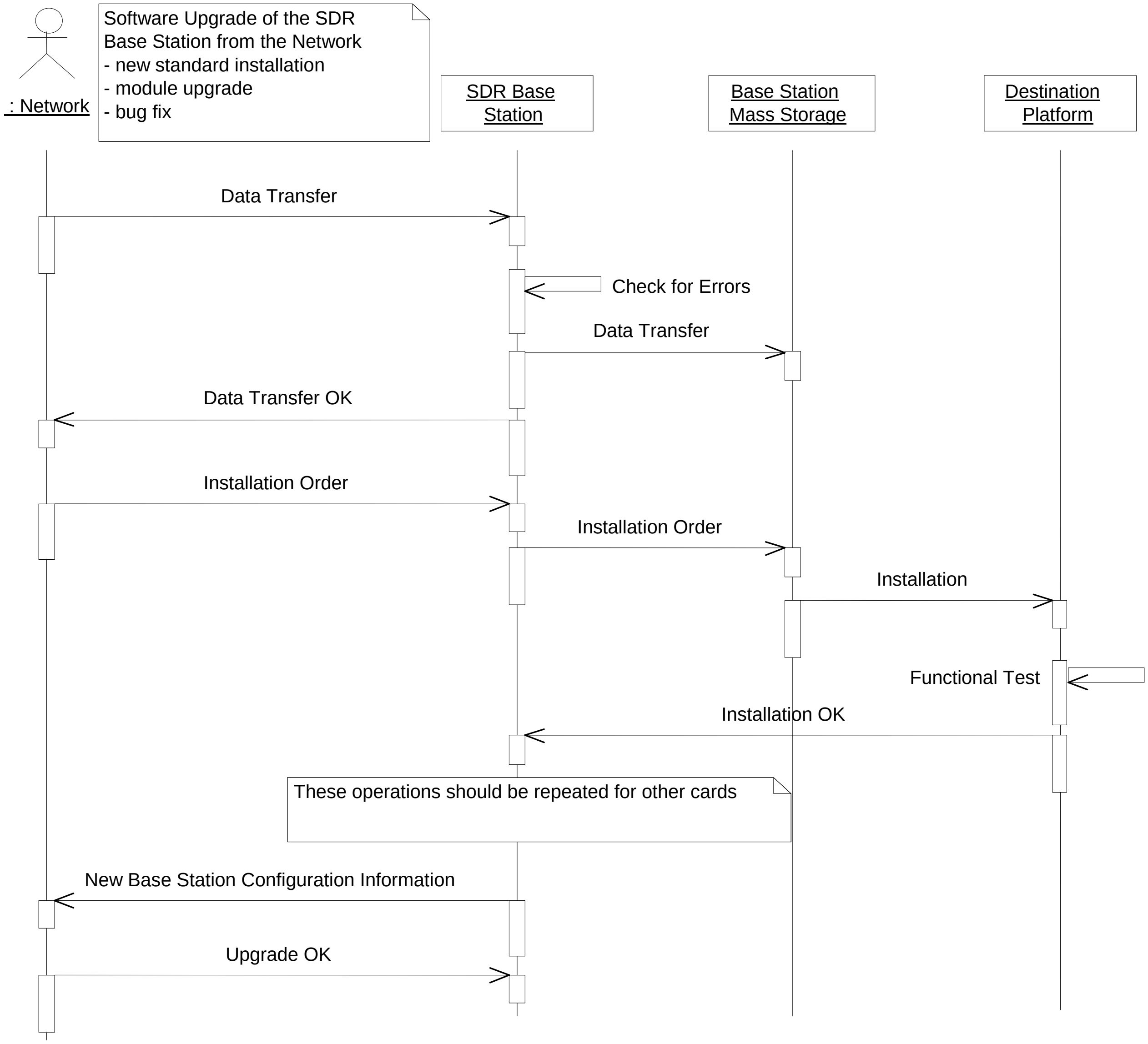


Fig 15: Successful download operation of an air interface module initiated by the network

6 Base Station Systems (Top Down)

6.1 Access methods

6.1.1 Second Generation

6.1.1.1 GSM

GSM is a TDMA-derived air interface that is dominant in Europe and many other parts of the world.

6.1.1.2 The TDMA Air Interface – GSM, IS 136

GSM is the prevalent cellular system in Europe, while TDMA based on IS-136 is one of several schemes used for cellular and personal communications services (PCS) in the US. The structure of a TDMA air interface is based on definition of a time interval for repetitive transmission of frames. It is very similar to the scheme used for T1 carrier as shown in Figure 3. Each frame contains a few hundred bit-times, broken up into individual time slots. GSM, for example, had 26 time slots of 8 bits each in a frame. Some time slots are used for control information, and the rest are allocated to individual calls. Each mobile unit is closely synchronized to the network so it knows precisely when to come on and transmit its information to the base station. On receive the mobile knows to listen only when its time slot begins, and to listen to the next 8 bits.

TDMA operates on a relatively narrow carrier bandwidth. 200KHz is a typical value for GSM. Each base station is designed to operate with a number of frequencies at the same time, with pairs of separated frequencies used for transmit and receive.

Operation of the air interface involves close interaction between the mobile and the base station. The following items are functions impact the base station system structure.

Power control is used in TDMA systems to instruct the mobile on how much power should be transmitted. Use of minimum power reduces interference and extends battery life.

Handoff is the process by which a mobile is changed from operation with one base station to another.

Decryption is the process of removing bit scrambling done to avoid interception of traffic over the air.

Frequency Hopping is the process of changing the carrier frequency at regular intervals. Hopping helps avoid fading in the radio channel, and provides an added element of security.

Time of arrival (TOA) measurement. The timing of the mobile transmit is controlled so that the transmission starts enough ahead of the time slot to compensate for propagation delay. These offsets are proportional to the link range, so measurements from several base stations can be used to geolocate the mobile unit.

6.1.1.3 The CDMA Air Interface – IS95

CDMA operates with relatively wide carrier channels, typically 1.25MHz in width. All of the channels within that carrier transmit a broadband signal at the same time. Each bit in the transmitted signal, however, is spread using a specific one of a number of carefully designed orthogonal codes. The spread codes are then transmitted in sequence.The receiver brings in the RF from all of the transmitters, and looks at the signals at very specific times as specified by the code in use by the transmitter of interest. Then a statistical correlation of a number of samples is used to determine whether the transmitted bit was a one or zero.

As in TDMA, operation of the air interface involves close interaction between the mobile and the base station. The following items impact the base station functional capability.

Power Control is crucially important in CDMA. All transmitters must operate at the lowest possible level because the level of the noise floor influences the total performance of a carrier.

Handoff is very different in CDMA because of its capability to do a soft handoff. In a soft handoff two base stations simultaneously work with the mobile, providing two paths for the traffic. When one of them becomes too far away to be effective it is dropped out.

Link Management is enhanced by CDMAs ability to resolve multipath by time-shifting the shadow signal so it is phase-matched to the primary signal.

6.1.2 Third Generation

Third generations systems will utilize advanced CDMA technology, and will focus on the users need to work with wireless digital data as well as voice.

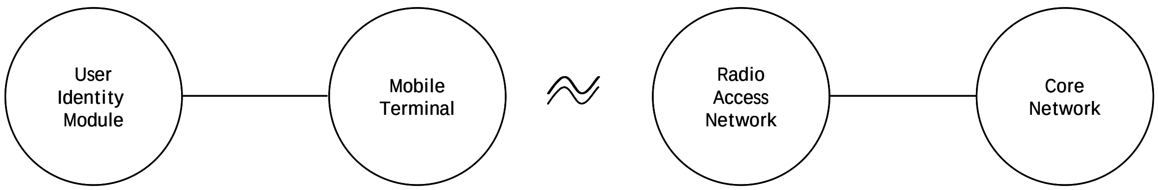


Figure 16. IMT-2000 Overview

Figure 16 shows a very high-level view of the chief components of the 3G architecture. It retains a radio-oriented view of the role of the base station and its supporting connections.

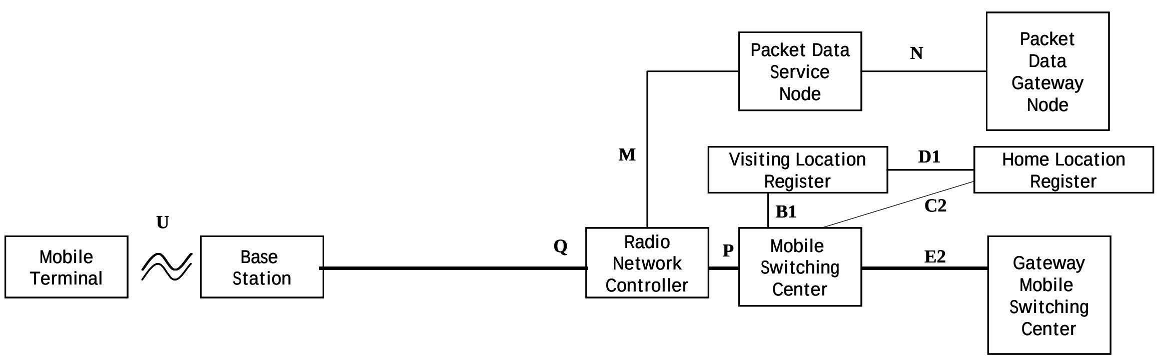


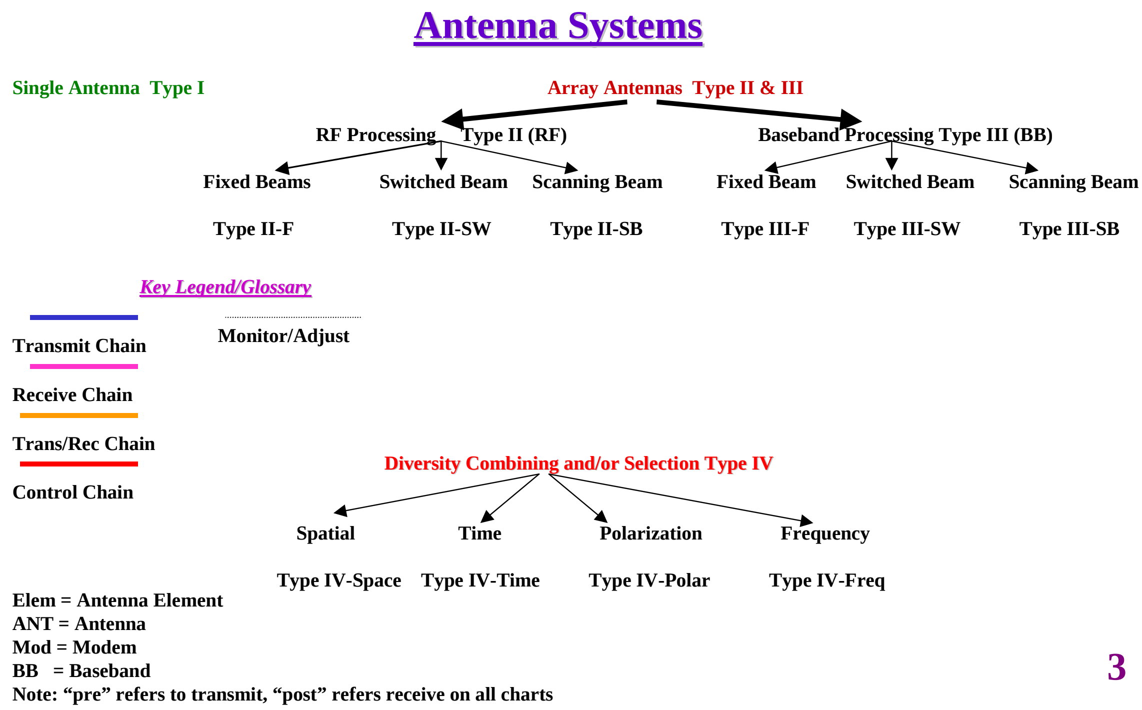
Figure 20. IMT-2000 Simplified

Figure 20 is a similar picture with the designations of the interfaces between major components. At the radio network controller it splits off data packets, and handles them in the packet data gateway mode, completely separate from the voice connection through the gateway mobile switching center.

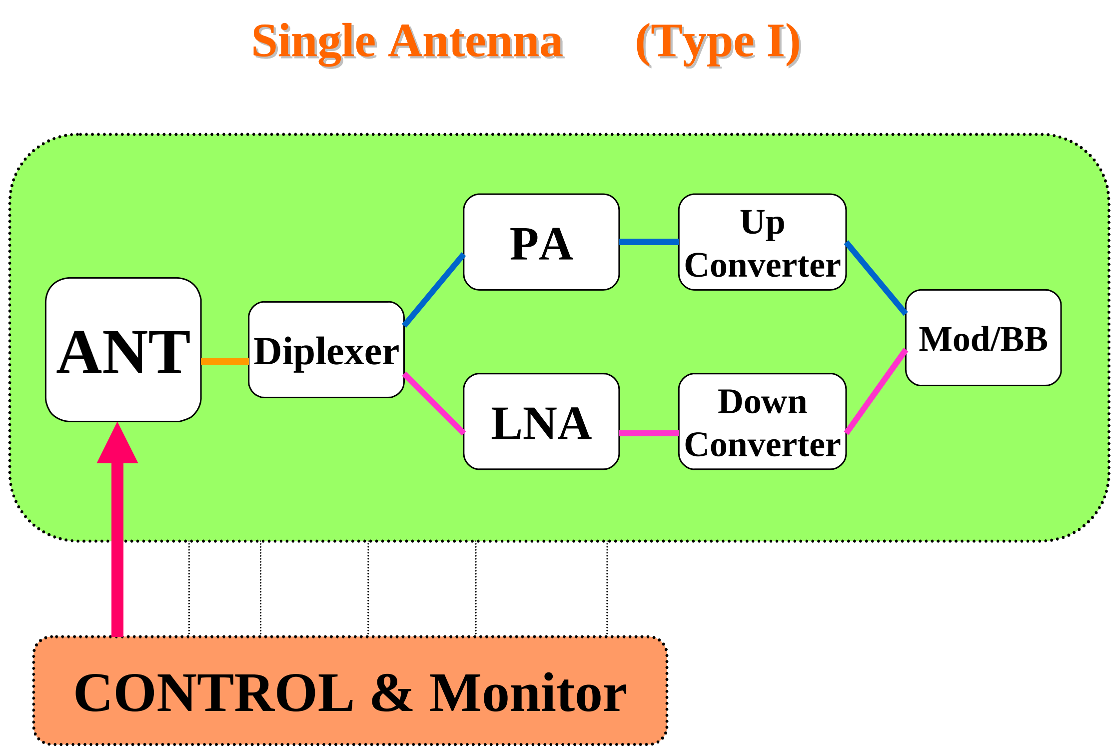
7 Base Station Structures (Bottom UP)

7.1.1 Antenna Types

The following is a taxonomy of antenna types.



7.1.1.1 Single Antenna



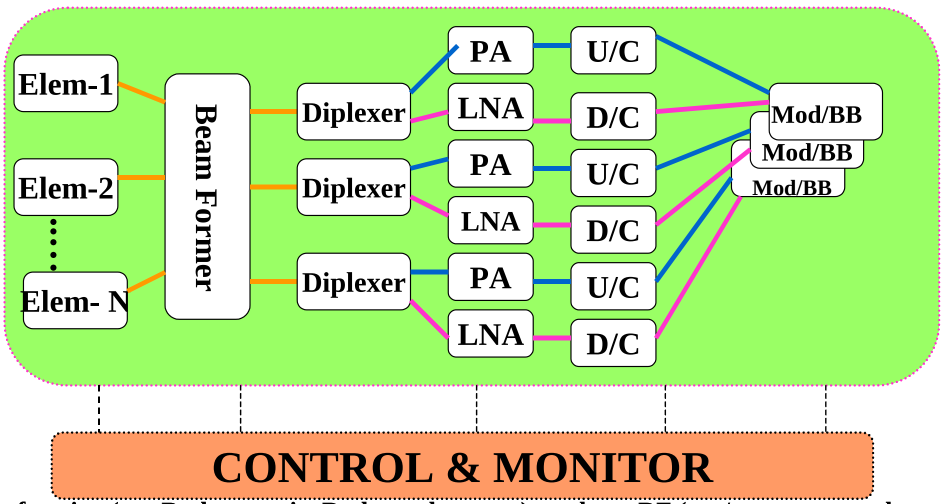
Antenna may have any type of element (yagi, LPA, dipole, etc.). May have a rotator or antenna tuning network. May have separate receive and transmit antenna, eliminating diplexer.

7.1.1.2 Array Antenna

7.1.1.2.1 Processing at RF

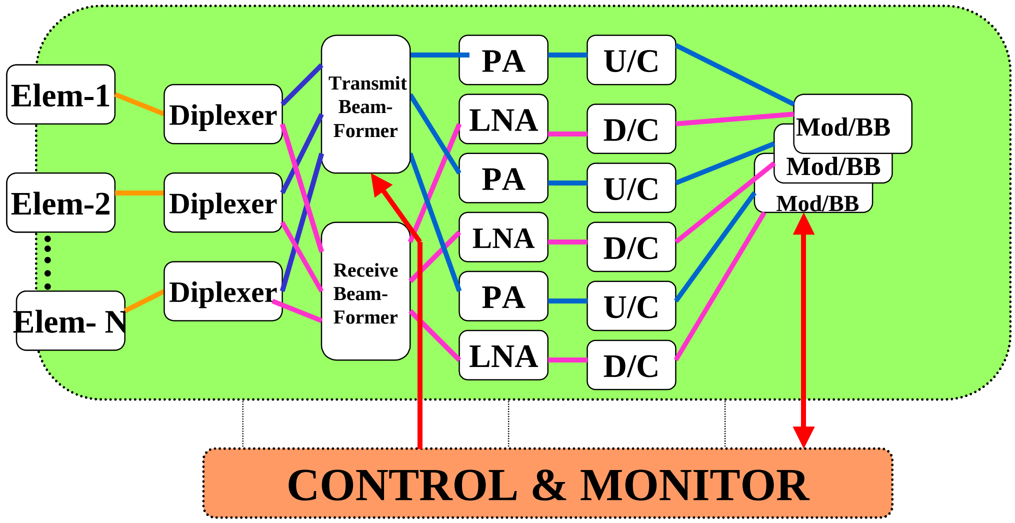
7.1.1.2.1.1 Fixed Beams

Array Antenna Processing at R
Fixed Beams (Type II F a T/R)



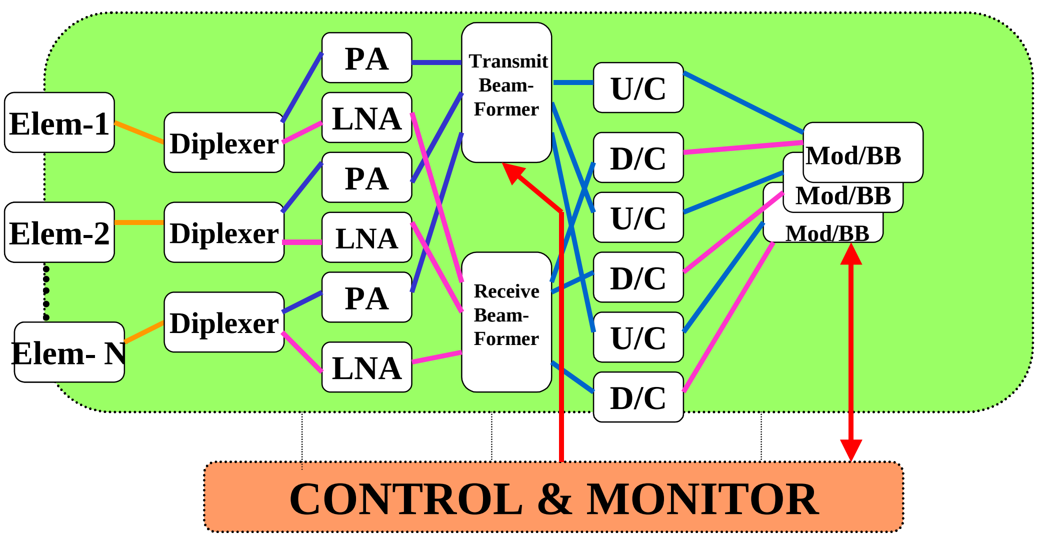
Beamforming (e.g. Butler matrix, Rothman lens, etc.) can be at RF (pre/post antenna elements or pre/post amplifiers) or at IF (pre/post converters). Shown is at antenna elements, which may require true time-delay beamformer depending on beamwidths and transmit and receive frequency separation. Otherwise, separate beamforming for receive and transmit for all configurations (RF, IF, etc.) would be required -- refer to charts 6, 7, and 8. Selection of beam(s) for both transmit and receive usually determined by received signal algorithms. Maximum number of orthogonal beams is one less than the number of elements.

Array Antenna Processing at RF
Fixed Beams (Type II F b T/R)



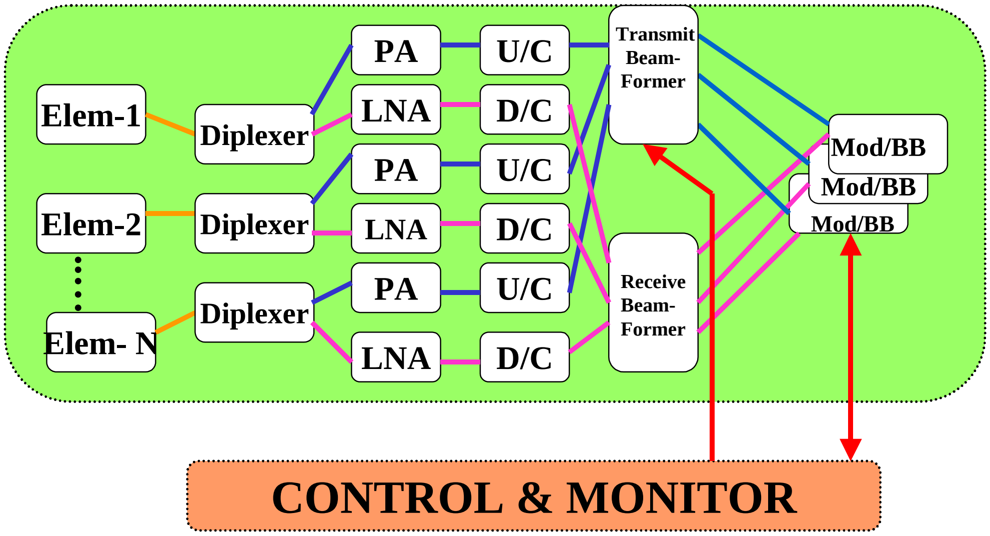
For this version, both transmit and receive beamforming is performed between the diplexers and the amplification system. Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.

Array Antenna Processing at RF
Fixed Beams (Type II F c T/R)



Both transmit and receive beamform selection is performed between the amplification system and the conversion system. Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.

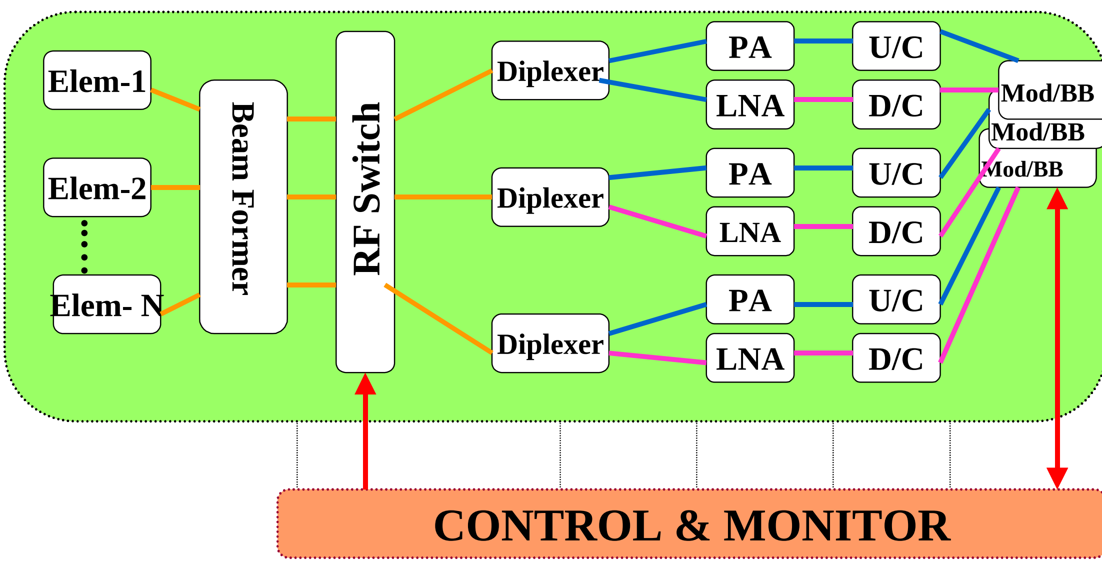
Array Antenna Processing at RF Fixed Beams (Type II F d T/R)



Both transmit and receive beamform selection is performed between the conversion subsystem and the modulator/ baseband subsystems Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.

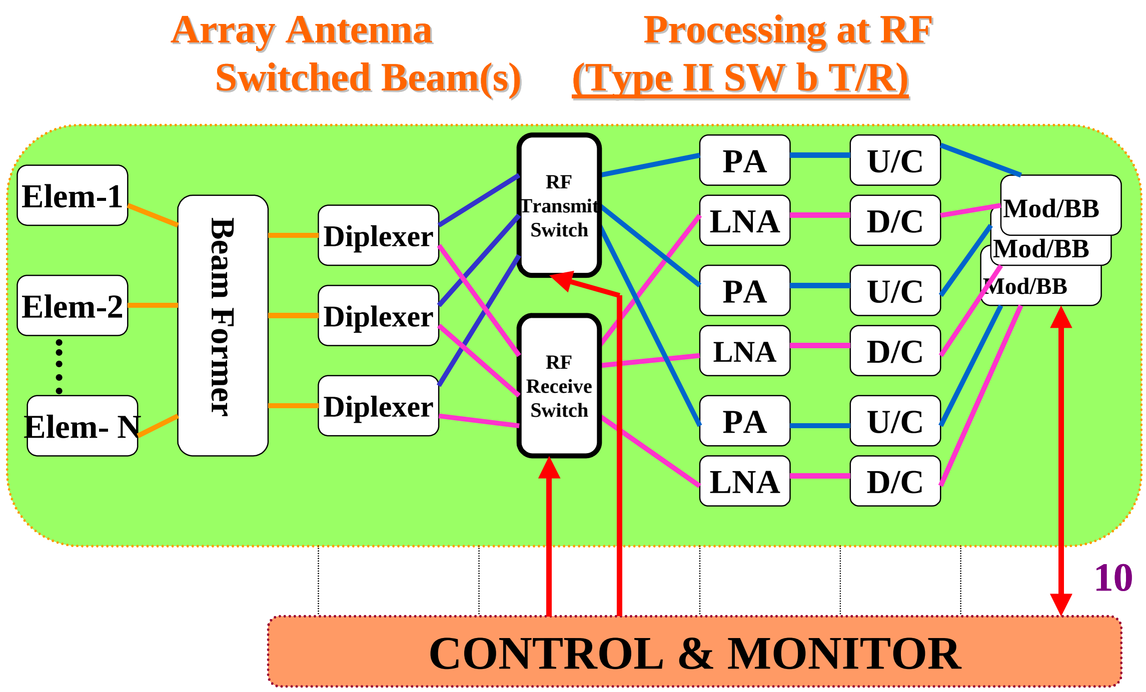
Note: Because the beamforming is done separately for the transmit and the receive it is possible to have additional configuration beyond the four shown here. This achieved be placing the transmit and the receive beamformers in separate electrical locations.

Array Antenna Processing at RF Switched Beam(s) (Type II SW a T/R)

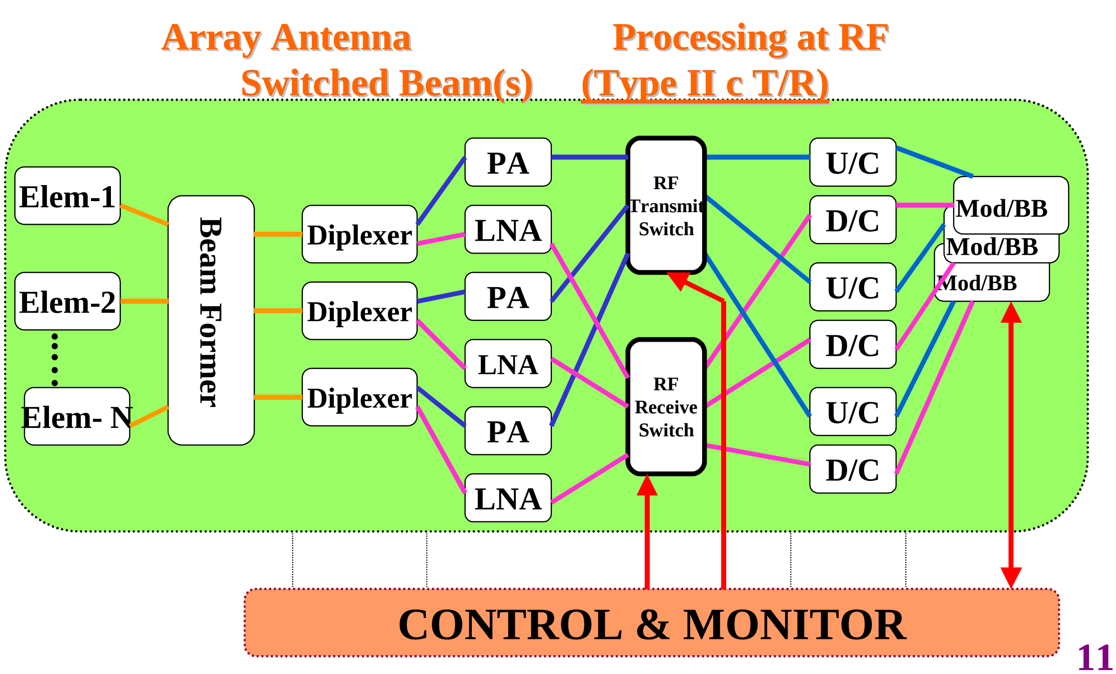


This is the first in a series of 10 switched beam systems. In all of these variations the multiple beam(s) are fixed and the RF switch selects which beam(s) shall be used. The versions differ with respect to the electrical location of switch and the beamformer. In this version both the switch and the beamformer are between diplexer and the antenna elements. Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.

7.1.1.2.1.2 Switched Beams

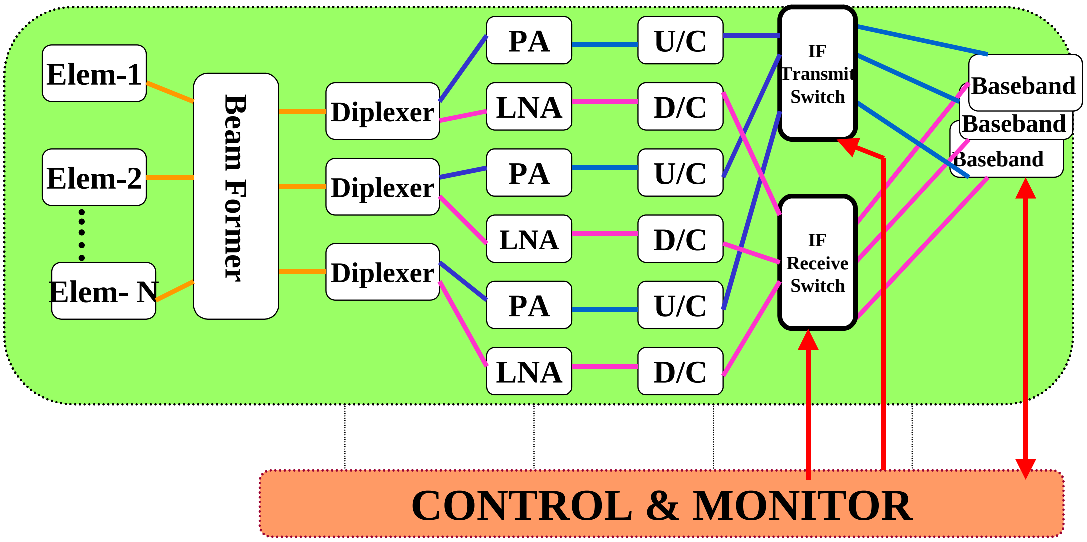


The multiple beams are fixed and the RF switch selects which beam shall be used. In this configuration switch is separated from the beamformer by diplexer. The beamformer is connected directly to the antenna elements. Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.



The multiple beams are fixed and the RF switch selects which beam shall be used. In this case the switch is separated from the beamformer by diplexer and the amplification systems. The beamformer is connected directly to the antenna elements. Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.

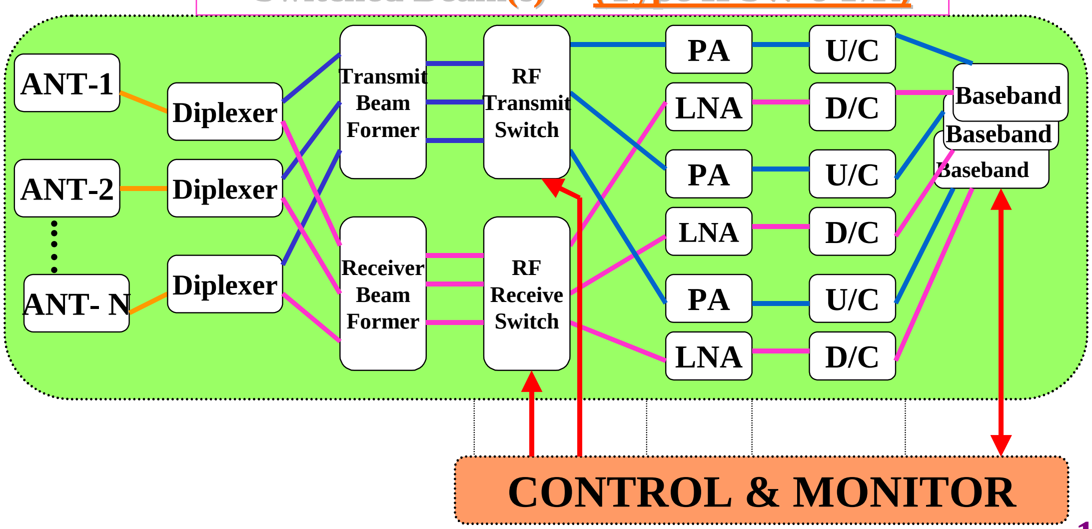
Array Antenna Switched Beam(s) Processing at RF (Type II SW d T/R)



12

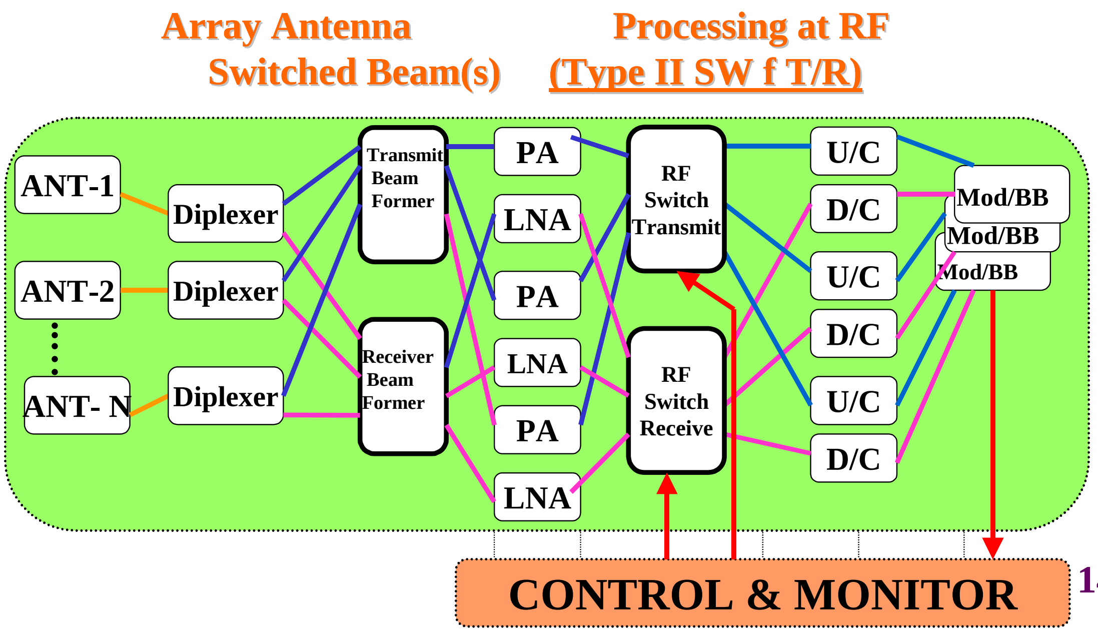
The multiple beams are fixed and the RF switch selects which beam shall be used. In this case the switch is located IF and beamformer is between diplexer and the amplification systems. The beamformer is connected directly to the antenna elements. Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.

Array Antenna Switched Beam(s) Processing at RF (Type II SW e T/R)



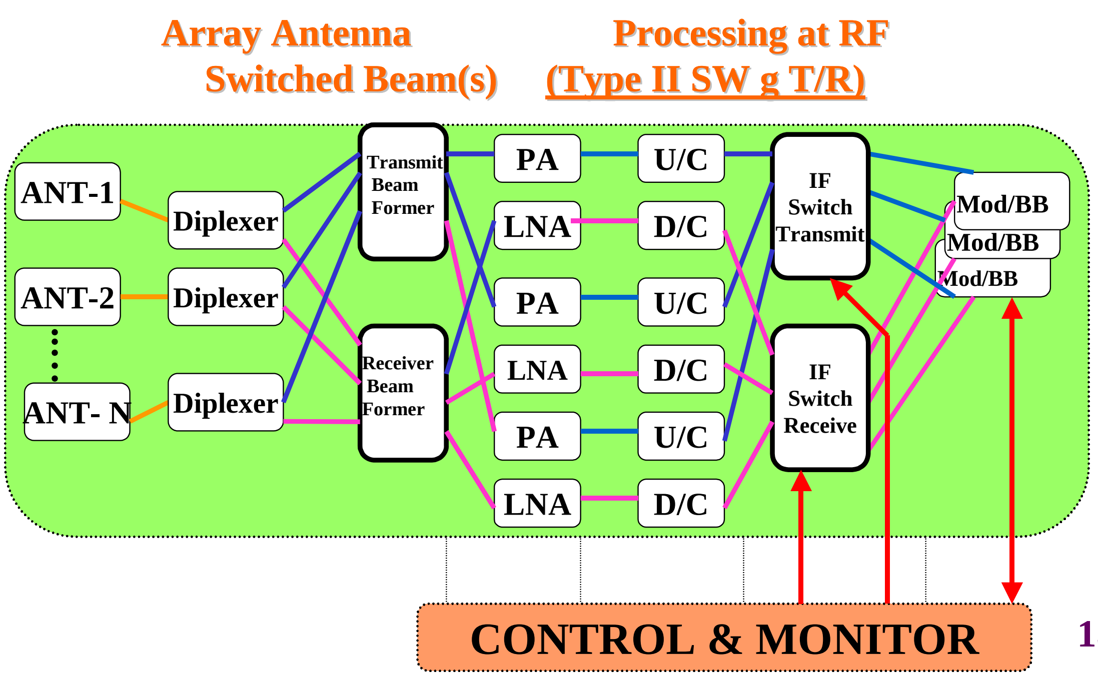
13

The multiple beams are fixed and the RF switch selects which beam shall be used. In this case the switch and the beamformer are co-located between the diplexers and the amplification subsystems. The beamformers is connected directly to the diplexers . Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.



14

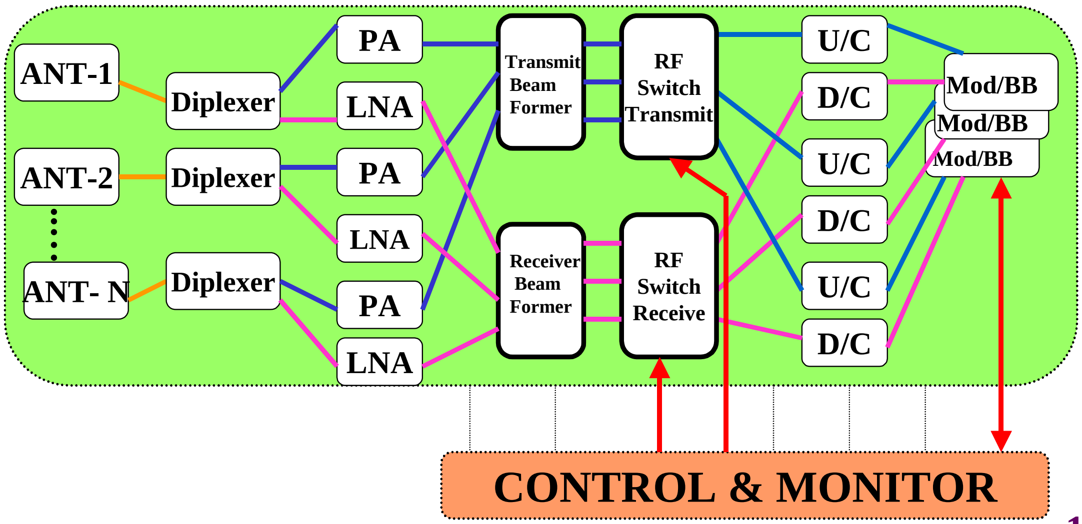
The multiple beams are fixed and the RF switch selects which beam shall be used. In this case the switch and the beamformer are separated by the amplification subsystem. The beamformers are connected directly to the diplexers . Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.



15

The multiple beams are fixed and the RF switch selects which beam shall be used. In this case the switch and the beamformers are separated by the amplification and the conversion subsystem. The beamformers are connected directly to the diplexers . Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.

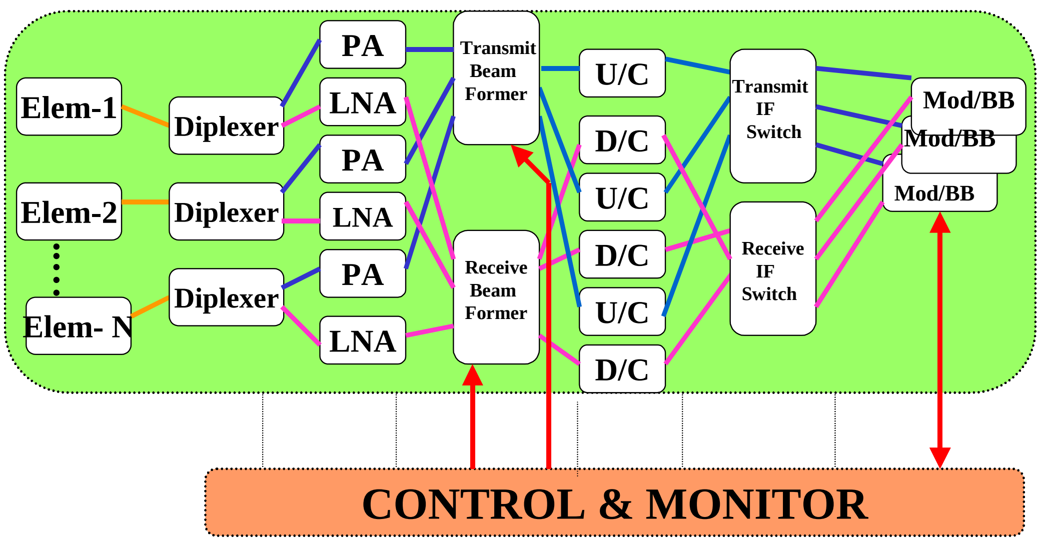
Array Antenna Switched Beam(s) Processing at RF (Type II SW h T/R)



16

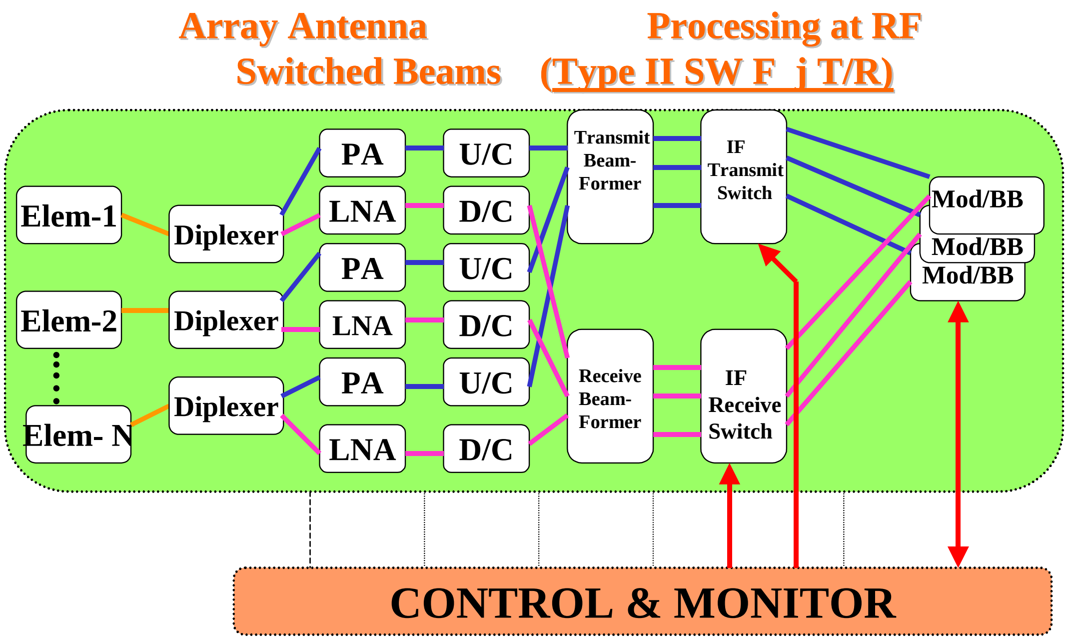
The multiple beams are fixed and the RF switch selects which beam shall be used. In this case the switch and the beamformers are connected together and are electrically located between amplification and conversion subsystem. The beamformers are connected directly to the LNA for the receive and the PA for the transmit. Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.

Array Antenna Switched Beams Processing at RF (Type II SW F i T/R)



17

The multiple beams are fixed and the RF switch selects which beam shall be used. In this case the receive and transmit beam formers are located electrically between the amplification subsystem and the conversion subsystem. The receive and transmit IF switches are located between the conversions subsystem and the Modulation/Baseband subsystem. Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.

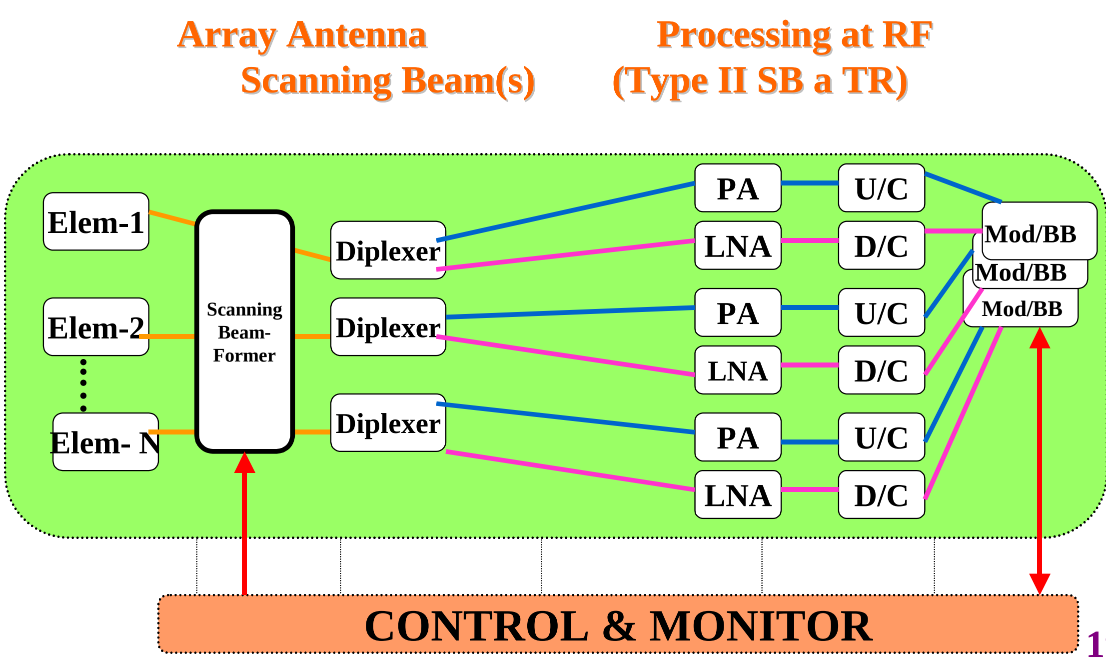


18

The multiple beams are fixed and the RF switch selects which beam shall be used. In this case the receive and transmit beam formers and the IF transmit and receive switches are located electrically next to each other between the conversion and the Modem/Baseband subsystems. Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.

Note: **In the foregoing presentation the transmit and receive beamformers and the transmit and receive RF/IF switches were moved around the diagram in pairs to create new subsystem configurations. If they were moved around individually there could be and additional 12 configurations the switched type of antenna subsystem (i.e., four things taken two at a time). They authors chose not to show these additional configurations but rather mentions them in passing.**

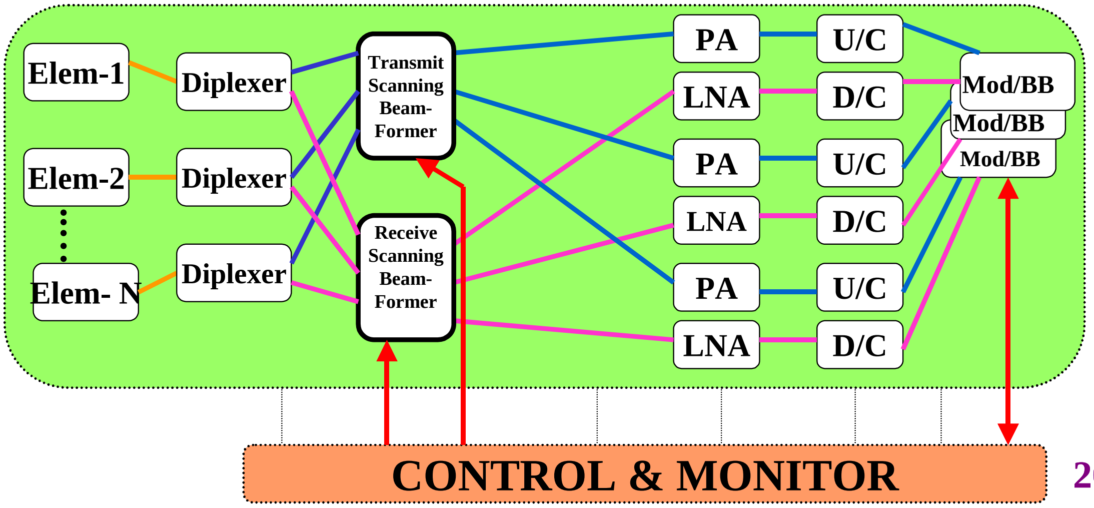
7.1.1.2.1.3 Scanning Beams



19

The scanning beam antenna system electronics forms single or multiple beams, for transmit and receive. In this case the scanning beam former is electrically located between the antenna elements and the diplexer. Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.

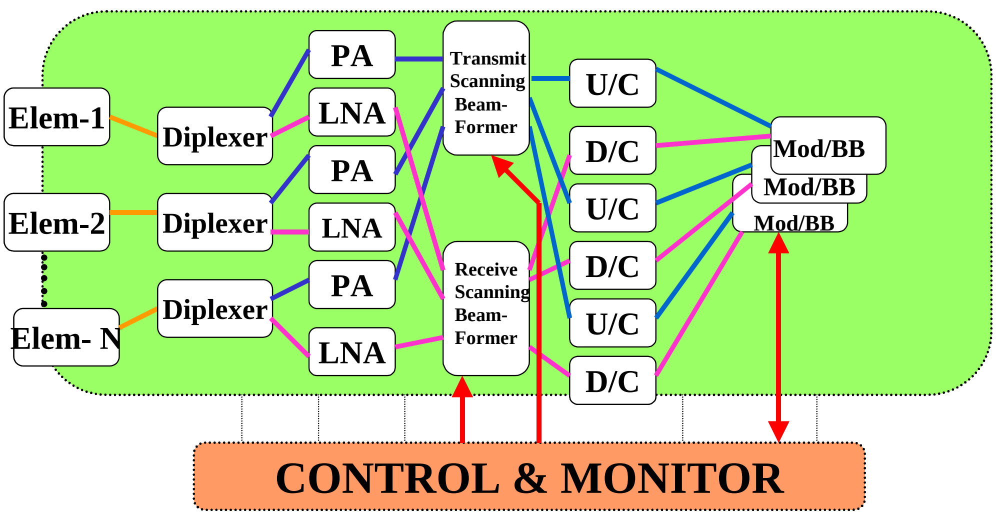
Array Antenna Scanning Beam(s) Processing at RF (Type II SB b T/R)



20

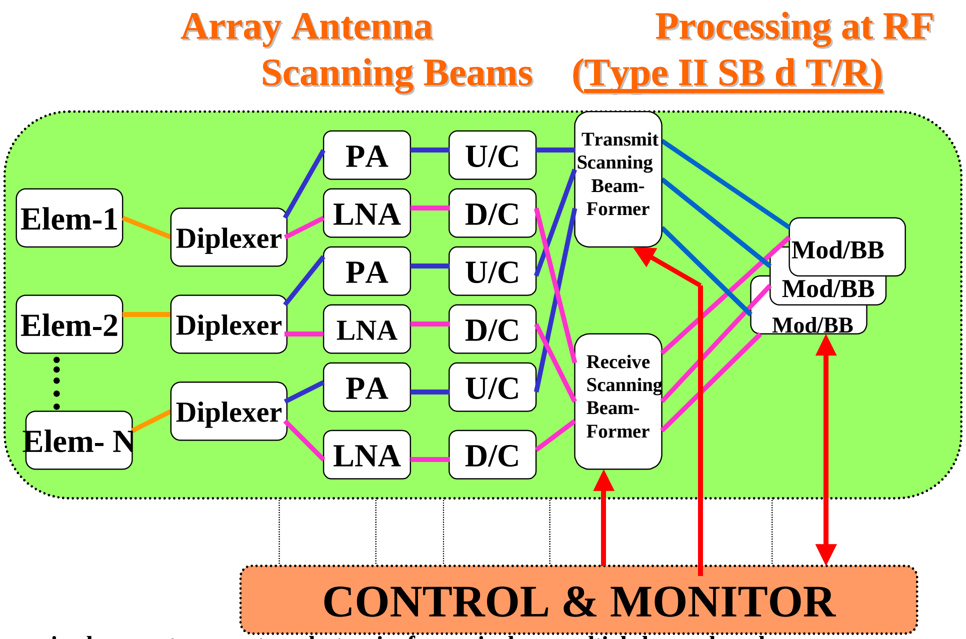
The scanning beam antenna system electronics forms single or multiple beams based upon some measured figure merit. In this case there are individual transmit and receive beam former and is electrically located between the diplexer and amplifications subsystems. Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.

Array Antenna Scanning Beams Processing at RF (Type II SB c T/R)



21

The scanning beam antenna system electronics forms single or multiple beams based upon some measured figure merit. In this case the scanning beam former is broken down into a transmit and receive beam former and is electrically located between the conversion and amplifications subsystems. Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.



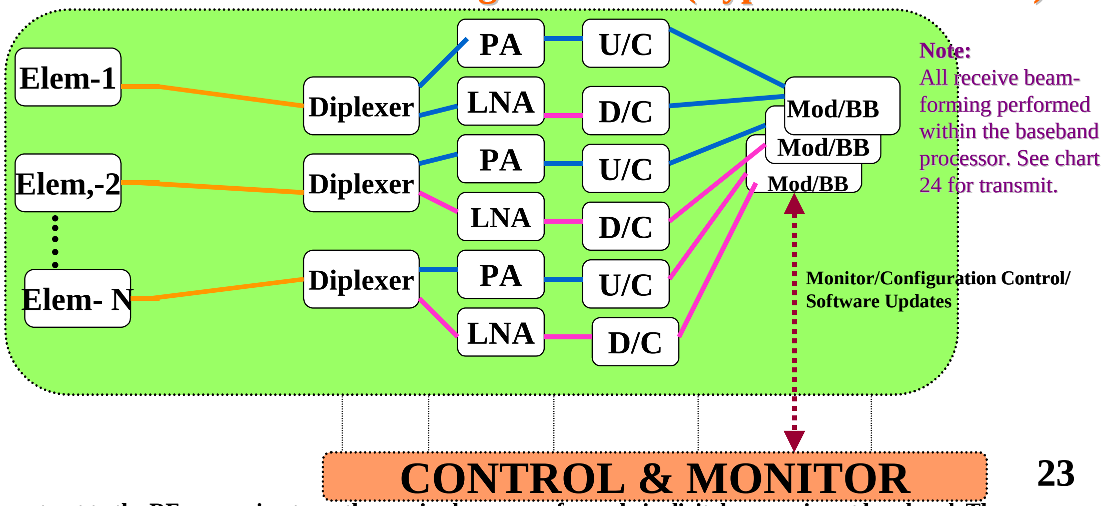
22

The scanning beam antenna system electronics forms single or multiple beams based upon some measured figure merit. In this case the scanning beam former is broken down into a transmit and receive beam former and is electrically located between the conversion and Modem/Baseband subsystems. Selection of beam(s) for both transmit and receive usually determined by received signal algorithms.

Note: In the analysis presented in pages 20 through 22 note that the receive and transmit scanning beamformer were moved about the diagram in pairs. It is conceivable that the transmit and receive beamformers could be moved about the diagram independently, post the diplexer, creating additional system configurations beyond those treated here.

7.1.1.2.2 Processing at Baseband

Array Antenna Fixed/Switched/Scanning Beams — Processing at Baseband (Type III F/SW/SB R)

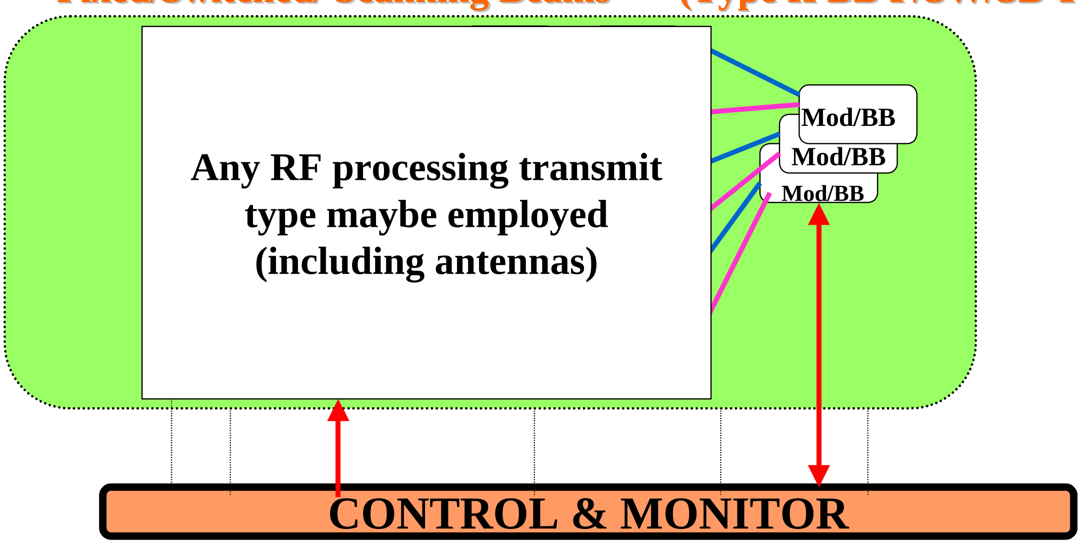


23

In contrast to the RF processing type, the receive beams are formed via digital processing at baseband. The advantage is that virtually any number of receive beams can be formed and shaped, and individually scanned and need not be orthogonal. However, for transmit the beams must be formed at RF or IF in the same manner as (previously shown) RF processing techniques. Transmit beam characteristics (forming, shaping, etc.) can be optimized from information derived from the receive digital processing at baseband. Refer to chart 24 for transmit.This type has the capability of being fully adaptive on receive and highly adaptive on transmit.

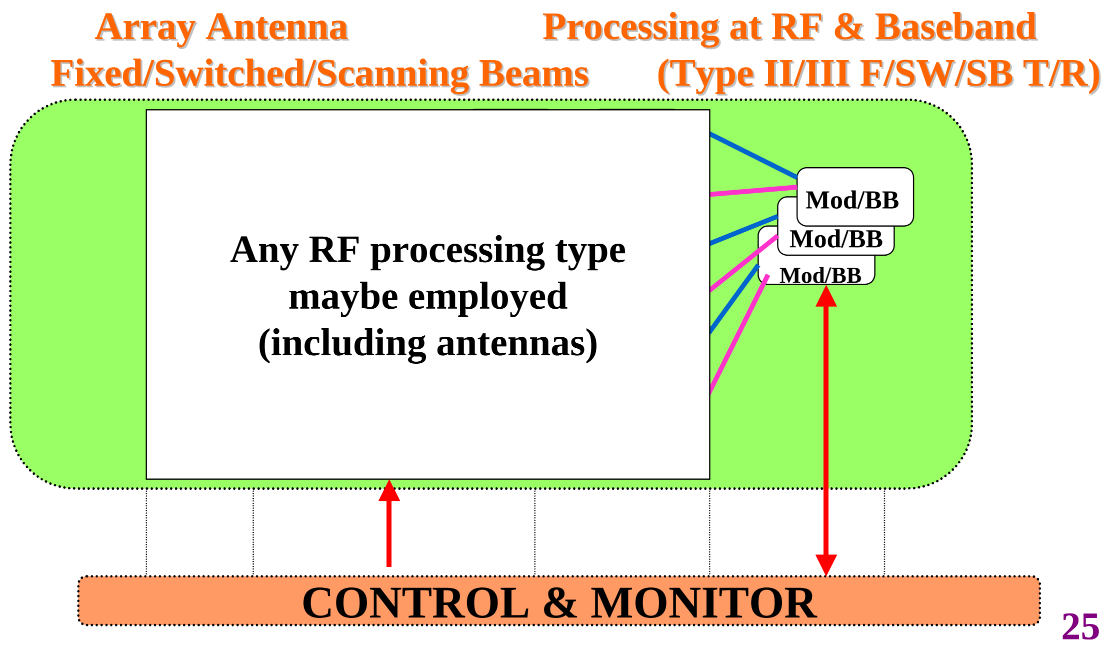
Note: See chart 24 for baseband transmit beamforming

Array Antenna Fixed/Switched/ Scanning Beams — Processing at Baseband (Type II BB F/SW/SB T)

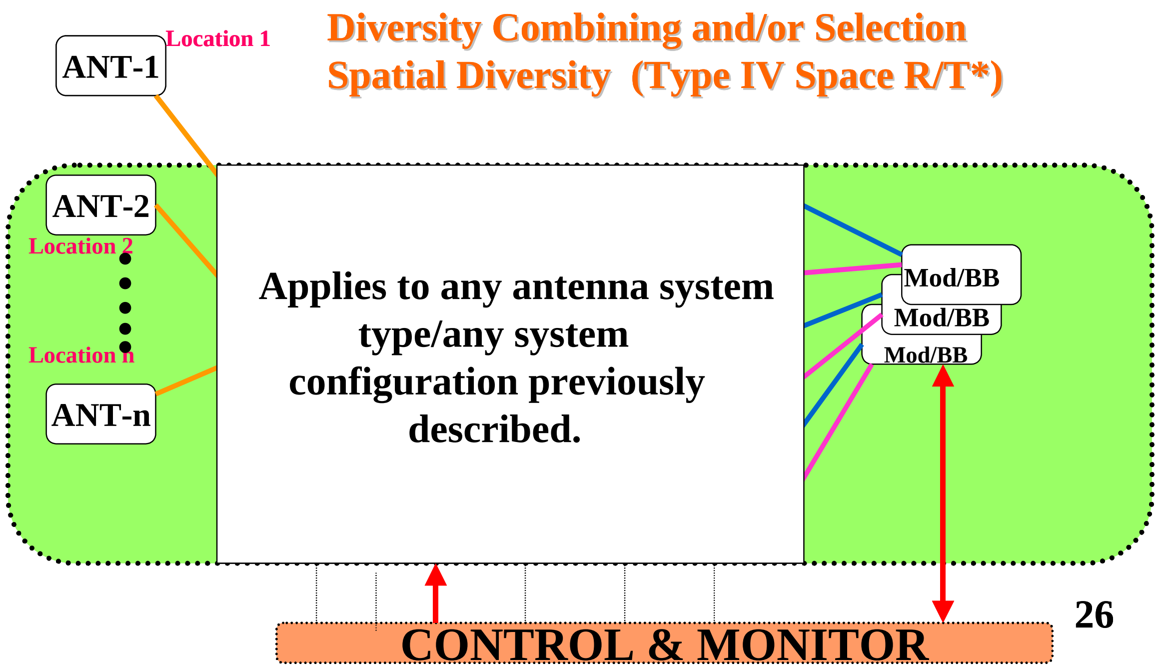


24

Shown is case for the transmit mode. Transmit beam characteristics (forming, shaping, etc.) can be optimized from information derived from the receive digital processing at baseband.

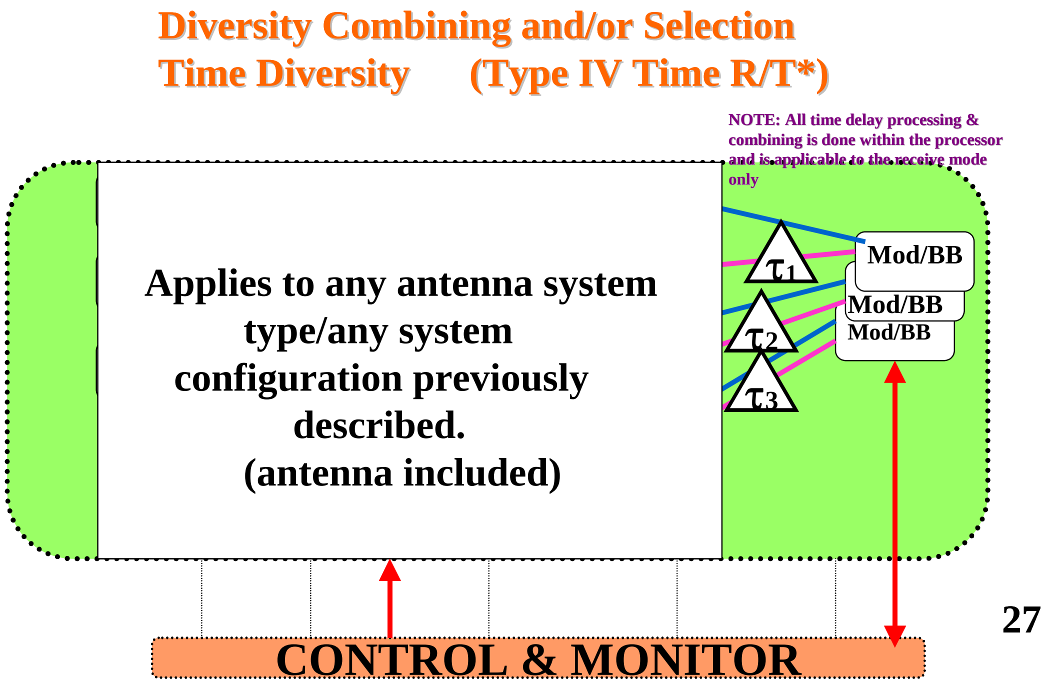


This configuration employs both Type II (RF processing) and Type III (baseband processing). All previous charts would apply for this configuration. This configuration has the capability of being fully adaptive on receive and on transmit.



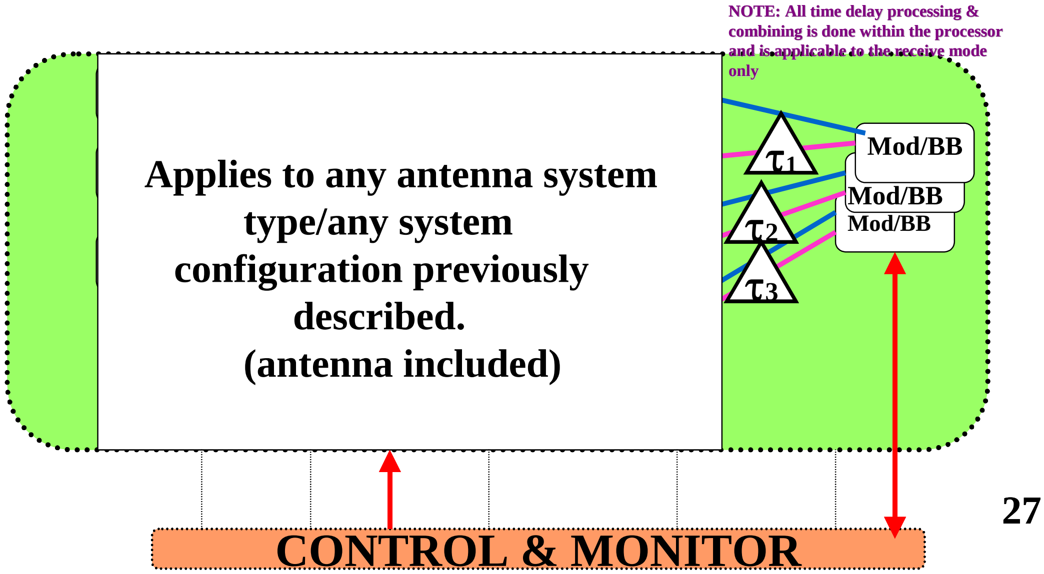
Can be applied to any of the antenna types (previously cited). Applicable only on receive. Selection can be accomplished @ RF/IF/ Baseband. Combining or selection can be accomplished baseband only. Typically two spatially separated antennas are associated with a diversity system: typically employed to minimize the effects of fades by spatially separating the antennas. Baseband processing algorithms usually employed to determine optimum antenna for transmit.*

7.1.1.3 Diversity Combining – Selection



Variable time delays are inserted by the modem baseband processing system to improve received signal quality.Can be applied to any of the antenna systems types (previously cited). Applicable only on receive. Selection can be accomplished @ RF/IF/ Baseband. Combining or selection can be accomplished baseband only. Typically employed to minimize the effects of fades by delaying signal received from the antennas. Baseband processing algorithms usually employed to determine optimum antenna delay for transmit.*

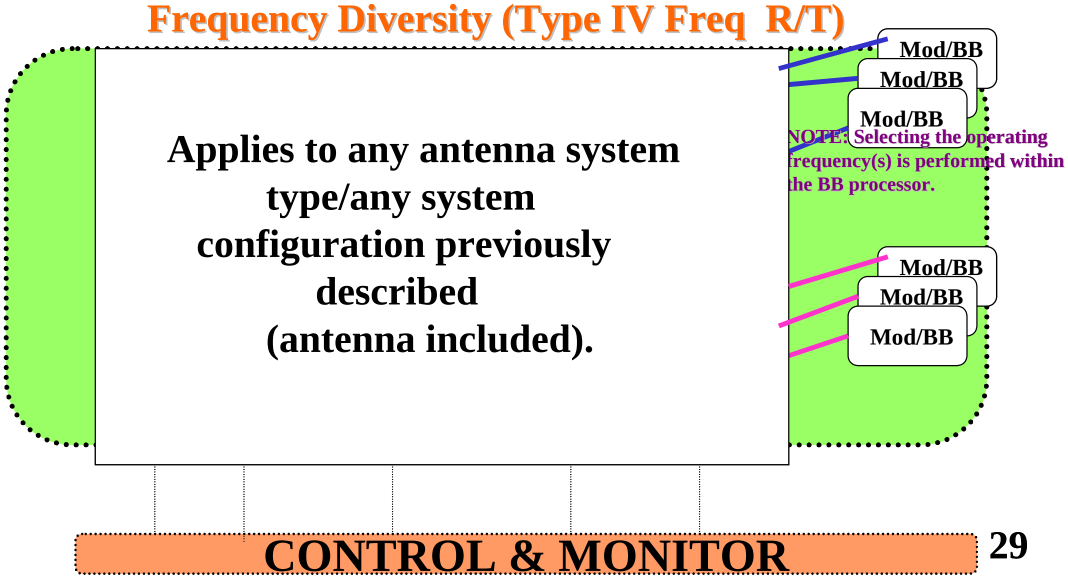
Diversity Combining and/or Selection
Time Diversity (Type IV Time R/T*)



27

Variable time delays are inserted by the modem baseband processing system to improve received signal quality.Can be applied to any of the antenna systems types (previously cited). Applicable only on receive. Selection can be accomplished @ RF/IF/ Baseband. Combining or selection can be accomplished baseband only. Typically employed to minimize the effects of fades by delaying signal received from the antennas. Baseband processing algorithms usually employed to determine optimum antenna delay for transmit.*

Diversity Combining and/or Selection
Frequency Diversity (Type IV Freq R/T)

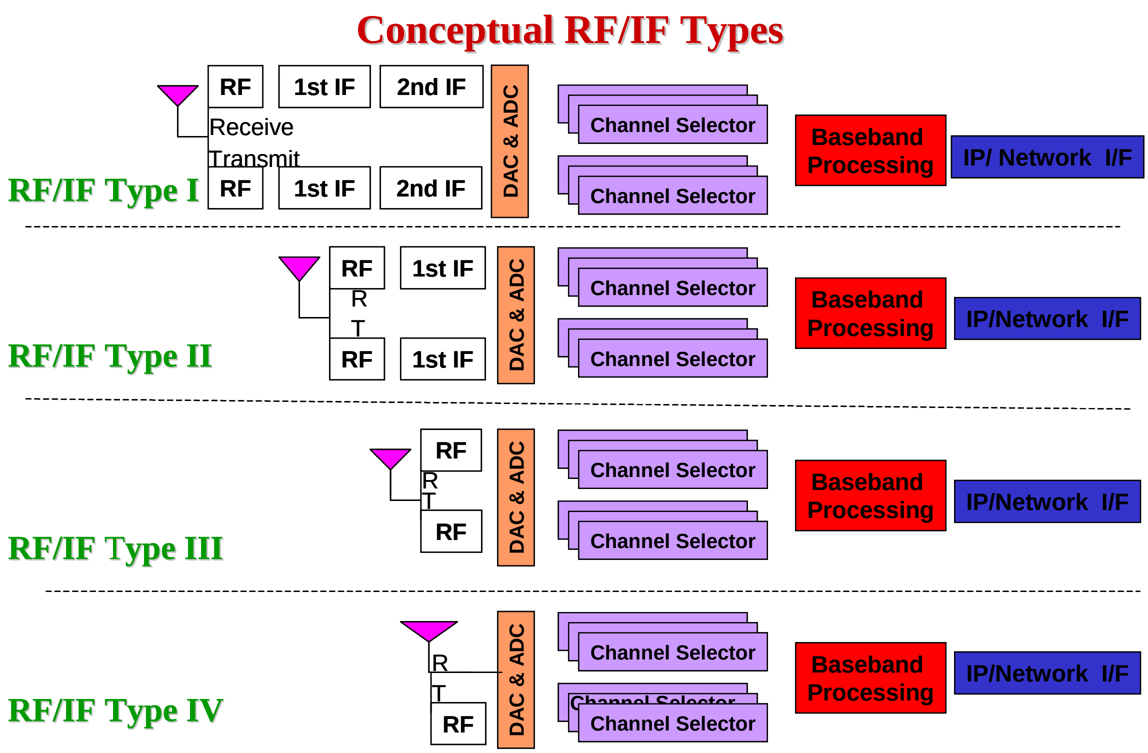


29

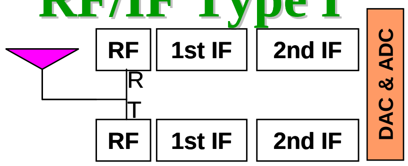
The same configuration employs two different carriers. Can be applied to any of the antenna types (previously cited). Applicable only on receive. Selection can be accomplished @ RF/IF/ Baseband. Combining or selection can be accomplished baseband only. Typically employed to minimize the effects of fades by changing the frequency the received at the antennas. Baseband processing algorithms usually employed to determine optimum frequency for transmit.*

7.1.2 RF/IF types

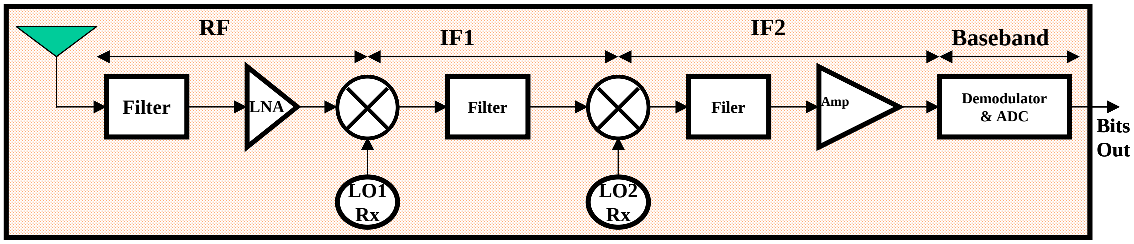
The following is a taxonomy of RF/IF structures



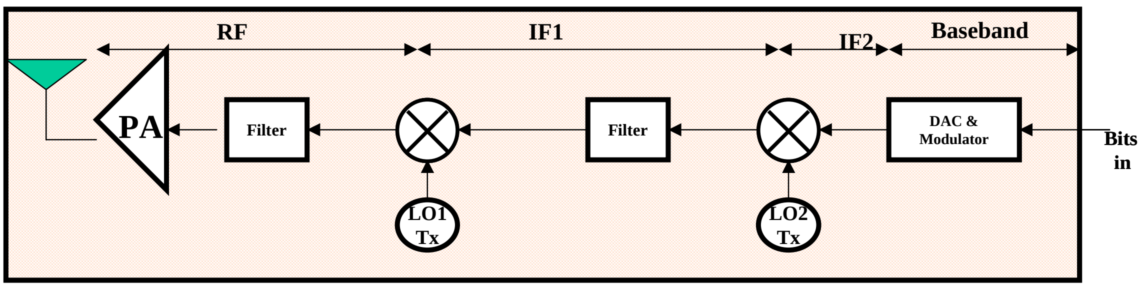
RF/IF Type I



This implementation employs two stages to frequency translate to the IF frequency input to the demodulator/ADC on the receive side and produce the RF frequency from the IF output of the modulator/DAC on the transmit side.The filters are used to optimize the bandwidth and eliminate unwanted products resulting from the conversion processes. The system typically requires accurate and stable Local Oscillators, and the LNA and conversion processes tend to limit linearity.

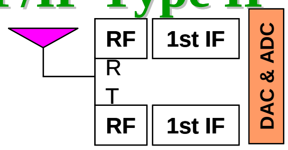


Receive

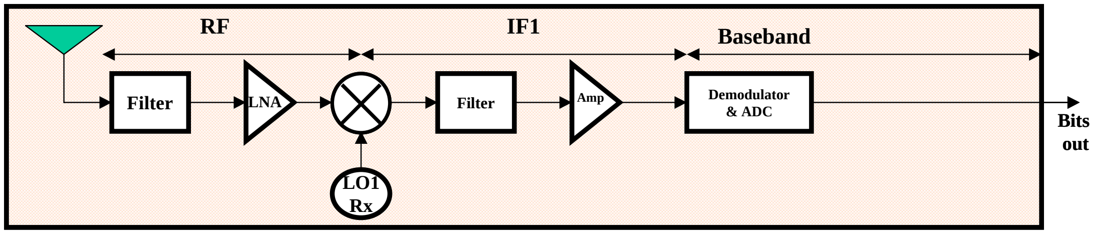


Transmit

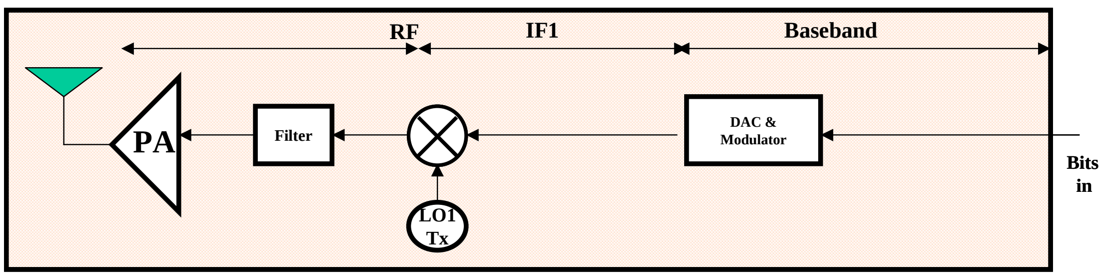
RF/IF Type II



This implementation employs one stage to frequency translate to the IF frequency input to the demodulator/ADC on the receive side and produces the RF frequency from the IF output of the modulator/DAC on the transmit side.The filters are used to optimize the bandwidth and eliminate unwanted products resulting from the conversion processes. The system typically requires accurate and stable Local Oscillators, and the LNA and conversion processes tend to limit linearity.



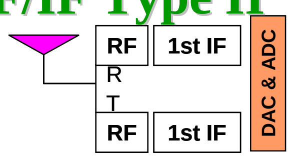
Receive



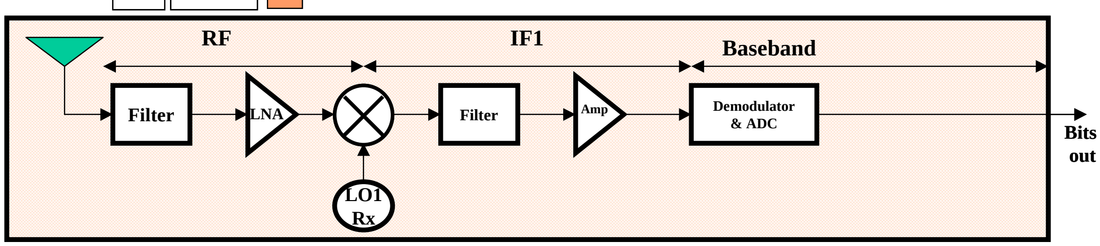
5

Transmit

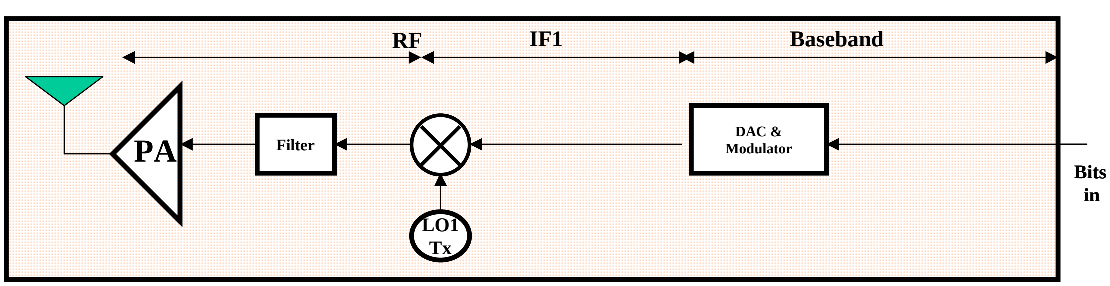
RF/IF Type II



This implementation employs one stage to frequency translate to the IF frequency input to the demodulator/ADC on the receive side and produces the RF frequency from the IF output of the modulator/DAC on the transmit side.The filters are used to optimize the bandwidth and eliminate unwanted products resulting from the conversion processes. The system typically requires accurate and stable Local Oscillators, and the LNA and conversion processes tend to limit linearity.

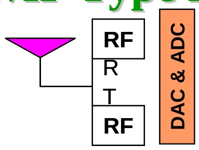


Receive

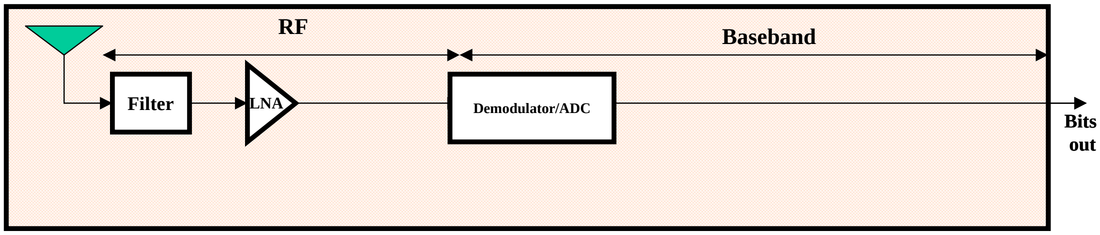


Transmit

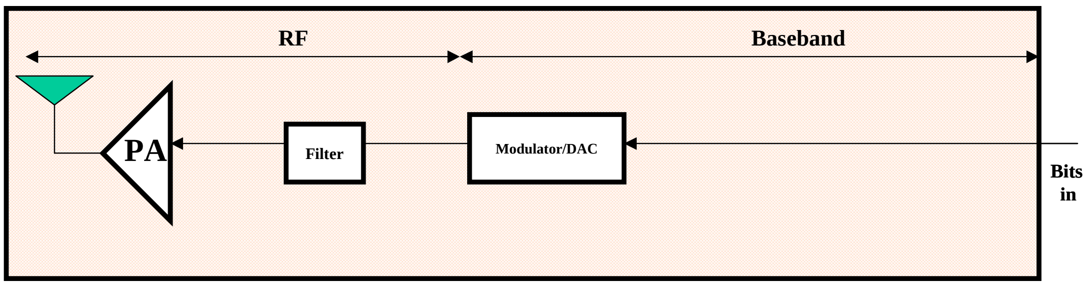
RF/IF Type III



In this implementation there is no conversion/IF process. On the receive side the RF signal after filtering and amplification is applied directly to the demodulator/ADC and on the transmit side the modulator/DAC produces the RF signal. The filters are used to optimize the bandwidth and eliminate unwanted products generated by the modulation/DAC process. The LNA on the receive side tends to limit linearity.

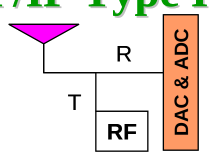


Receive

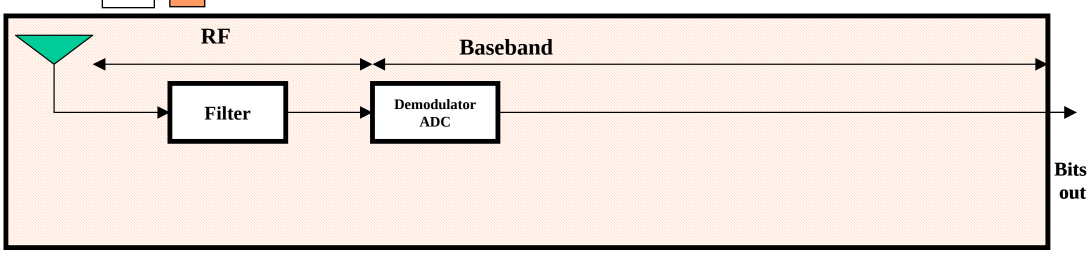


Transmit

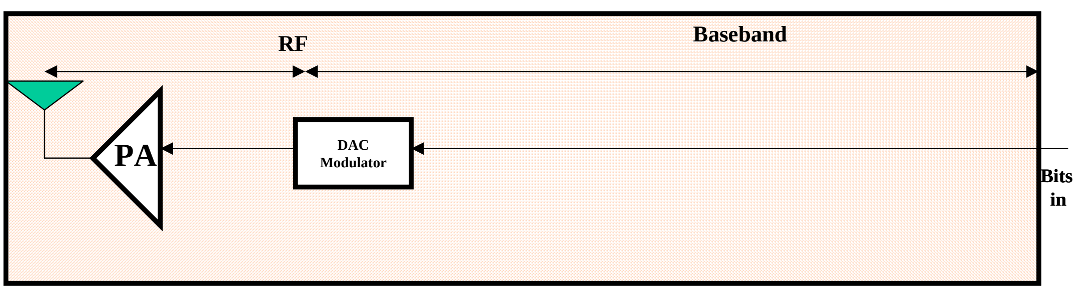
RF/IF Type IV



In this implementation there is no conversion/IF process. On the receive side the RF signal is converted directly to digital format using an ultra high speed ADC/demodulator to produce the baseband bit stream. On the transmit side the baseband signal is processed by the digital modulator and converted directly to the RF signal using an ultra high speed DAC/modulator. This implementation is the most advanced type and offers the potential for the ultimate SDR.

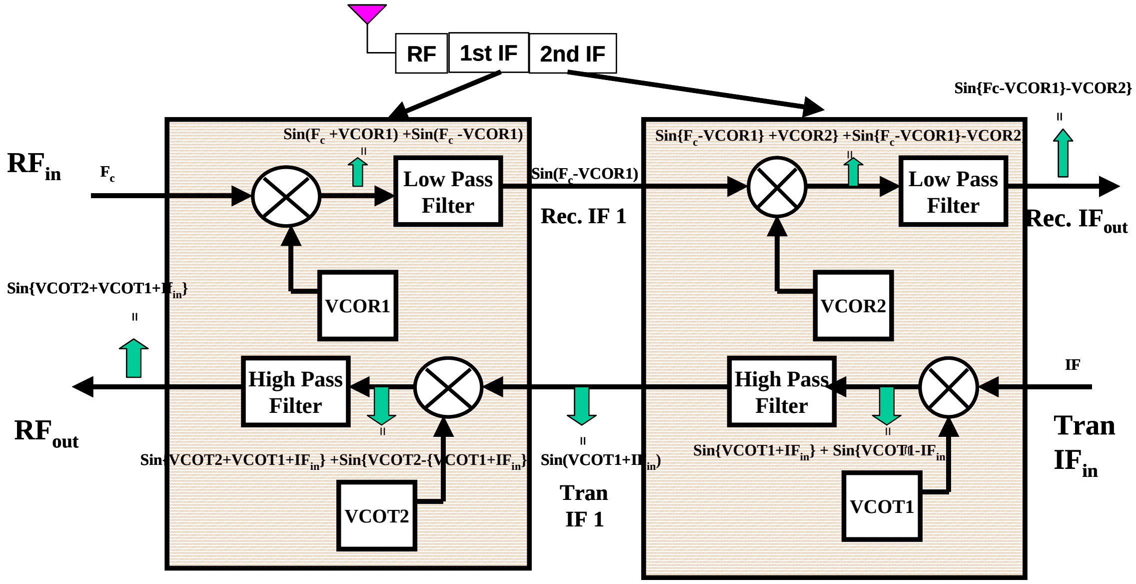


Receive

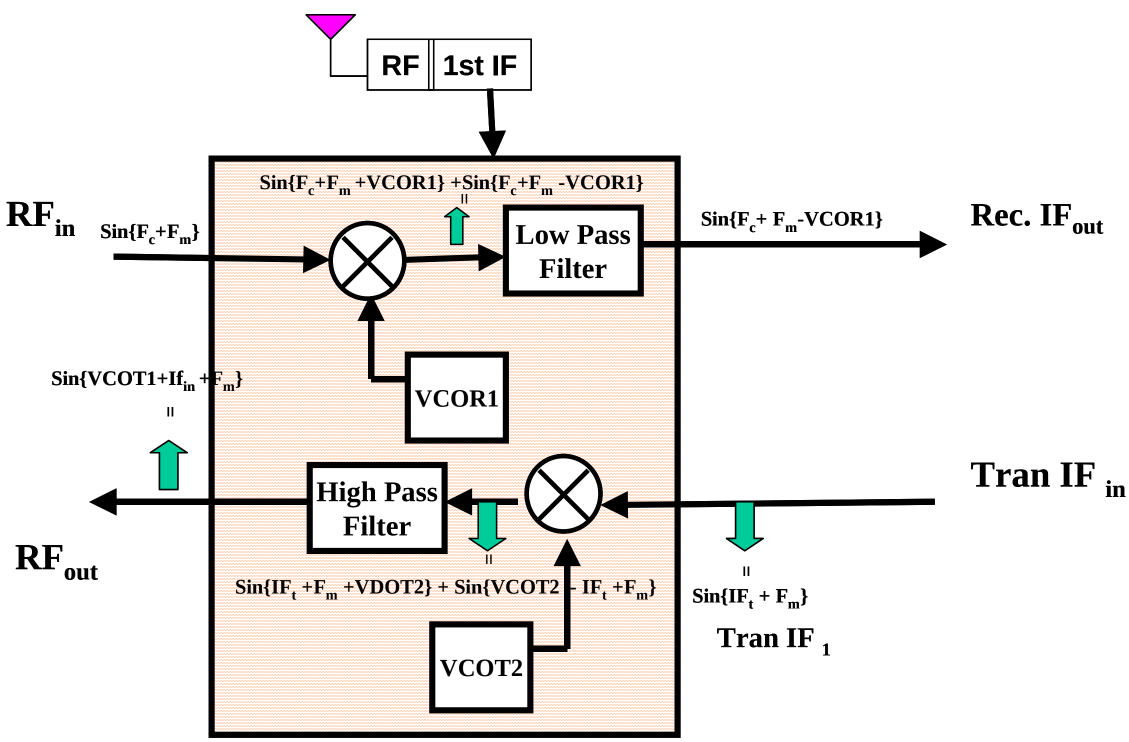


Transmit

Double Conversion

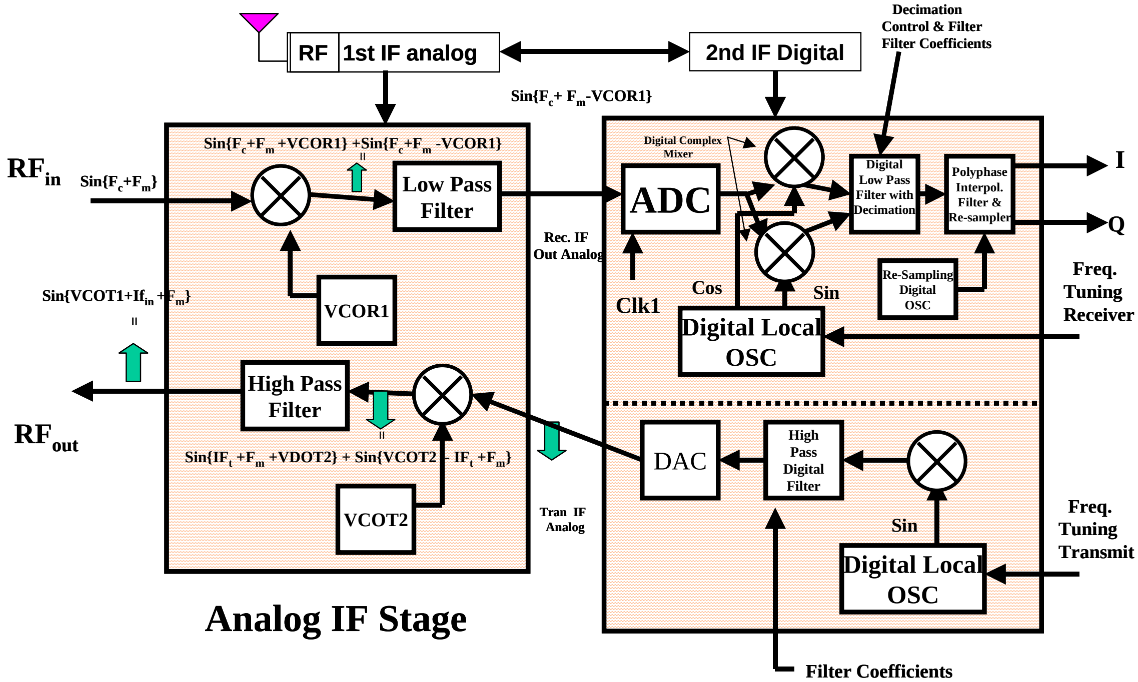


Single Conversion

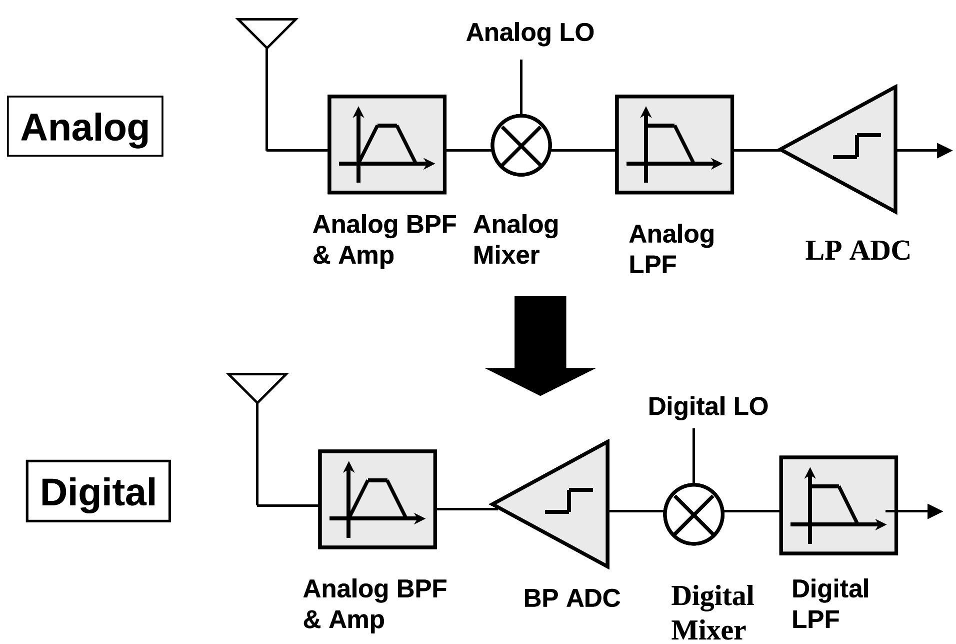


Mixed Conversion

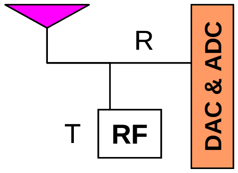
Analog and Digital

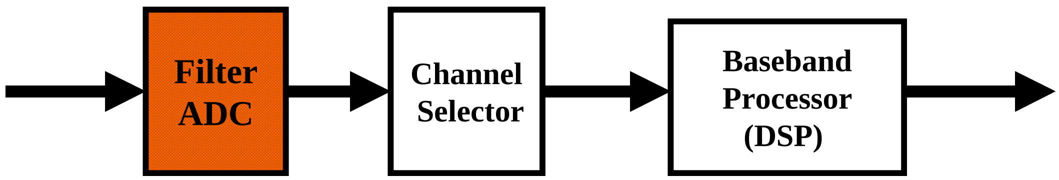


Digital vs. Analog Conversion



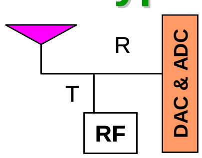
RF/IF Type IVa

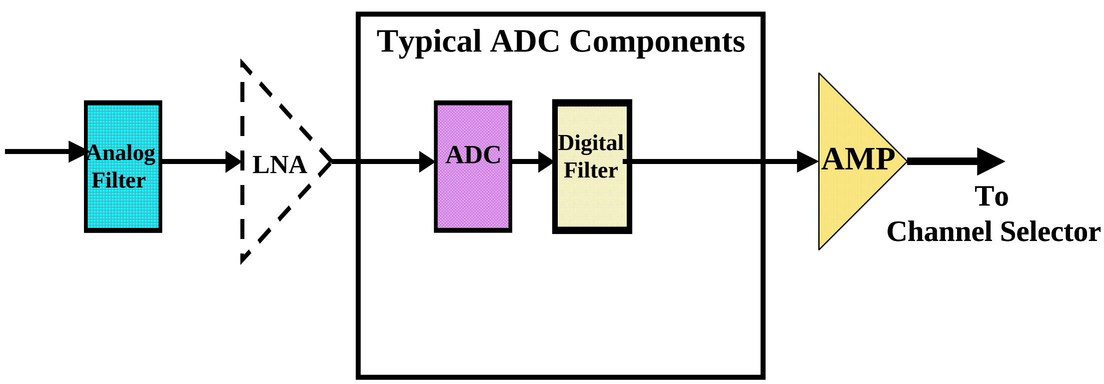




Receive

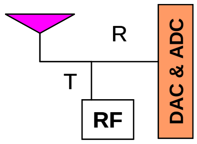
RF/IF Type IVa

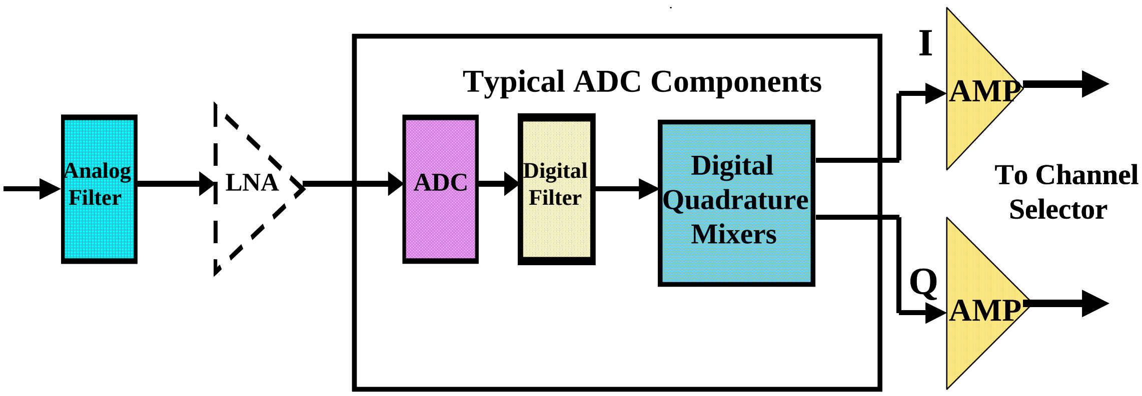




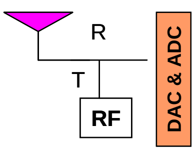
Receive

RF/IF Type IVb

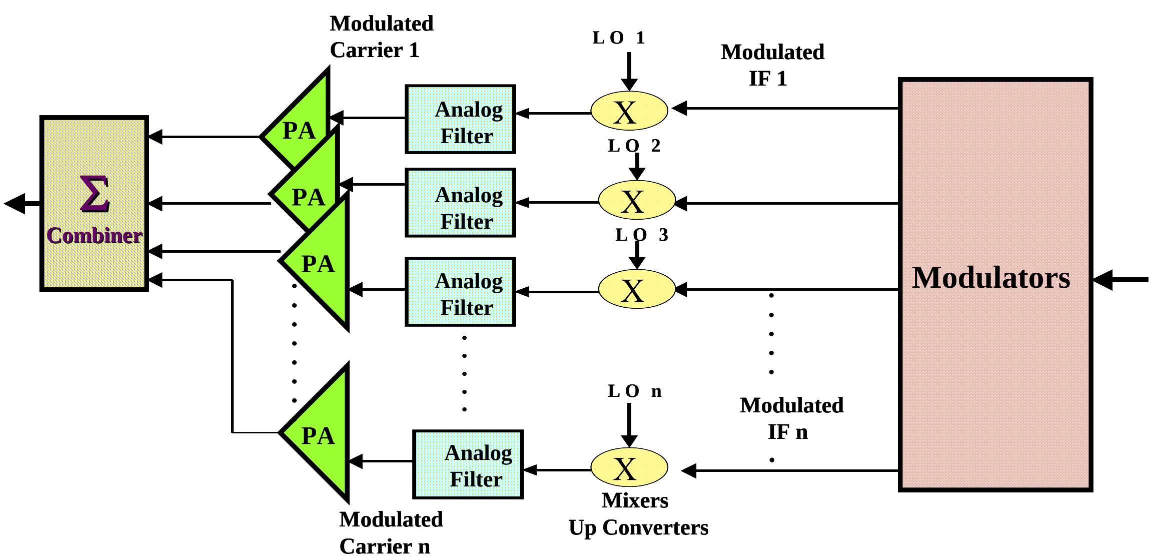




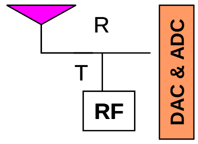
Receive



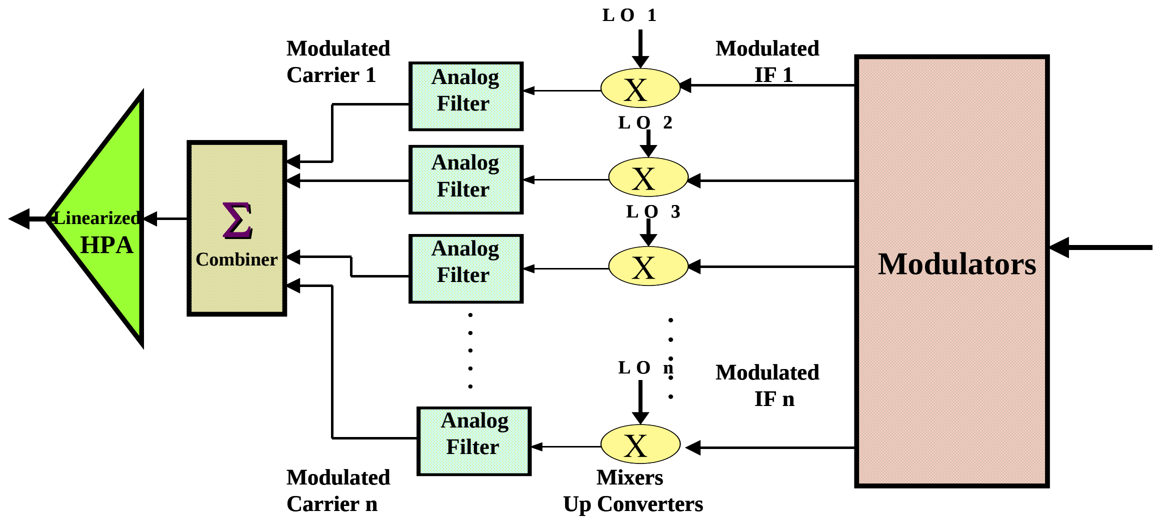
RF/IF: Analog Multiple Carriers (Multiple PAs)



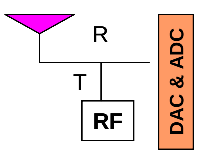
Transmit



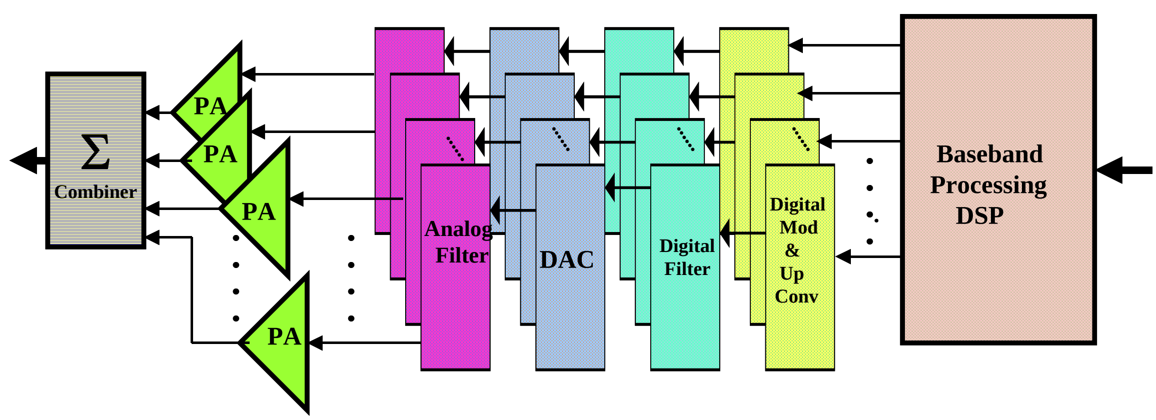
RF/IF: Analog Multiple Carriers (Single HPA)



Transmit



RF/IF: Digital Multiple Carriers (Multiple PAs)

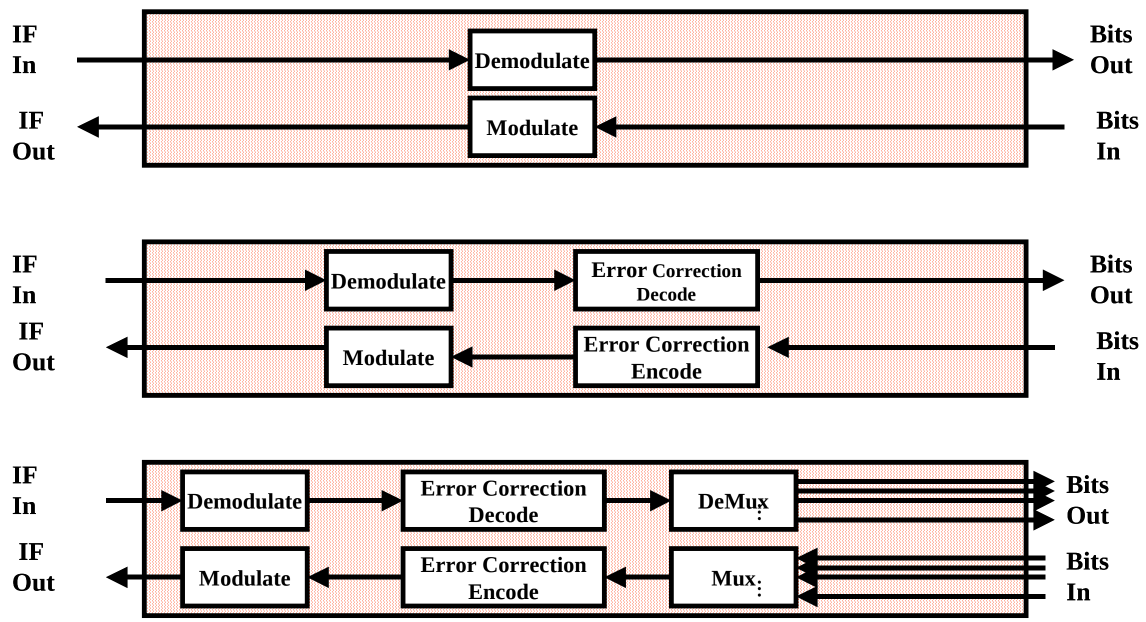


Transmit

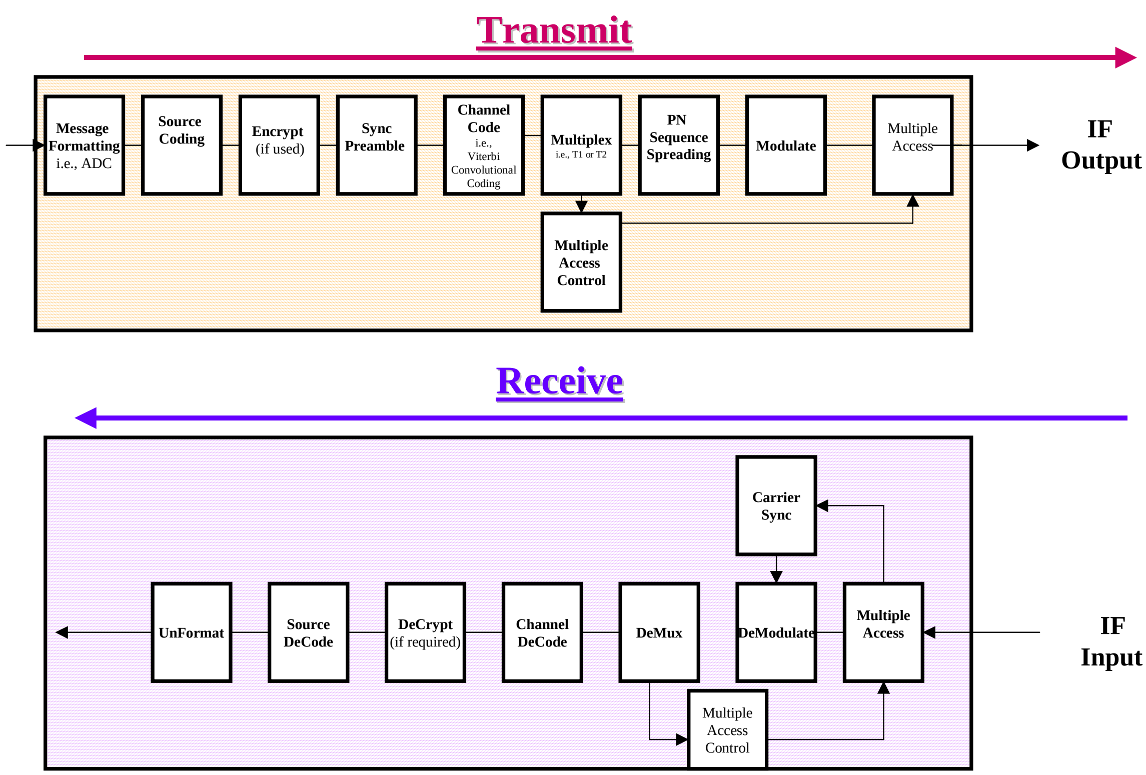
7.1.3 Modem types

The following is a taxonomy of modem types.

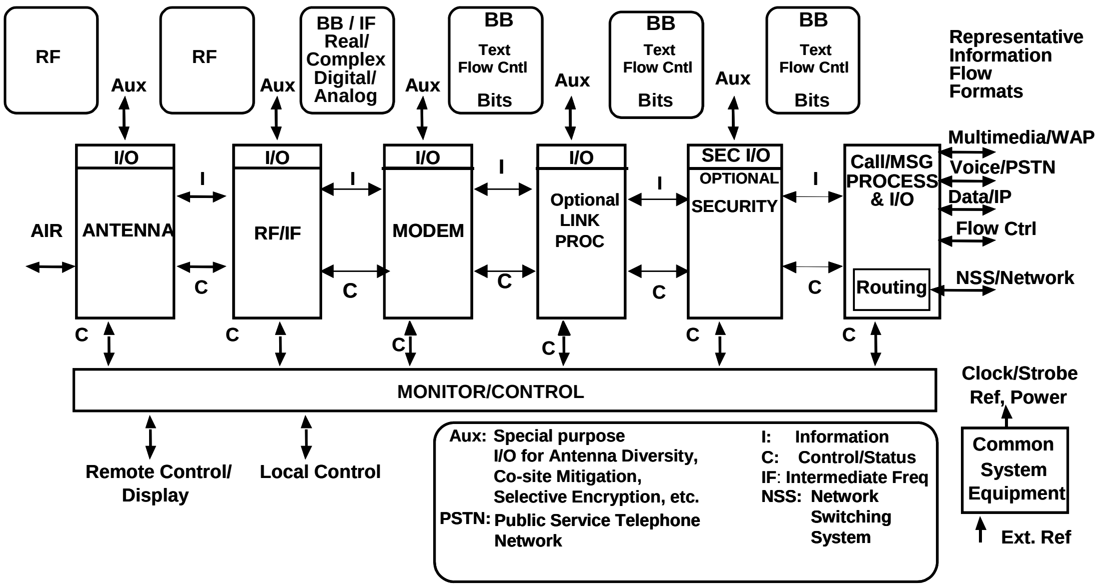
Digital Modem Evolution



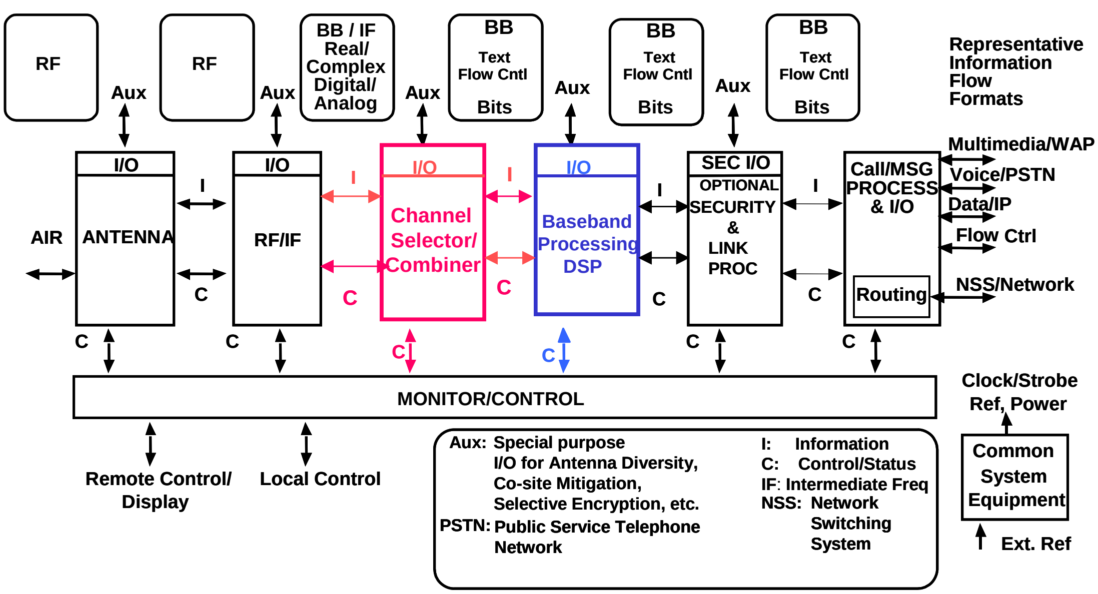
Typical functions performed in a modern digital modem



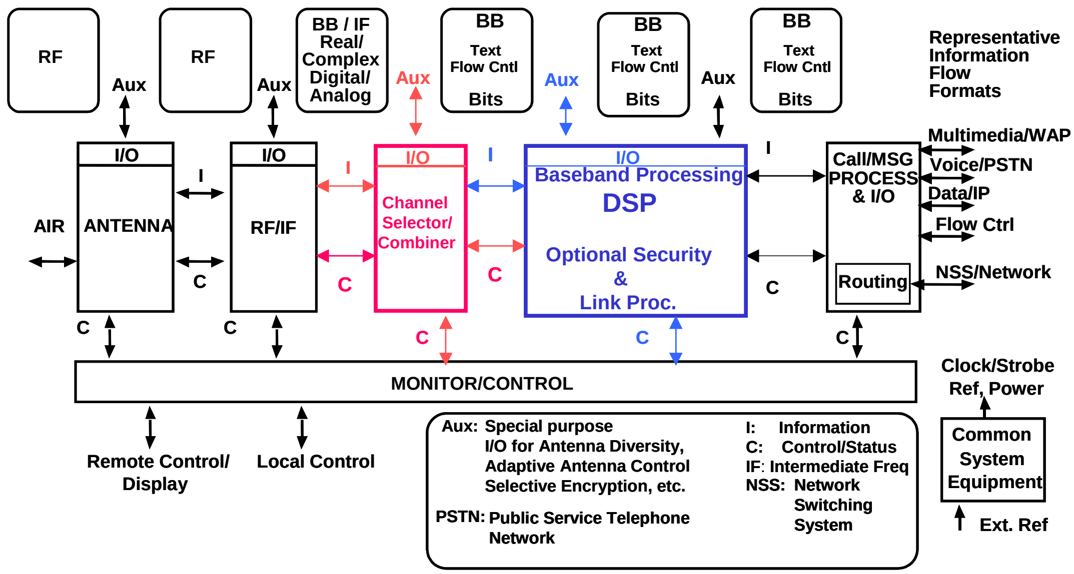
Generalized Functional SDR Architecture



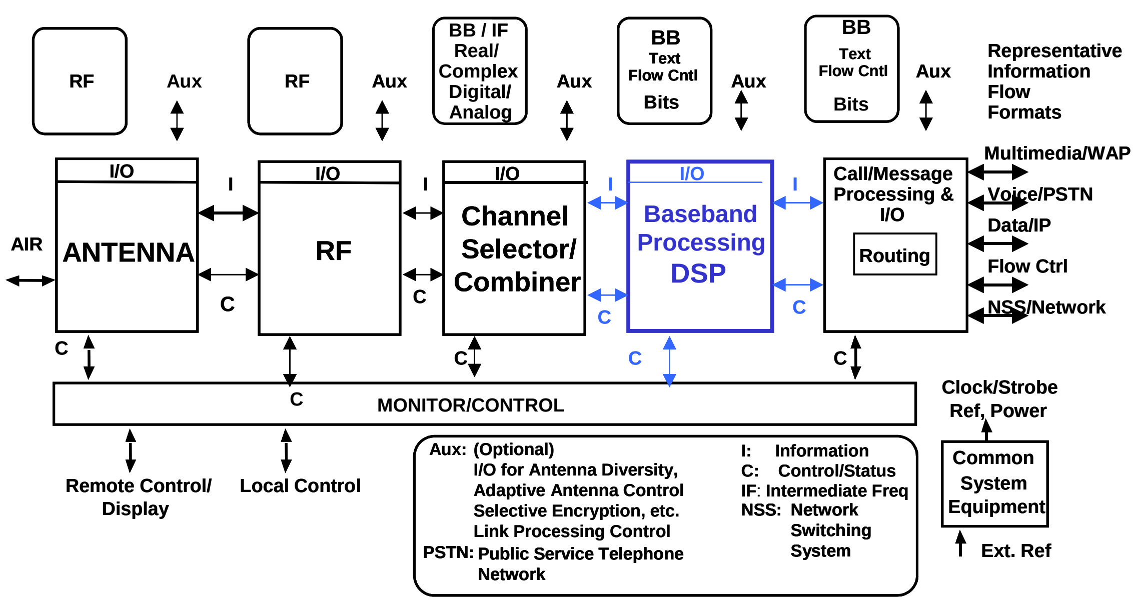
Generalized Functional SDR Architecture



Generalized Functional SDR Architecture Commercial



Generalized Functional SDR Architecture Commercial



SDR
Channel Selector/Combiner
Advanced Functionality

Trend toward High-Speed Digital Processing Technology

- Fully digital frequency tuning and channel selection
- Common digital sample rate for multiple air interfaces
- Programmable decimation and interpolation rates to support a very wide range of channel bandwidths