PULSE COMPRESSION

PERMITS A LONG PULSE TO ACHIEVE;

- IMPROVED RANGE RESOLUTION
- A LARGE RADIATED ENERGY

PULSE COMPRESSION CAN BE ACHIEVED THROUGH MODULATION OF THE TRANSMITTED SIGNAL, (WHICH INCREASES THE B.W), AND BY PROCESSING THE RECEIVED SIGNAL WITH A MATCHED FILTER. THE MATCHED FILTER COMPRESSES THE DURATION OF THE TRANSMITTED PULSE TO $\frac{1}{B}$, WHERE B, IS THE BANDWIDTH OF THE TRANSMITTED PULSE.

ADVANTAGES: IMPROVED RANGE RESOLUTION.
IMPROVED RANGE ACCURACY.
CLUTTER REDUCTION.
IMPROVED AVERAGE POWER.

DISADVANTAGES: SHORT PULSE ⇒ LARGER B.W.
COMPLEX SIGNAL PROCESSING.

FUNDAMENTAL CONCEPT: "TAG" EACH PORTION OF THE TRANSMITTED SIGNAL, TO GIVE RANGE INFORMATION OVER THE DURATION OF THE PULSE. THIS SIGNAL CAN THEN BE PROCESSED TO EXTRACT THIS RANGE INFORMATION.

PULSE - COMPRESSION RATIO

A MEASURE OF THE DEGREE TO WHICH A PULSE CAN BE COMPRESSED;

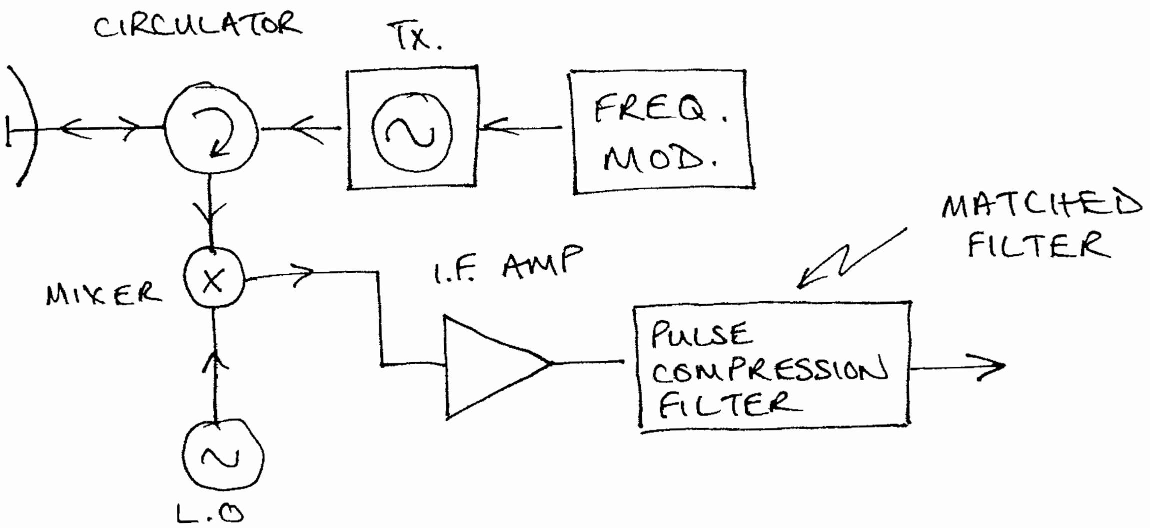
$$PCR = \frac{\text{UNCOMPRESSED PULSE WIDTH}}{\text{COMPRESSED PULSE WIDTH}} = B\tau$$

B - BANDWIDTH , τ - UNCOMPRESSED PULSE WIDTH.

TYPICAL PCR VALUES ARE 100 - 200 , CAN BE AS HIGH AS 10^6 IN SOME CASES.

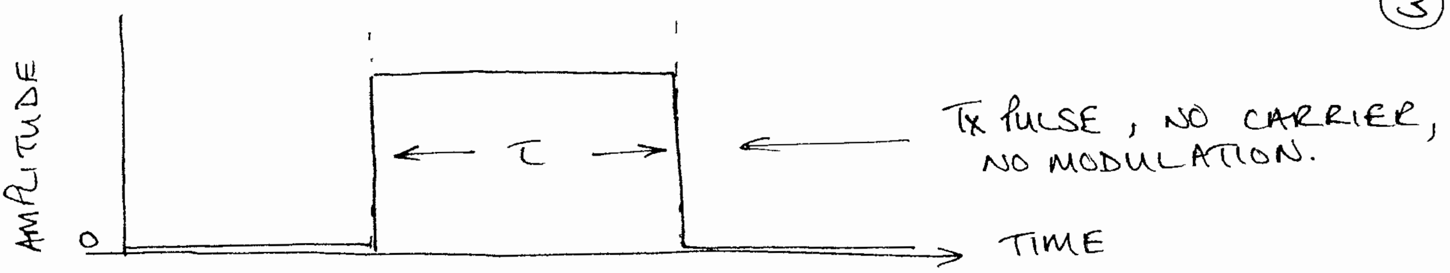
IMPLEMENTATION OF PULSE COMPRESSION

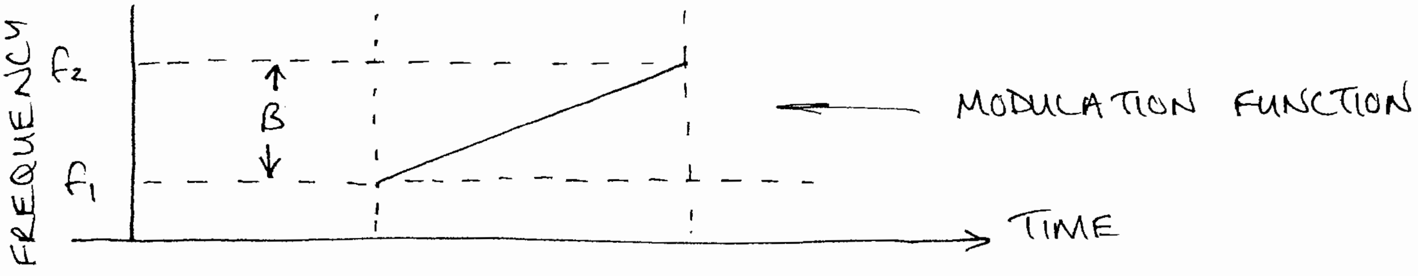
LINEAR F.M. PULSE COMPRESSION:

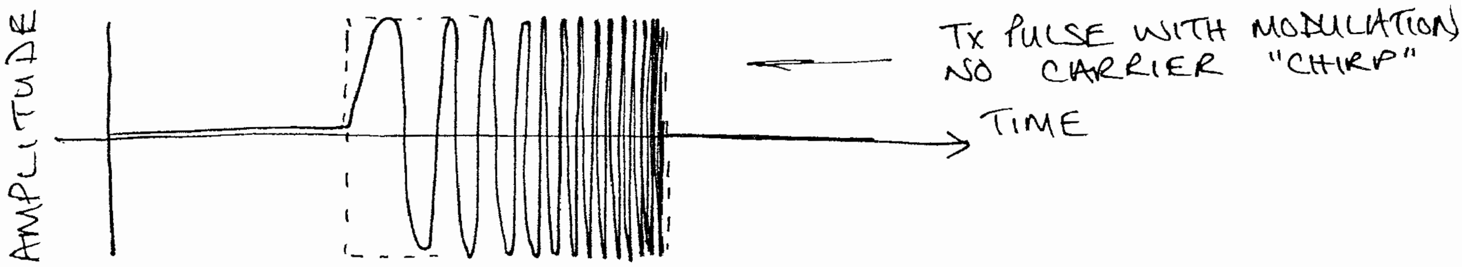


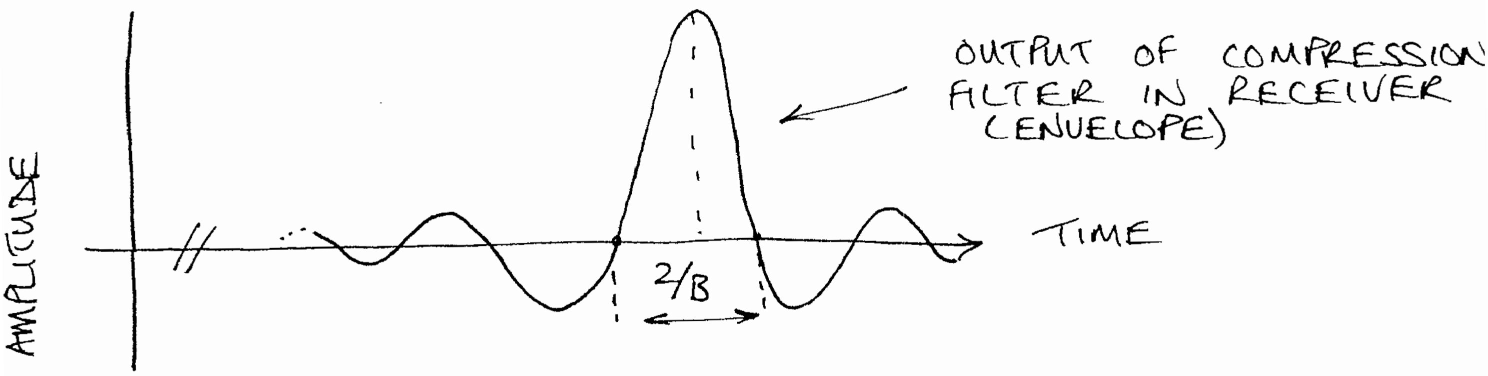
TECHNIQUE PATENTED BY R.H. DICKE, 1945

TRADITIONAL APPROACH TO IMPLEMENTING THE PULSE COMPRESSION FILTER IS TO USE A DISPERSIVE DELAY LINE - DELAY $\propto$ FREQUENCY









PULSE COMPRESSION FILTERS

DISPERSIVE DELAY LINE – USED TO SPEED-UP THE TRAILING EDGE OF A PULSE, AND SLOW-DOWN THE LEADING EDGE SO AS TO CAUSE TIME COMPRESSION

PULSE COMPRESSION FILTERS CAN ALSO BE IMPLEMENTED USING DSP TECHNIQUES

HOWEVER DESPITE THE ENORMOUS SIGNAL PROCESSING CAPABILITY OF MODERN DSP, IN SOME APPLICATIONS IT IS STILL NOT FAST ENOUGH.

DISPERSIVE DELAY LINES OFTEN USE SURFACE ACOUSTIC WAVE (SAW) TECHNIQUES, TRANSDUCERS CAN BE ETCHED/PRINTED ONTO A SUBSTRATE SUCH AS QUARTZ OR YIG (YTTRIUM-IRON-GARNET)

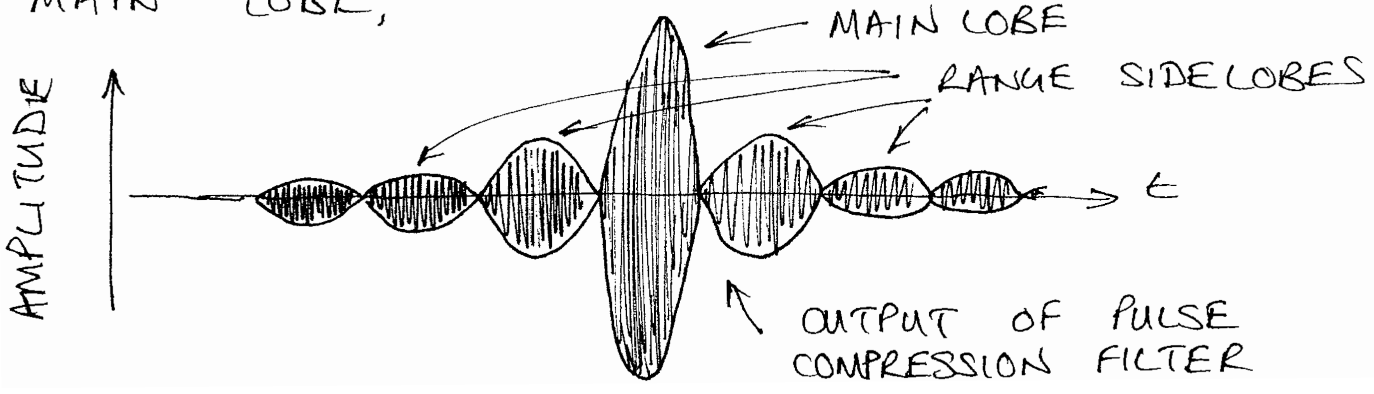
SAW DEVICES ARE SIMPLE, LOW-COST, SMALL AND HIGHLY REPRODUCIBLE IN MANUFACTURE. SAW DEVICES HAVE BEEN USED IN SYSTEMS WITH PCR > 10,000 AND $\tau < 1ns$.

TIME / RANGE SIDELOBES

WITH A UNIFORM PULSE SHAPE AND LINEAR F.M. THE COMPRESSED PULSE SHAPE HAS THE FORM;

$$\frac{\sin(\pi B t)}{\pi B t}.$$

THEREFORE, THE COMPRESSED PULSE HAS TIME OR RANGE SIDELOBES, EITHER SIDE OF THE MAIN LOBE;



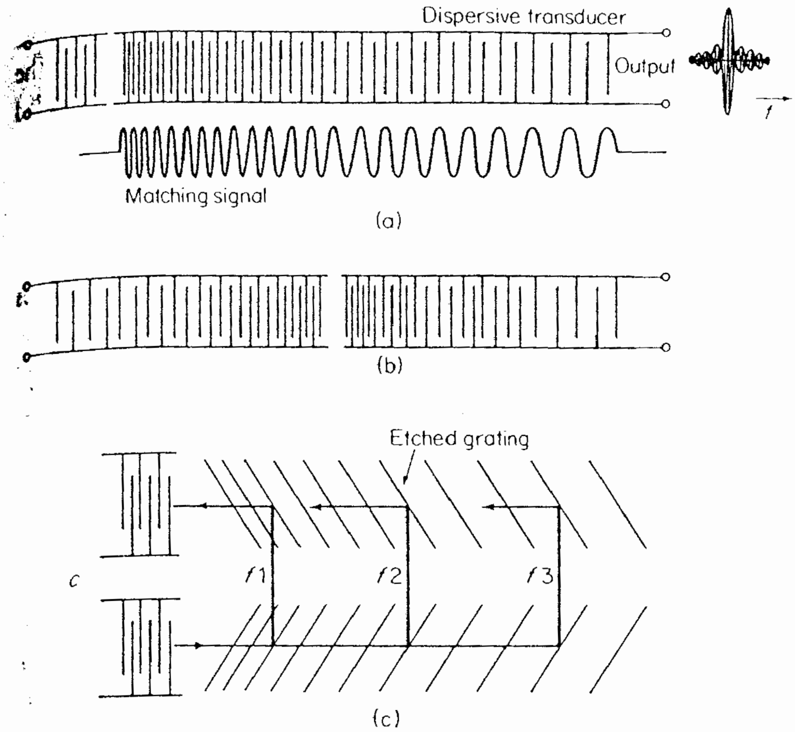


Figure 11.17 Three basic forms of SAW interdigital transducers for linear FM pulse compression. (*a*) Dispersive delay line with dispersion designed into one transducer; (*b*) dispersion in both transducers, and (*c*) a reflective array compressor (RAC). (*From Maines and Paige,*[21] *courtesy of Proc. IEEE.*)

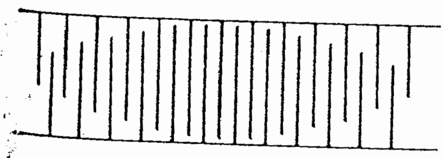


Figure 11.18 Interdigital transducer (nondispersive) showing overlap of comb fingers, or electrodes, to provide an amplitude weighting along the pulse.

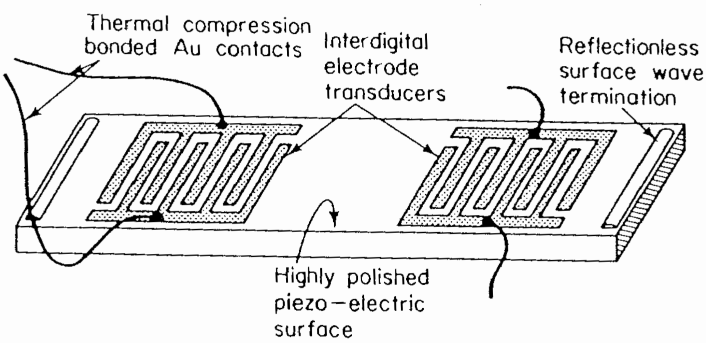


Figure 11.16 Schematic of a simple surface acoustic wave (SAW) delay line. (*From Bristol,*[22] *Courtesy Proc. IEEE.*)

[THIS IS THE SAME PROBLEM AS WE HAVE WITH UNIFORM APERTURE DISTRIBUTIONS IN ANTENNAS]

RANGE SIDELOBES CAUSE PROBLEMS: RANGE AMBIGUITIES, STRONG/LARGE TARGETS NEARBY MAY MASQUERADE THEMSELVES AS, OR MASK, SMALLER TARGETS AT LONGER RANGE

RANGE SIDELOBES CAN BE CHANGED BY CHANGING THE WEIGHTING OF THE PULSE SHAPE (EITHER AT THE TRANSMITTER OR RECEIVER)

WEIGHTING FUNCTION	PEAK SIDELOBE (dB)	RELATIVE MAINLOBE WIDTH
UNIFORM	-13.2	1.0
$\cos^2$	-31.7	1.65
DOLPH-CHEBYSHEV	-40.0	1.35
HAMMING.	-42.8	1.50

SIDELOBE SUPRESSION COMES AT THE EXPENSE OF SNR DEGRADATION DUE TO THE WEIGHTING FUNCTION LOSS

OTHER FORMS OF PULSE-COMPRESSION

- PHASE-CODING - BARKER CODES, PN SEQUENCES
- NON-LINEAR FM

MATCHED FILTERS

A NETWORK WHOSE FREQUENCY RESPONSE MAXIMIZES THE OUTPUT PEAK-SIGNAL-TO-NOISE (POWER) RATIO IS CALLED A <u>MATCHED FILTER</u>.

MATCHED FILTERS, OR THEIR EQUIVALENTS ARE USED FOR ALMOST ALL RADAR RECEIVERS.

SIGNAL BW > Rx BW => LOWER SNR
SIGNAL BW < Rx BW => LOWER SNR

THERE IS AN OPTIMUM BANDWIDTH THAT MAXIMIZES THE SNR.

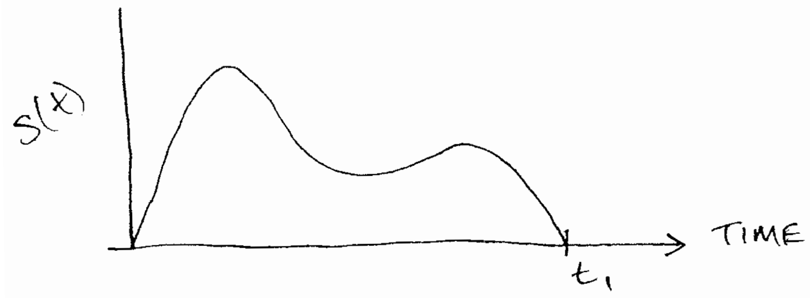
IT CAN BE SHOWN (VIA THE SCHWARTZ INEQUALITY) THAT THE FREQ RESPONSE $H(f)$, OF A FILTER THAT MAXIMIZES THE SNR FOR AN INPUT SIGNAL $s(t)$ IS;

$$H(f) = S^*(f) \exp(-j2\pi f t_1)$$

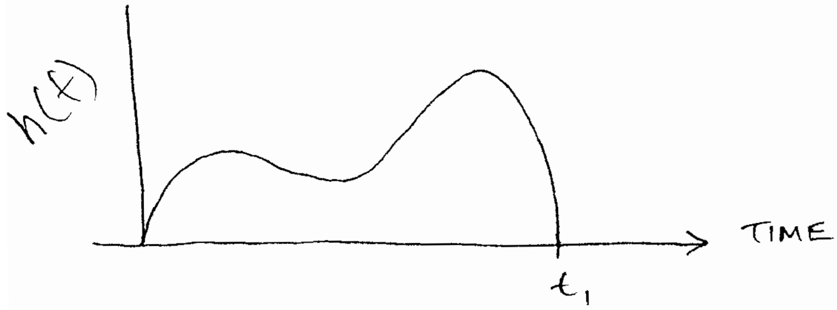
$S^*(f)$ = COMPLEX CONJUGATE OF $S(f)$
t_1 = TIME AT WHICH SIGNAL IS AT MAXIMUM

$$S(f) = \int_{-\infty}^{\infty} s(t) \exp(-j2\pi f t)\, dt.$$ (FOURIER TRANSFORM OF INPUT SIGNAL)

THIS IS PROBABLY BEST SHOWN GRAPHICALLY ...



RECEIVED SIGNAL:
s(t)



IMPULSE RESPONSE OF THE MATCHED FILTER:
h(t)

THE MATCHED FILTER FORMS THE CROSS-CORRELATION BETWEEN s(t) (WHICH IS CORRUPTED BY NOISE) AND A REPLICA OF THE TRANSMITTED SIGNAL (WHICH IS "BUILTIN" TO THE MATCHED VIA ITS FREQ. RESPONSE. IN THE ABSENCE OF NOISE, THE OUTPUT IS THE AUTO-CORRELATION.

AMBIGUITY DIAGRAMS e AMBIGUITY FUNCTIONS

THE AMBIGUITY DIAGRAM REPRESENTS THE RESPONSE OF THE MATCHED FILTER TO THE SIGNAL FOR WHICH IT IS MATCHED, AS WELL AS TO MIS-MATCHED (DOPPLER SHIFTED SIGNALS). IGNORING NOISE, THE MATCHED FILTER OUTPUT IS;

$$\text{OUTPUT} = \int_{-\infty}^{\infty} S_r(t)\, S^*(t - T_R')\, dt.$$

$S_r(t)$ = RECEIVED SIGNAL
$S(t)$ = TRANSMITTED SIGNAL ($S^*(t)$ ITS CONJUGATE)
T_R' = RANGE TIME DELAY

TRANSMITTED SIGNAL;

$$s(t) = u(t)\exp(j2\pi f_0 t)$$

$u(t)$ = COMPLEX MODULATION FUNCTION (SUCH AS A RECTANGULAR PULSE TRAIN)

f_0 = CARRIER FREQUENCY.

THE RECEIVED SIGNAL WE CAN ASSUME WILL HAVE THE SAME FORM, BUT TIME AND DOPPLER SHIFTED;

$$S_r(t) = u(t-T_0)\exp[j2\pi(f_0+f_D)(t-T_0)]$$

IF WE SET $T_0 = 0$, $f_0 = 0$ AND DEFINE $T_0 - T_R' = T_R$ WE CAN WRITE THE MATCHED FILTER OUTPUT AS;

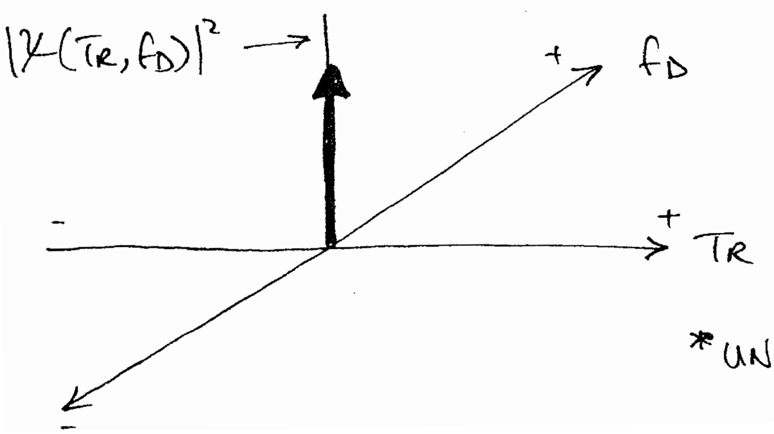
$$\chi(T_R, f_D) = \int_{-\infty}^{\infty} u(t)\,u^*(t+T_R)\exp(j2\pi f_D t)\,dt.$$

$T_R > 0$ INDICATES A TARGET BEYOND T_0

$f_D > 0$ INDICATES AN APPROACHING TARGET.

$|\chi(T_R, f_D)|^2$ – IS THE AMBIGUITY FUNCTION

THE PLOT OF $|\chi(T_R, f_D)|^2$ IS THE AMBIGUITY DIAGRAM



IDEAL AMBIGUITY DIAGRAM* (IMPULSE AT ORIGIN)

*UNATTAINABLE!

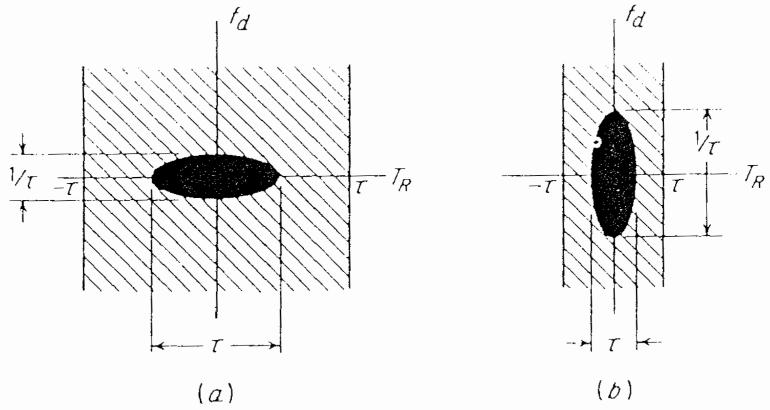


Figure 11.10 Two-dimensional ambiguity diagram for a single pulse of sine wave. (*a*) Long pulse; (*b*) short pulse.

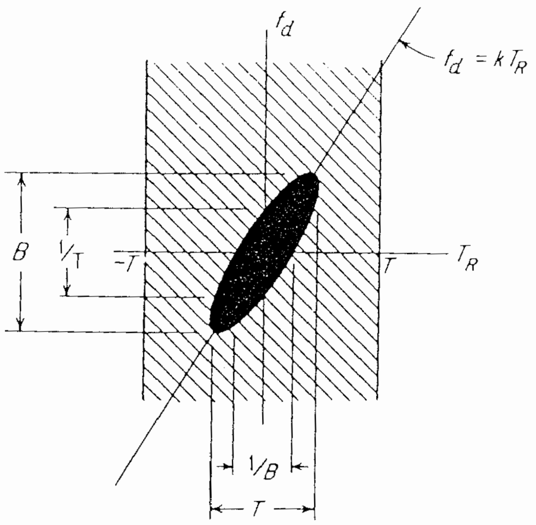


Figure 11.12 Ambiguity diagram for a single frequency-modulated pulse. (Also called the *chirp* pulse-compression waveform.)