Low Probability of Intercept Radar

Short Course on Radar and Electronic Warfare

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Seeing, without being seen…

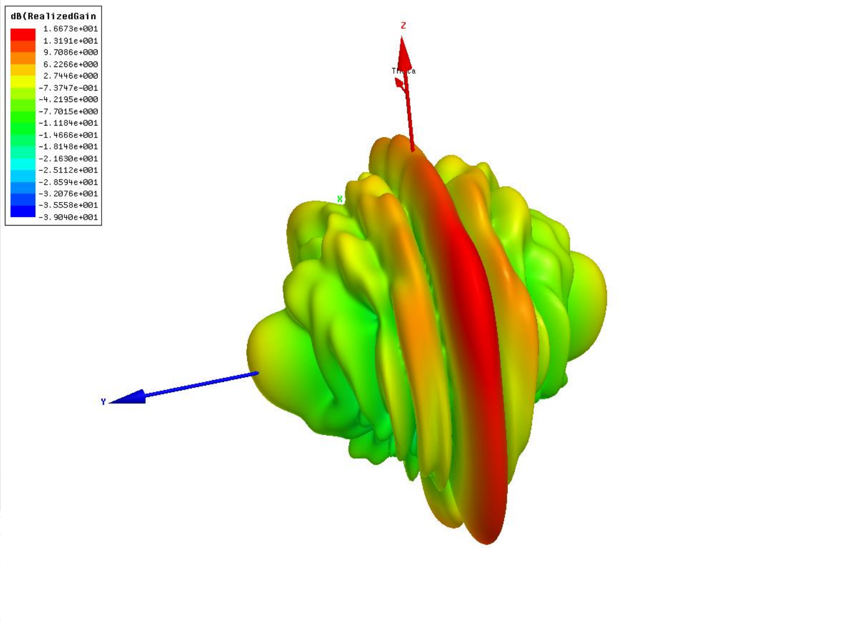
- Low probability of intercept radar implies, that due to:
  - Low peak and average power
  - Wide bandwidth
  - Frequency or modulation variability
- The radar is difficult to intercept with a passive receiver
- Relies on antenna patterns, scan patterns, and wavefroms

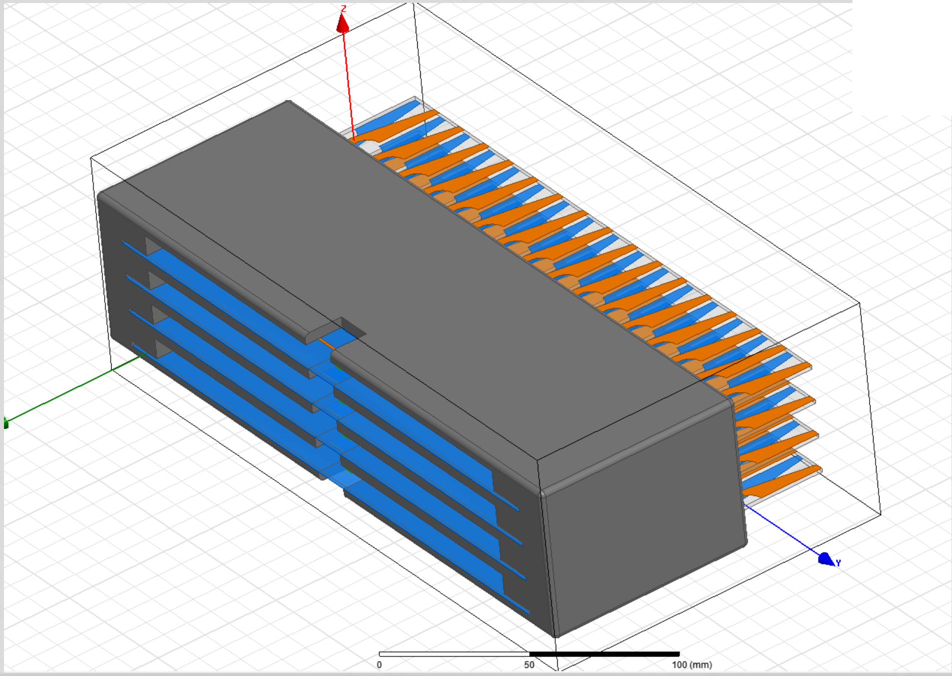
Low Probability of Identification

- A radar that uses a specially emitted waveform intended to prevent a non-cooperative intercept receiver from intercepting and detecting its emission, but if intercepted, makes identification of the emitted waveform modulation and its parameters difficult

LPI – Array Patterns

- Need to reduce the side lobe levels
- Also prevents jamming





Array Amplitude Weighting

- Apply a amplitude distribution to the phased array elements
- Uniform => narrowest beam width
- Binomial => smallest side lobes
- Tschebyscheff => best compromise between side lobes and beam width
- LPI implies side-lobes below -45 dB

Binomial Array

$$(1+x)^{m-1} = 1 + (m-1)x + \frac{(m-1)(m-2)}{2!}x^2 + \cdots$$

M = 1	1
M = 2	1 1
M = 3	1 2 1
M = 4	1 3 3 1
M = 5	1 4 6 4 1
M = 6	1 5 10 10 5 1
	⋮
M = 10	1 9 36 84 126 126 84 36 9 1

Tschebyscheff Array

- The related polynomials for the array weighting are:

$$T_m = \cos[m\cos^{-1}(z)] \qquad -1 \leq z \leq +1$$
$$T_m = \cosh[m\cosh^{-1}(z)] \qquad z < 1, z > +1$$

- The math is ugly, see “Antenna Theory – Analysis and Design” by Balanis for more details

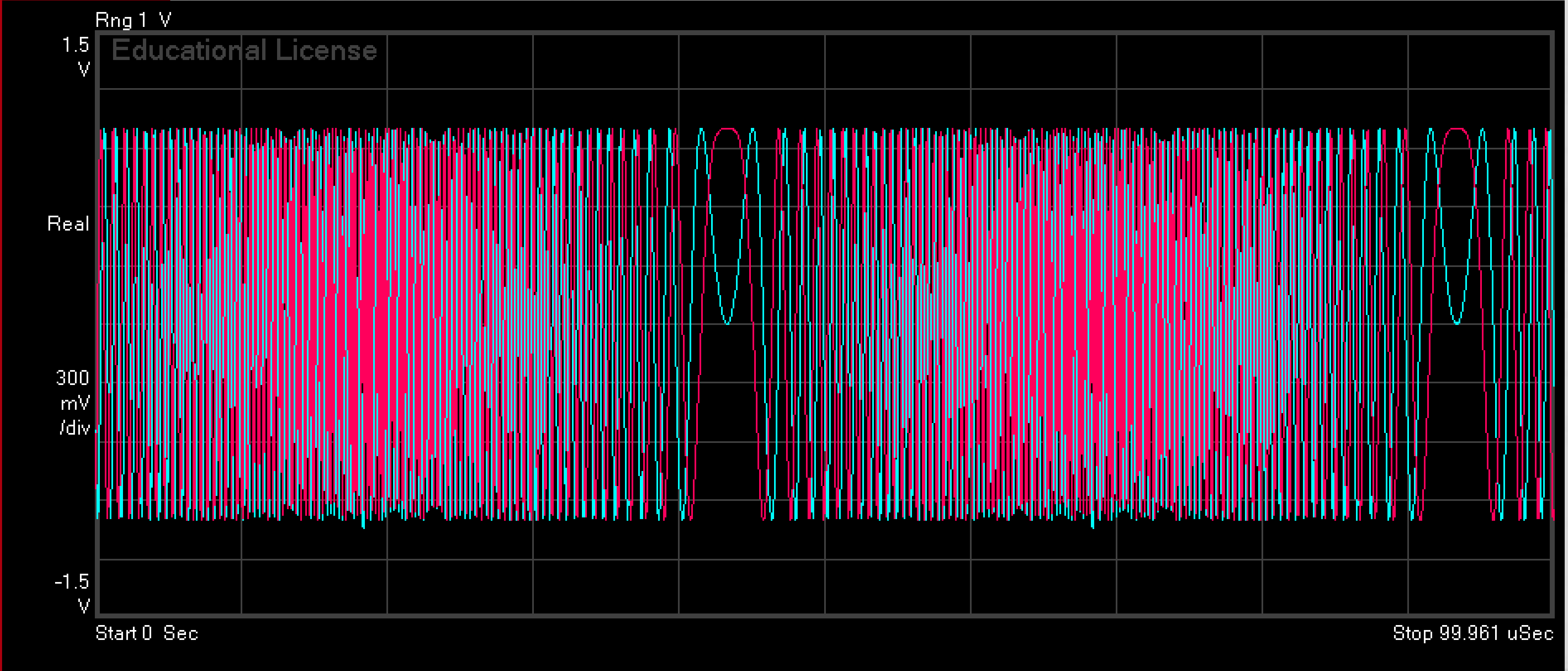
Scan Patterns

- Raster Scan is very predictable
- LPI generally scan to limit the target illumination time to short, infrequent, and often unpredictable intervals
- Don’t be predictable!

Reducing Peak Power

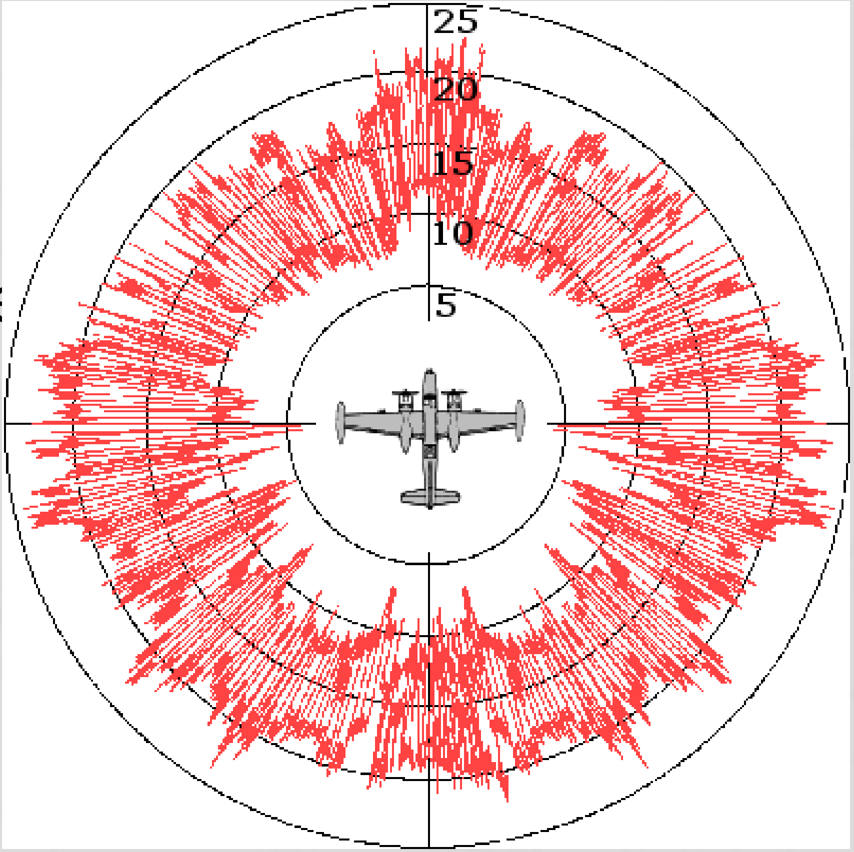
- Move to a CW signal

$$P_{avg} = P_t \frac{\tau}{T}$$



Power Management

- Why transmit at max power all the time?
  - Don't!
- Limit the power to the range and detection requirements



CW Requires Modulation!

- Linear or non-linear frequency modulation
- Phase modulation (PSK and Barker codes)
- Frequency hopping (FSK) and Costas arrays
- Combined frequency and phase modulation (FSK and PSK)
- Noise modulation

Pulse Compression

- Processing gain from matched filter

$$PG_R = \frac{\mathrm{SNR_{Ro}}}{SNR_{Ri}}$$

- Depends on time-bandwidth product and integration
- Probability of detection, false alarm and SNR out are related through:

$$SNR_{Ro} = A + 0.12AB + 1.7B$$

$$A = \ln\left(\frac{0.62}{P_{fa}}\right)$$

$$B = \ln\left(\frac{P_d}{1 - P_d}\right)$$

Processing Gain

- For FMCW radars

$$PG_R = t_m \Delta F$$

- For non-coherent integration for N_I intervals the processing gain is increase by $\sqrt{N_I}$
- For phase coded radars

$$PG = N_c$$

- where N_c is the number of subcodes

Who Sees Who First?

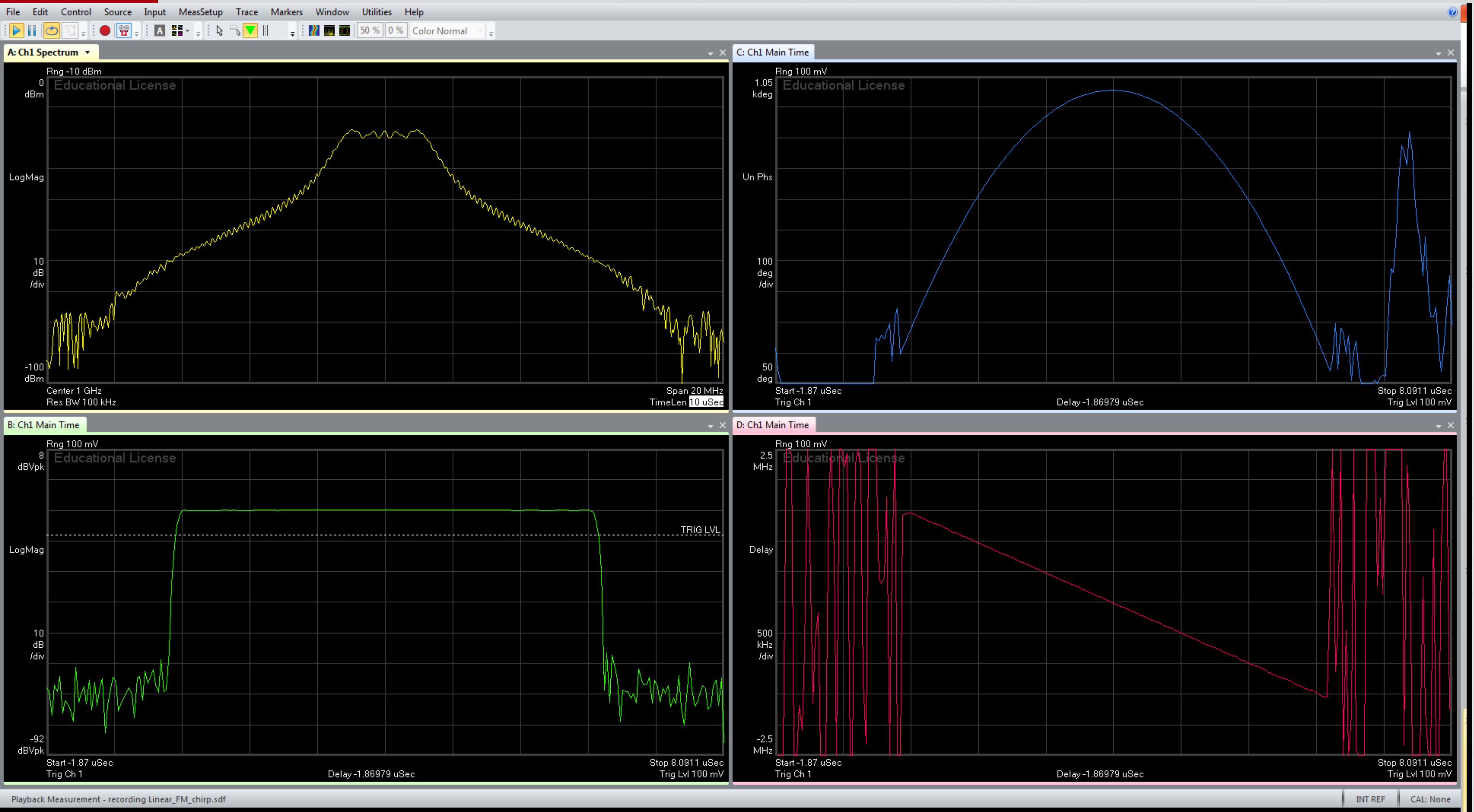
- Radar maximum detection range:

$$R_{max} = \left[\frac{P_{CW} G_t G_r \lambda^2 \sigma}{(4\pi)^3 k T_0 F_R B_{Ri} (SNR_{Ri})}\right]^{1/4}$$

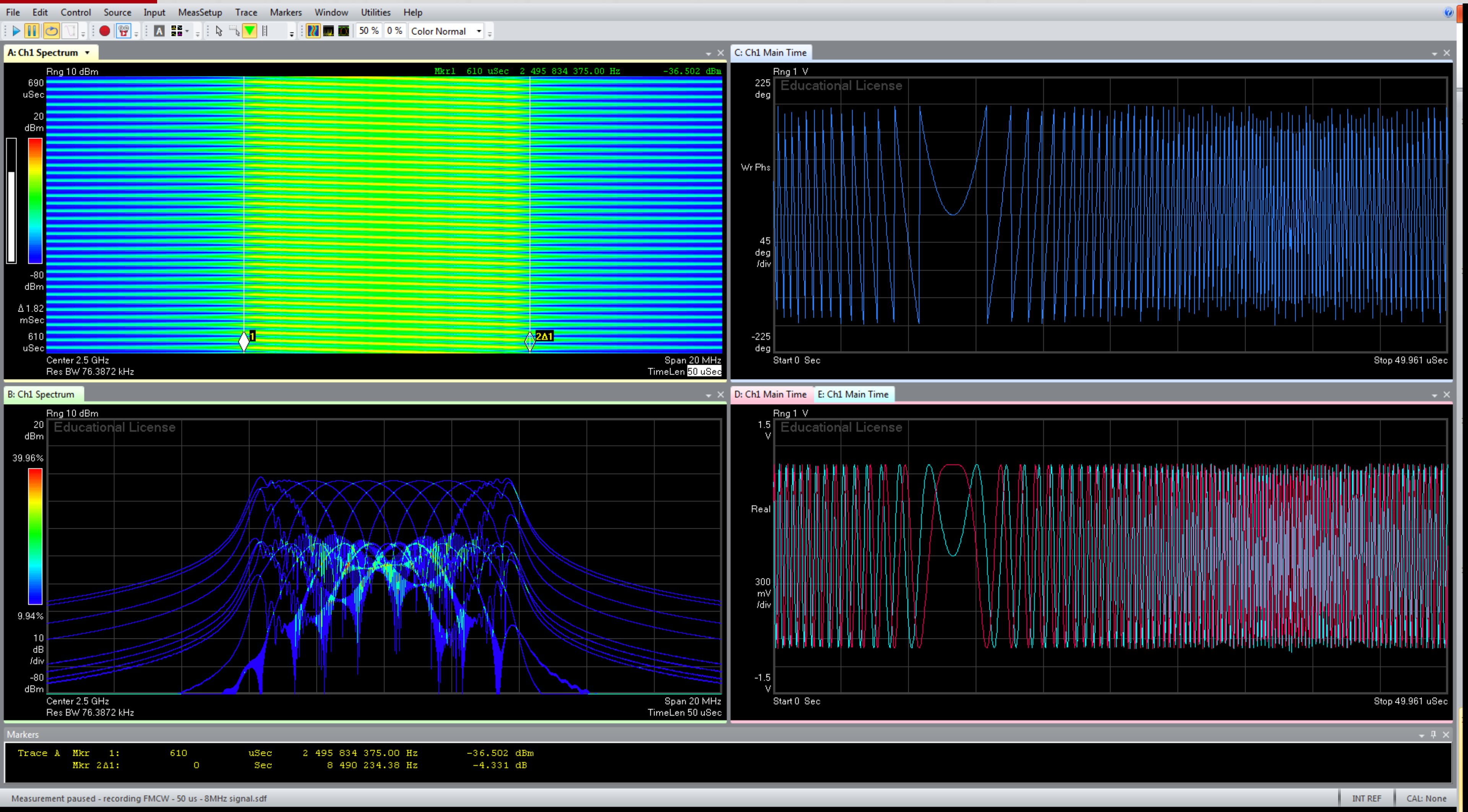
- Interception range

$$R_{I_{max}} = \left[\frac{P_{CW} G_t' G_I \lambda^2}{(4\pi)^2 k T_0 F_I B_I \left(SNR_{I_i}\right)}\right]^{1/2}$$

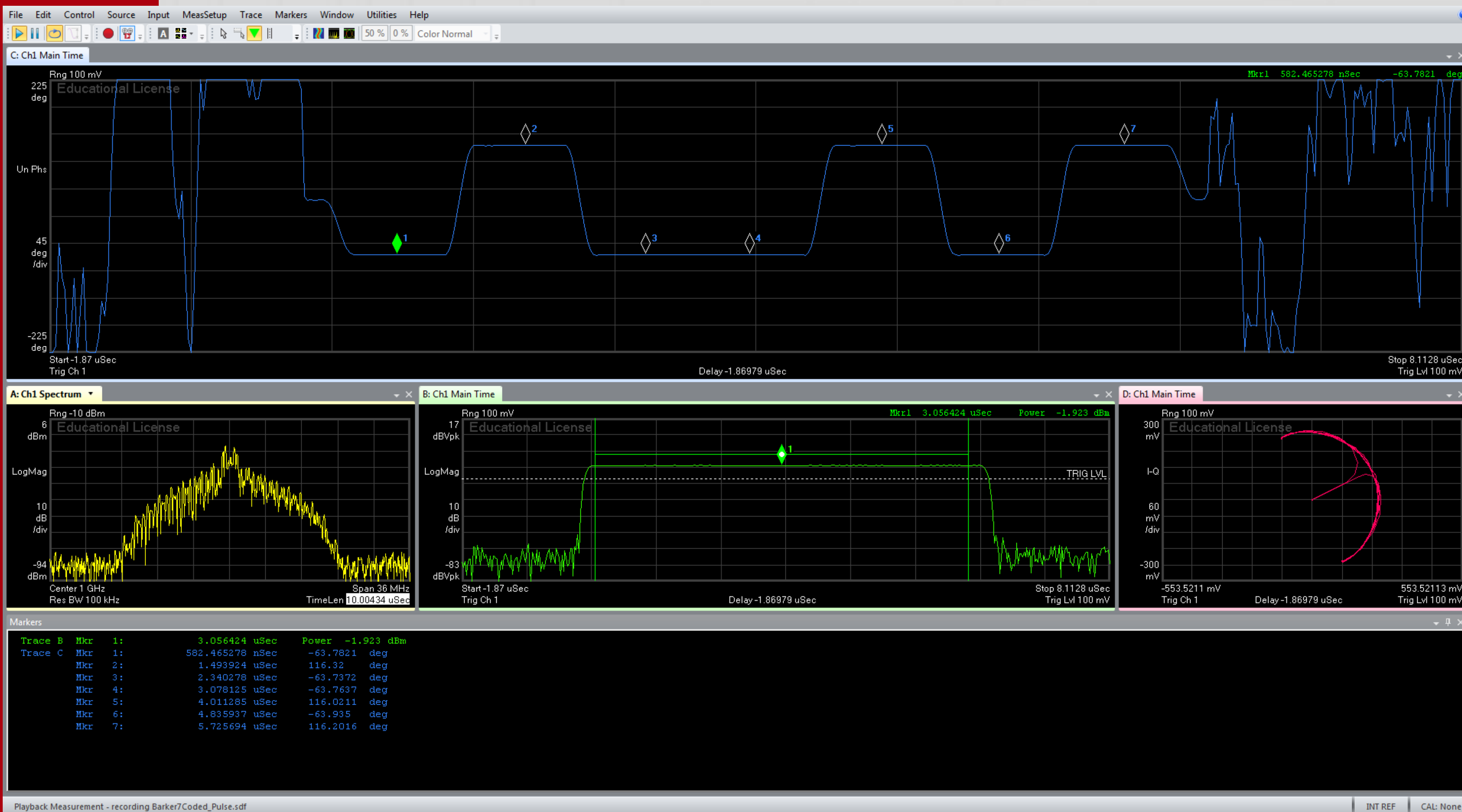
LFM Waveform



FMCW Waveform

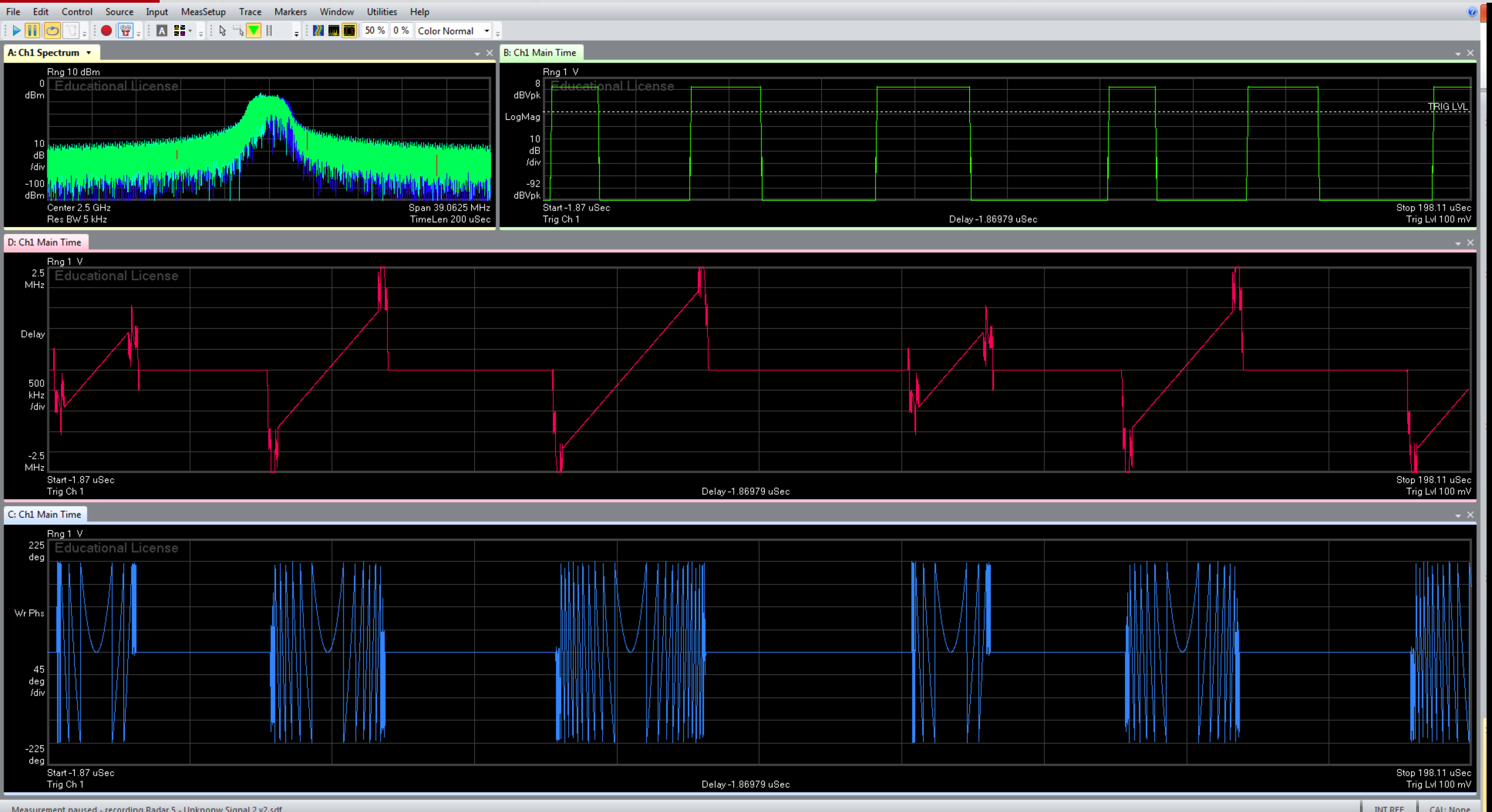


Barker Code

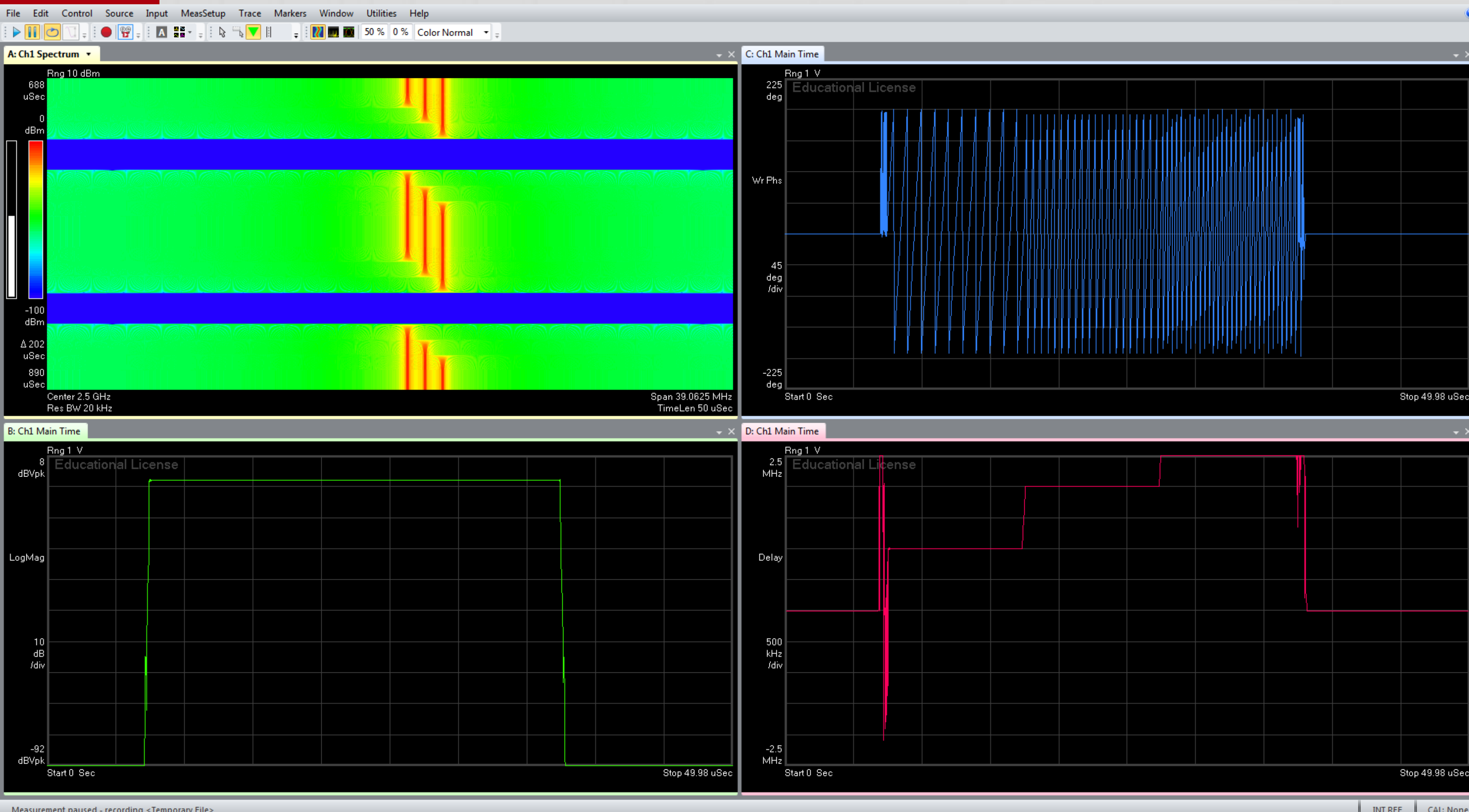


File Edit Control Source Input MeasSetup Trace Markers Window Utilities Help
C: Ch1 Main Time
Rng 100 mV
Mkr1 582.465278 nSec -63.7821 deg
225 deg
Un Phs
45 deg /div
-225 deg
Educational License
Start -1.87 uSec
Trig Ch 1
Delay -1.86979 uSec
Stop 8.1128 uSec
Trig Lvl 100 mV
A: Ch1 Spectrum
Rng -10 dBm
6 dBm
LogMag
10 dB /div
-94 dBm
Center 1 GHz
Span 36 MHz
Res BW 100 kHz
TimeLen 10.00434 uSec
B: Ch1 Main Time
Rng 100 mV
Mkr1 3.056424 uSec Power -1.923 dBm
17 dBVpk
LogMag
TRIG LVL
10 dB /div
-83 dBVpk
Start -1.87 uSec
Trig Ch 1
Delay -1.86979 uSec
Stop 8.1128 uSec
Trig Lvl 100 mV
D: Ch1 Main Time
Rng 100 mV
300 mV
I-Q
60 mV /div
-300 mV
-553.5211 mV
553.52113 mV
Trig Ch 1
Delay -1.86979 uSec
Trig Lvl 100 mV
Markers
Trace B Mkr 1: 3.056424 uSec Power -1.923 dBm
Trace C Mkr 1: 582.465278 nSec -63.7821 deg
Mkr 2: 1.493924 uSec 116.32 deg
Mkr 3: 2.340278 uSec -63.7372 deg
Mkr 4: 3.078125 uSec -63.7637 deg
Mkr 5: 4.011285 uSec 116.0211 deg
Mkr 6: 4.835937 uSec -63.935 deg
Mkr 7: 5.725694 uSec 116.2016 deg
Playback Measurement - recording Barker7Coded_Pulse.sdf
INT REF
CAL: None

3 Different LFM Pulses + Jitter



FSK Pulse



File Edit Control Source Input MeasSetup Trace Markers Window Utilities Help
50 % 0 % Color Normal
A: Ch1 Spectrum
Rng 10 dBm
688 uSec
0 dBm
-100 dBm
Δ 202 uSec
890 uSec
Center 2.5 GHz
Res BW 20 kHz
Span 39.0625 MHz
TimeLen 50 uSec
C: Ch1 Main Time
Rng 1 V
Educational License
225 deg
Wr Phs
45 deg /div
-225 deg
Start 0 Sec
Stop 49.98 uSec
B: Ch1 Main Time
Rng 1 V
Educational License
8 dBVpk
LogMag
10 dB /div
-92 dBVpk
Start 0 Sec
Stop 49.98 uSec
D: Ch1 Main Time
Rng 1 V
Educational License
2.5 MHz
Delay
500 kHz /div
-2.5 MHz
Start 0 Sec
Stop 49.98 uSec
Measurement paused - recording <Temporary File>
INT REF
CAL: None