COURSE 9
AUTOMOTIVE RADAR

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INTRODUCTION

- Radar technology for use in vehicles has been investigated since the 1970's and has been employed for vehicles since the 1980's
- Initial usage of microwave was for collision warning applications on commercial vehicles (ambulances, buses, trucks)
- The main advantage of radars compared to other types of sensors (optical, ultrasonic) is that they perform equally well during the day, night and most weather conditions
  - Significantly less atmospheric attenuation in adverse weather conditions
  - No performance degradation due to dirt or road grime
- After several years of implementation in commercial vehicles radar sensors transitioned to the broader automotive applications

INTRODUCTION

- The main systems of the vehicle using radar are the following:
  - Collision warning and avoidance
  - ACC (Adaptive Cruise Control)
  - Stop & Go
  - Airbag pre-crash trigger
  - Lane change, parking assistant
  - Radar imaging, target identification
- For the implementation of a fully automated driving system sensor fusion needs to be developed, combining information from:
  - Medium- or long-range radar (76-77GHz)
  - Short range radar (24 GHz, 77-81GHz)

INTRODUCTION

- Vision sensors (cameras)
- Ultrasonic sensors
- Laser sensors (Lidar)
- Infrared sensors
- GPS receivers
- uWave and mmWave transceivers for V2X communications

- Due to critical impact of these sensors on various systems and passenger safety, it is important to conduct very accurate and extensive verification and calibration of the sensors

AUTOMOTIVE RADAR TECHNOLOGY

- Early automotive radars were developed in the uWave frequency band (10-24GHz)
  - For the first CW/A applications the size of these devices was too large for usage in every vehicles, so the usage was restricted to trucks and buses
  - To reduce the physical size the frequency was increased to the mmWave range
    - At these frequencies antennas can be made electrically large to produce the required high directivity and narrow beamwidth, while keeping the physical size small enough for installation on all vehicles
    - Most mmWave radar systems operate in the 76-77GHz frequency range
- The first ACC systems were designed for highway driving only
  - ACC radar sensors provide range and closing rate information to the cruise control system, which can control the breaks, throttle and the automatic transmission of the vehicle

AUTOMOTIVE RADAR TECHNOLOGY

  - The ACC system adapts the speed of the vehicle according to the speed of the vehicle ahead in order to maintain a separation time interval between the vehicles
  - The radar system can be used to locate and track multiple targets on the road ahead in order to anticipate traffic conditions
  - The ACC system only apply the breaks up to a specific level if additional breaking is required the system is deactivated and the driver must take control
- Second generation systems make use of multiple radar sensors to extend the ACC system to city driving or stop-and-go traffic
  - For most applications beyond highway ACC, multiple radar sensors must be used in conjunction with the long range forward looking 76-77GHz ACC radar
    - These sensors are short range and are used to monitor the traffic in front , on the side, and behind the vehicle
    - Sensor types for near range applications: infrared, vision, ultrasonic, microwave

AUTOMOTIVE RADAR TECHNOLOGY

- The unlicensed Industrial Scientific Medical (ISM) band at 24.125GHz is used for short range radar
- In some countries (USA, Europe, Australia, New Zeeland) is permitted the of ultra wide band (UWB) technology in the 22-29GHz frequency range for automotive radar
  - Short range radar does not require high gain antennas
  - These radar sensors do not need to detect objects further than 30m away and their angular coverage is broad
    - Lower gain antennas with wider beamwidths can be used → radar sensors are physically small enough for all vehicle types
    - The technology at 24GHz is more mature and is lower in cost

ACC RADAR REQUIREMENTS

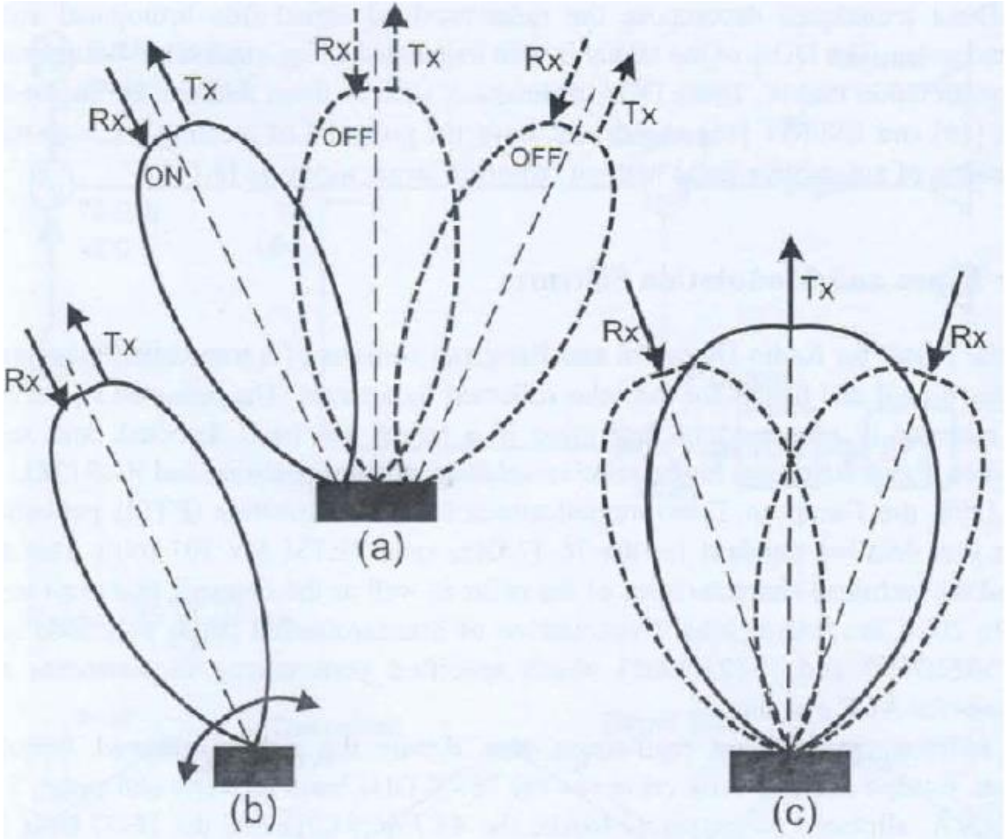
- The ACC radar must be able to detect targets of varying sizes up to 200m ahead
  - These targets could be moving relative to the radar at speeds of up to 250km/h
  - The radar must have angular coverage of at least ±8° in the azimuthal plane
    - This coverage is needed to track the targets in the lanes ahead especially when approaching curves in the road; detection of vehicles cutting into the driver's lane
  - In the elevation plane the radar angular coverage must be narrow to reduce the effect of ground bounce signals and reflections from overhead structures
- Typical performance requirements of ACC radars:
  - Transmit frequency: 76 77GHz; Transmit power: >10dBm; Target detection distance: range: 2 150m, accuracy: <± 1m; Relative velocity: range: 250km/h, accuracy: < ± 1km/h; Angular coverage: azimuth: ± 8° wide coverage with ± 3° minimum resolution; Antenna gain: 26 34dBi, Antenna sidelobe level: >20dB; Update rate: >10Hz

ACC RADAR ANTENNA TYPES

- The DOA (direction of arrival) of a radar signal can be obtained using various analog and digital techniques
  - For ACC radar sensors analog or digital beamforming techniques are the most common
  - These include electrically switching multi-beam antennas, continuous scanning single beam antennas and amplitude or phase monopulse
    - For multi-beam antennas in the horizontal plane, the ACC system continuously switches between 3 or 7 overlapping transmit/receive beams – each beam has ±3° width
    - A mechanical or electrical scanning antenna is used to sweep across the desired coverage angle with a narrow 3° single beam antenna
    - Some radar sensors transmit a single wide-beam of 12° width and use monopulse to locate other vehicles
    - In the vertical plane a single-beam antenna with sufficiently narrow beamwidth is used

ACC RADAR ANTENNA TYPES

- ACC radar antenna beam configurations for the horizontal plane:
  - (a) switched beam – one beam receiving at any time
  - (b) single scanning beam
  - (c) monopulse – one transmit and two receive beams



RADAR TYPES AND MODULATION SCHEMES

- Radar (Radio Detection and Ranging) consists of a transceiver that transmits a modulated signal and listens for the echo reflected by a target
- The reflected signal at the receiver is processed to determine if a target was detected and to extract information about it: range, velocity, angular position, RCS (Radar Cross Section)
- In 1998 ETSI published the first detailed standard for 76-77GHz radar.
- In 2002 ISO published standards which specified performance requirements and test procedures for ACC systems
  - Government regulations also dictate the radar's allowed frequency of operation:
    - Europe: 76-77GHz; USA: 46.7-46.9GHz, 76-77GHz; Japan (Asia Pacific): 60-61GHz, 76-77GHz
    - The 76-77GHz band is common to all standards and it became the de facto standard

RADAR TYPES AND MODULATION SCHEMES

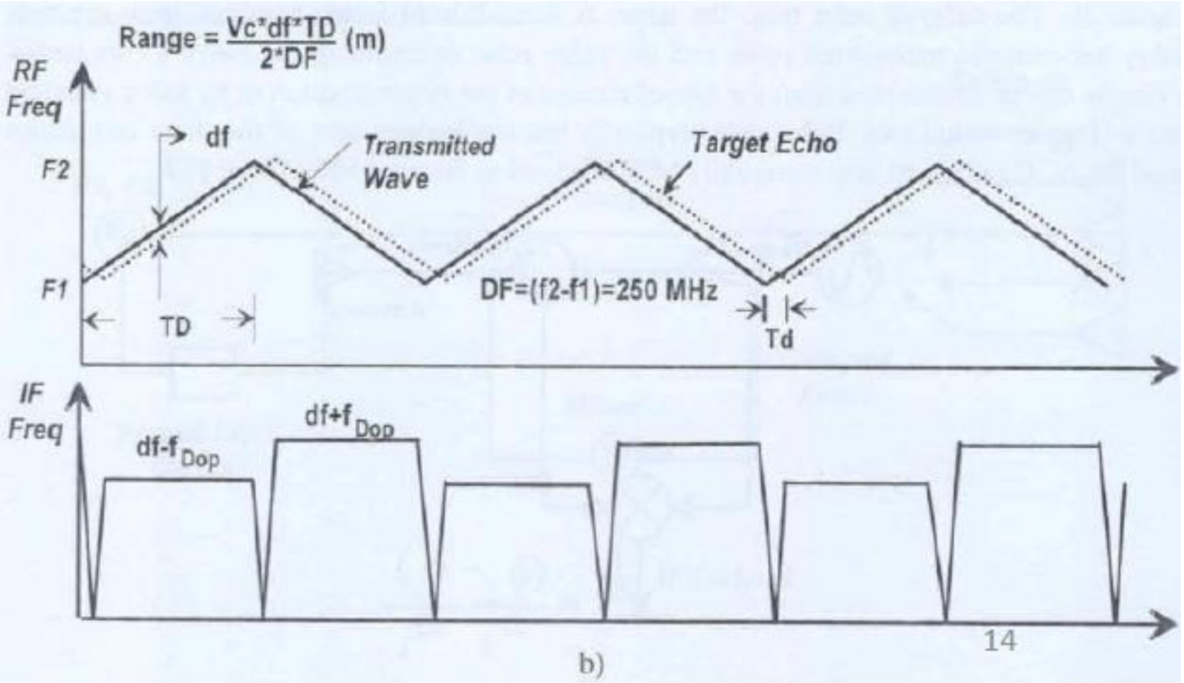
- Most of the ACC radar manufacturers relied upon their experiences in building military radar to develop the technologies for ACC
  - The major effort is in meeting the cost and size targets required of these sensors
- All the 76-77Ghz ACC systems use either one or a combination of the following techniques (as specified by the ETSI standard):
  - Frequency modulated continuous wave (FM-CW) –the most used
  - Frequency shift keying (FSK)
  - Pulse modulation schemes
    - Research on using spread spectrum transceivers that have a combined use of inter-vehicle communications as well as radar

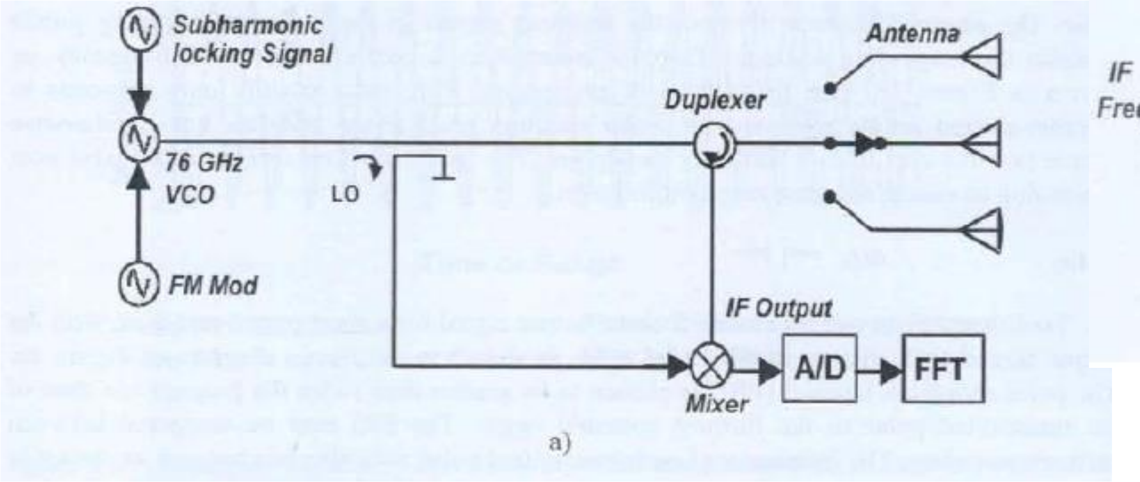
RADAR TYPES AND MODULATION SCHEMES – FM-CW

- The FM-CW radar transmits a CW signal whose frequency is modulated as a function of time with a periodic waveform, such as a sawtooth waveform
  - Typically, the frequency deviation is on the order of 150-300MHz with a period of approximately 1ms
- The signal reflected by the target will be delayed in time and demodulated in the radar receiver, along with the transmitted signal
  - The demodulation output is the intermediate frequency (IF) or beat frequency
  - For a moving target the beat frequency is different for the positive and the negative slopes of the modulation waveform
  - The average of the beat frequencies determines the range to the target and the difference contains the Doppler (or velocity) information
  - The linearity of the frequency sweep at 76.5GHz is critical
    - A Gunn oscillator is used with a PLL; newer designs use MMIC (Monolithic microwave integrated circuit,) based VCO
    - The post processing of the FM-CW signal is usually done using FFT DSP techniques

RADAR TYPES AND MODULATION SCHEMES – FM-CW

- (a) FM-CW radar circuit diagram
- (b) Saw-tooth waveform and IF beat frequency for range and Doppler measurements



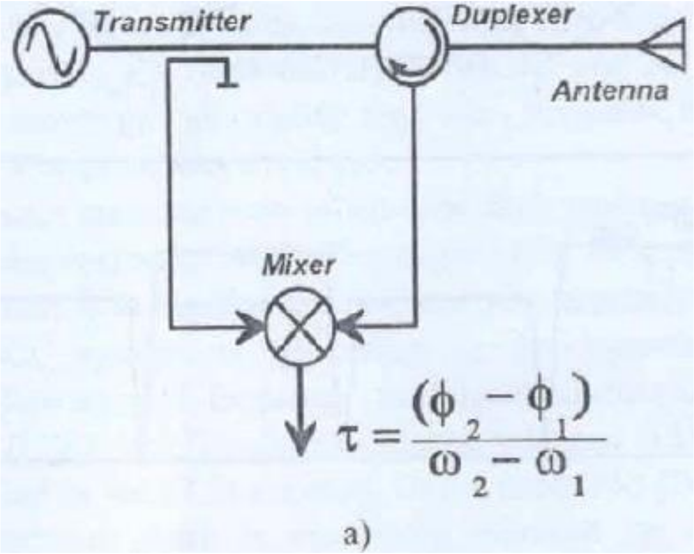


RADAR TYPES AND MODULATION SCHEMES – FSK

- The FSK is a narrow-band variant of the FM-CW radar
  - The radar transmits a CW signal whose frequency is typically changed in multiple steps of 150-1000kHz every microsecond
  - The IF output is processed in a similar manner to the FM-CW radar
  - The phase difference between the received signal at the different frequency points contains the range data while the Doppler information is contained in the IF frequency
  - Due to its type of processing, FSK radar usually only responds to Doppler shifted return signals
  - FSK radar requires good phase stability and extensive post processing to ensure accurate range information
  - FSK radar is simple and low cost from hardware point of view

RADAR TYPES AND MODULATION SCHEMES – FSK

- (a) FSK radar circuit diagram
- (b) Phase offsets to measure range and the IF frequency to measure Doppler



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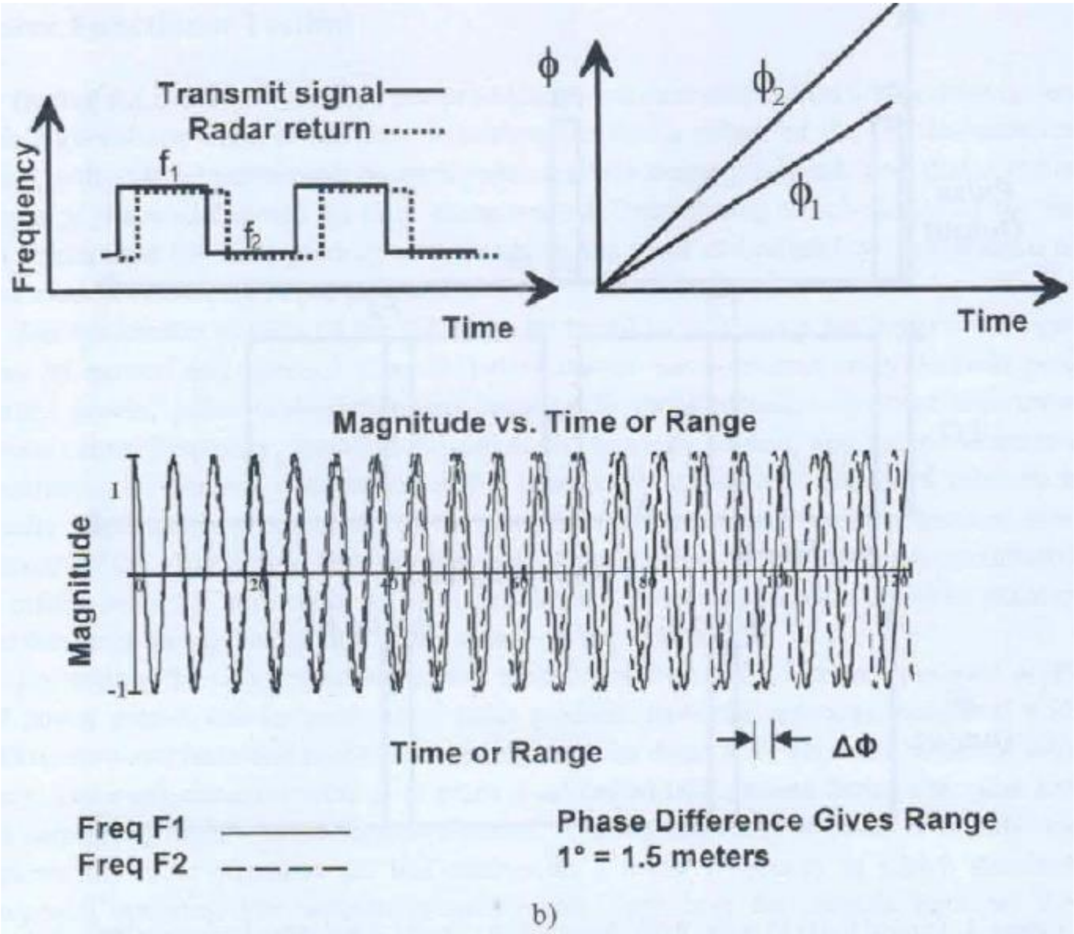

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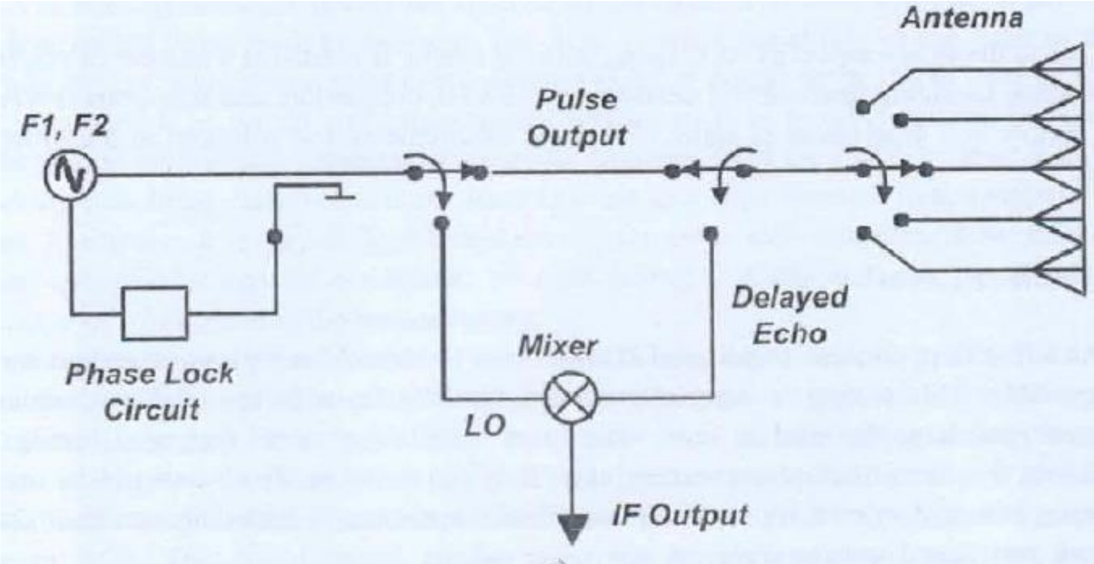
RADAR TYPES AND MODULATION SCHEMES – PULSE

- Traditional pulse radar switches ON the output signal for a short period and then, with the output turned OFF, listens to the target echo
- The pulse repetition interval (PRI) is chosen to be greater than twice the propagation time of the transmitted pulse to the furthest potential target
  - The PRI may be staggered between subsequent pulses
  - The frequency of each transmitted pulse may also be changed
  - The delayed echo from the target is demodulated in the receiver
    - The time delay between the transmitted pulse and the pulse echo determines the range to the target
    - Velocity can be determined from the rate of change of the target position or by using pulse-Doppler techniques
    - Pulse radar typically has the highest cost of the three techniques used for ACC radar

RADAR TYPES AND MODULATION SCHEMES – PULSE

- (a) Pulse Doppler radar circuit diagram
- (b) Pulse timing diagram



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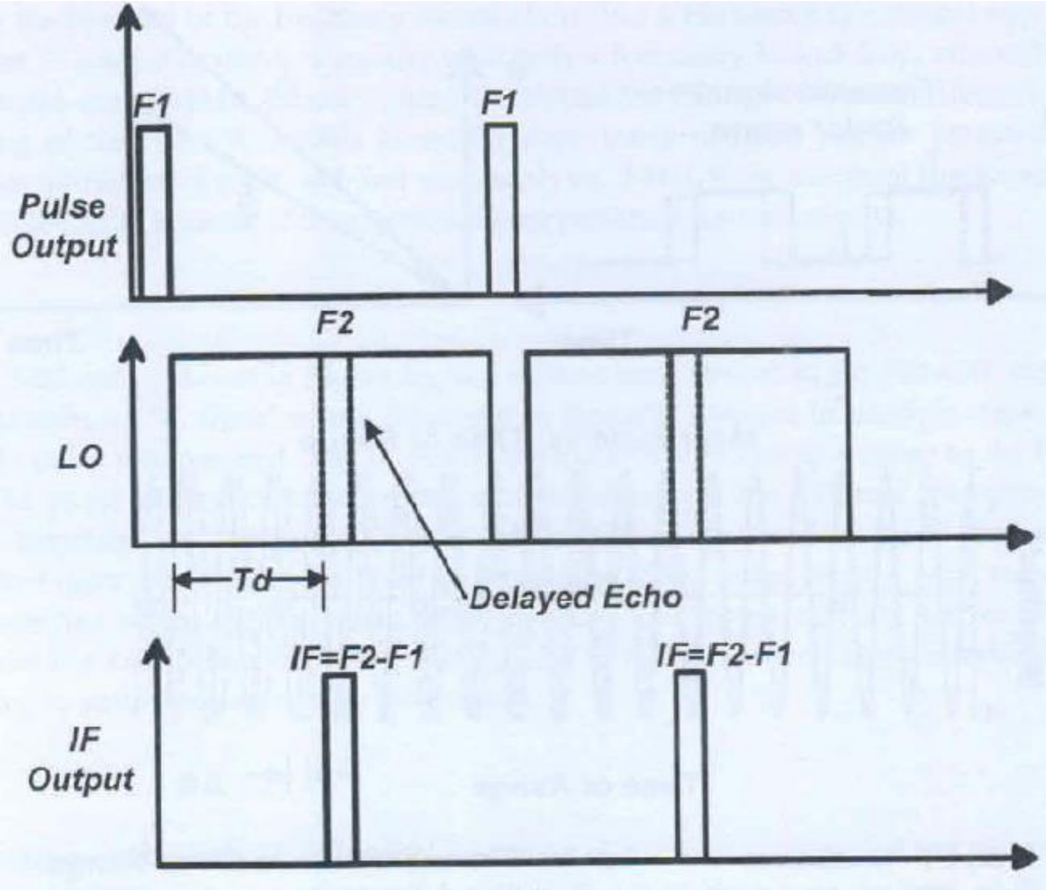

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ACC RADAR TEST REQUIREMENTS

- Due to the safety aspects of ACC radar, detailed testing is needed in research and development, production and after-market service
- Component level
  - The main radar components tested are: oscillators, frequency multipliers, mixers, amplifiers, switches
- Sensor functional testing
  - During R&D and low-volume pre-production, full characterization of the radar is needed
  - With high volume mass-production a subset of the full characterization testing will be performed on each radar module being produced
  - The transmitter part of the radar can be tested by analyzing the transmitted signal in terms of power, timing and spectral characteristics
    - The alignment of the antenna within the radar module housing must be checked
    - For accurate measurements of antenna patterns, the test antenna must be set up in the far field region, the distance of the far field is a function of the antenna size, typically 1.5-7m

ACC RADAR TEST REQUIREMENTS

- The best approach for testing the receiver of the radar is to have a known target reflecting the transmitted signal back to the radar
  - For ACC systems, the ability of the radar to detect moving targets, with known radar cross section, at ranges up to 150m must be tested
    - In most R&D and production facilities, it is not possible to perform these tests in anechoic chambers
    - Road testing is costly and may not provide accuracy or consistency in the measurements
  - A repeatable and accurate solution that allows this testing to be done in a confined space uses electrically simulated targets instead of physical targets
  - A target simulator receives the signal transmitted by the radar, delays it in time, modifies its amplitude and frequency and transmits it back to the radar
    - The receive and transmit antennas of the target simulator must be in the far field region of the radar, which could be as close as 1.5m

ACC RADAR TEST REQUIREMENTS

- Vehicle manufacturer must perform positional and angular alignment of the sensor on the automobile to insure accurate system operation
- Radar misalignment is one of the most significant problems for these radar systems
  - An angular error of 2° can cause a displacement of 4m at a distance of 120m – this will cause the radar to report that a target is straight ahead, when in fact is in the next lane
  - The radar must be installed on the vehicle such that the beam maximum of the radar receive antenna is pointing in the direction of vehicle motion this direction is represented by the thrust vector of the automobile
  - The total offset angle or misalignment error is the sum of the misalignment between the radar housing reference and the antenna beam, and between the radar housing and the vehicle thrust vector

ACC RADAR TEST REQUIREMENTS

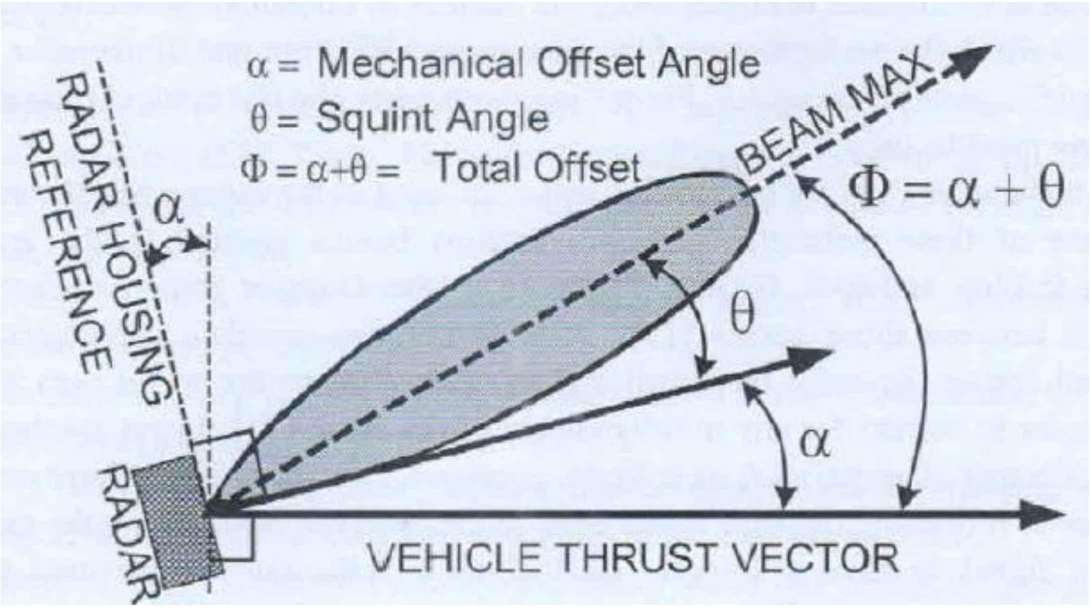
- Optical mechanical alignment
  - A laser beam is used – the orientation of the radar mounted on the vehicle is adjusted until the laser beam is pointing in the direction of the trust vector
  - Simple and low-cost technique but with limited accuracy
- Using internal angle measurement
  - For radar systems that can measure angle of arrival, placing a physical or simulated target in the direction of the trust vector allows the radar to measure the angle of the signal reflected from the target
  - Using these information, the orientation of the radar sensor mounted on the vehicle can be adjusted until the internal (total offset angle) is at 0°
    - All the RF alignment errors are accounted with this method

ACC RADAR TEST REQUIREMENTS

- RF alignment
  - Most ACC radar systems have angle measurement capability in the azimuth plane, but not in the elevation plane
  - RF alignment techniques can be used for measuring the beam maximum of the transmit antenna
    - One technique measures the power of the transmit beam and determines its maximum by adjusting the radar angle to get a peak power reading, or determines symmetry points along the beam pattern – the accuracy is limited by the beamwidth of the radar transmit antenna
    - Another approach is to use a passive interferometer system
      - Such a system replaces one receiver by 4 receivers, 2 in the azimuth plane and 2 in the elevation plane
      - The receivers are located at fixed distances apart from each other, with the radar positioned at the centerline of each antenna pair
        - The ratio between the received signals at the two antennas in a plane produces a sharp null in the direction of the beam maximum – a sharp null usually requires less sensitive receivers to measure accurately than a broad peak

ACC RADAR TEST REQUIREMENTS

- Angular errors when installing radar on vehicles



- Radar alignment system