## Embedded Systems

- Agenda:
  - What is an embedded system?
  - Example - mobile phone handset
    - GSM cellular telephony
    - handset design
    - System-on-Chip (SoC) design
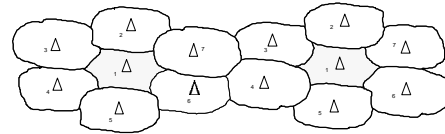 - designing embedded systems

What is an embedded system?

- A computer the user can't program?
  - the computer is just a system component
  - often the program is fixed
  - interacting in real-time with external events
- sometimes the distinction is fuzzy
  - is a PDA an embedded system?
  - is a games console an embedded system?
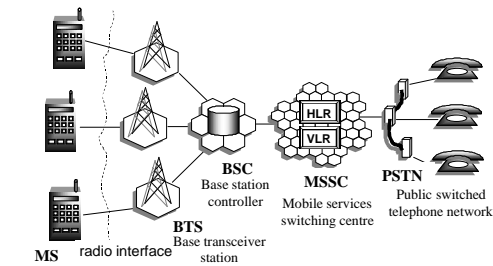- 90% of computers are embedded!
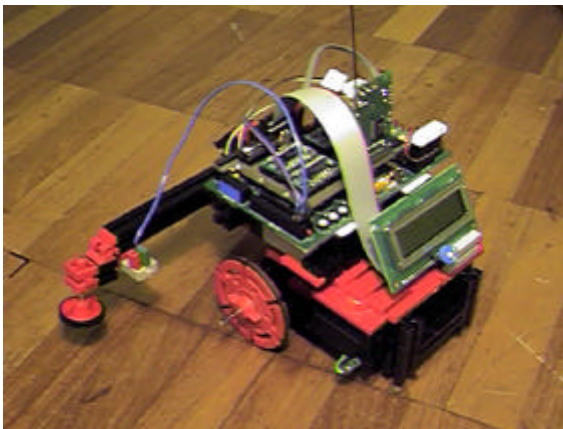
The Cellular Concept

- Coverage area of a transmitter called a cell
- Radio Propagation
  - power decreases by $1/distance^2$ (ideal), $1/distance^4$ (real).
- Spectrum scarcity, so reuse frequencies

GSM Architecture

BSC Base station controller
MSSC Mobile services switching centre
PSTN Public switched telephone network
BTS Base transceiver station
MS Mobile station   radio interface

Radio Interface

- **T**ime **D**ivision **M**ultiple **A**ccess (TDMA)

TDMA frame **(4.615 ms)**
BTS transmits
MS transmits
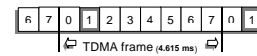
  - Assigned spectrum is divided into 8 time slots, numbered 0 to 7 (called a Frame)
  - Each time slot is assigned to an individual user
  - MS & BTS do not transmit at the same time
  - The radio transmission during a time slot is called a *burst*
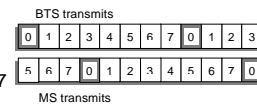
Operation of the Handset

- **Transmit speech**
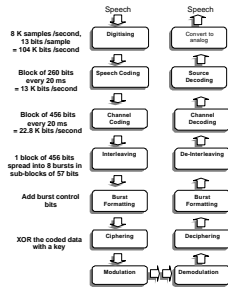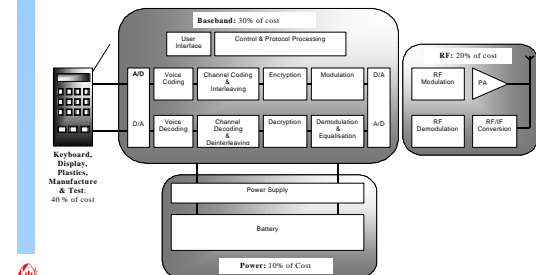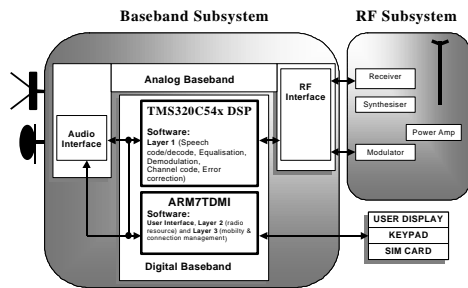 - analog voice is digitised and band-limited
  - data rates reduced by compression
  - encode then interleave to reduce transmission errors
  - add burst information and cipher for security
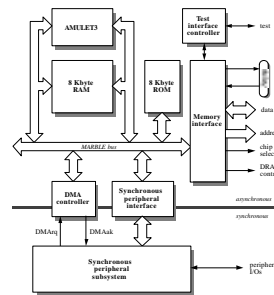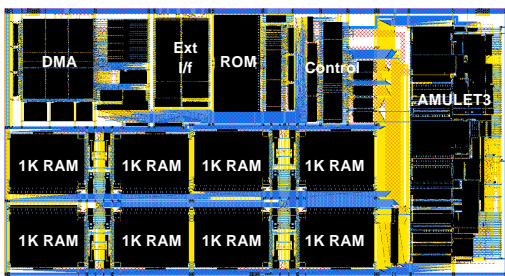 - convert up frequency and transmit

Speech ⇩	Speech ⇧
8 K samples /second, 13 bits /sample = 104 K bits /second	Digitising	Convert to analog
Block of 260 bits every 20 ms = 13 K bits /second	Speech Coding	Source Decoding
Block of 456 bits every 20 ms = 22.8 K bits /second	Channel Coding	Channel Decoding
1 block of 456 bits spread into 8 bursts in sub-blocks of 57 bits	Interleaving	De-Interleaving
Add burst control bits	Burst Formatting	Burst Formatting
XOR the coded data with a key	Ciphering	Deciphering
	Modulation	Demodulation

Partitioning the design

Baseband: 30% of cost

User Interface, Control & Protocol Processing

A/D, Voice Coding, Channel Coding & Interleaving, Encryption, Modulation, D/A

D/A, Voice Decoding, Channel Decoding & Deinterleaving, Decryption, Demodulation & Equalisation, A/D

RF: 20% of cost — RF Modulation, PA, RF Demodulation, RF/IF Conversion

Keyboard, Display, Plastics, Manufacture & Test: 40 % of cost

Power Supply, Battery

Power: 10% of Cost

A Typical Implementation

Baseband Subsystem **RF Subsystem**

Analog Baseband

RF Interface

Receiver, Synthesiser, Power Amp, Modulator

TMS320C54x DSP
Software:
Layer 1 (Speech code/decode, Equalisation, Demodulation, Channel code, Error correction)

Audio Interface

ARM7TDMI
Software:
User Interface, **Layer 2** (radio resource) and **Layer 3** (mobility & connection management)

USER DISPLAY
KEYPAD
SIM CARD

Digital Baseband

System-on-Chip: e.g. AMULET3i

AMULET3, Test interface controller, test

8 Kbyte RAM, 8 Kbyte ROM, Memory interface, data, address, chip selects, DRAM control

MARBLE bus

DMA controller, Synchronous peripheral interface

DMArq, DMAak

Synchronous peripheral subsystem, peripheral I/Os

asynchronous / synchronous

AMULET3i - physical SoC layout

DMA, Ext I/f, ROM, Control, AMULET3

1K RAM, 1K RAM, 1K RAM, 1K RAM

1K RAM, 1K RAM, 1K RAM, 1K RAM

Embedded systems: conclusions

- **design constraints differ**
  - especially in real-time performance
- **general-purpose machines contain embedded subsystems:**
  - disk, keyboard, battery, modem, …
- **SoC designs feature strongly**
- **90% of all computers are embedded**
  - a lot of folk are employed making them