Velkommen

OZ8JYL

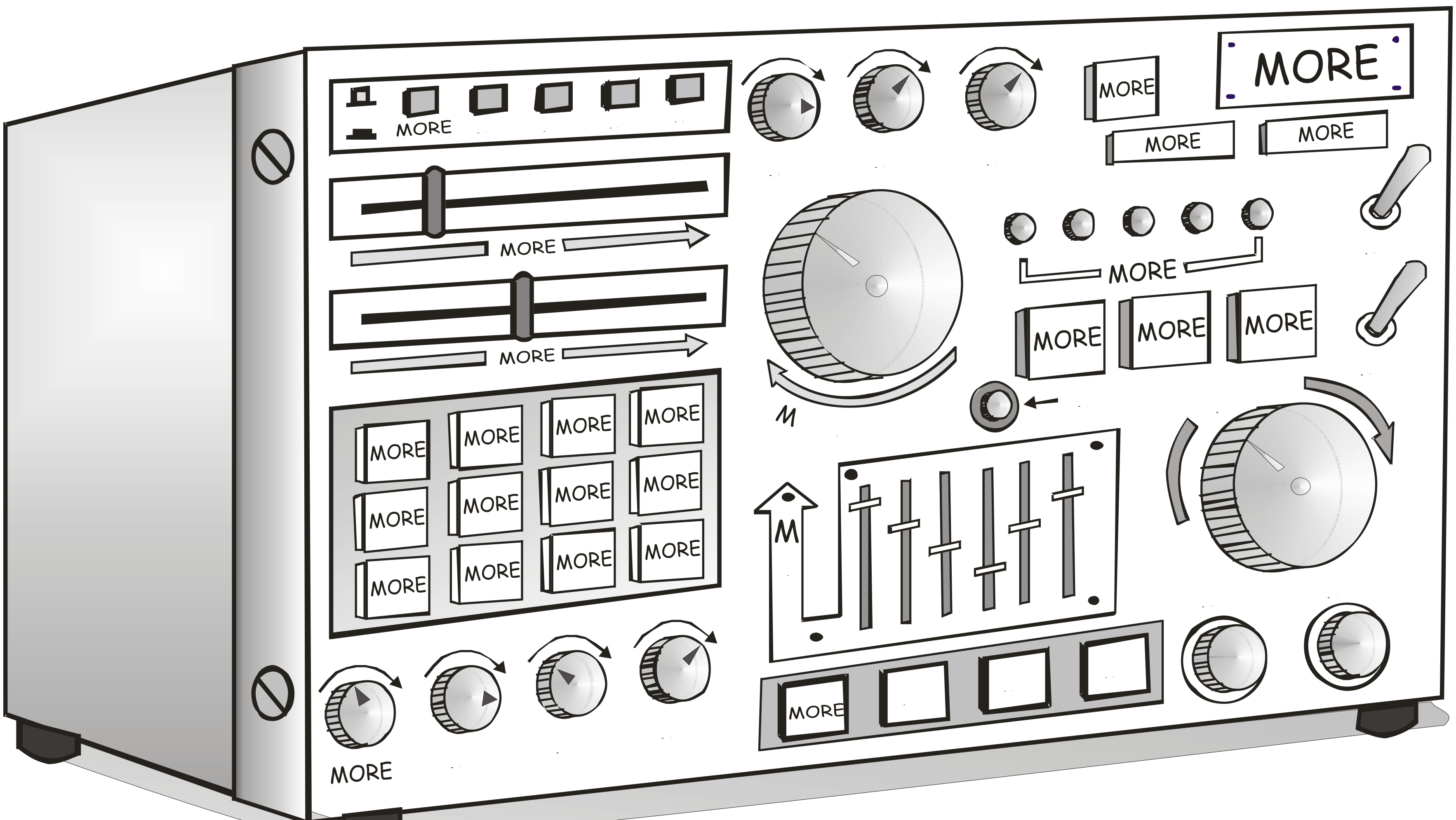
CLUB STATION

AALBORG

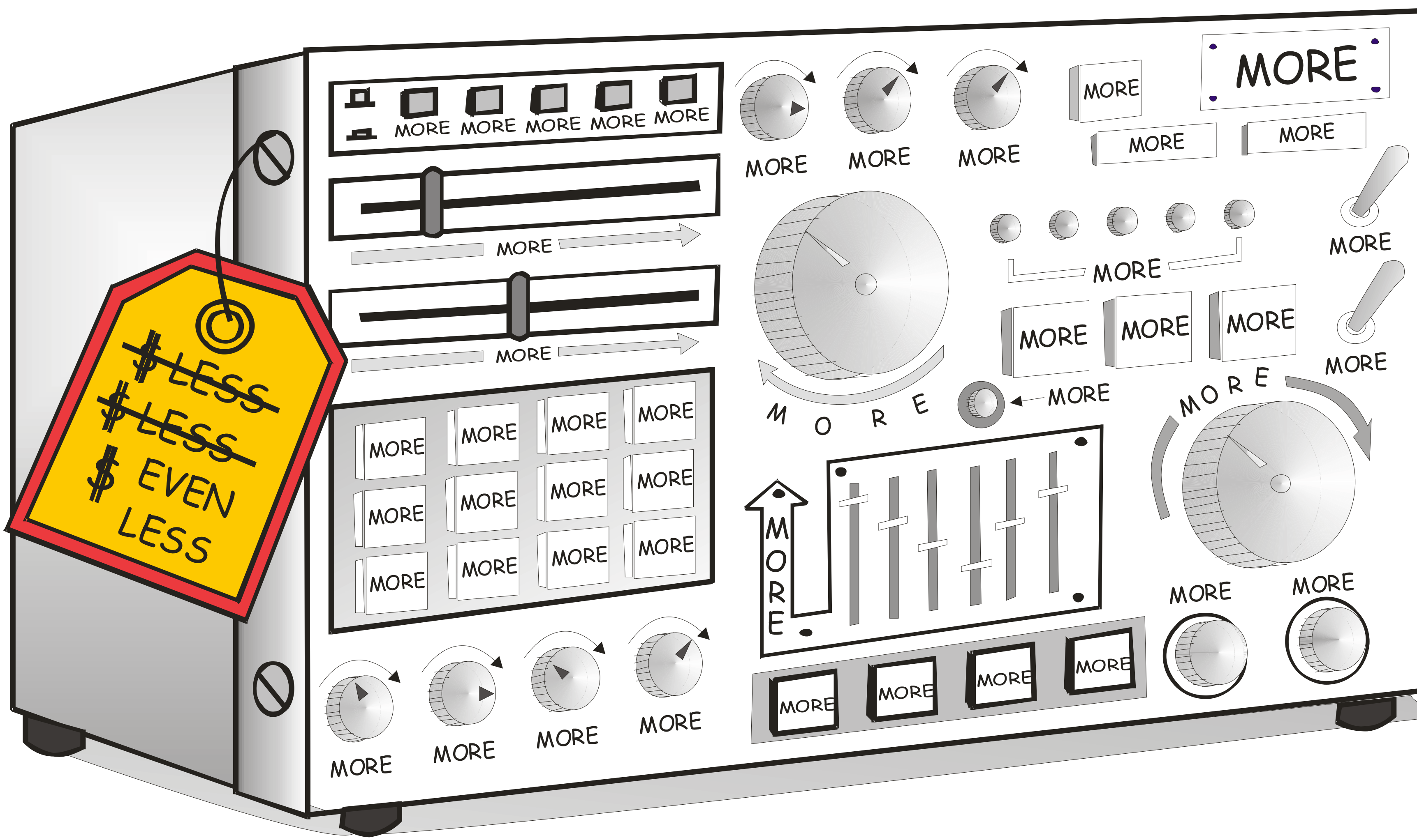
SDR – hvad, hvorfor, hvordan

Peter Koch, Civiling., PhD
lektor, Aalborg Universitet

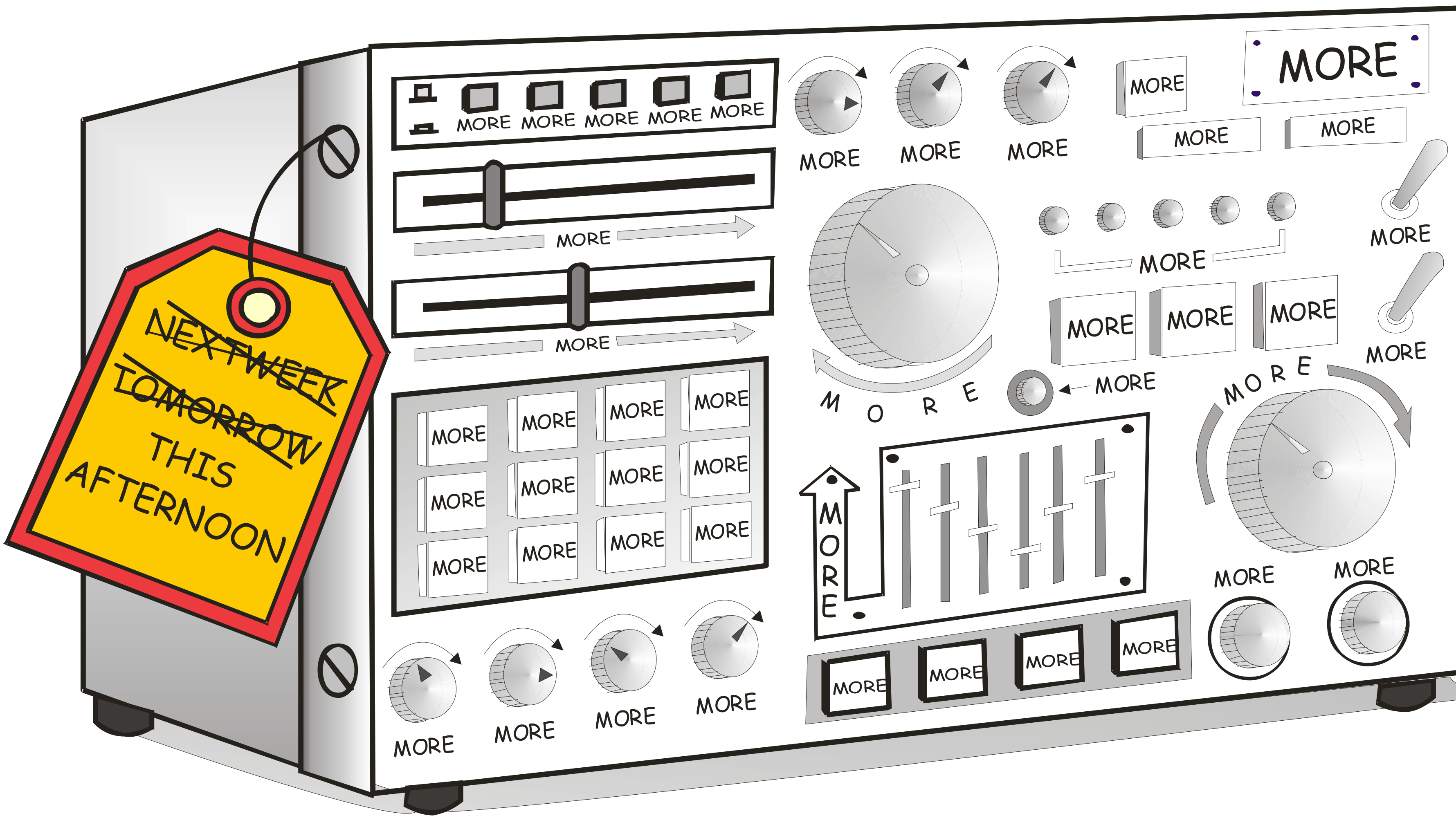
Hvad kunden ønsker…



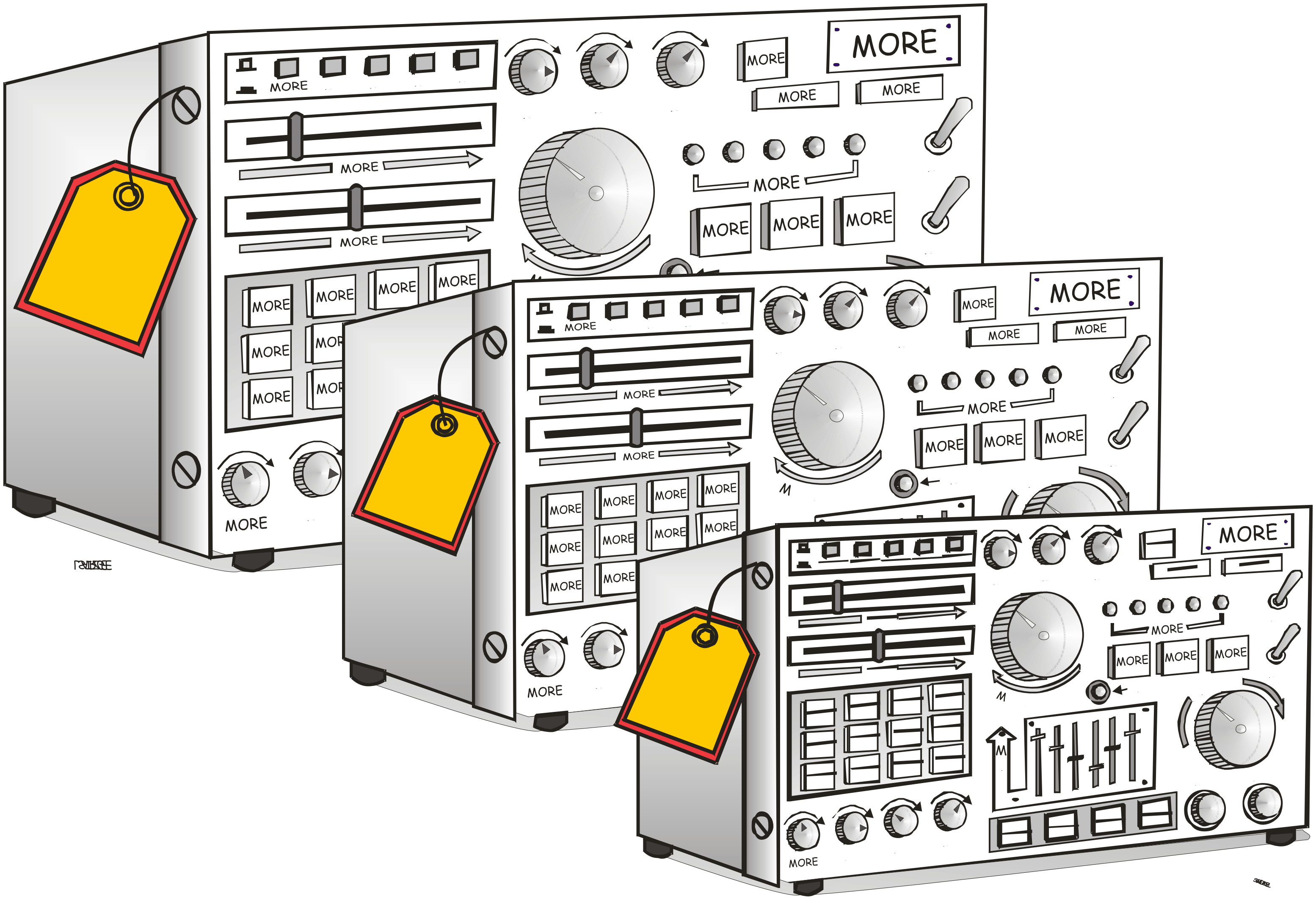
Hvad kunden vil betale...



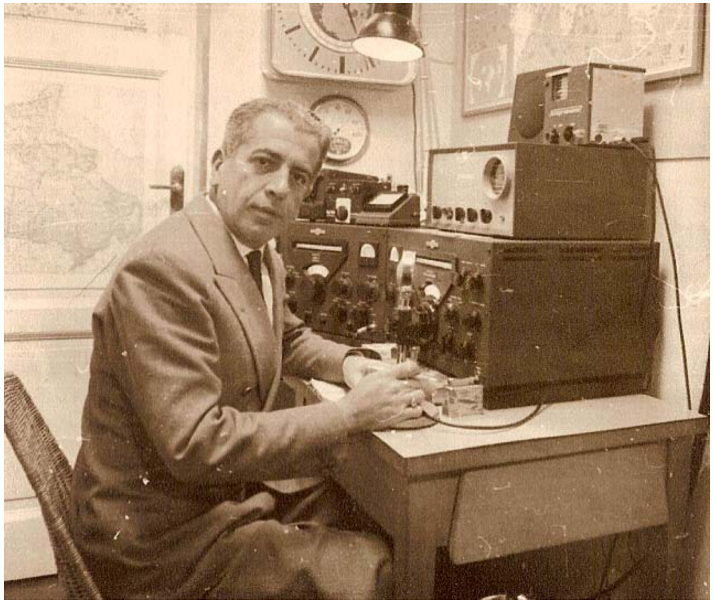
Kundens ønske til leveringstid…



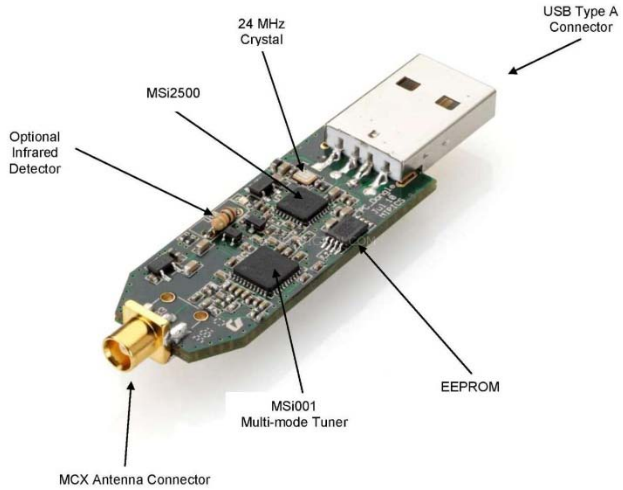
Kundens ønske til størrelse…



Urealistisk..??

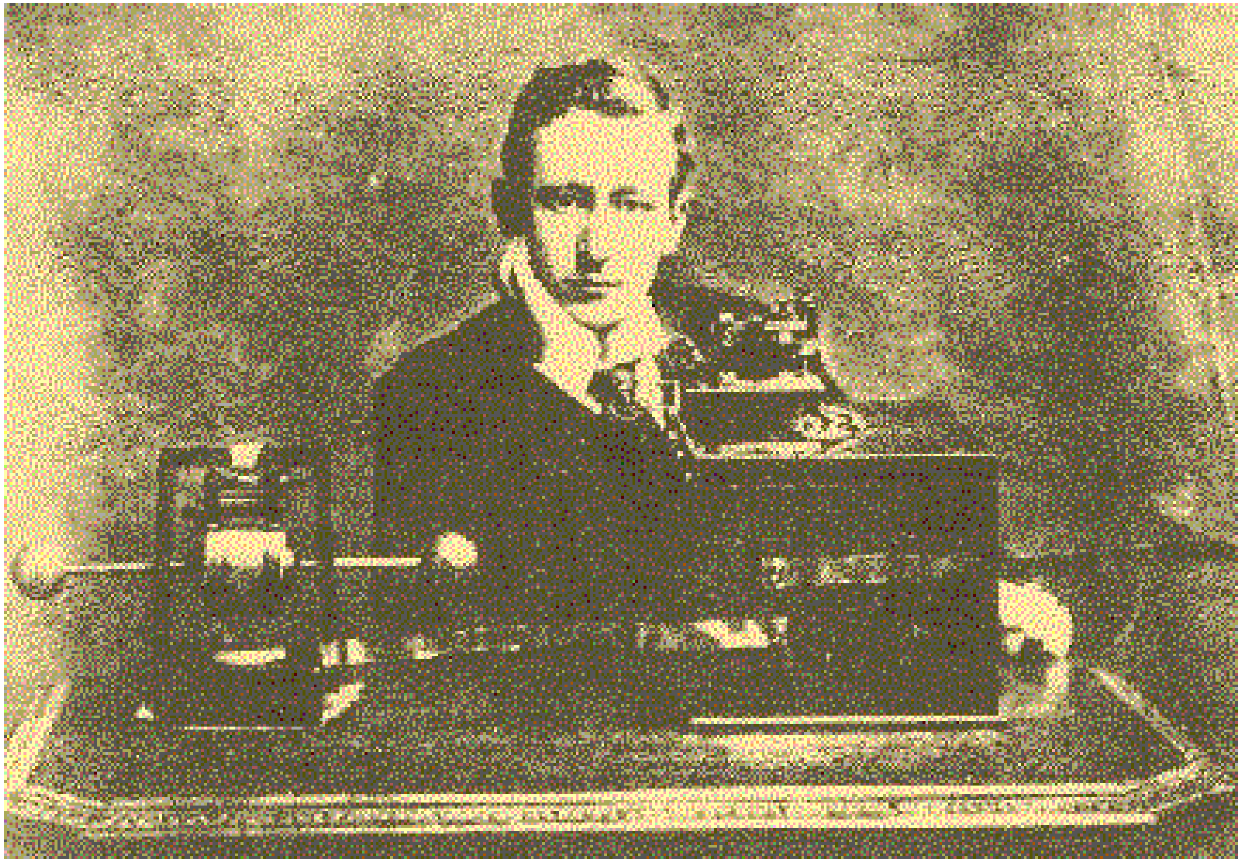


Ja, helt sikkert i ”gamle dage” …



…men ikke nødvendigvis i dag.

”It is dangerous to put limits on wireless”



Gugliemo Marconi
1932

So, what is Software Radio..??

"A radio in which some or all of the physical layer functions are software defined"

- Mange standarder
- Mange protokoller
- Meget funktionalitet til lille pris
- Lille fysisk størrelse
- Remote fejl-korrektion og opdateringer
- Adaptive security

"Software Radio"
- omtales første gang i 1985

NEW RESEARCH LAB LEADS TO UNIQUE RADIO RECEIVER

**by Space Systems Technology Group, Garland Division*

Necessity does indeed lead to invention. A group of Garland E-Teamers had to create an ultra-fast data processor, configured as a digital radio receiver, because their large general purpose computer was too slow to run a promising new radio signal processing technique being developed in an R&D project. Experts who have seen it — customers, consultants, associate contractors — all agree that the new digital computer based receiver, called the Software Radio, has the potential to revolutionize the field of processing very complex radio signals.

* **The Software Radio** is the first sellable product produced in the new Digital Signal Processing Laboratory (DSP Lab) of Garland's Space Systems Department. The primary goal of this Lab is to provide research personnel the capability to develop and test advanced receiver processing concepts for signals of interest to Space Systems — signals received at such low levels that they are literally buried in radio noise. Many of these signals have such poor quality that traditional signal processing receivers provide little, if any, useful information. The new DSP Lab will also be used as a signal analysis facility to process and extract the transmitted information from other radio signals which have been received under adverse conditions by various customers and sent to the lab on magnetic tape. Wideband signals received at signal strengths as low as -20dB can be processed.

This unique Lab was established in an Independent Research and Development project by a team of Space Systems scientists and engineers. The team was led by Russell McKown and included Phil Evans, John McKown, Gary Breaux, Tom Summers and Dillard Lane. Over $500,000 of E-Systems capital equipment was integrated to create the first phase of the DSP Lab last August. This new signal processing concept quickly attracted widespread attention and the Lab is now being expanded in a customer-funded project to develop and demonstrate a full scale Software Radio.

The Lab became a necessity because of advances in signal processing techniques. Here is the story.

Space Systems scientists have devoted considerable research effort over the past four years to the development of higher performance digital receivers. The emphasis of the research to date has been directed toward the processing of frequency-modulated and phase-modulated digital signals (signals in which the information is pulse coded into a string of ones and zeros), which are received in the presence of severe radio interference. The present set of receiver designs in Space Systems is based on an E-Systems proprietary concept called Adaptive Digital Demodulation and Synchronization (ADDS). This method uses digital matched filters which automatically adapt to the characteristics of the incoming signal environment to synchronously demodulate complex signals embedded in very heavy interference.

Although they had obtained impressive performance for ADDS based receivers before last year, the team had measured this performance using idealized computer simulations which operated at a small fraction of the full rate of the wideband signals. Further ADDS development would require testing at computational rates available heretofore only in specially designed high speed hardware processors. They would have to design and build an engineering prototype receiver. However, although ADDS based receivers enjoy a performance/cost ratio that is significantly better than for competing designs, a hardware prototype development effort would still require considerable time and IR&D funding. Hence the idea for the DSP Lab with a software processor operating in relatively low cost commercially available high speed computers.

The Lab consists of three basic equipment groups: tape and disk recorder equipment, control/monitoring and analysis equipment, and digital processing equipment. Signals to be processed are introduced from wideband analog or digital tape recorders into the digital processors under control of the operator's monitoring console. Processed signals are stored on the magnetic disk for examination on the analysis equipment or for forwarding to a general purpose computer for off-line analysis.

The processing horsepower of the Lab is supplied by a bank of sixteen FPS 5430 Array Processors — very high speed but special purpose digital computers. The heart of the Lab, the device which permits a single stream of data to be partitioned into parallel array processors and then successfully

reunited, is a DPS 2400 Dimensional Processor, a special input/output controller with memory. Together, the DPS 2400 and the FPS 5430s provide the high speed data transfers and computational power which permit the functions of a high performance digital receiver to be executed at full speed in a software implementation. This means that the DSP Lab's Software Radio is programmable, like any other computer. Unlike special purpose hardware processors, it can be quickly converted to perform different processing functions on received signals having different formats or different noise environments.

The DSP 2400 contains 24 Megabyte/sec internal data bus and mass memory system and a series of programmable 12 Megabyte/sec data interfaces. The FPS 5430 is an integrated package of four array processors which offers a computational rate of 60 million floating point operations per second — 60 Megaflops. (An "operation" is an arithmetic multiply or add.) Both units have high-level software development packages and extensive assembly code libraries which can be hosted on Space System's VAX 11/780 computer using the VMS operating system.

* **With the DSP Lab**, new ADDS based receiver designs can be conveniently implemented as full speed software processors and then be realistically tested. This not only provides a proof-of-concept demonstration (always required by prospective customers) but also produces a saleable digital signal processor. These software based digital receivers are capable of complete end-to-end processing of signals which cannot be successfully handled by existing hardware based receiver designs.

Dillard Lane (seated) and Gary Breaux at the operator's console of the DSP Lab, use the software radio to search for an unusual signal in a heavy interference spectrum.

04 1985

Formaliseres i start-90’erne

Joseph Mitola III
“The Godfather” of software radio

"A software radio is a radio whose channel modulation waveforms are defined in software. That is, waveforms are generated as sampled digital signals, converted from digital to analog via a wideband DAC and then possibly upconverted from IF to RF. The receiver, similarly, employs a wideband Analog to Digital Converter (ADC) that captures all of the channels of the software radio node. The receiver then extracts, downconverts and demodulates the channel waveform using software on a general purpose processor."

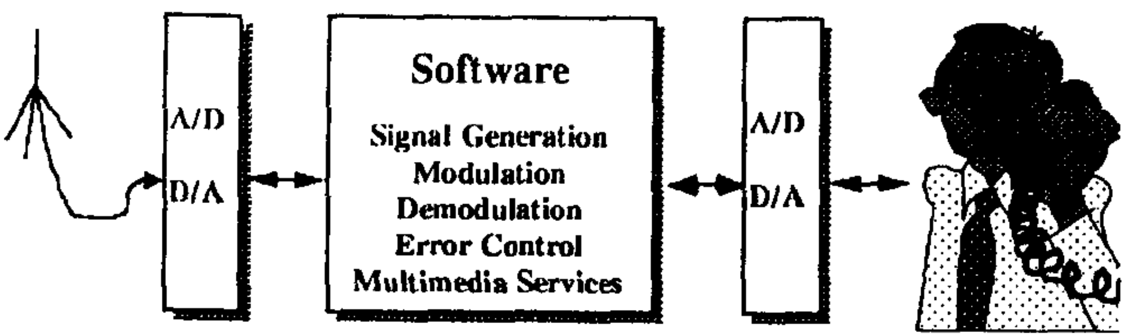


Fig. 1. An Idealized Software Radio

Software Radios; Survey, Critical Evaluation and Future Directions

IEEE National Telesystems Conference, 1992

sdrforum.org (*)
- introducerer i start-00'erne en taksonomi

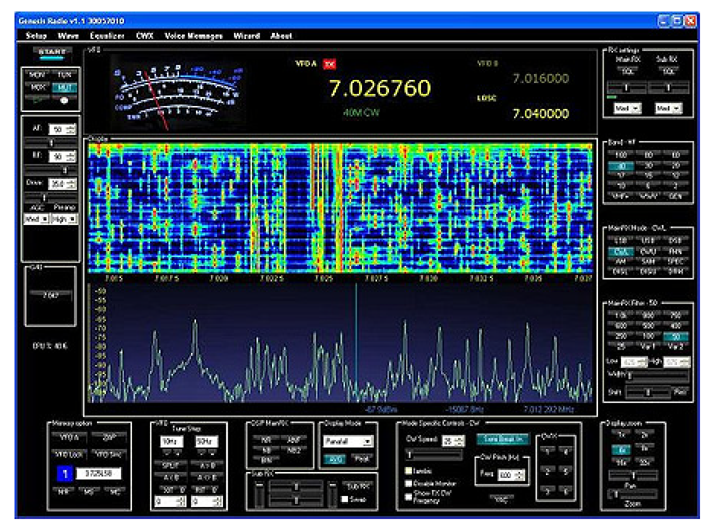
Hardware Radio, HR

Software Controlled Radio, SCR

Software Defined Radio, SDR

Ideal Software Radio, ISR

Ultimate Software Radio, USR



* I dag http://www.wirelessinnovation.org/

Major technology driver

Joint Tactical Radio System (JTRS), US Department of Defense

• Påbegyndt i 1997 pba. mange inkompatible systemer

"US army had short-range models for talking with the reconstruction team; longer-range versions for reaching headquarters 25 miles away; and a backup satellite radio in case the mountains blocked the transmission. An Air Force controller carried his own radio for talking to jet fighters overhead and a separate radio for downloading streaming video from the aircraft. Some of these radios worked only while the troopers were stationary; others were simply too cumbersome to operate on the move."

• Afbrudt 15 år senere i 2012

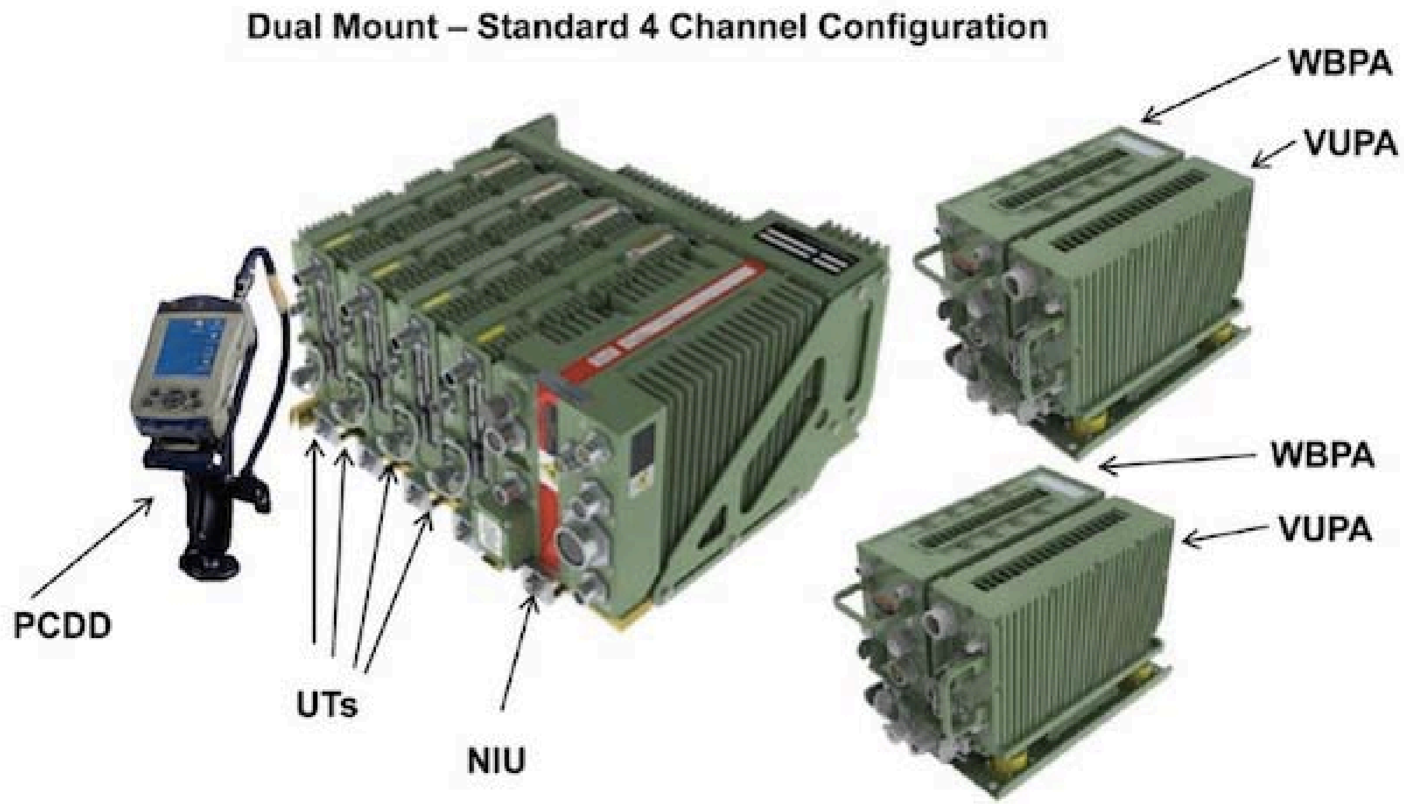
"Our assessment is that it is unlikely that products resulting from the JTRS Ground Mobile Radio (GMR) development program will affordably meet Service requirements, and may not meet some requirements at all. Therefore, termination of the program is necessary."

• Pris; 6 mia. USD

• Men…

The core of JTRS is the *Software Communications Architecture (SCA)*, an application framework for radios built on the *Common Object Request Broker Architecture (CORBA)* and a POSIX-based real-time operating system. SCA has managed to find a life outside of DOD in an open-source implementation that runs on Windows and Linux, called OSSIE.

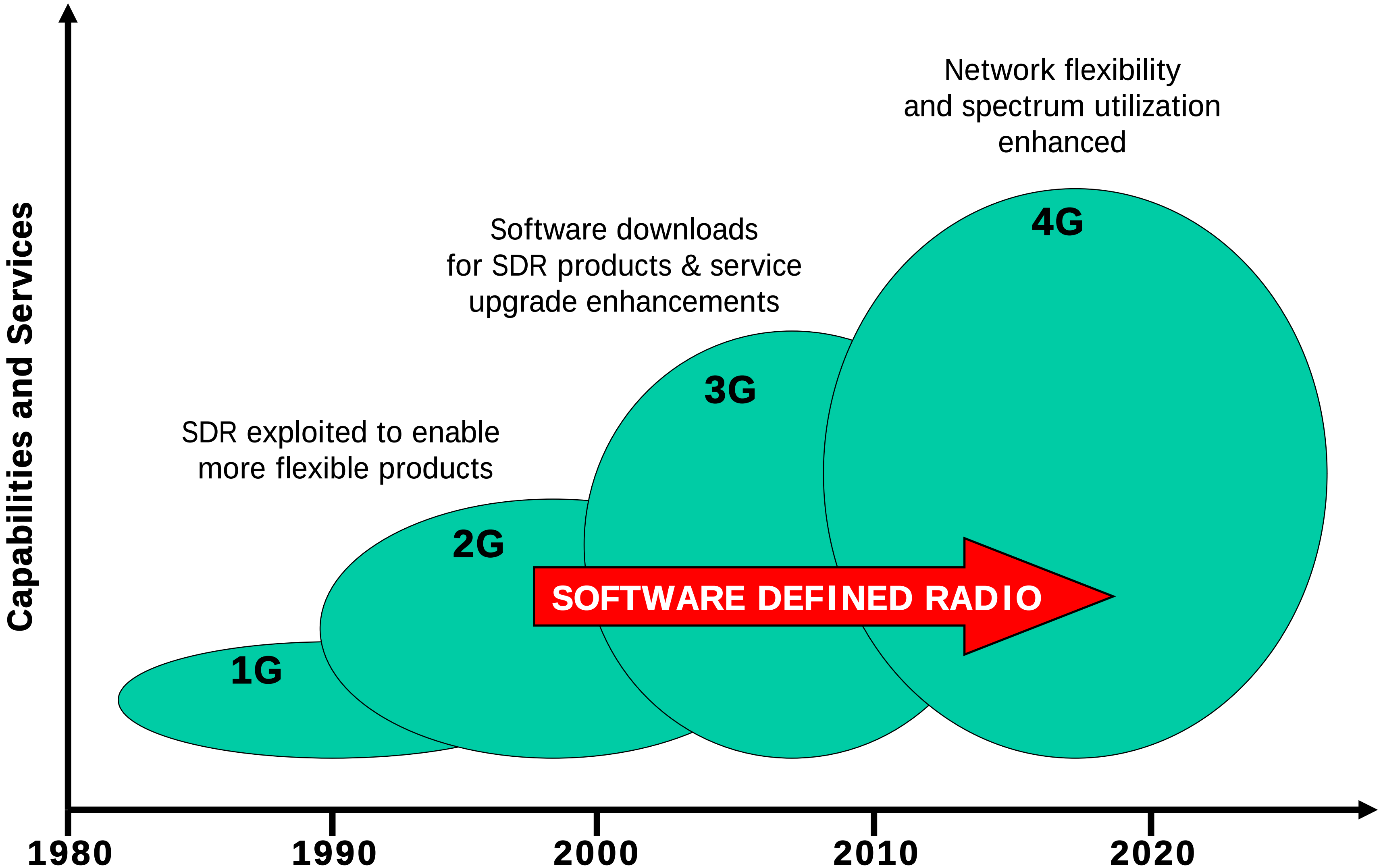
JTRS – Ground Mobile Radio



NIU – Network Information/Security Unit
PCDD – Portable Control Display Device
UT – Universal Transceiver
VUPA – VHF (Very High Frequency)/UHF (Ultra High Frequency) Power Amplifier
WBPA – Wideband Power Amplifier

…men så er der jo heldigvis andre applikationsområder

Mobile Communication



Artikel i IEEE Spectrum, April 2009

THE UNIVERSAL HANDSET

Software-defined radio will let cellphones speak Wi-Fi, 3G, WiMax, and more

by PETER KOCH & RAMJEE PRASAD

Time was when most radio sets had no software at all, and those that had any didn't do much with it. But Joseph Mitola III, an engineer working for a company called E-Systems (now part of Raytheon), envisioned something very different—a mostly digital radio that could be reconfigured in fundamental ways just by changing the code running on it. In a remarkably prescient article he wrote in 1992 for the IEEE National Telesystems Conference, he dubbed it software-defined radio (SDR).

A few short years later, Mitola's vision became reality. The mid-1990s saw the advent of military radio systems in which software controlled most of the signal processing digitally, enabling one set of electronics to work on many different frequencies and communications protocols. The first example was the U.S. military's Speakeasy radio, which allowed units from different branches of the armed forces to communicate effectively for the first time. But the technology was costly and rather unwieldy—the first design took up racks that only a large vehicle could carry around.

WWW.SPECTRUM.IEEE.ORG

TAVIS COBURN

WWW.SPECTRUM.IEEE.ORG APRIL 2009 · IEEE SPECTRUM NA 37

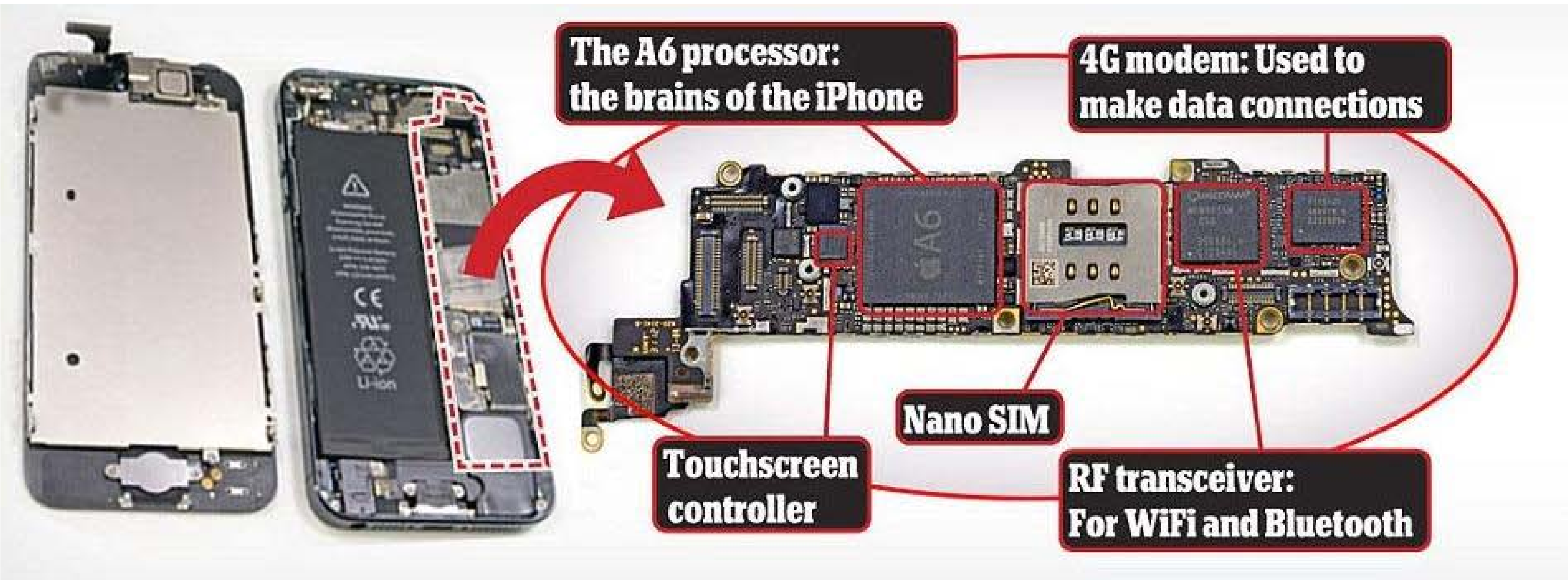
SDR – The Holy Grail..??

Do We Still Need Software Defined Radio?
By Craig Mathias Networkworld.com, on Mon, 05/04/09 - 8:42am.

Technically, yes, absolutely. But in practice, an SDR-based handset may no longer be necessary. It's my guess that, by 2015 or so, essentially all handsets will need only LTE (with backwards compatibility) and Wi-Fi (802.11n, of course, also with backwards compatibility) - a little WiMAX, OK, sure, but that's it. So, if, let's say, 80% of the worlds handsets can be built from a simple chipset that just does LTE and Wi-Fi, SDR in that capacity is of much less interest, although I expect that base stations will still be built fundamentally from SDR. A handset chipset that covers the LTE/Wi-Fi bases should be less expensive than one built from SDR, and consume less power as well.

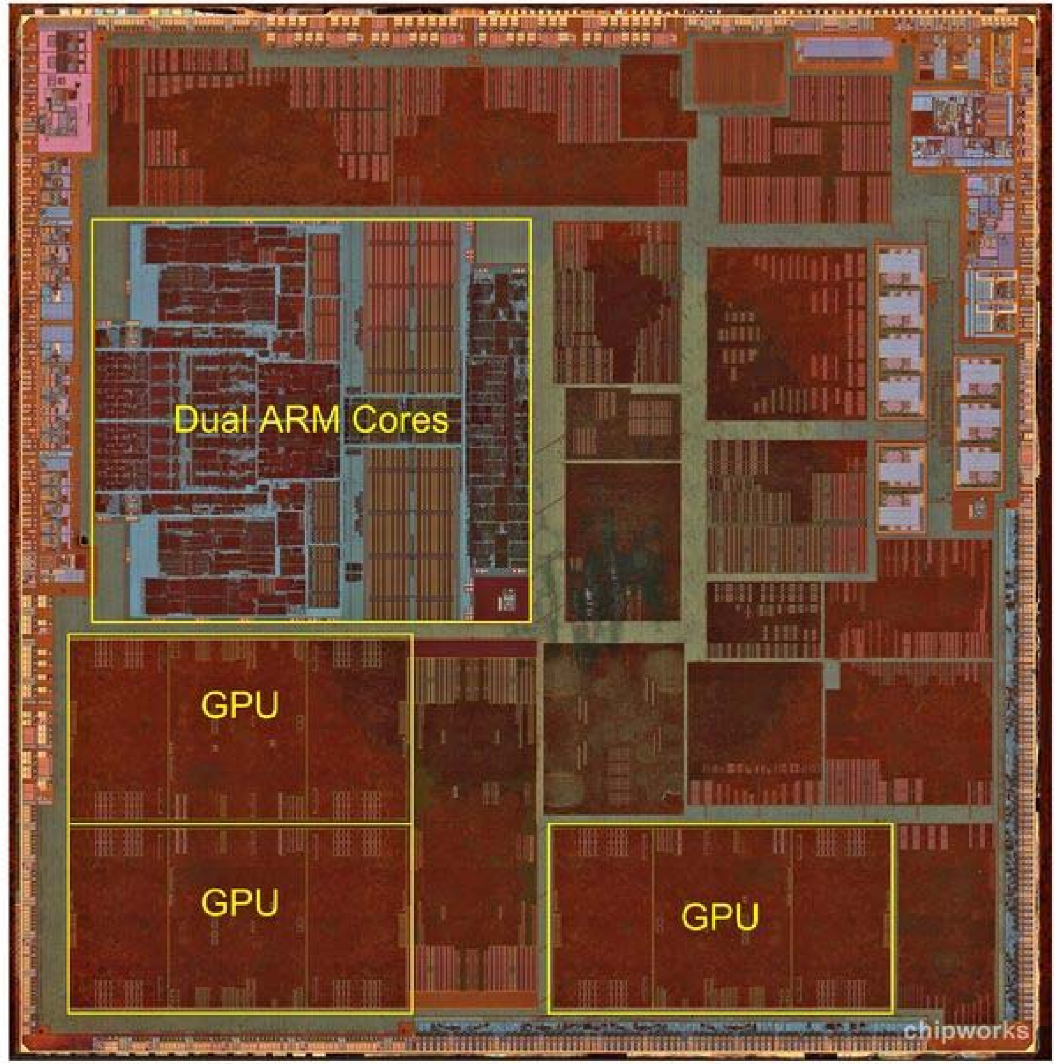
This is not to say that the many other benefits of SDR - including design flexibility and the ability to fix bugs and add features in the field - aren't valuable. They are. But these may simply be just too expensive given the need to control costs across the entire wireless WAN value chain, but especially in handsets. So, SDR remains technically interesting, and it may find a place in some implementations, but I'm beginning to doubt that it's the holy grail of handset design.

What's inside an iPhone 5..??



The Apple A6 processor

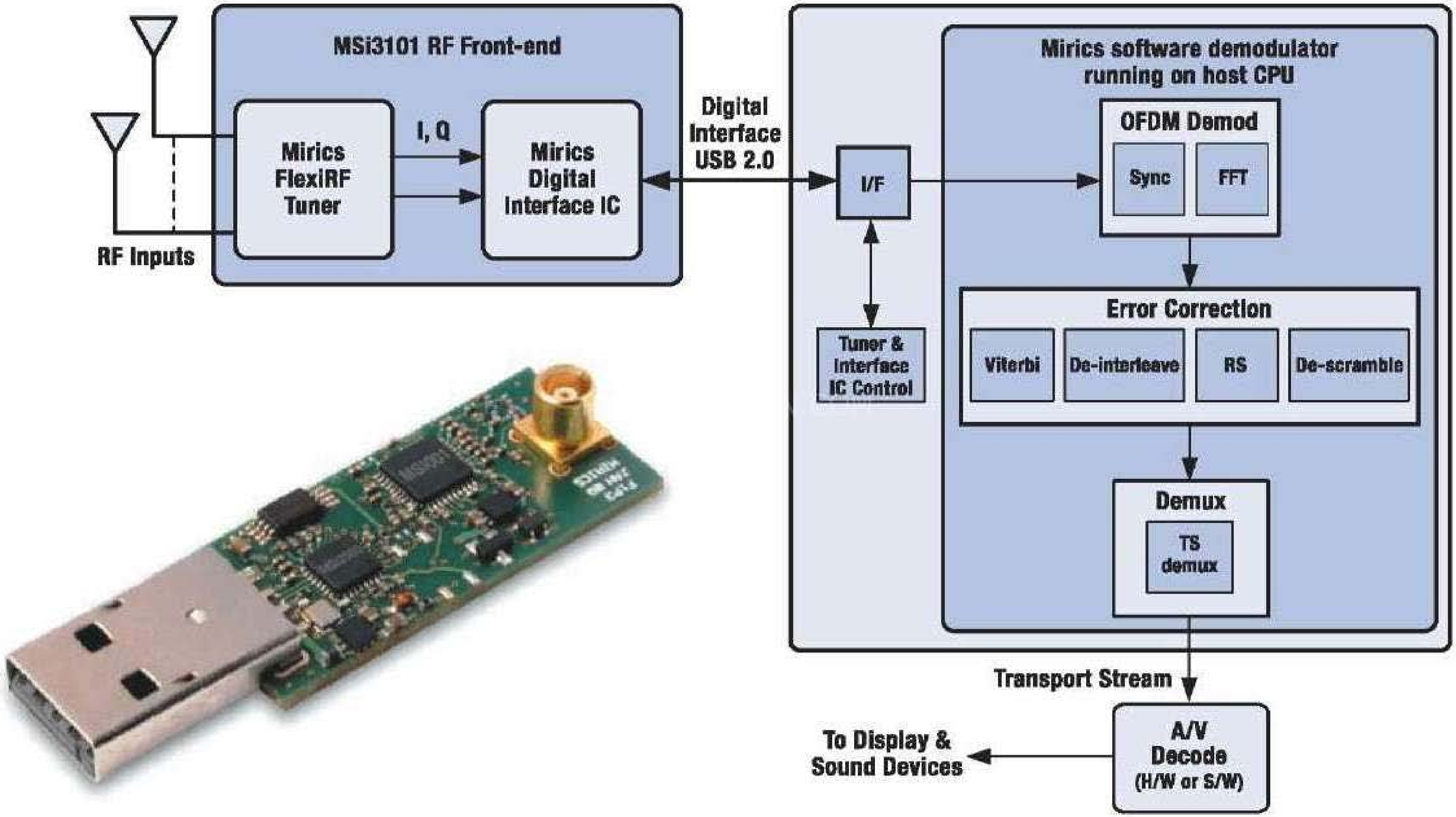
Produced	From September 21, 2012 to September 9, 2015
Designed by	Apple Inc.
Common manufacturer(s)	Samsung
Max. CPU clock rate	1.3 GHz
Min. feature size	32 nm
Instruction set	ARM, Thumb-2
Microarchitecture	Swift; ARMv7-A compatible
Product code	S5L8950X
Cores	2
L1 cache	32 KB instruction + 32 KB data
L2 cache	1 MB
Predecessor	Apple A5
Successor	Apple A7
GPU	PowerVR SGX543MP3 (triple-core)
Application	Mobile



Modern Handset Platform = Radio Chip Sets + Multiple Processors

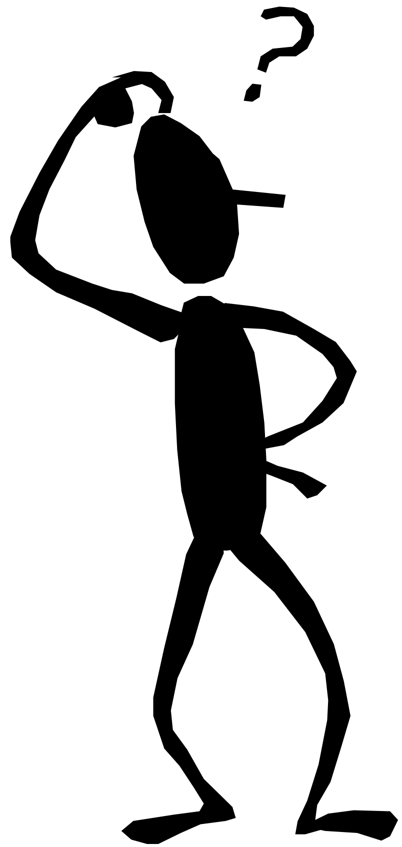
Så jo, kritikerne fik ret – i hvert fald for så vidt mobil-kommunikation angår…

Men SDR er så afgjort i live – ”det myldre frem med PC dongles”

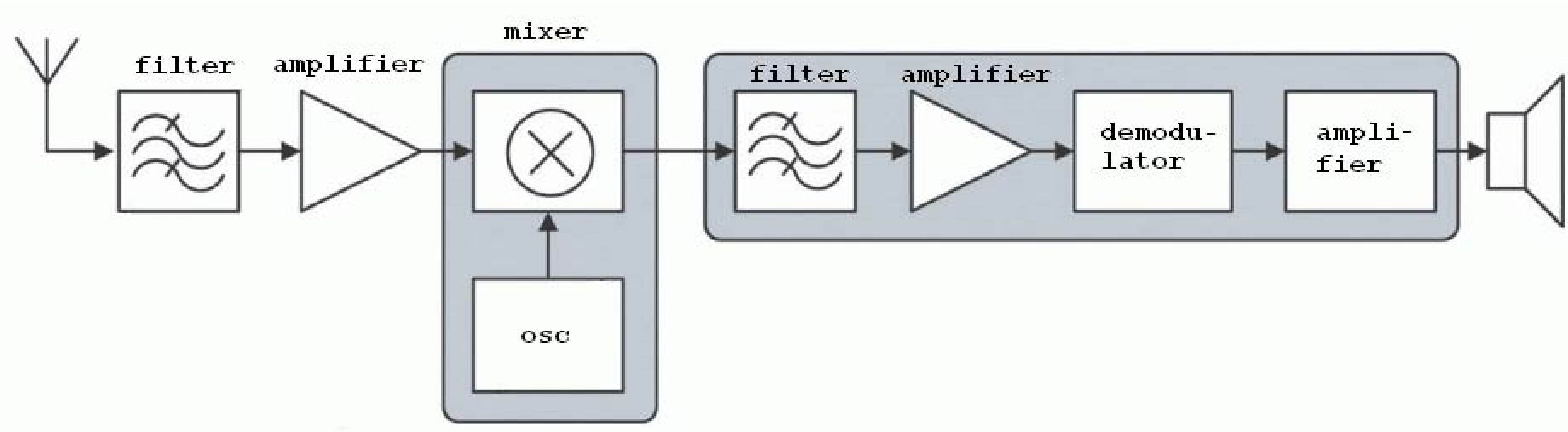


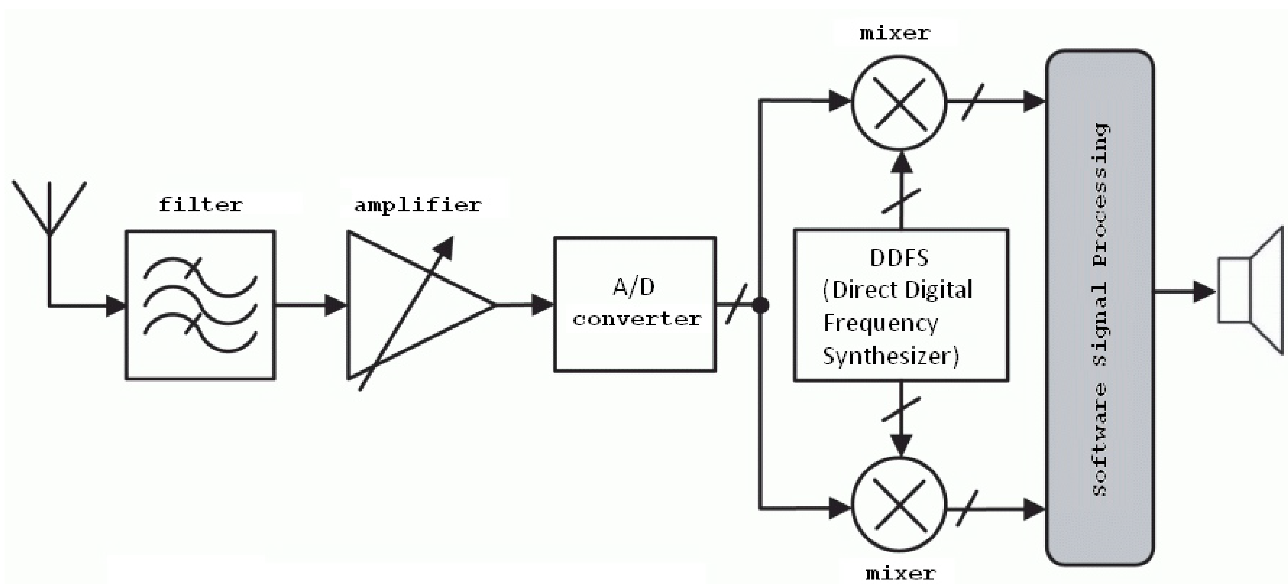
Og specielt indenfor Ham Radio myldrer det frem med Stand-alone SDR

Men hvordan gør vi så…??



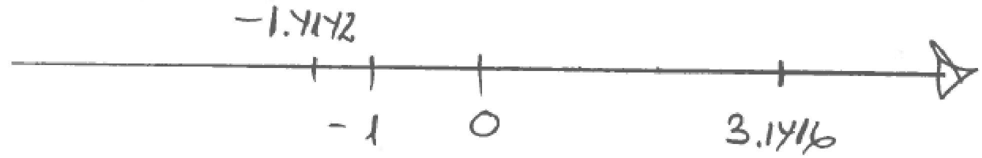
Fra analog til digital (software) radio





Lidt om komplekse tal

NORMALT BENYTTER VI MÆNGDEN AF REELLE TAL $\mathbb{R}$, DVS. ALLE DE TAL, SOM KAN AFBILDES SOM DECIMAL·TAL PÅ EN TAL·AKSE FRA $-\infty$ TIL ∞.



VED AT INDFØRE EN ABSTRAKTION KAN VI DEFINERE EN ANDEN TALMÆNGDE $\mathbb{C}$, SOM VI KALDER DE KOMPLEKSE TAL

$$\alpha = x + jy$$

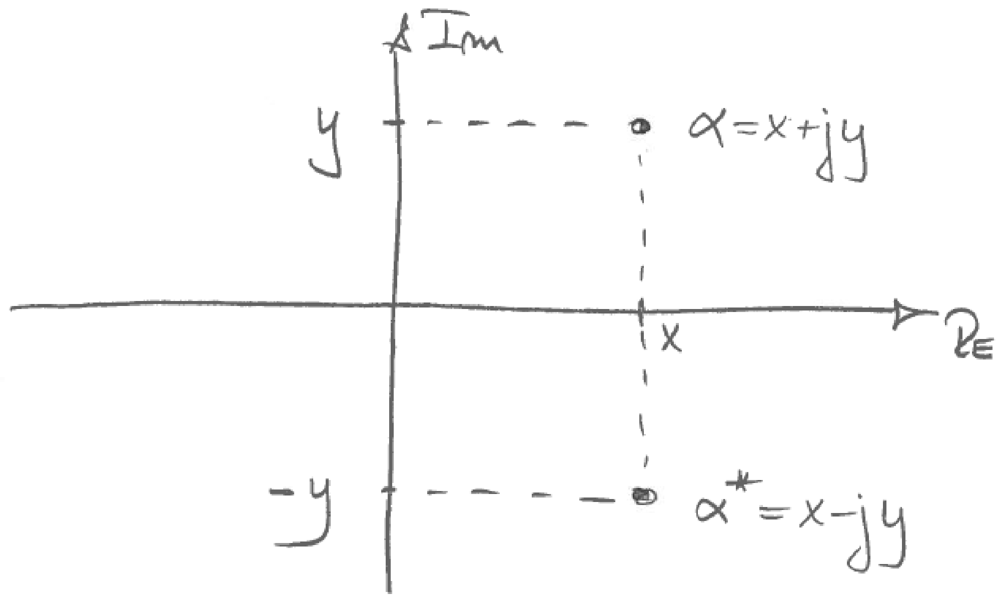
x : α's REAL·DEL

y : α's IMAGINÆRE DEL

TALLET j ER EN ABSTRAKTION, $j = \sqrt{-1}$
DVS. DET TAL, SOM MULTIPLICERET MED SIG SELV GIVER -1.

Det komplekse tal-plan

VI INDFØRER ET KOORDINAT·SYSTEM, HVOR X·AKSEN REP. REAL·DELEN OG Y·AKSEN REP. IMAGINÆR·DELEN



DVS AT DE KOMPLEKSE TAL FINDES I ET TAL·PLAN (OG IKKE PÅ EN TAL·AKSE).

BEGGE AKSER „INDEHOLDER" REELLE TAL FRA $\mathbb{R}$.

Basale regne-regler

$$\alpha = x + jy$$

$$\beta = s + jt$$

ADDITION:

$$\alpha + \beta = (x+s) + j(y+t)$$

2 REELLE ADDITIONER

MULTIPLIKATION:

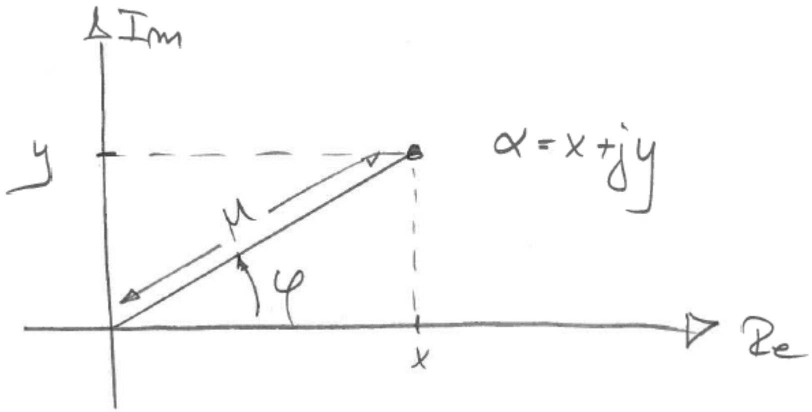
$$\alpha \cdot \beta = (x+jy)(s+jt)$$

$$= (x \cdot s - yt) + j(xt + ys)$$

4 REELLE MULTIPLIKATIONER

2 REELLE ADDITIONER.

Repræsentation af komplekse tal



1) REKTANGULÆR FORM

$$\alpha = x + jy$$

2) TRIGONOMETRISKE FORM

$$\alpha = M(\cos\varphi + j\sin\varphi)$$

3) POLÆR FORM

$$\alpha = M \cdot e^{j\varphi}$$

SES VED;

$$e^{z} = 1 + z + \frac{z^2}{2!} + \frac{z^3}{3!} + \frac{z^4}{4!} + \frac{z^5}{5!} + \frac{z^6}{6!} + \cdots$$

$$e^{j\varphi} = e^{z}\Big|_{z=j\varphi} = 1 + j\varphi - \frac{\varphi^2}{2!} - j\frac{\varphi^3}{3!} + \frac{\varphi^4}{4!} + j\frac{\varphi^5}{5!} - \frac{\varphi^6}{6!} \cdots$$

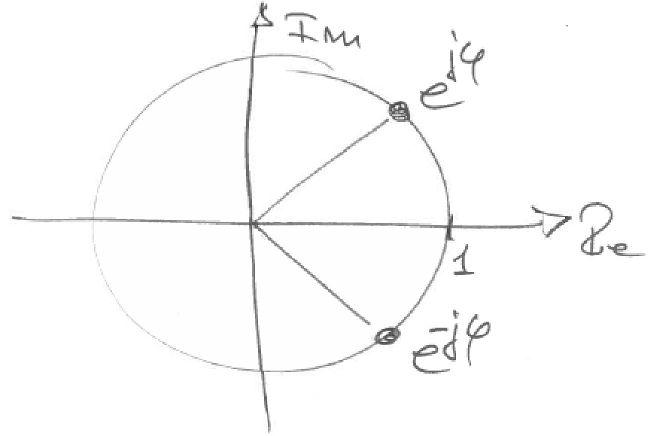
$$= \cos\varphi + j\sin\varphi$$

Repræsentation af komplekse tal

ALTSÅ $e^{j\varphi} = \cos\varphi + j\sin\varphi$

OG $e^{-j\varphi} = \cos\varphi - j\sin\varphi$

EULER's IDENTITET



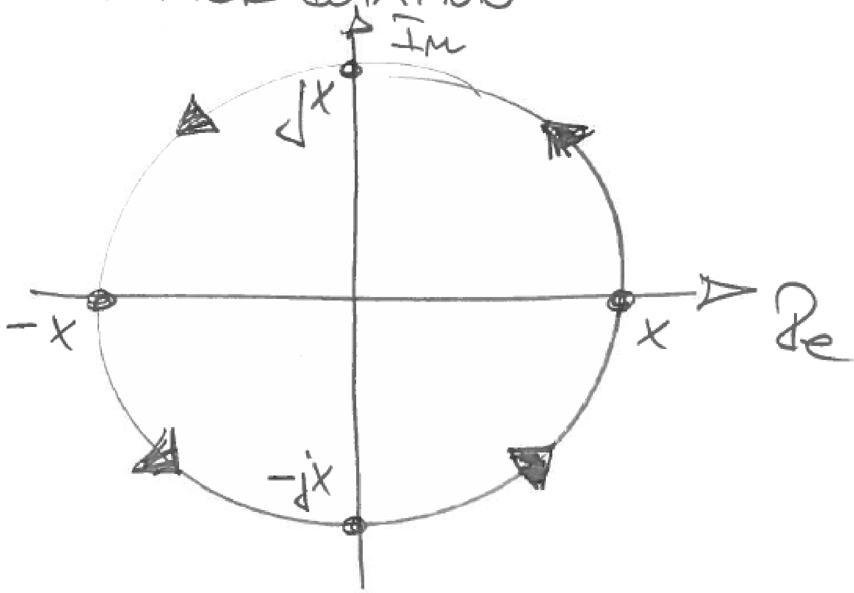
4) LÆNGDE/VINKEL - FORM

$$\alpha = M\angle\varphi$$

SÅ; KOMPLEKSE TAL KAN OPFATTES SOM VECTORER i Re/Im-PLANEN

Vektor-rotation

VEKTOR·ROTATION



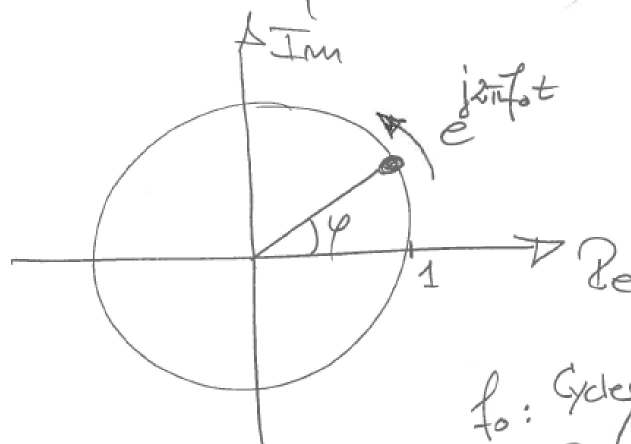
$$x \cdot j = jx$$
$$jx \cdot j = -x$$
$$-x \cdot j = -jx$$
$$-jx \cdot j = x$$

HVIS MAN HAR ET KOMPLEKS TAL, SÅ VIL MULTIPLIKATION MED j RESULTERE I ET NYT KOMPLEKS TAL, SOM ER ROTERET 90° MOD URET I DET KOMPLEKSE TAL·PLAN

Komplekse tal som funktion af tiden

ANTAG ET KOMPLEKS TAL MED M = 1 OG
EN FASEVINKEL, SOM ØGES OVER TID;

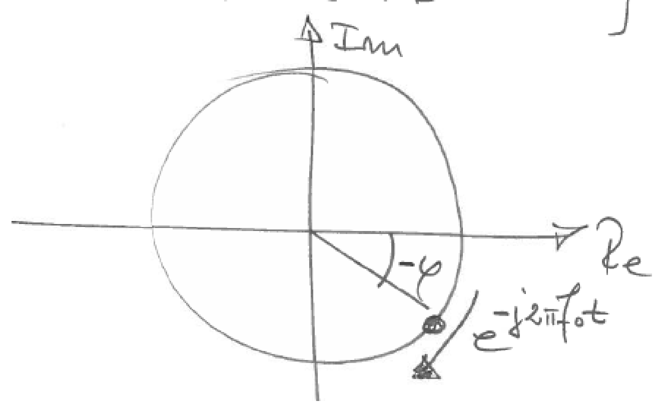
$e^{j2\pi f_0 \cdot t}$ DVS. $\varphi(t) = 2\pi f_0 \cdot t$



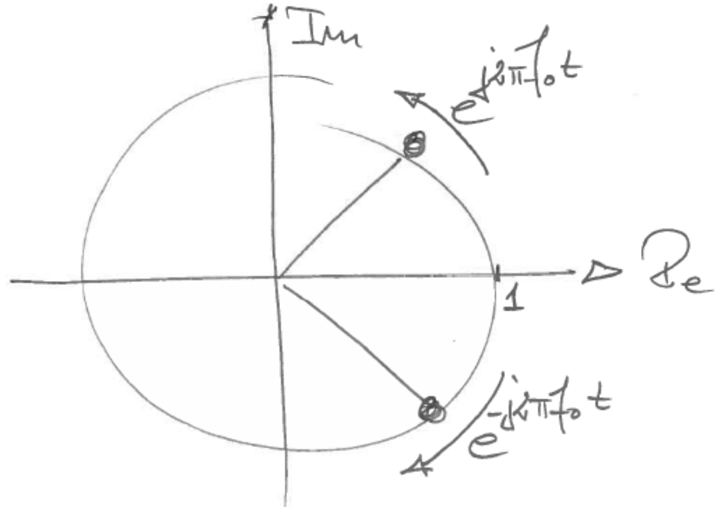
f_0 : Cycles/sec [Hz]

$2\pi f_0$: Rad/sec

OG DET KOMPLEKS KONJUGEREDE TAL;



Begge tal i samme komplekse tal-plan



HVIS VI FORESTILLER OS, AT VI OBSERVERER BEGGE TAL SAMTIDIG, SÅ „SER" VI ALTSÅ TALLET $e^{j2\pi f_0 t} + e^{-j2\pi f_0 t}$ SOM VED HJÆLP AF EULER'S IDENTITET OMSKRIVES:

$$e^{j2\pi f_0 t} + e^{-j2\pi f_0 t}$$

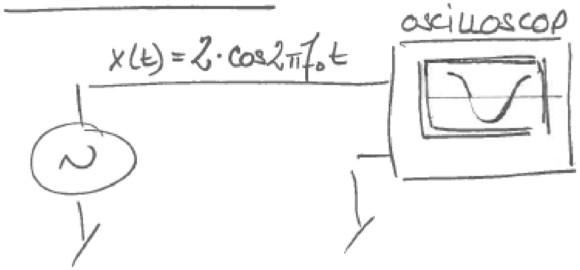
$$= \cos 2\pi f_0 t + j \sin 2\pi f_0 t + \cos 2\pi f_0 t - j \sin 2\pi f_0 t$$

$$= 2 \cdot \cos 2\pi f_0 t$$

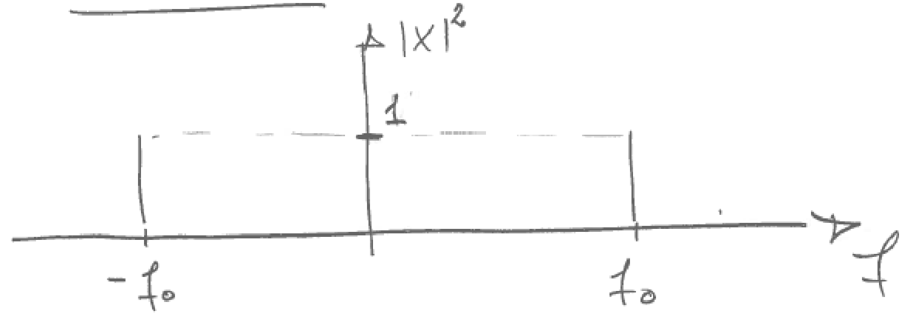
ALTSÅ ET REELT SIGNAL (TAL), SOM INDEHOLDER BÅDE EN POSITIV OG EN NEGATIV FREKVENS-KOMPOSANT !!!

Teori versus praksis

SIGNAL I PRAKSIS



SIGNAL I TEORIEN

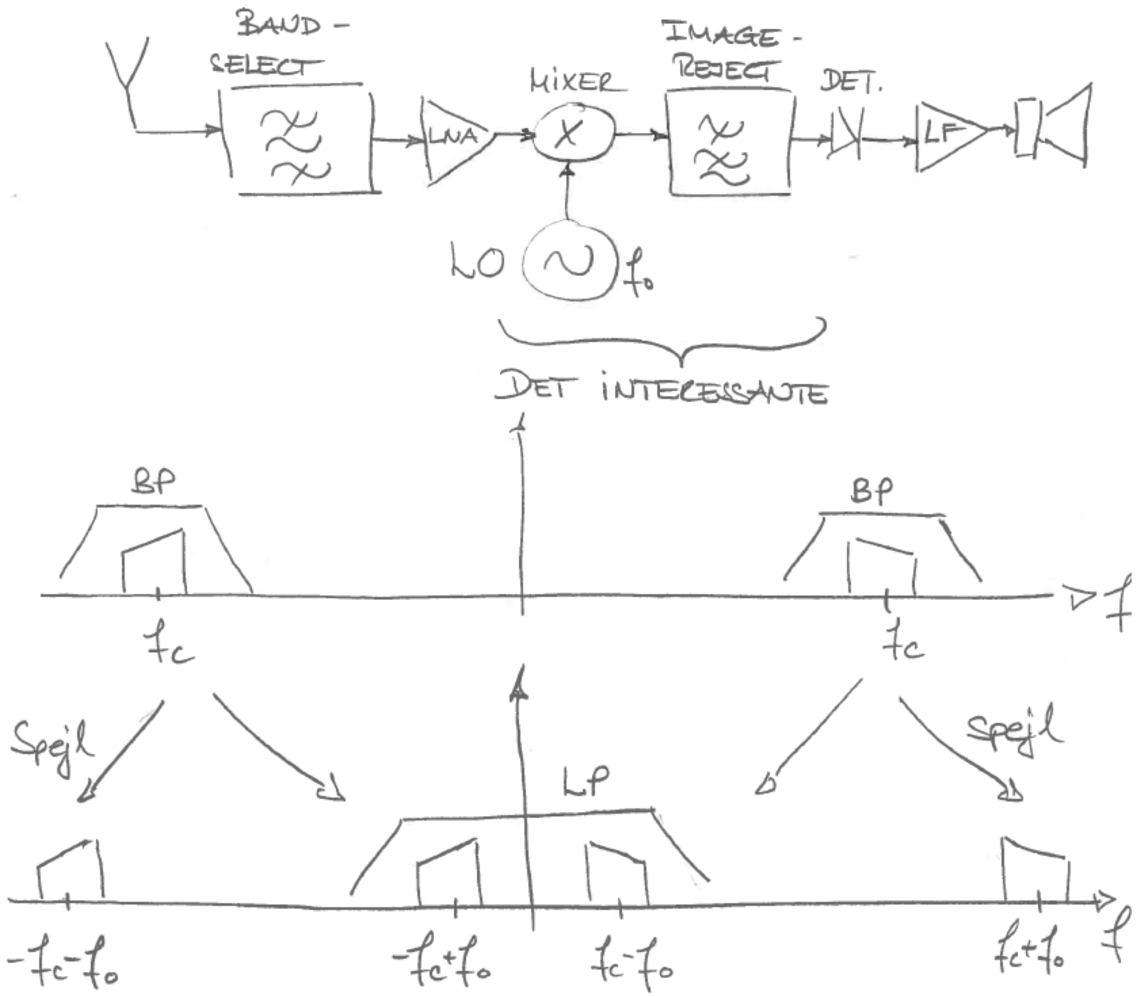


DER ER ALTSÅ LIGE SÅ MEGET ENERGI I DE NEGATIVE FREKVENSER SOM DER ER I DE POSITIVE

DENNE ERKENDELSE ER VIGTIG I FORBINDELSE MED KONSTRUKTION AF TRANSMITTER/RECEIVER SYSTEMER

I AFTEN VIL VI UDELUKKENDE SE PÅ MODTAGEREN.

Topologi for analog AM-modtager



SIGNAL'INDHOLDET VED SPEJL'FREKVENSERNE ER EN KONSEKVENS AF DEN ANALOGE MIXERS VIRKEMÅDE (DIODE, TRANSISTOR).

Udfordring

KAN VI KONSTRUERE EN MIXER SOM <u>IKKE</u> GENERERER DE UØNSKEDE SPEJL (OG ANDRE BLANDINGSPRODUKTER) ??

JA!

ANTAG, AT VI OBSERVERER ET REELT SIGNAL $x_r(t)$. DETTE SIGNAL KAN UDTRYKKES I TERMER AF ET KOMPLEKS SIGNAL;

$$X(t) = x_r(t) + j\,x_i(t) \quad \text{HVOR } x_i(t) = 0$$

ANTAG, AT VI HAR EN IDEEL KOMPLEKS MULTIPLIKATOR

$$Y(t) = X(t) \cdot e^{j\omega_0 t} = y_r(t) + j\,y_i(t)$$

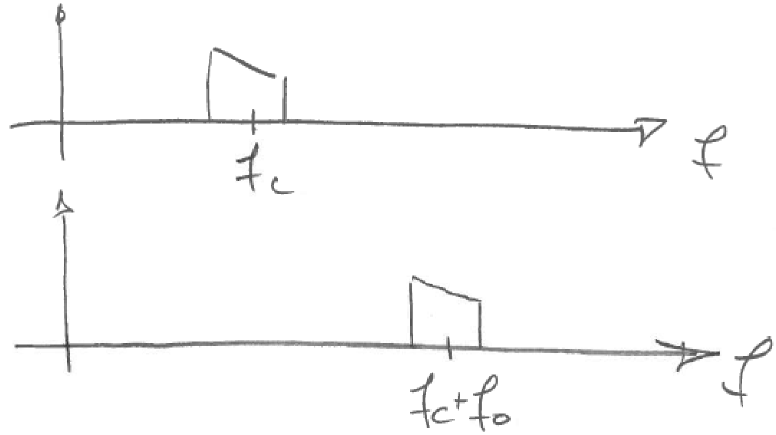
FREKVENSANALYSE AF $Y(t)$;

$$Y(f) = \mathcal{F}(Y(t)) = \mathcal{F}\left(X(t) \cdot e^{j2\pi f_0 t}\right) = X(f + f_0)$$

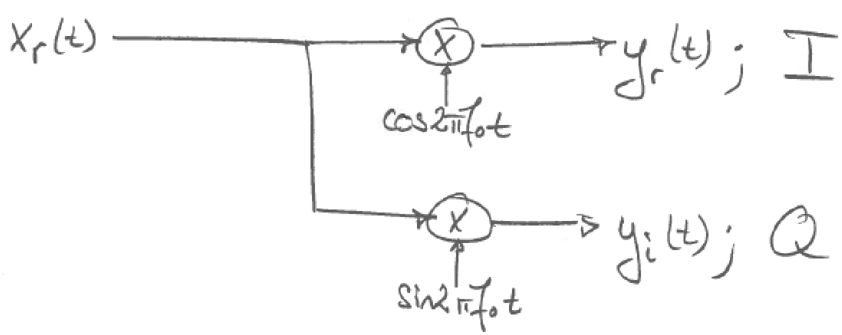
OBS!

Complex heterodyne

VED HJÆLP AF EN KOMPLEKS EKSPONENTIAL-FUNKTION KAN VI ALTSÅ FLYTTE ET SIGNAL I FREKVENS UDEN AT INTRODUCERE SPEJL.



FRA EULER VED VI, AT $e^{j2\pi f_0 t} = \cos 2\pi f_0 t + j \sin 2\pi f_0 t$



I : IN-PHASE SIGNAL

Q : QUADRATURE SIGNAL

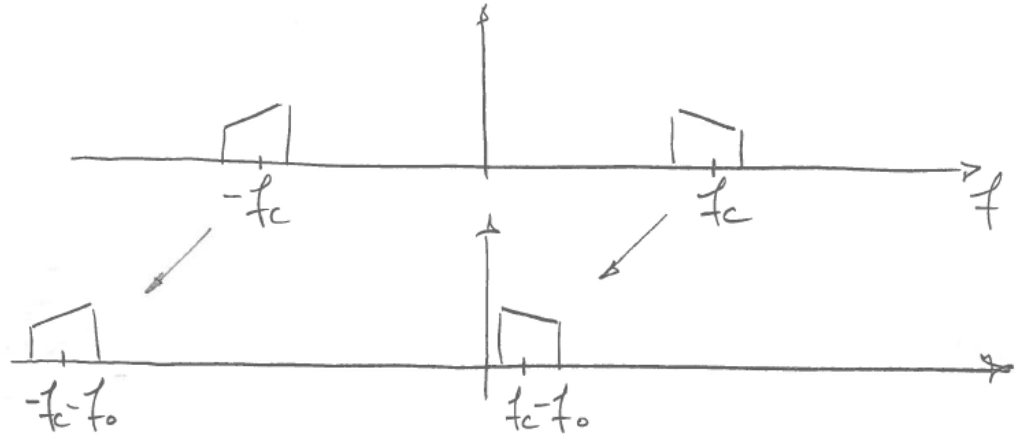
Quadrature mixer

ET ØNSKE KUNNE NU VÆRE AT FLYTTE SIGNALET NED I BASE-BAND OMRÅDET;

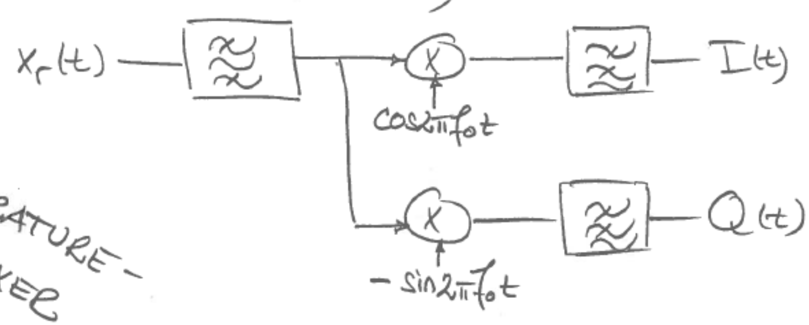
$$Y(t) = x_r(t) \cdot e^{-j2\pi f_0 t} = x_r(t)\left(\cos 2\pi f_0 t - j \sin 2\pi f_0 t\right)$$

$$\Downarrow$$

$$Y(f) = X(f - f_0)$$



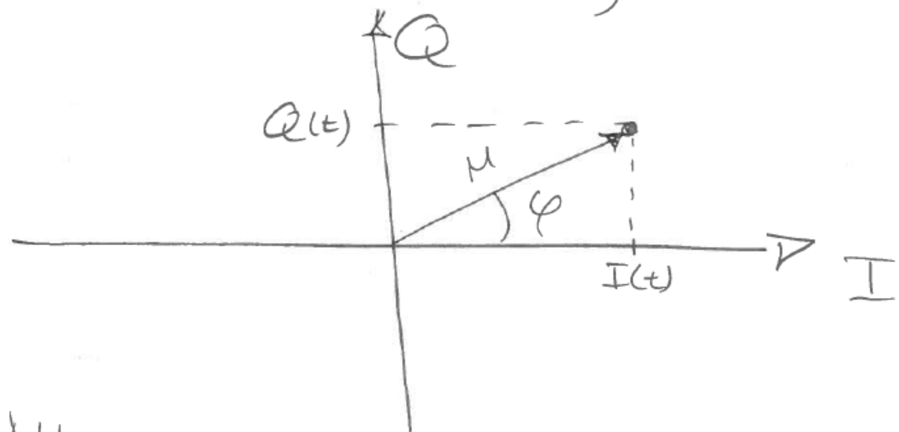
VI ER FORTSAT INTERESSERET I AT FJERNE DEN NEGATIVE FREKVENSKOMPOSANT SAMT AT SIKRE GOD BÅND-SELEKTERING. DERFOR;



QUADRATURE-MIXER

Give me I/Q and I can demodulate everything…

SNAP-SHOT AF I OG Q ;



AM-DEMODULATION

$$\mu(t) = \sqrt{I^2(t) + Q^2(t)}$$

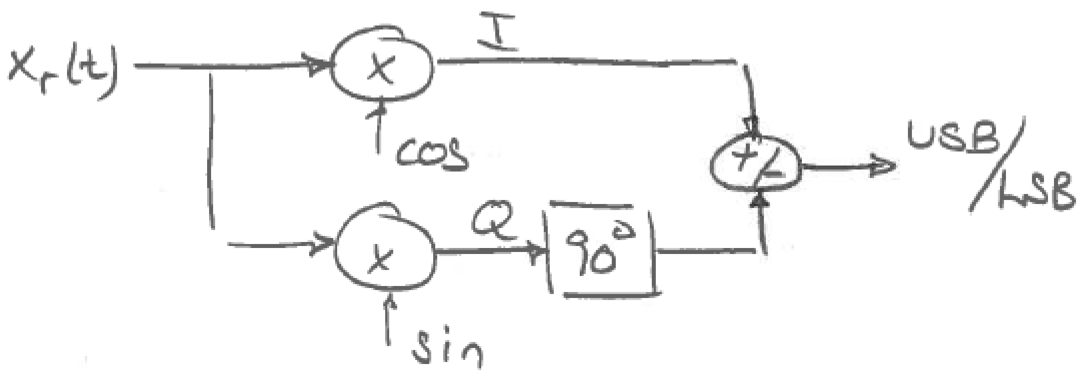
PM-DEMODULATION

$$\varphi(t) = \arctan\left(\frac{Q(t)}{I(t)}\right)$$

FM-DEMODULATION

$$f(t) = \frac{d\varphi(t)}{dt} \simeq \varphi(t) - \varphi(t-\Delta t)$$

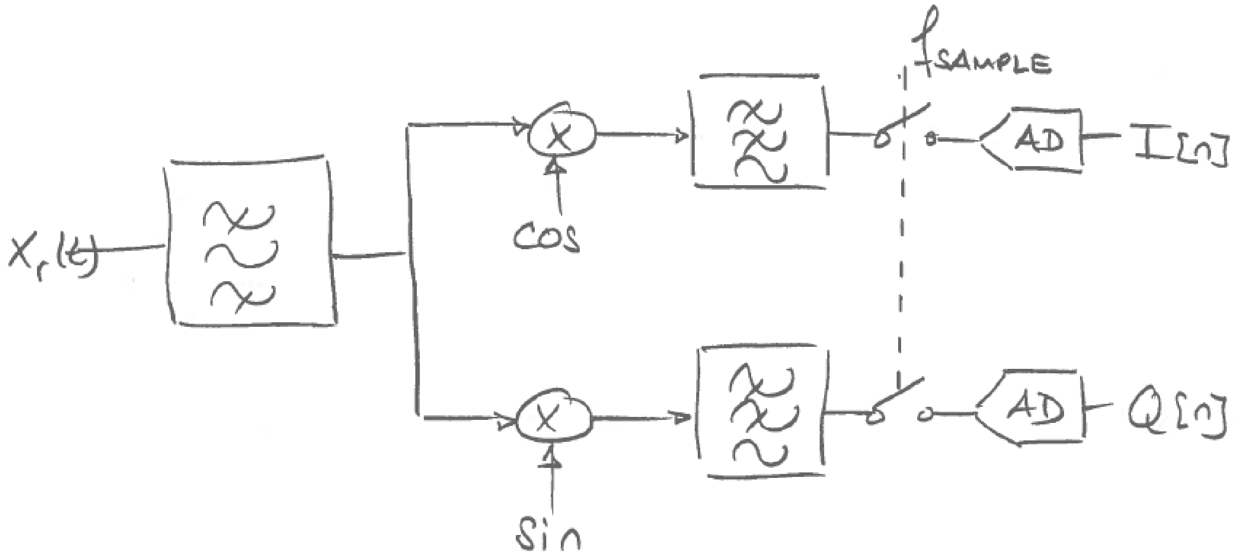
…og hvad med SSB-SC



Men fortsat ikke en software radio

VI SKAL OVER I DET DIGITALE DOMÆNE

— DET KOMMER VI VHA ET SAMPLE/HOLD KREDSLØB OG EN ANALOG-TO-DIGITAL CONVERTER

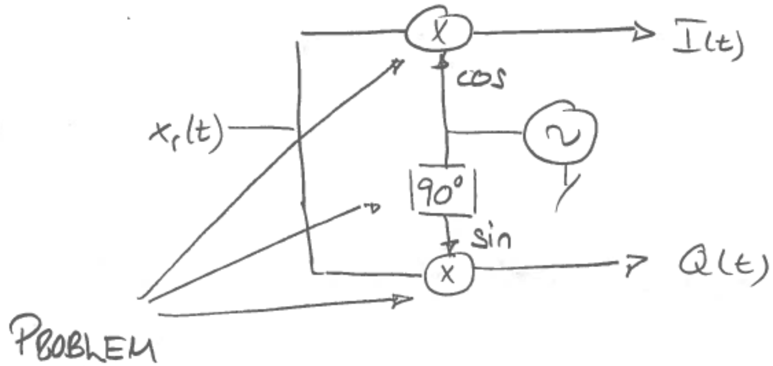


- QUADRATURE SAMPLING MIXER.
- DIRECT CONVERSION RECEIVER (INGEN MELLEM-FREKVENS)

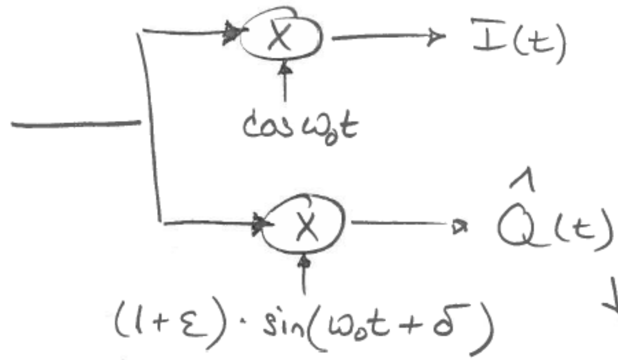
Pause

Det løser ikke alle vores problemer

PROBLEMET ER IMIDLERTID, AT VORES COS- OG SIN-MULTIPLIKATIONER FOREGÅR I DET TIDS- OG AMPLITUDE-KONTINUERTE DOMÆNE. HER ER DET VANSKELIGT AT KONSTRUERE TO MATCHED MULTIPLIKATORER SAMT ET KORREKT FASE-DREJ



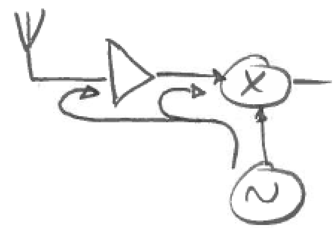
STØJ-MODEL FOR I/Q
GAIN AND PHASE IMBALANCE



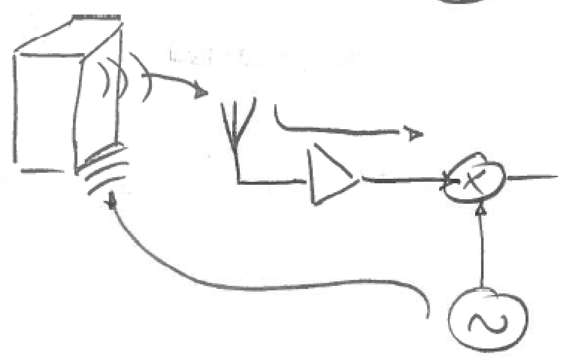
KORREKT DEMODULATION ER HERMED UMULIGGJORT.

Andre problemer ifm. DC-modtagere

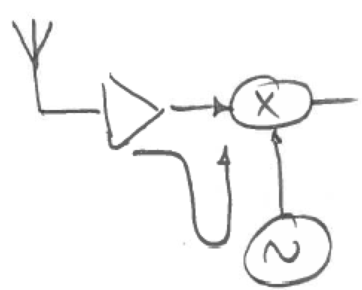
- 1/f NOISE
- DC OFFSET



LO LEAKAGE

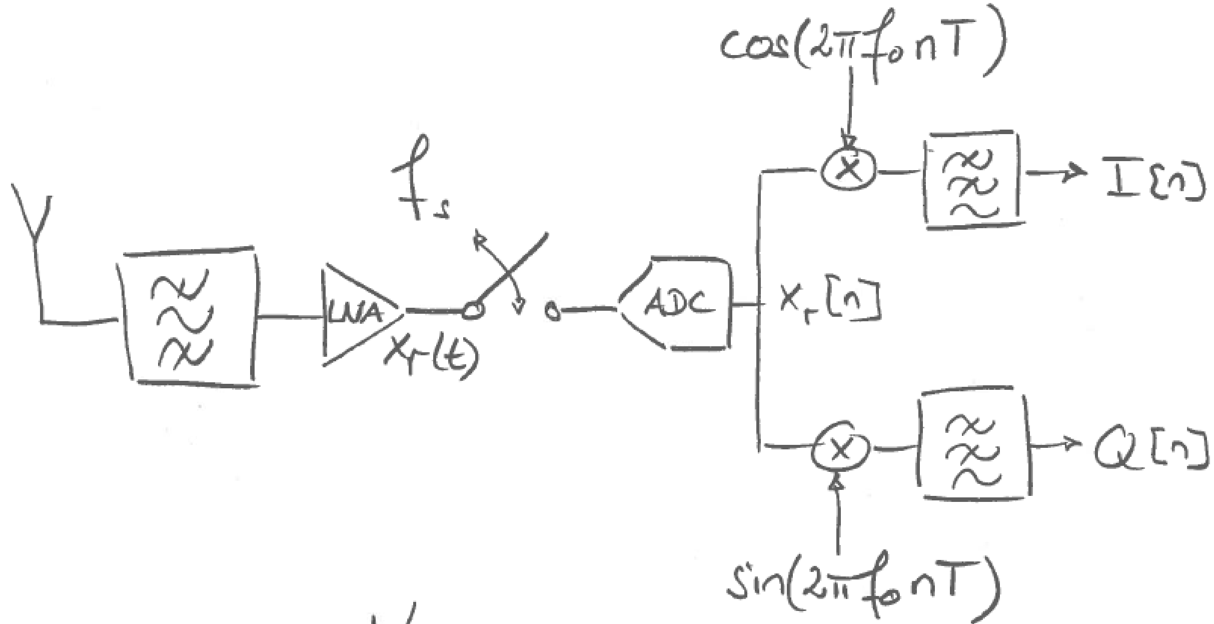


REFLECTION



STRONG IN-BAND INTERFERER

Vi flytter S/H og ADC fremad…
Direct Digital Conversion (DDC)



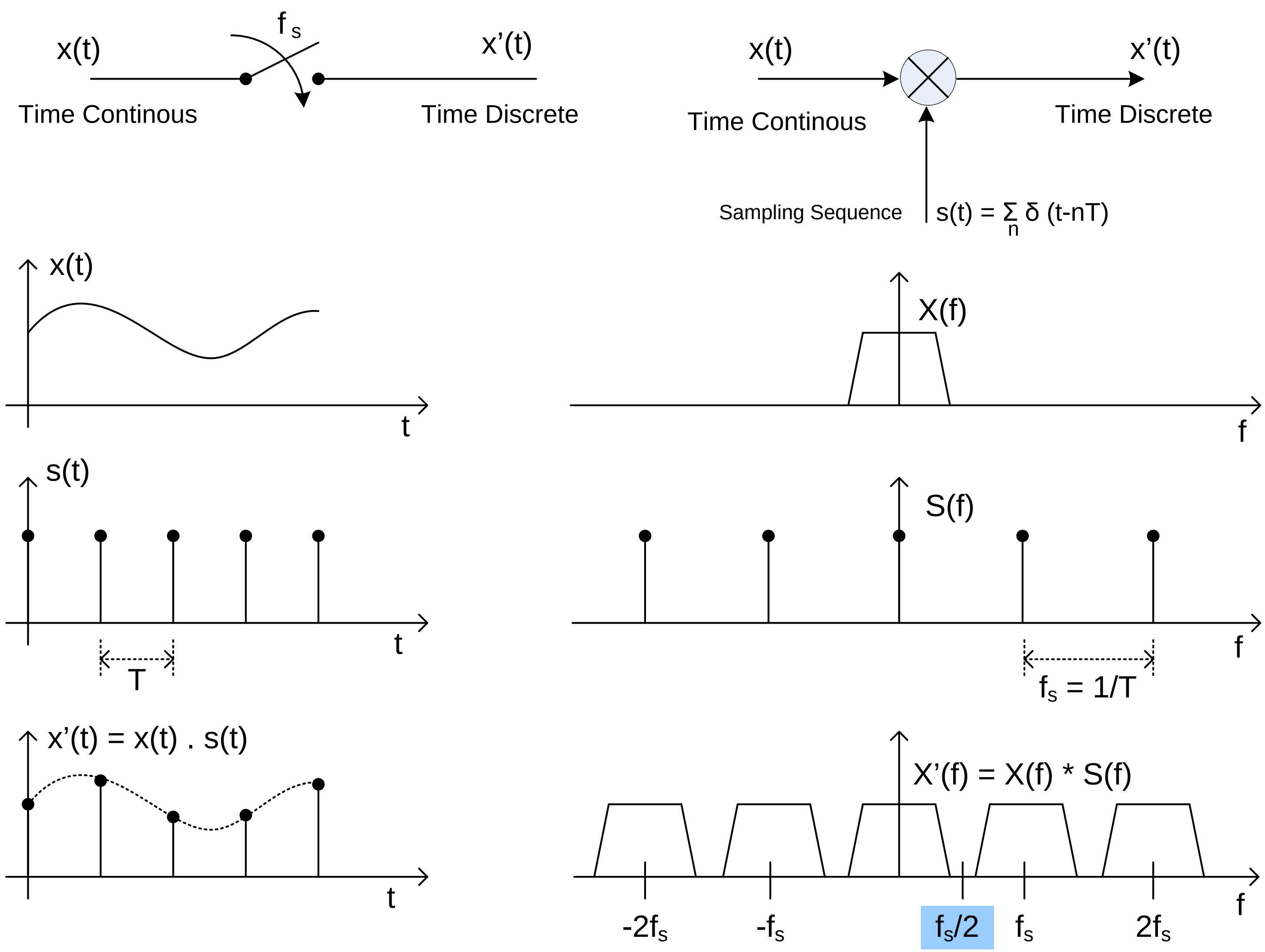
HVOR $T = 1/f_s$

$x_r[n]$ ER ET DIGITALT SIGNAL, DVS. DISKRET I BÅDE TID OG AMPLITUDE.

DE TO DOWN-CONVERSION MULTIPLIKATIONER UDFØRES ALTSÅ I DET DIGITALE DOMENE.

→ NYE UDFORDRINGER!

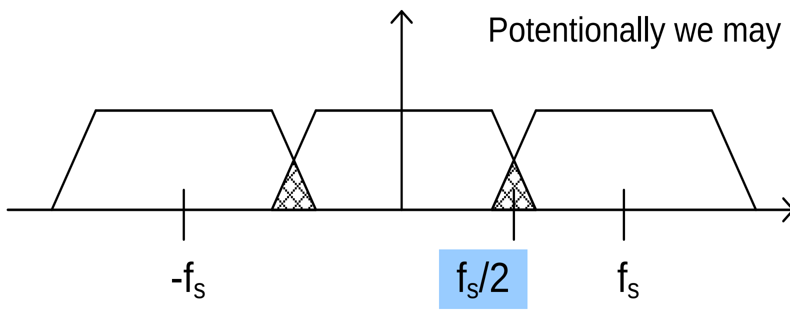
Lidt om sampling



Lidt om sampling

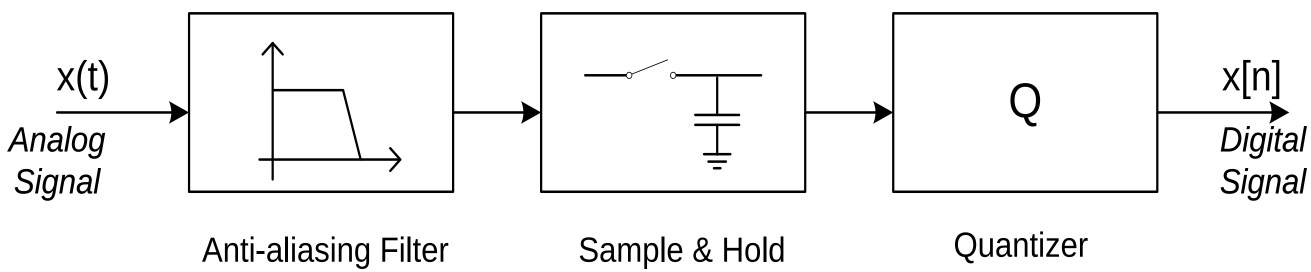
- Discrete Time → Periodic Frequency

Potentionally we may get this scenario !!



$$f_s > 2\,f_{max}$$

- Anti-aliasing Filter



Dette er jo et voldsomt problem for meget højfrekvente signaler, grundet krav til A/D-converterens hastighed, opløsning, effektforbrug, pris og størrelse, men så er det jo godt vi har Shannon…

Bandpass Sampling (Under Sampling)

Shannon siger; $f_S > 2\ B_{max}$

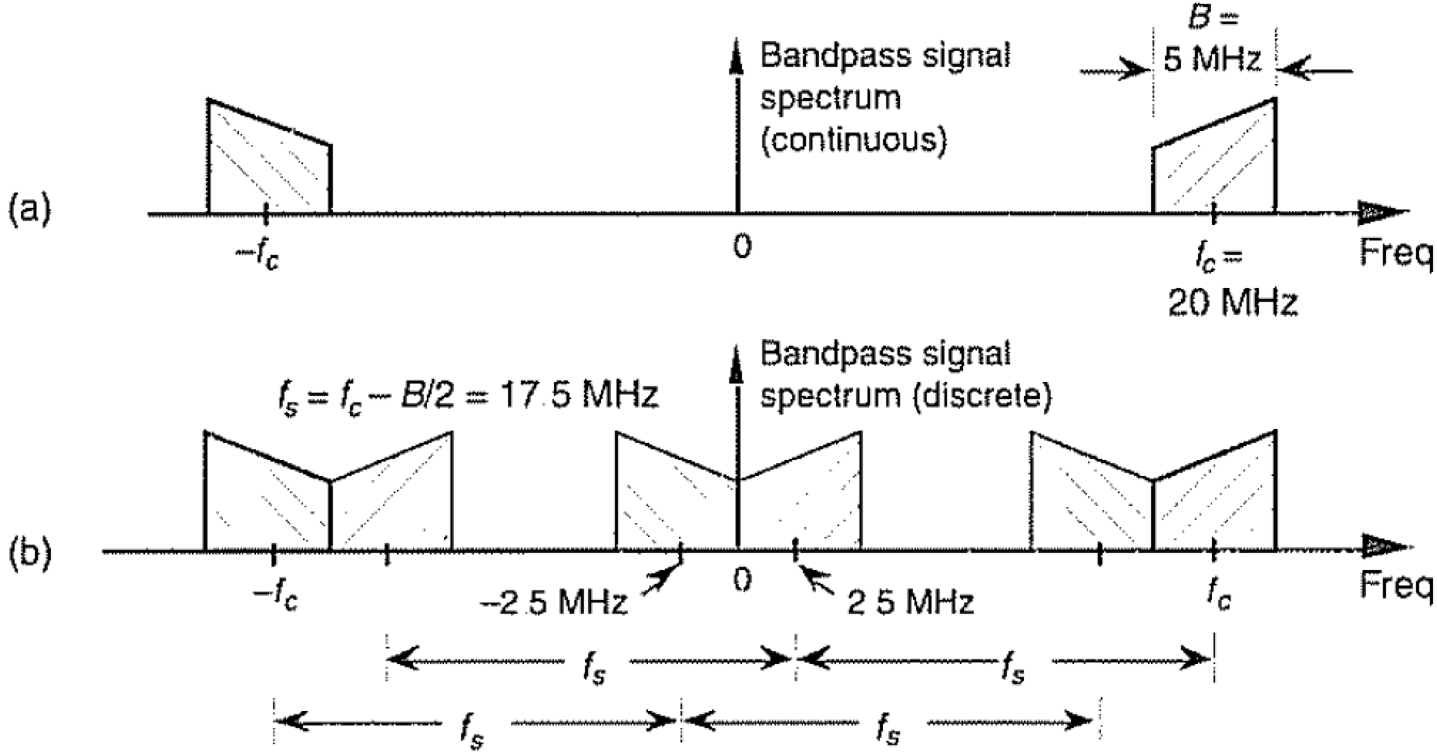
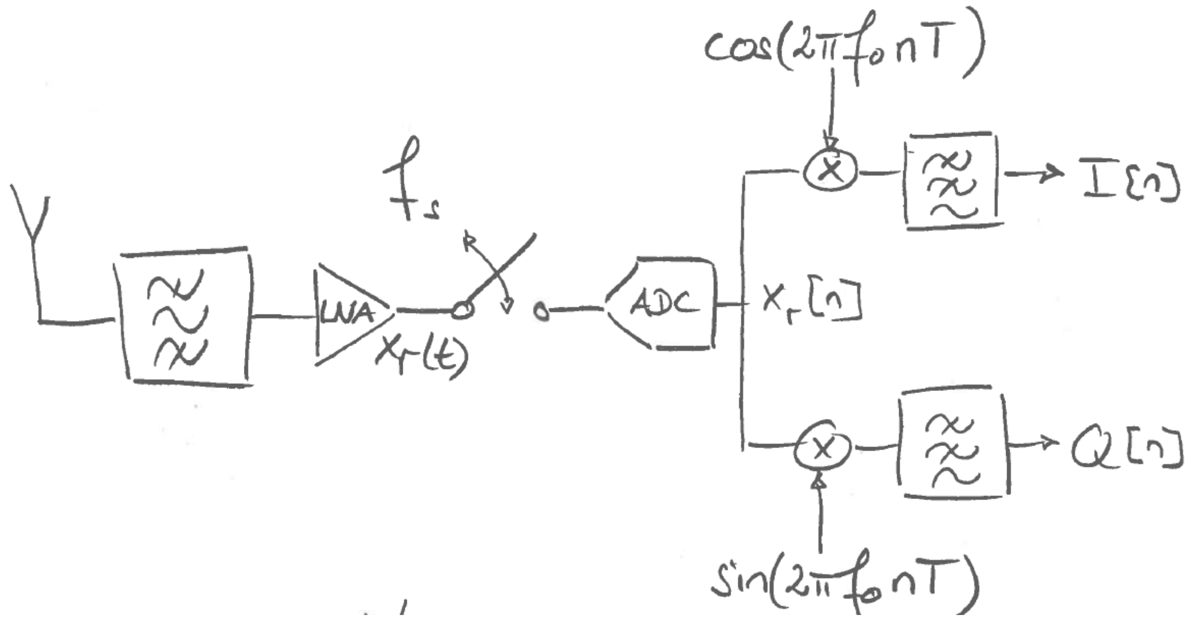


Figure 2-7 Bandpass signal sampling: (a) original continuous signal spectrum; (b) sampled signal spectrum replications when sample rate is 17.5 MHz.

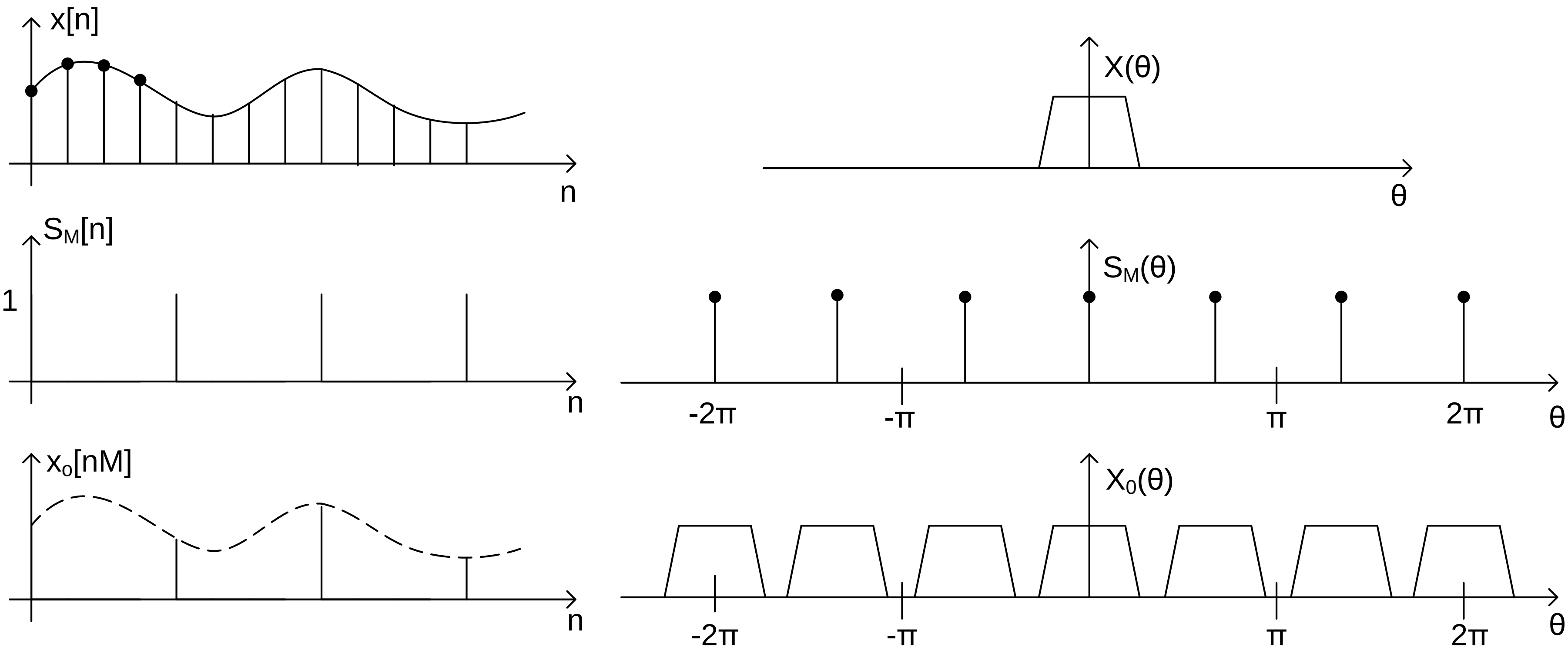
Sample Rate Conversion



Efter down-conversion og (kanal-) filtrering har I/Q-signalet en båndbredde, som ikke ikke nødvendigvis berettiger den høje sample-frekvens f_s

For at reducere beregningsbehovet i (software) demodulatoren, kunne man argumentere for ned-sampling af de to sekvenser.

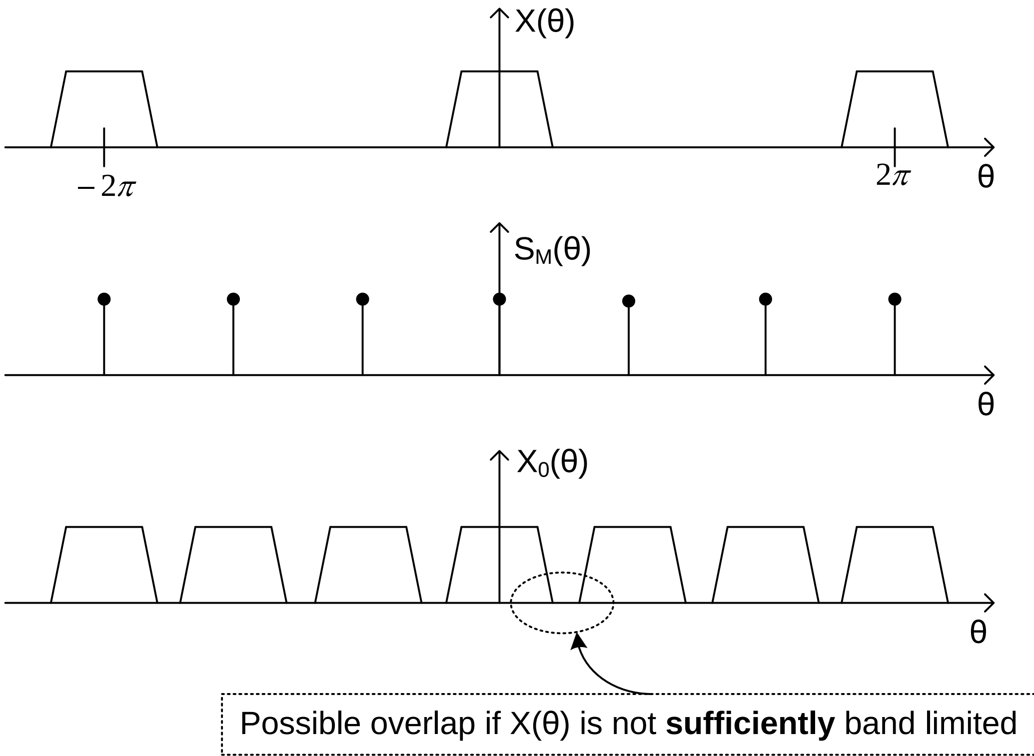
Down sampling



Re-sampling makes the spectrum periodic within θ ε [-π, π]

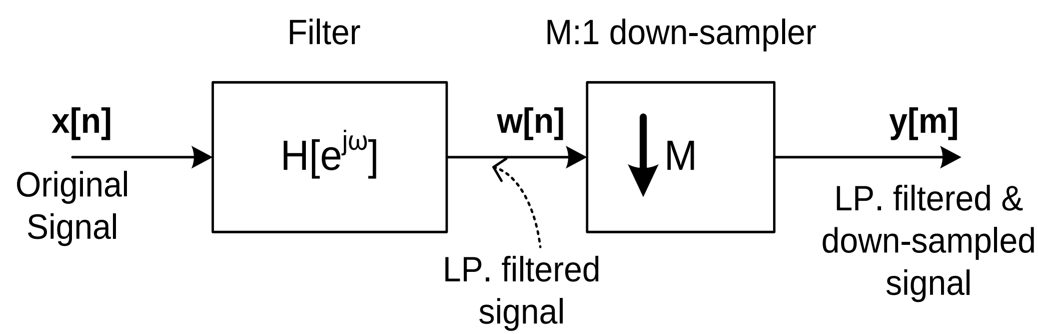
- **x_o[nM] indeholder det samme antal samples som sekvensen x[n], og derfor er der i realiteten ikke foretaget nogen "sample rate" reduktion endnu… Men nu er det resulterende spektrum blevet periodisk indenfor området fra –π til π…**

Down sampling

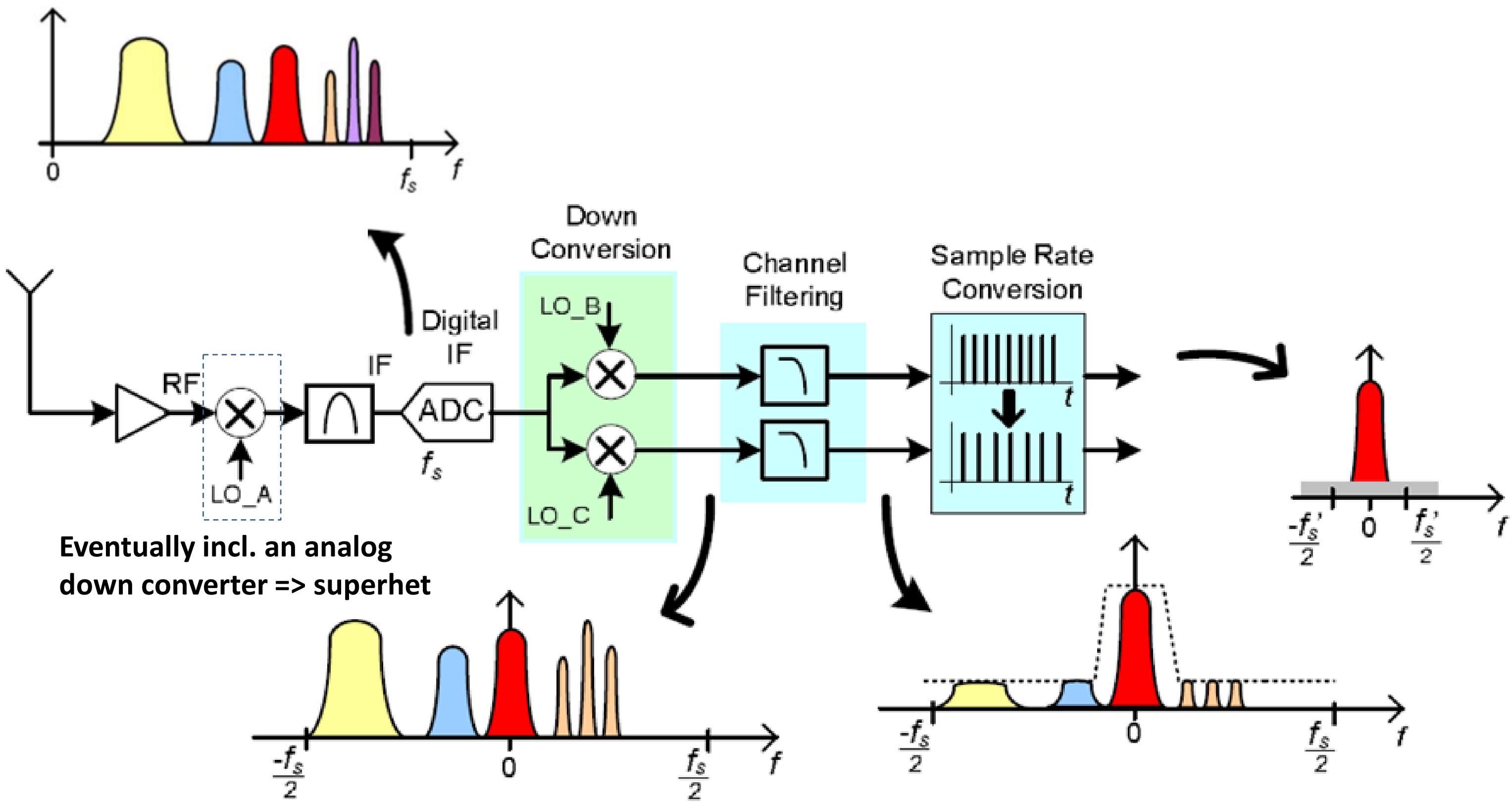


For at undgå aliasing, LP pre-filtreres sekvensen x[n] inden nedsampling

$$H(e^{j\omega}) = \begin{cases} 1 & \text{for } |\omega| \leq \dfrac{\pi}{M} \\ 0 & \text{otherwise} \end{cases}$$

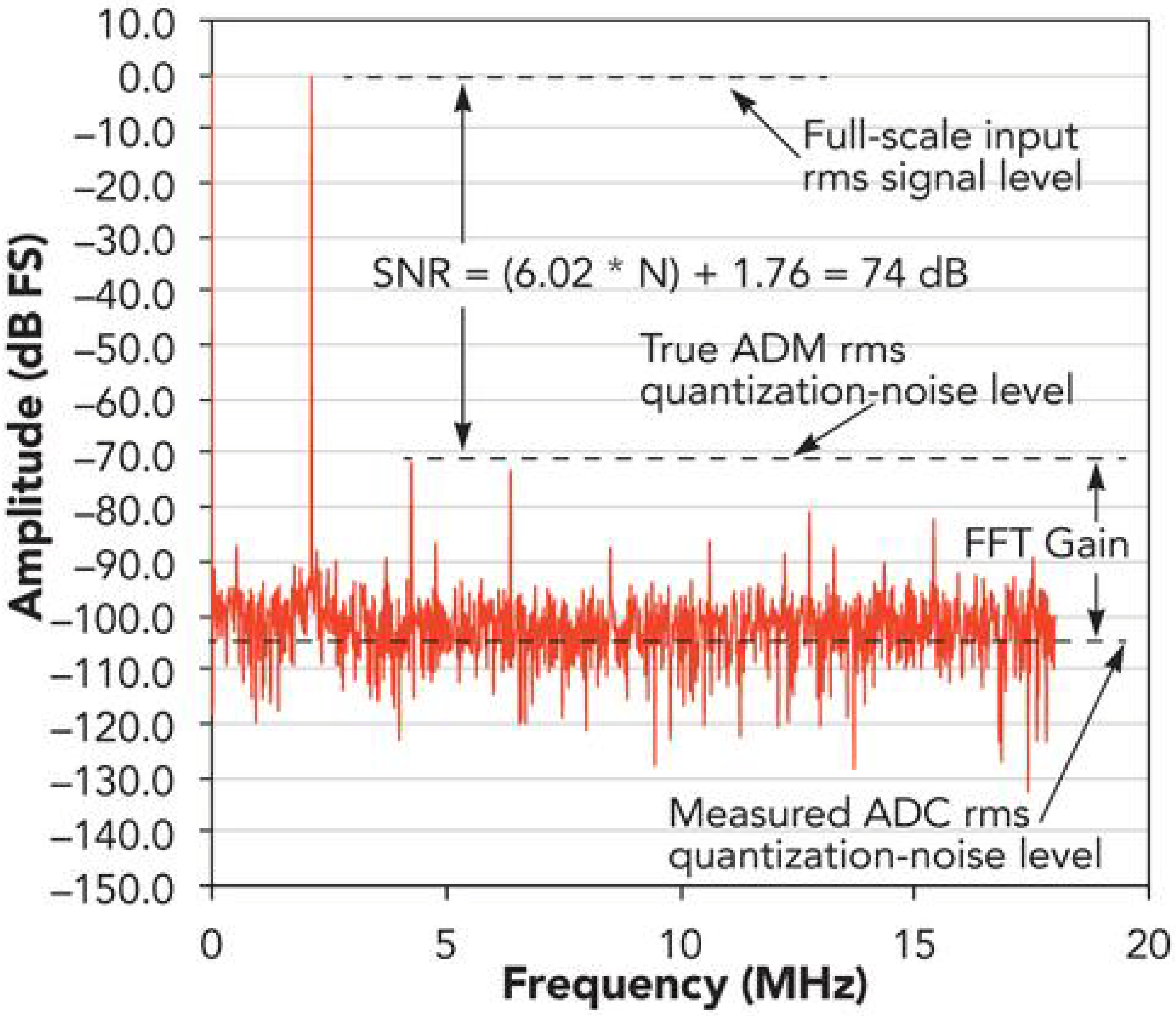


Endelig modtager-topologi

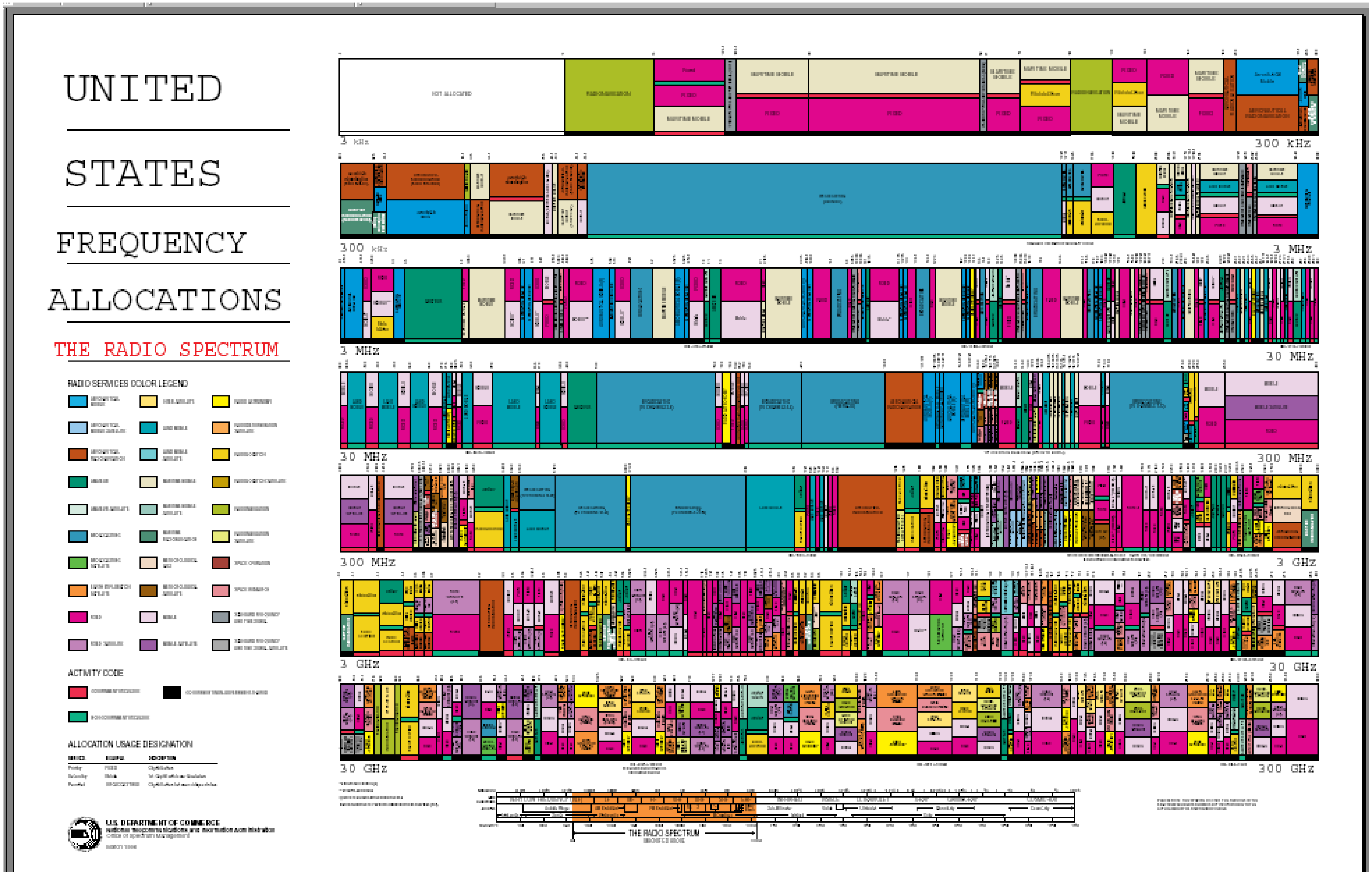


Eventually incl. an analog down converter => superhet

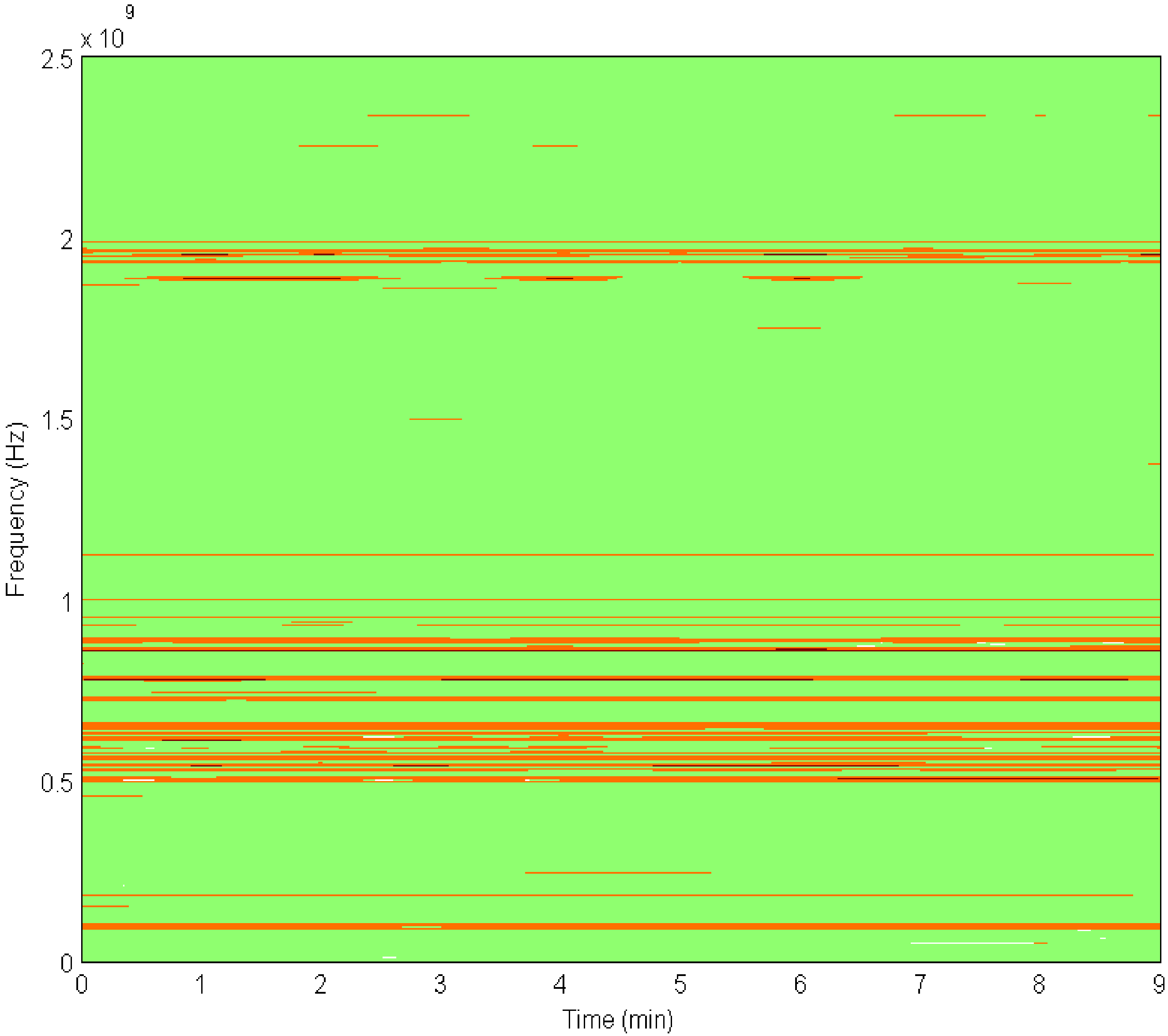
ADC’en og dens dynamik



Spektrum – en begrænset ressource



Hallo – anyone out there..??



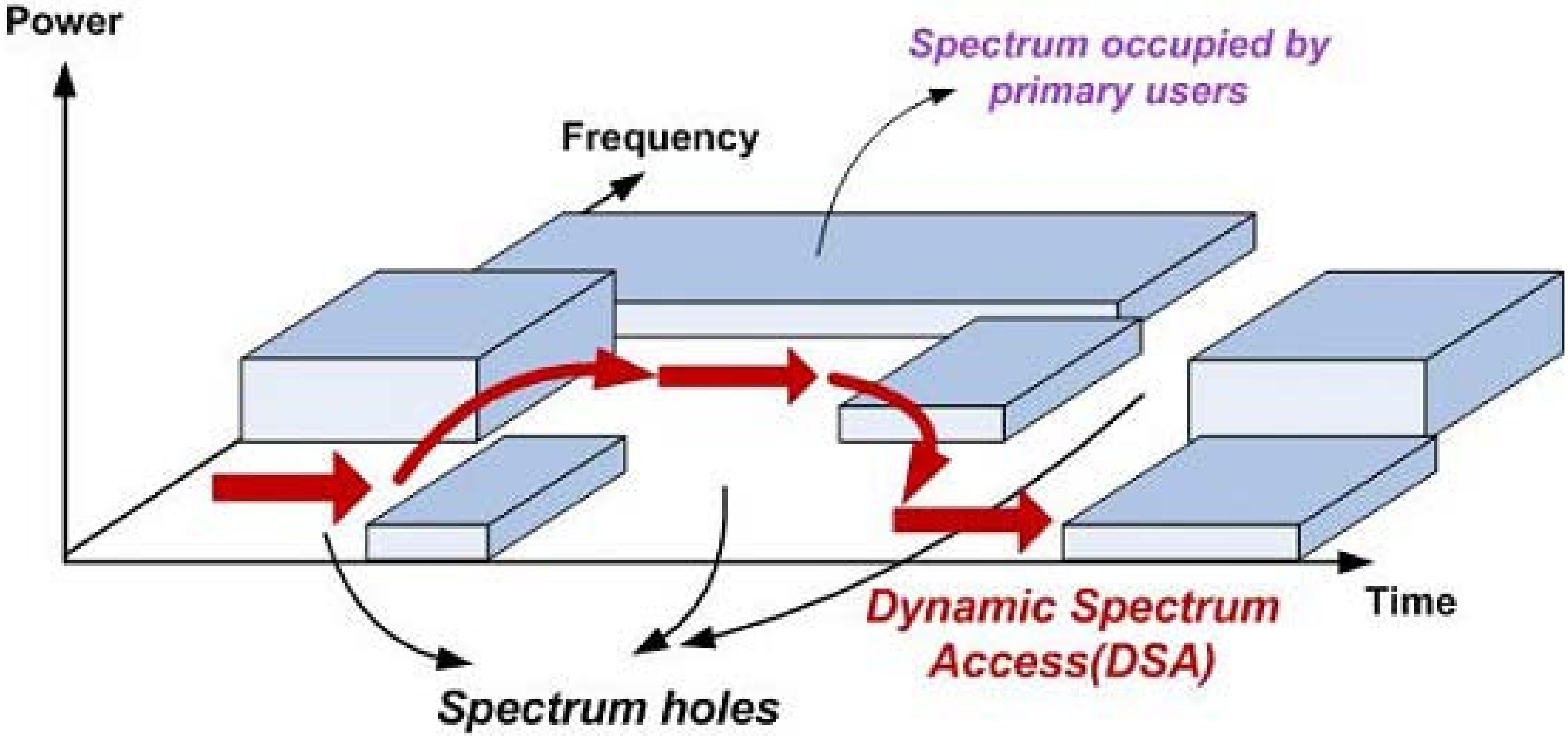
Lad os gi’ radioen lidt intelligens

- **Cognitive Radio (CR)**
is a type of wireless transmission in which communication systems are aware of their environemt and internal state, and can make decisions about their radio operating behavior based on that information and predefined objectives.

- **Dynamic Spectrum Access (DSA)**
is the real-time adjustment of spectrum utilisation in response to changing circumstances and objectes.

- **Software Defined Radio (SDR)**
is a necessary technology for implementing CR and DSA

Dynamic Spectrum Access

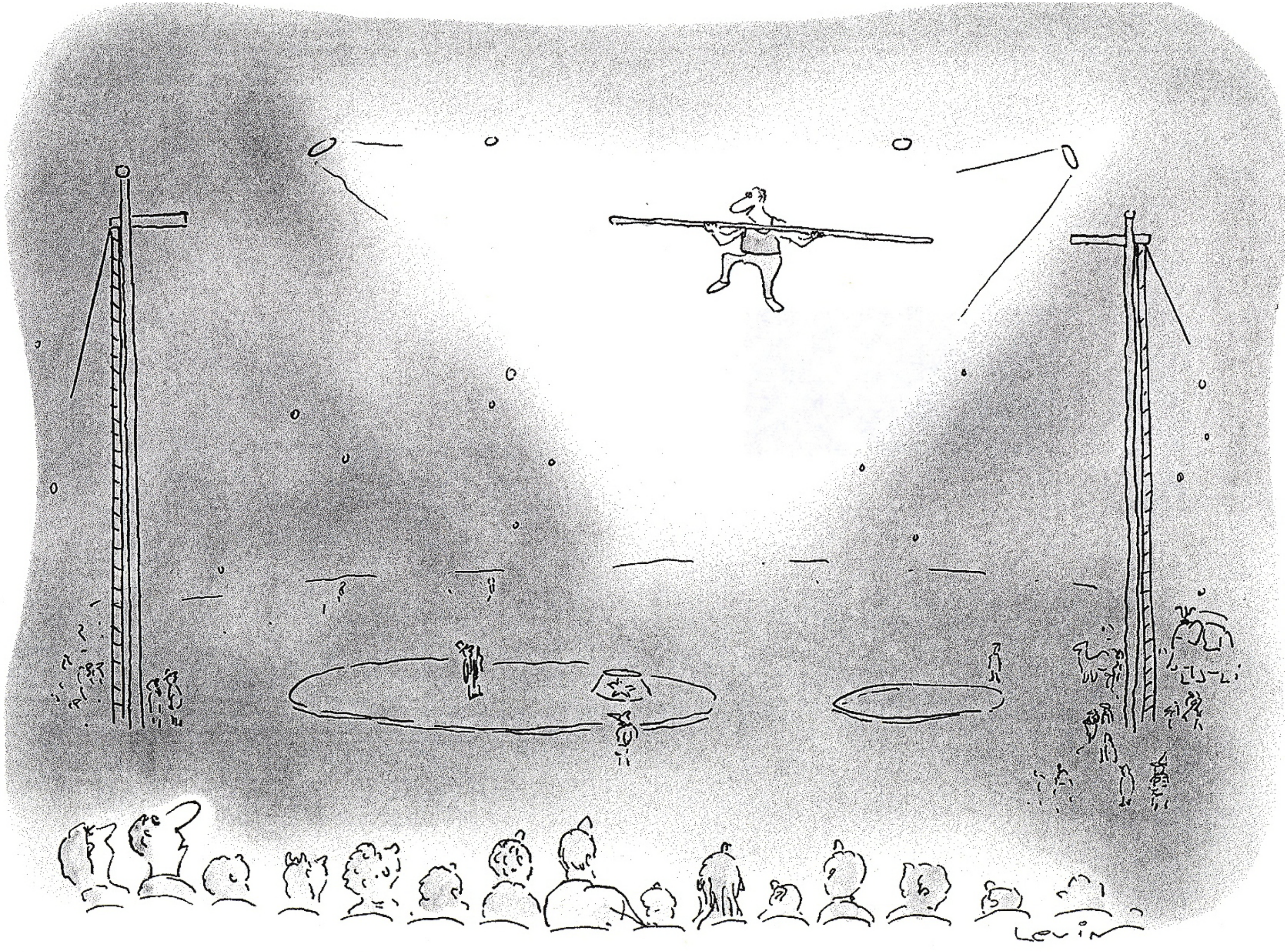


Cognitive Radio

Adapt to

- **changing free spectrum**
- **changing noise/interference**
- **jamming signals**
- **remaining battery life**
- **changing applications**

So, what is Software Radio…??



"It appears to be some kind of wireless technology."

Referencer

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9. Special thanks to Prof. Fred Harris, San Diego State University, CA, USA, for borrowing selected slides.