

# Turbo Codes for Deep Space Communications:

## CCSDS 131.0-B-2 standard implementation

Final project for the Channel Coding course

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# Standard specifications

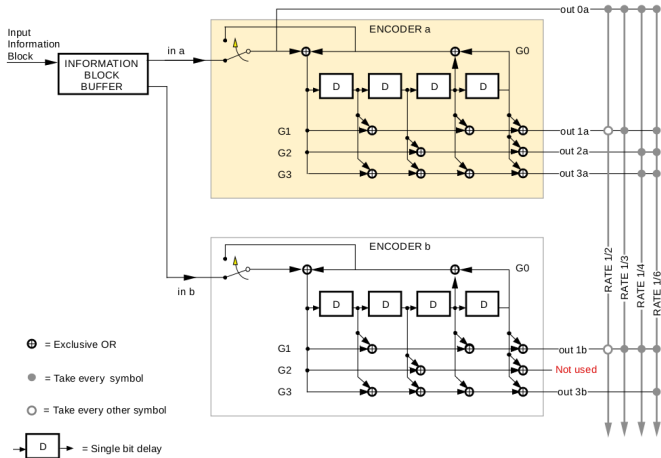
The standard specifies different input packet lengths  $k$

- 1784
- 3568
- 7136
- 8920

...and different code rates  $R$

- $1/2$
- $1/3$
- $1/4$
- $1/6$

# Encoder structure



2

Convolutional codes defined through forward and backward connection vectors



# Example: defining a code in C

```
// define first code
int N_components = 2;
char *forward[N_components];
forward[0] = "10011";
forward[1] = "10101";

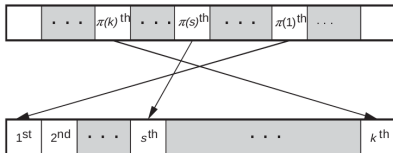
char *backward = "0011";

t_convcode code = convcode_initialize(forward, backward,
                                      N_components);

t_turbocode turbo = turbo_initialize(code, code, pi,
                                     info_length);
```



# Interleaver



$i$ -th bit of the interleaved packet is the  $\pi(i)$ -th bit of the original packet

Information block length	$k_1$		$k_2$		$k_3$
1784	8	×	223	×	1
3568	8	×	223	×	2
7136	8	×	223	×	4
8920	8	×	223	×	5

# Building the interleaver

```
 $p = [31 \ 37 \ 43 \ 47 \ 53 \ 59 \ 61 \ 67]$   
for  $s = 1$  to  $k$  do  
     $m = (s - 1) \bmod 2$   
     $i = \text{floor}[(s - 1)/(2k_2)]$   
     $j = \text{floor}[(s - 1)/2] - ik_2$   
     $t = (19i + 1) \bmod (k_1/2)$   
     $q = t \bmod 8 + 1$   
     $c = (p_q j + 21m) \bmod k_2$   
     $\pi(s) = 2(t + ck_1/2 + 1) - m$   
end for
```



- BCJR (in log domain) on upper and lower code
- scheduling as seen in class
- number of iterations is tuned accordingly
- puncturing is applied at reception for an easier implementation  $\hat{r}[i] = r[i] \cdot p[i], 1 \leq i \leq (k+4)/R$

# Example: defining a code in C

```
int *decoded = NULL;
for (int i = 0; i < iterations; i++) {

    // run BCJR on upper code
    convcode_extrinsic(streams[0], lengths[0],
                      &messages, code.upper_code,
                      noise_variance, 0);

    // apply interleaver
    message_interleave(&messages, code);

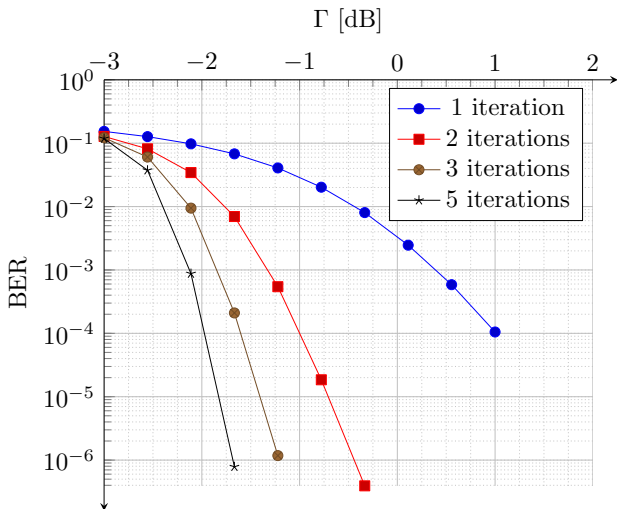
    // run BCJR on lower code
    decoded = convcode_extrinsic(streams[1], lengths[1],
                                &messages, code.lower_code,
                                noise_variance,
                                i == (iterations - 1));

    // deinterleave
    message_deinterleave(&messages, code);
}
```





# Effect of increasing number of iterations



# Effect of increasing number of iterations

```
gianluca@ursula: ~/deepspace-turbo/bin $ ./deepspace_turbo --help
-y / --skip-confirm
    skip confirmation dialog after summarizing simulation parameters. Useful when automating simulations.

    -h / --help
    print this help dialog.

-o / --output FILENAME
    save results in a comma-separated format in FILENAME. If this argument is not used, the results will be saved in a file named with the current date and time.

-c / --packet-count INTEGER
    set the number of packets to encode/decode. INTEGER can be given in exponential notation i.e. 1e4 for 10000 packets.

-C / --cores INTEGER
    set the number of CPU cores to use.

-k / --multiplier INT
    set the input packet length through the following formula: packet-length = 223 * 8 * multiplier

-l / --packet-length INTEGER
    set the number of information bits in a packet. Exponential notation can be used.

-m / --min-SNR FLOAT
    set the lower extreme of the SNR range to test.

-M / --max-SNR FLOAT
    set the upper extreme of the SNR range to test.

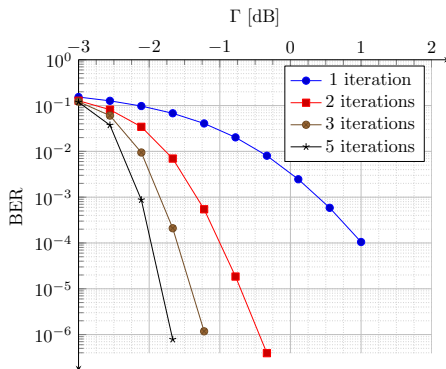
-n / --SNR-points INTEGER
    set the number of linearly spaced points inside the interval [min-SNR, max-SNR]

-i / --iterations
    set the number of iterations for the turbo decoding algorithm.
```



# Different packet sizes

# First type of modulator

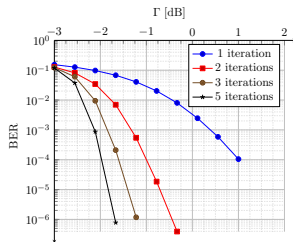
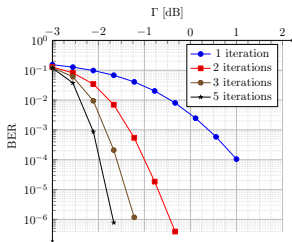


[Cho et al., 2011]

11 Large footprint required to obtain adequate modulation depth



# Novel design: slot waveguides

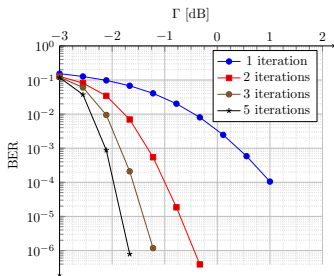


$\lambda = 1550$  nm,  $n_{co} = 1.46$ ,  $n_{cl} = 3.48$ ,  $w_{co} = 101$  nm. [Xu et al., 2004]

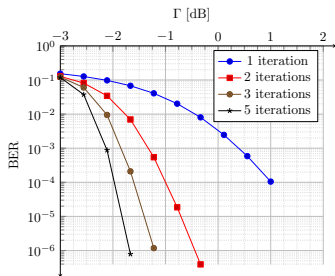
Absorbed power per unit area

$$P \propto \frac{1}{2} |\mathbf{E}| \cdot \frac{\text{Im}\{\varepsilon_{eff}\}}{|\varepsilon_{eff}|}$$

# Wavelength and Voltage dependency

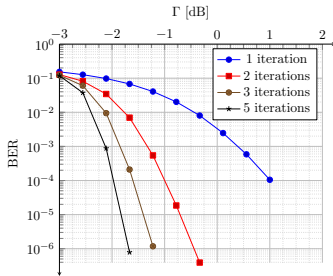


Bandwidth > 1.25 THz



$\Delta V = 1.32 V$

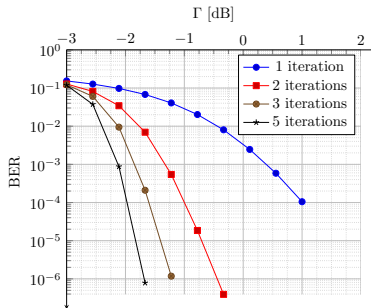
# Plasmonic-graphene waveguide modulator



Cu is preferred (CMOS compatible), but has higher losses than Au, Ag.

# Plasmonic-graphene waveguide modulator

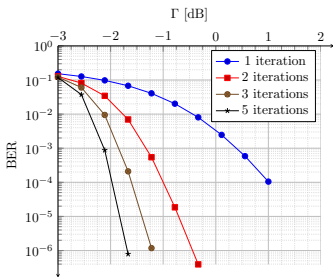
200 nm wide, silicone nitride 10 nm thick (both layers), length 120 nm.



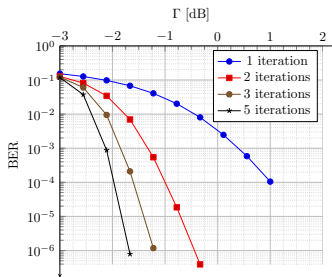
Footprint  $\sim 2 - 3 \mu m^2$



# Wavelength and Voltage dependency



Bandwidth  $> 1$  THz



$\Delta V = 1.38$  V

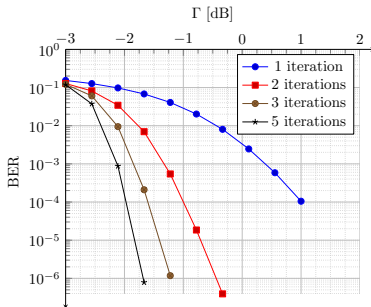
Energy consumption  $\sim 0.12$ - $0.13$  pJ/bit

# Did we meet any requirement?

- high bandwidth Yes
- energy efficiency Yes
- compatibility with on-chip electronic components Yes
- low insertion loss Yes
- small footprint Kinda
- high switching speed Potentially

# Recent advances: graphene-on-silicon MZI

- Fix one arm in "dielectric state" (low loss) of graphene
- Exploit changes in  $Re\{\epsilon_{eff}\}$  wrt gate voltage to induce phase change



[Phatak et al., 2016]

# References I



Cho, S., Yoon, M. C., Kim, K. S., Kim, P., Kim, D., Ulin-avila, E., and Zentgraf, T. (2011).

**A graphene-based broadband optical modulator.**

*Nat. (UK)*, 474(7349):64–6767.




Phatak, A., Cheng, Z., Qin, C., and Goda, K. (2016).

**Design of electro-optic modulators based on graphene-on-silicon slot waveguides.**

*Optics Letters*, 41(11):2501.



## References II

-  Xu, Q., Almeida, V. R., Panepucci, R. R., and Lipson, M. (2004).  
Experimental demonstration of guiding and confining  
light in nanometer-size low-refractive-index material.  
*Optics letters*, 29(14):1626–1628.



Thank you!

