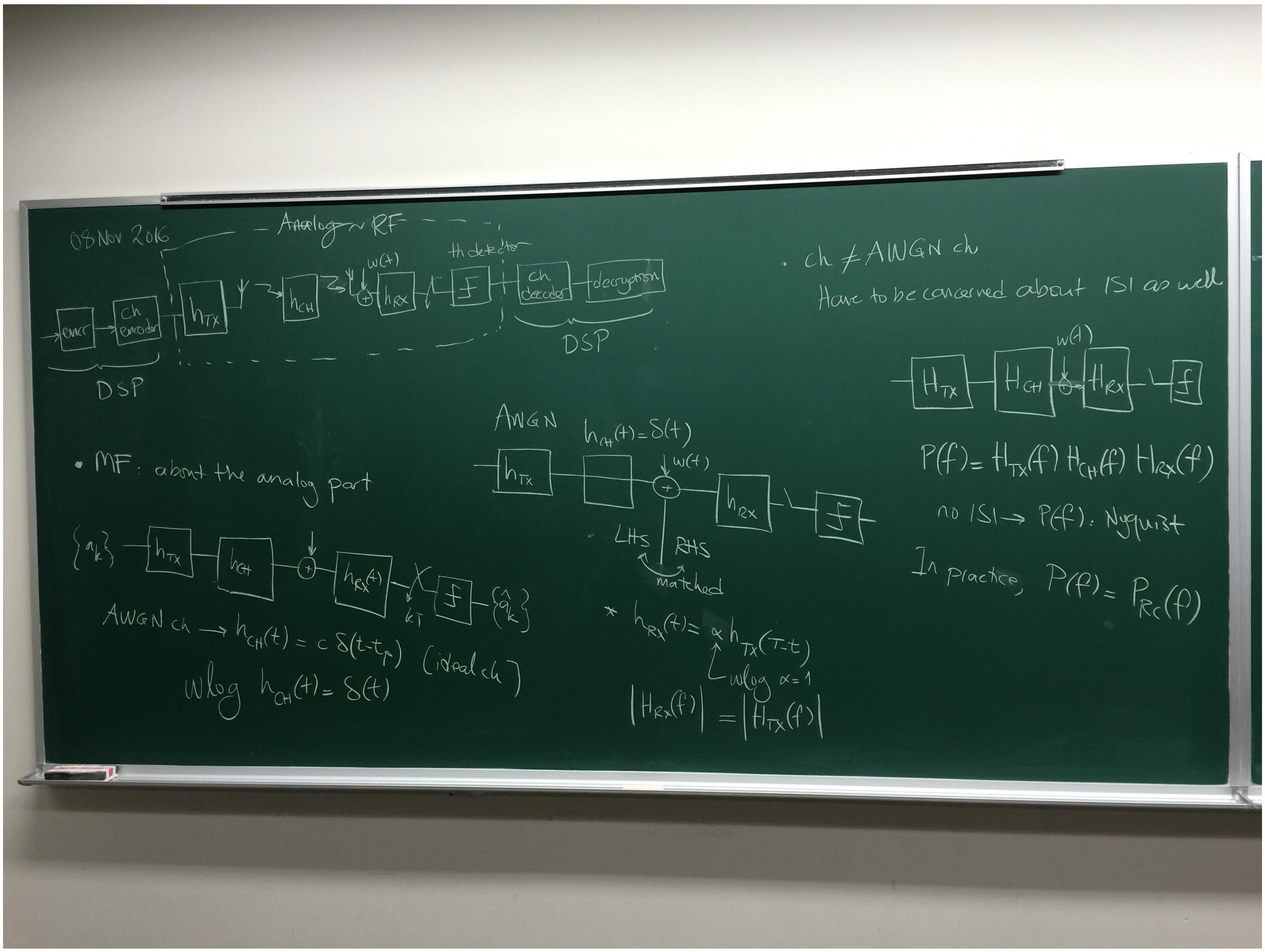
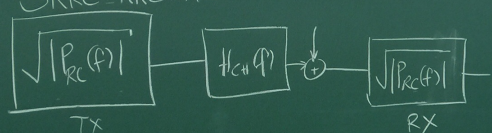

08 Nov 2016
Analog ~ RF
encr
ch encoder
h_{TX}
h_{CH}
$w(t)$
h_{RX}
th detector
ch decoder
decryption
DSP
DSP
• ch ≠ AWGN ch
Have to be concerned about ISI as well
H_{TX}
H_{CH}
H_{RX}
$P(f) = H_{TX}(f)\, H_{CH}(f)\, H_{RX}(f)$
no ISI → $P(f)$: Nyquist
In practice, $P(f) = P_{RC}(f)$
AWGN
$h_{CH}(t) = \delta(t)$
LHS
RHS
matched
* $h_{RX}(t) = \alpha\, h_{TX}(T-t)$
wlog $\alpha = 1$
$|H_{RX}(f)| = |H_{TX}(f)|$
• MF: about the analog part
$\{a_k\}$
$h_{RX}(t)$
kT
$\{\hat{a}_k\}$
AWGN ch → $h_{CH}(t) = c\,\delta(t - t_p)$ (ideal ch)
wlog $h_{CH}(t) = \delta(t)$

SRRC = RRC = rRC



* will work if $H_{CH}(f) = 1$

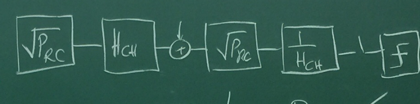
$h_{CH}(t) = \delta(t)$

- no ISI (ISI removed)
- best protection against noise

} multiobjective optimization

* if $H_{CH}(f) \neq 1 \longrightarrow$ Nyquist X

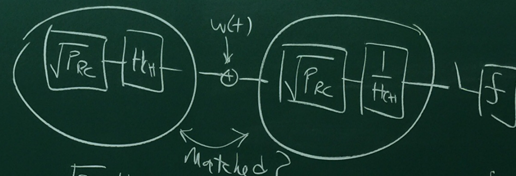
fix: Equalization



* $\sqrt{P_{RC}}\, H_{CH} \sqrt{P_{RC}} \frac{1}{H_{CH}} = P_{RC}$ ✓

ISI is removed completely

but ultimate noise supression (MF) is disturbed

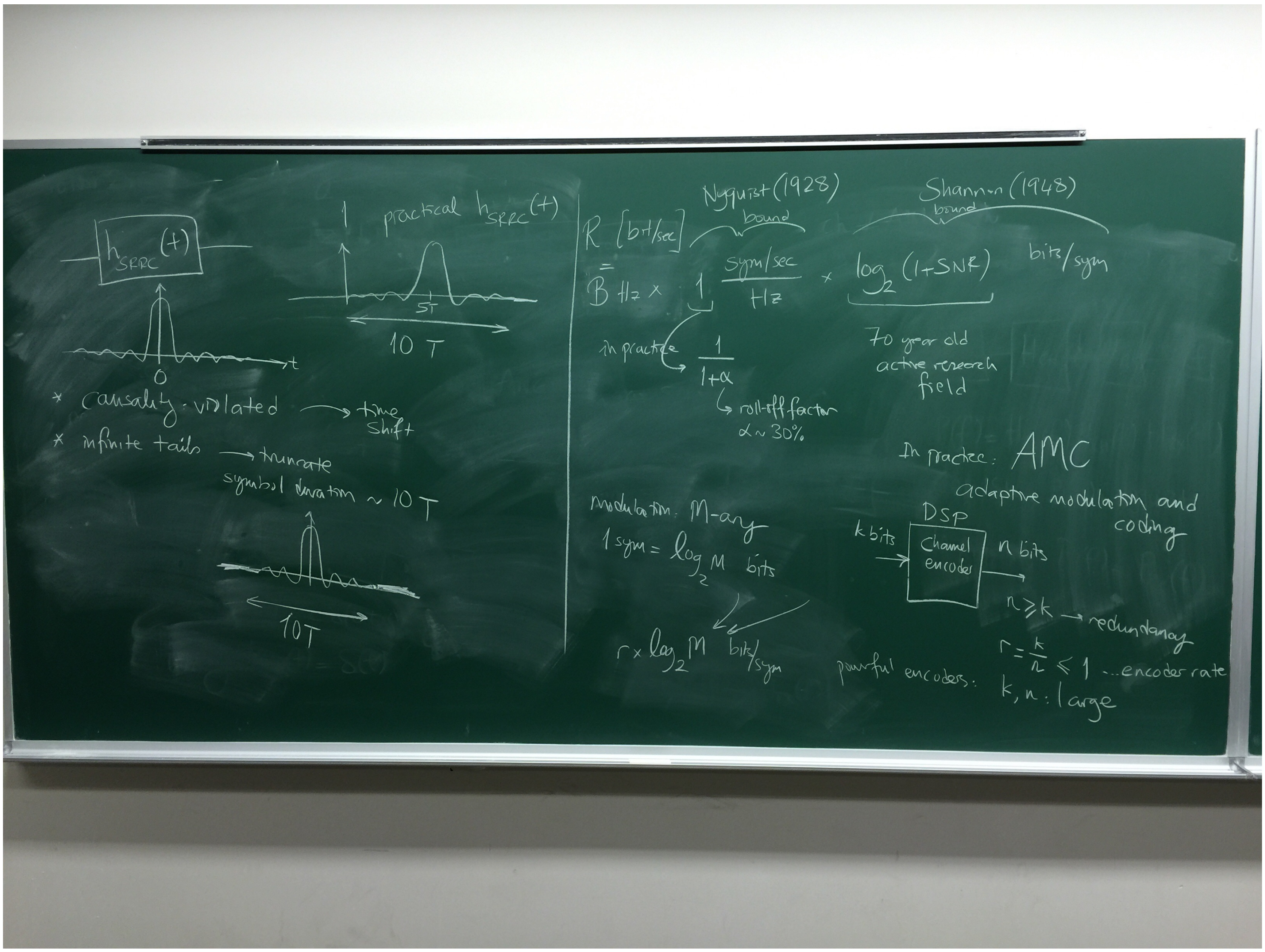


$\sqrt{P_{RC}}\, H_{CH} \neq \sqrt{P_{RC}} \frac{1}{H_{CH}}$

noise amplification, due to aggressiveness in removing ISI

Best strategy:

Desing an eql ($H_{eql}(f)$) which will remove as much ISI as possible, while maximizing SNR as much as possible at the same time



$h_{SRRC}(t)$
practical $h_{SRRC}(t)$
5T
10 T
0
t
* causality violated → time shift
* infinite tails → truncate
symbol duration ~ 10 T
10T
Nyquist (1928)
bound
Shannon (1948)
bound
R [bit/sec]
=
B Hz × 1 sym/sec / Hz × $\log_2$ (1+SNR) bits/sym
in practice 1/(1+α)
roll-off factor
α ~ 30%
70 year old
active research
field
In practice: AMC
adaptive modulation and
coding
modulation: M-ary
1 sym = $\log_2 M$ bits
r × $\log_2 M$ bits/sym
DSP
k bits
Channel encoder
n bits
n ≥ k → redundancy
r = k/n ≤ 1 ...encoder rate
powerful encoders: k, n : large

Q: 16QAM, convolutional encoder $r = \frac{2}{3}$

SRRC with $\alpha = 0.25$

$f(SNR)$

BW = 2 MHz

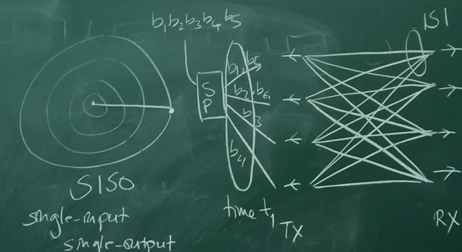
Find transmission rate

$f(SNR) < \log_2(1+SNR)$

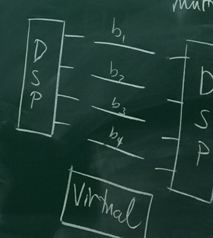
$$R = 2\times10^6 \text{ Hz} \times \frac{1}{1+0.25} \frac{\text{sym/sec}}{\text{Hz}} \times \left(\frac{2}{3} \times \log_2 16\right) \text{ bits/sym}$$

$$= 2 \times \frac{4}{5} \times \frac{2}{3} \times 4 \times 10^6$$

$$= \frac{64}{15} \text{ Mbits/sec}$$



4x4 MIMO
multiple-input
multiple-output



MIMO
~1995
Telatar, Foschini

MIMO

$$R_{max} = n\,B\,\log_2(1+SNR)$$

$n \rightarrow \min(\#\text{ of TX ant}, \#\text{ of RX ant})$

P_s: total RX power

$$SNR = \frac{P_s/n}{P_N} = \frac{P_s/n}{BN_0} = \frac{P_s}{nBN_0}$$

LTE ~

802.11ah ~ ~1 Gbps

Zigbee 3 Gbps

$n = 4$

$B = 100\,MHz$

64 QAM, $r = \frac{5}{6}$

$$4 \times 10^8 \times \frac{5}{6} \times \log_2 64 \quad (\text{= } 5)$$

$= 2$ Gbps