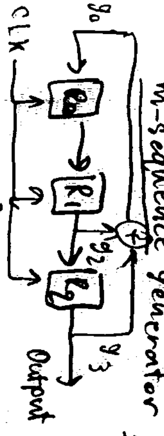
Galois field → symbols 0 and 1
→ binary operation → modulo-2

$0 \oplus 0 = 0$  $0 \oplus 1 = 1$  $1 \oplus 0 = 1$  $1 \oplus 1 = 0$
$0 \cdot 0 = 0$  $0 \cdot 1 = 0$  $1 \cdot 0 = 0$  $1 \cdot 1 = 1$

m-sequence generator




$g_i$'s are coeffi. of primitive polynomial

| Time | $R_0$ | $R_1$ | $R_2$ |
|---|---|---|---|
| 0 | 1 | 0 | 0 |
| 1 | 0 | 1 | 0 |
| 2 | 1 | 0 | 1 |
| 3 | 1 | 1 | 0 |
| 4 | 1 | 1 | 1 |
| 5 | 0 | 1 | 1 |
| 6 | 0 | 0 | 1 |
| 7 | 1 | 0 | 0 |

$g(x) = x^3 + x^2 + 1$ (Deg. r=3)
1 specifies closed → connection
0 specifies open → no connection
Cycle over all possible $2^r - 1$ nonzero states

CDMA Orthogonal (real-valued)

$\langle c_1, c_2 \rangle = \int_0^T c_1(t) c_2(t) dt = 0$

CDMA has soft capacity limit instead of TDMA & FDMA

K-user orthogonal CDMA system Rate R bps

∴ Bandwidth $= \frac{1}{2} RK$

Hadamand length $2^n$  $W_2^1 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} W_0 \\ W_1 \end{bmatrix}$, $W_{2^n} = \begin{bmatrix} W_{2^{n-1}} & W_{2^{n-1}} \\ W_{2^{n-1}} & \overline{W}_{2^{n-1}} \end{bmatrix}$

Gold code → is the combination of 2 m-sequence generator

2G System → D-AMPS: 30 kHz carrier, 3 user/carrier
GSM: 200 kHz carrier, 8 full-rate user/carrier

SC/FDE $\{x_n\}$ → Add CP/PS → channel → Remove CP → N-Point DFT → Equalization → N-pt. IDFT → Detect →

OFDM $\{x_n\}$ → N-pt. IDFT → Add CP/PS → Ch. → Remove CP → N-pt. DFT → Equalization → Detect →

OVSF
UL 4 to 256
DL 4 to 512

Smaller SF = Faster data rate

Spreading Codes [ 1st Orthogonal walsh codes (for channelization code)
2nd not necessary orthogonal / Built from PN code (Scrambling codes)

Three steps towards modern OFDM
1) Mitigate Multipath (ISI → Multicarrier modulation (FDM))
2) Gain Spectral Effeciency → orthogonality for the carriers
3) Achieve Efficient Implementation → FFT and IFFT
completely eliminate ISI and ICI → Cyclic prefix

OVSF code Disadvantages [ Poor autocorrelation property
When code shift one bit, will effect to not orthogonality

(C) → (C,C), (C,−C)

DFT $S[n] = s\left(n\frac{T_s}{N}\right) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} S_k \exp\left(j\frac{2\pi k}{T_s} n \frac{T_s}{N}\right) = \sqrt{N}\, IDFT\{S\}[n]$

OFDM $s(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} S_k \exp\left[j\frac{2\pi k t}{T_s}\right], 0 \le t \le T_s$

$= \sum_{k=0}^{N-1} S_k \underbrace{\frac{1}{\sqrt{N}} 1_{[0,T_s]}(t) \exp\left(j\frac{2\pi k t}{T_s}\right)}_{c_k(t)}$

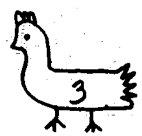
CDMA $s(t) = \sum_{k=0}^{l-1} S_k c_k(t)$
TDMA $s(t) = \sum_{k=0}^{l-1} S_k c(t - kT_s)$
FDMA $s(f) = \sum_{k=0}^{l-1} S_k c(f - k\Delta f)$

Convolution: Flip → Shift → Multiply add
$(x * h)[n] = \sum_m x[m] h[n-m]$

DFT N-point of an N-point.

$X[k] = \sum_{n=0}^{N-1} x[n] e^{-jnk\frac{2\pi}{N}} = \sum_{n=0}^{N-1} x[n] \psi_N^{-nk}$, $0 \le k < N$

Inverst DFT $x[n] = \frac{1}{N} \sum_{k=0}^{N-1} X[k] \psi_N^{nk}$, $0 \le n < N$

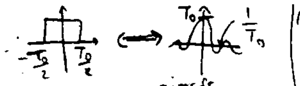



DFT $\psi_N = e^{j\frac{2\pi}{N}}$

$Q = \Psi_N$

pth row, qth column

$\psi_N^{-(p-1)(q-1)}$




$g(t - t_0) \Longleftrightarrow e^{-j2\pi f t_0} G(f)$

$e^{j2\pi f_0 t} g(t) \Longleftrightarrow G(f - f_0)$

$m(t)\cos(2\pi f_c t) \Longleftrightarrow \frac{1}{2}M(f - f_c) + \frac{1}{2}M(f + f_c)$

$s(t) = \sum_{k=0}^{N-1} m_k c(t - kT) \xrightarrow{\mathcal{F}} S(f) = C(f) \sum_{k=0}^{N-1} m_k e^{-j2\pi f k T}$

Multipath Fading: $h(t) = \sum_{i=0}^{v} \beta_i \delta(t - \tau_i)$

Single Carrier Transmission
• Baseband $s(t) = \sum_{k=0}^{N-1} S_k p(t - kT_s)$, $p(t) = \begin{cases} 1, & t \in [0, T_s) \\ 0, & \text{otherwise} \end{cases}$
• Passband $x(t) = Re\{s(t) e^{j2\pi f_c t}\}$

DFT $X[k] = \sum_{n=0}^{N-1} x[n] e^{-j\frac{2\pi}{N} k \times n}$

OFDM Orthogonality
time-domain $\langle a, b \rangle = \int_{-\infty}^{\infty} a(t)^* b(t) dt = 0$
frequency $\langle A, B \rangle = \int_{-\infty}^{\infty} A(f) B^*(f) df = 0$

$\Psi_N^{k \times n} = \left(e^{j\frac{2\pi}{N}}\right)^{k \times n}$

$x = \frac{1}{N} \Psi_N^* X \overset{DFT}{\Longleftrightarrow} X = \Psi_N x$

$S(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} S_k \exp\left(j\frac{2\pi k t}{T_s}\right), 0 \le t \le T_s$

$= \sum_{k=0}^{N-1} S_k \underbrace{\frac{1}{\sqrt{N}} \exp\left(j\frac{2\pi k t}{T_s}\right)}_{C_k(t)}$

Parseval's Theorem
$\langle x, y \rangle = \int_{-\infty}^{\infty} x(t) y^*(t) dt = \int_{-\infty}^{\infty} X(f) Y^*(f) df$

CDMA $S(t) = \sum_{k=0}^{l-1} S_k C_k(t) \xrightarrow{\mathcal{F}} S(f) = \sum_{k=0}^{l-1} S_k C_k(f)$
TDMA $S(t) = \sum_{k=0}^{l-1} S_k c(t - kT_s) \xrightarrow{\mathcal{F}} S(f) = C(f) \sum_{k=0}^{l-1} S_k e^{-j2\pi f k T_s}$
FDMA $S(f) = \sum_{k=0}^{l-1} S_k C(f - k\Delta f)$