ELFORSK seminarium

Stockholm, 11 april 2000

Lågspänningskablar som medium för bredband

Ingvar Fröroth
Inst. för Teleinformatik, KTH
SwedPower – Vattenfall AB

SMTP: ingvar@froroth.pp.se   http://hem.passagen.se/ingvarf/

Analysis objectives

- Signal propagation in LV lines & cables
  - Transmission line theory and numeric analysis (FD-FEM)
  - Generic models for distribution network layout
- Upper and lower bounds for signal level
  - Power constraints pertaining to EMC and EMI
  - Realistic noise introduced (impulse & interference)
- Coding, modulation, and medium access
  - Identify best suited coding & modulation schemes
  - Shared medium access considerations

☞ **Capacity bounds vs. distance (for each layout)**

– as raw data rate, made available to IP & higher layers

Research contributions

❍ Cable analysis methods
- Transmission lines
- Modes of propagation
- Simplified cable models
- FD-FEM field simulation

☞ **Secondary TL parameters**

❍ Network synthesis
- Matched network assumed
- Signal distribution scheme
- Attenuation per unit length

☞ **Signal spectrum for each customer access point**

❍ Analysis methods applied
- Geometry of real LV cables
- Fixed material parameters
- ~30 cable types modelled
- Significant factors identified

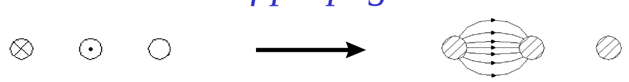
☞ **Freq. dependent TL parameters**

❍ Template networks
- Select customer access points
- Signal spectrum assessment
- Modulate available spectrum

☞ **Achievable data rate for each selected access point**

Transmission line theory

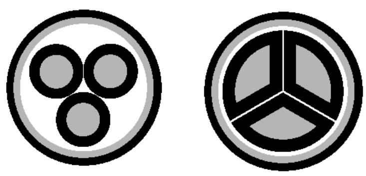
Modes of propagation



Transmission line analysis

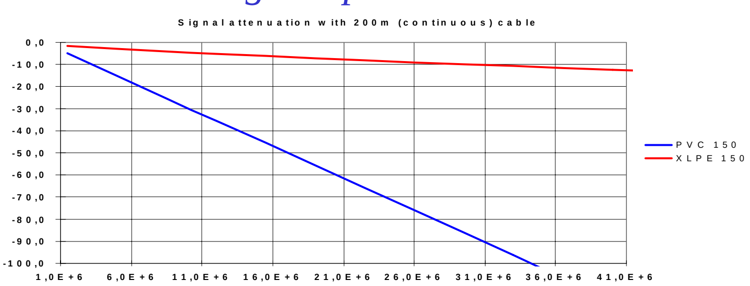
$$Z_c = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \qquad \gamma = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)}$$

LV cable types



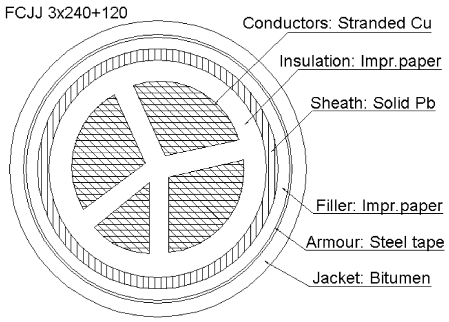
Not feasible for high frequency characteristics

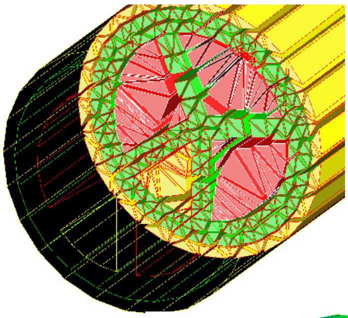
Signal spectrum

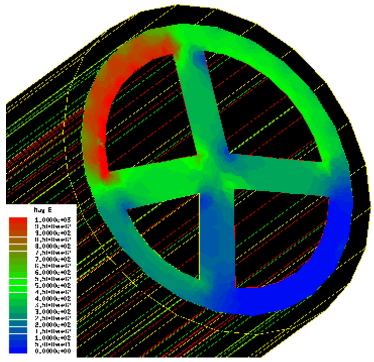


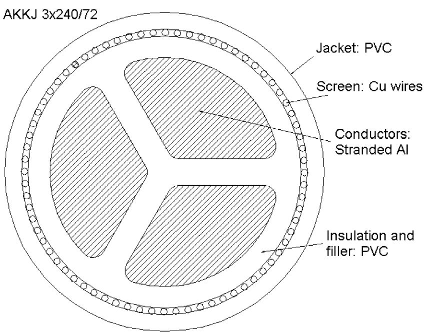
Cable models used with HFSS

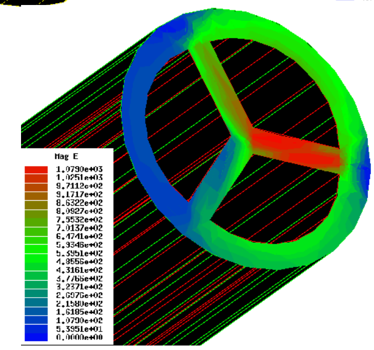
Cable geometry & materials







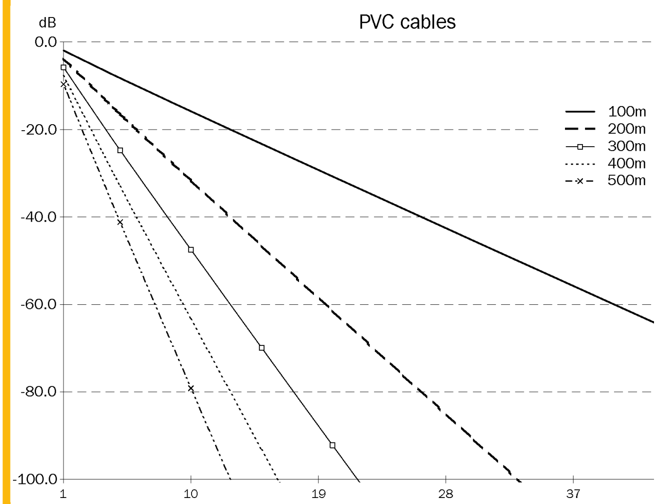


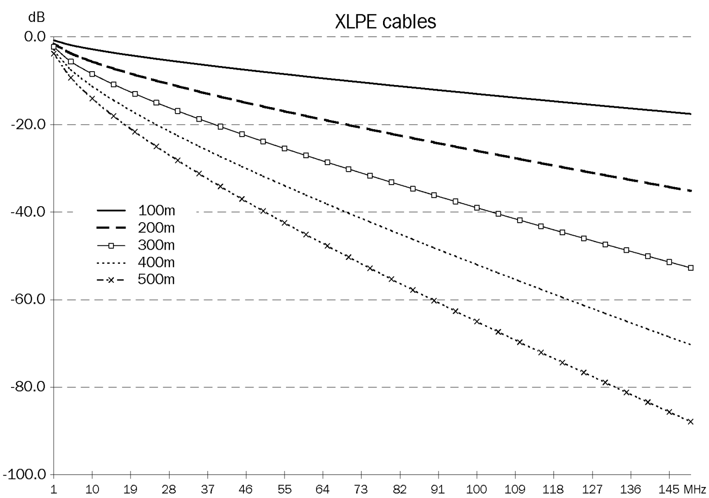


EM field simulation with simplified models

Cable attenuation vs. frequency

$$\alpha[dB] = A \cdot \sqrt{f} + B \cdot f$$





Allowable signal levels: CENELEC and CISPR limits

- largely in accordance with FCC part 15

Frequency band (meas. bandwidth 9 kHz)	Radiated emissions (10m) dB(µV/m) quasi-peak	Conducted emissions (mains terminal) dB(µV) quasi-peak	dB(µV) average
500 kHz to 5 MHz	-	56	46
5 to 30 MHz	-	60	50
30 to 230 MHz	30	-	-
230 MHz to 1 GHz	37	-	-

- No radiation limits below 30 MHz – measuring distance too small
- Extrapolate: Which limit implies the tightest tx power constraint?
- Conduction limits seem low – inline filters recommended

Allowable signal levels: Screening and containing

- Signal radiation limits are an issue
  - Shown by theoretical analysis and practical measurements
  - Underground cables with solid lead sheath nearly ideal
  - Overhead lines and cables are severe radiators
- Conduction limits are even lower
  - Signal power at customers, and at their neighbours
  - Set out from radiation limits, for largest coverage
  - Need some 40 dB suppression *at all customer sites*

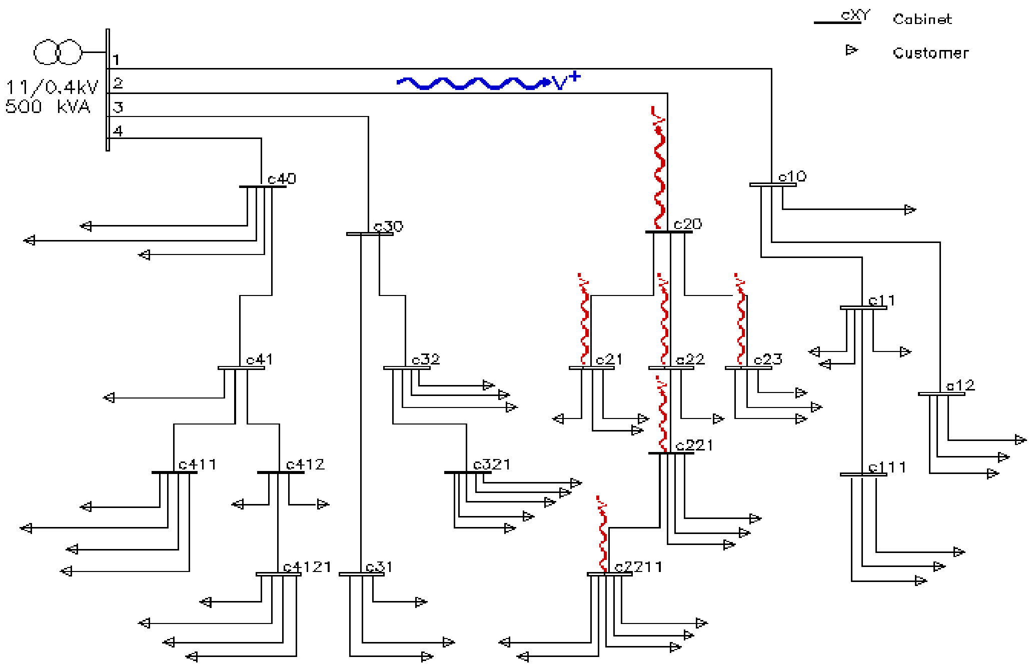
☞***Inline filters are more or less a prerequisite***

Available spectrum depth

- Signal ceiling given by radiation limits
  - Well-structured underground cable network
  - Only short (<10m) segments above ground
  - Assume sufficient filtering at customer premises
- Signal floor given by background noise
  - Noise measurements provide the input
  - Disregard interference ingress and impulse noise
  - Determine the level where signals are drowned

☞ ***80 dB is maximum SNR – the initial spectrum depth***

Low voltage networks



Network analysis tools

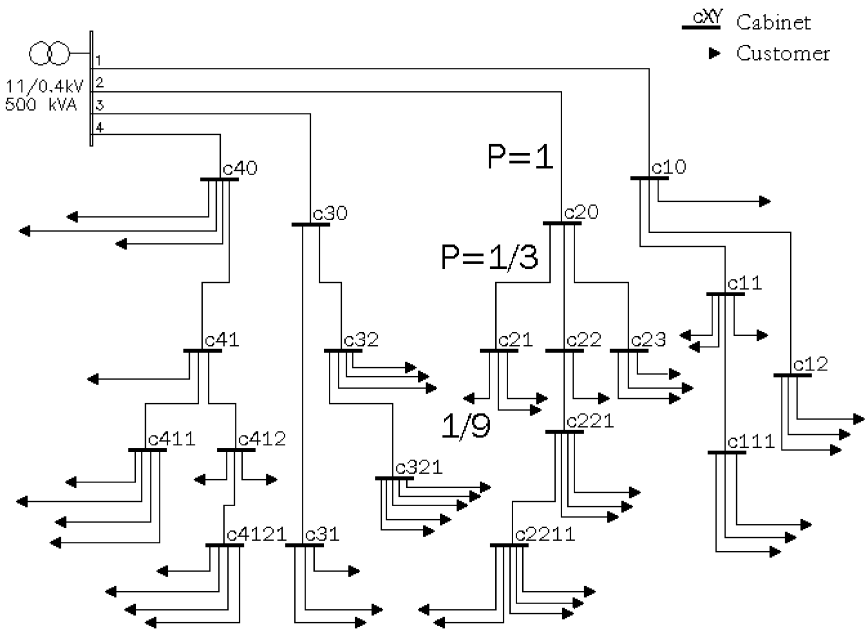
- Secondary TL parameters preferred
  - Primary parameters are frequency dependent
  - RLGC models work with one mode at a time

☞ **SPICE and many other tools inappropriate**

- Scattering matrixes - best analysis approach ?
  - Inter-modal coupling needs be considered
  - Full characterisation of terminations required

☞ **Substantial background research needed**

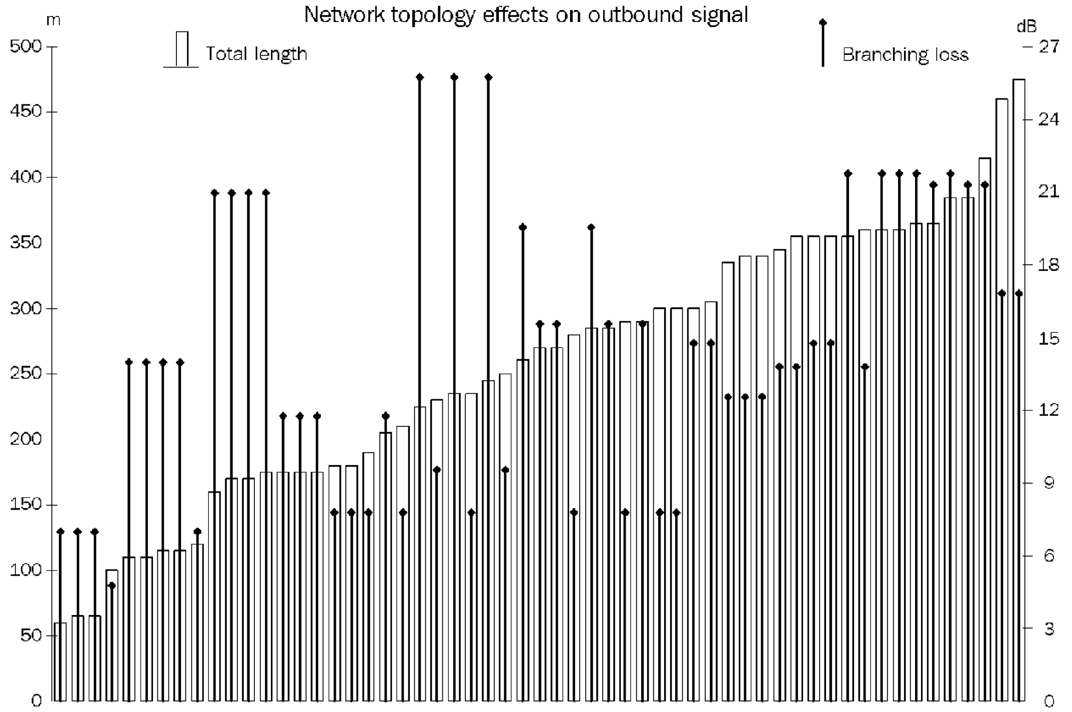
Signal power distribution



Incoming signal power is evenly split between outgoing cable routes.

Easy to do in decibels.

Village network template



VATTENFALL

Spectrum obstructions

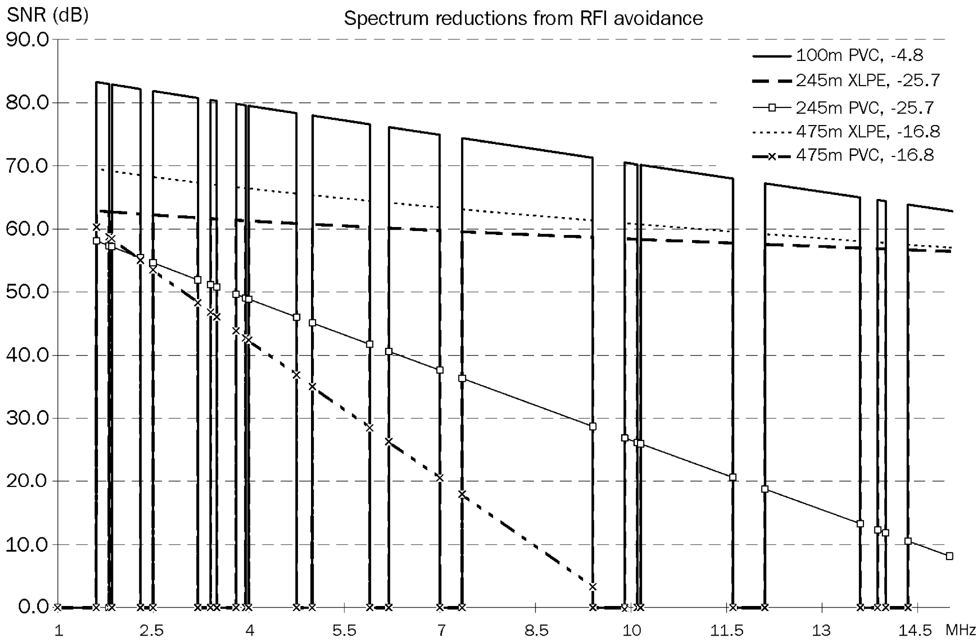
- Layout impairments
  - ☞ **Impedance discontinuities**
    - Dispersion and ISI
    - Unwanted modes
    - Radiation signal loss
  - ☞ **Power delivery priority**
    - Networks can change
    - Modification restricted
- Noise and disturbances
  - ☞ **External radio sources**
    - Broadcast stations
    - Amateur & Gov. radio
    - Consumer eq. ingress
  - ☞ **Internal disturbances**
    - Impulse noise
    - Signal cross talk

☞ **Available spectrum is non-continuous & time varying**

- should still be enough for several Mbit/s capacity

VATTENFALL

Interference avoidance



Distribution networks are sensitive to RF interference.

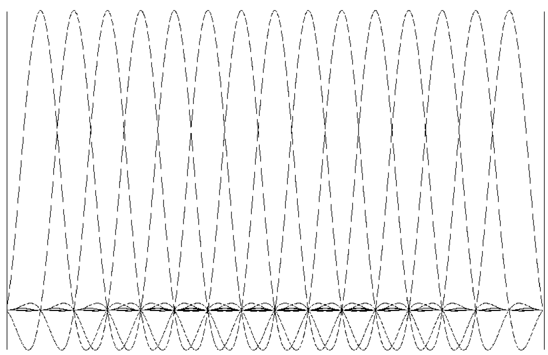
Avoid all bands allocated for broadcast and amateur radio.

Non-continuous spectrum

OFDM = Orthogonal Frequency Division Multiplex

OFDM uses a large number of carriers with overlapping spectra, modulating carriers individually.

OFDM is used in DSL and CATV, and in several wireless systems.



- *Divide overall spectrum into continuous segments with equal SNR*
- *Modulate each segment with the appropriate symbol alphabet*
- *Obtain overall capacity between any two points in a network*

Finally: Apply the entire model

Table 6-13: Capacity reduction in stages, single point example

SNR dB	bit/s per Hz	from	to	gross	net	kbit/s	-10%	kbit/s	-15%	kbit/s
		Village template, access point 4496, 100m, -4.8 dB BL, PVC cables								
> 45	9	1.00	19.00	18.000	12.662	111287	11.394	100142	9.686	85130
42-45	8.25	19.00	21.00	2.000	1.980	15952	1.782	14356	1.514	12197
39-42	7.5	21.00	23.00	2.000	1.150	8422	1.034	7573	0.878	6430
36-39	6.75	23.00	25.00	2.000	1.900	12524	1.710	11271	1.452	9571
33-36	6	25.00	27.00	2.000	1.570	9199	1.412	8273	1.200	7031
30-33	5.25	27.00	29.00	2.000	1.000	5126	0.900	4614	0.764	3916
27-30	4.5	29.00	31.00	2.000	1.300	5712	1.170	5141	0.994	4368
24-27	3.75	31.00	33.05	2.050	2.050	7507	1.844	6752	1.568	5742
21-24	3	33.05	35.10	2.050	2.050	6005	1.844	5402	1.568	4593
18-21	2.25	35.10	37.15	2.050	2.050	4504	1.844	4051	1.568	3445
15-18	1.5	37.15	39.20	2.050	2.050	3002	1.844	2701	1.568	2296
Total	**Mbit/s**					**184**		**166**		**141**

(p. 120)

Capacity allocation scheme

- Spectrum width strongly distance dependent
  - Only lowest frequencies available to sites far away
  - Equal capacity sharing requires frequency division
- Topology & take-up rate affects capacity
  - Total number of customers per distributor cable
  - Number of customers to share available capacity
- Overall capacity ceiling depends on cable
  - PE and XLPE insulated cables are outstanding
  - PVC insulated cables give lowest capacity

☞ ***10 Mbit/s peak rate for PVC, ~100 Mbit/s for XLPE***

Main conclusions & Future work

- Distribution grid communication
  - Has an obvious potential for broadband
- Long term capacity ceiling
  - 10 to 100 Mbit/s shared capacity
- Cable analysis experience
  - Complex structures require powerful analysis tools
- Network modelling issues
  - Impedance matching appears to be crucial

- **Suggested future work**
  - Validate and refine the cable models
  - Modal coupling, impedance matching
  - High frequency disturbance limits
  - Modulation, coding, multiple access

Future for broadband powerline

- Products and systems are fairly new
  - Still many prototypes, few proven systems
  - Numerous trials, but where are the roll-outs?
- Significant problems in real networks
  - Signal leakage and radiation, high signal losses
  - Large investments required, to realise the full potential
- Many competing access networks
  - ADSL, Cable modems, LMDS, …
  - Window of opportunity about to close?