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ENFOQUES PARA PROBAR SISTEMAS DE CONDUCCIÓN ALTAMENTE AUTOMATIZADOS EN LA PRODUCCIÓN Y EN EL CAMPO

(Sistema de Radar)

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RESUMEN

La conducción autónoma se convierte en un tema en auge durante décadas. Se han llevado a cabo muchos tipos de investigación para mejorar la seguridad, la protección y la eficiencia de esta tecnología. La fiabilidad de la tecnología de sensores tampoco se ha dejado de lado en esta discusión.

En el ámbito de una tesis de maestría, se visualiza el enfoque de la prueba para el radar automotriz. El enfoque se abrirá en cómo se puede probar la unidad de radar automotriz montada en el vehículo. Este documento explica el objetivo seleccionado, el concepto de prueba, el equipo de prueba, el montaje de la prueba y la metodología para la prueba del radar automotor en una sala cerrada. La metodología de este enfoque de prueba se aplica a las pruebas de radar de campo lejano en las que $\lambda <<$ alcance y $\lambda <<$ radio y objetivo se definieron como estáticos. Se diseñó el equipo apropiado para sostener el blanco durante la prueba y el diseño se finalizó después de considerar todos los requisitos de la prueba y se realizó la prueba analítica respectiva. Este enfoque de prueba puede examinar también la funcionalidad del radar para determinar el alcance y el ángulo del blanco con respecto al radar montado. La limitación de este estudio no es capaz de calcular la velocidad relativa ya que el blanco y el vehículo están estáticos. En adición, en este documento también se describe brevemente la configuración de las pruebas.

Además de utilizar el reflector de esquina triédrica, se utiliza un metal esférico sólido como objetivo para este enfoque. La esfera metálica tiene ventajas sobre los reflectores debido a la simplificación de la sección transversal del radar en la condición específica y a un error de seguimiento insignificante. Además, la polarización magnética puede ser despreciada debido a la forma simétrica y la superficie lisa de la esfera.

PALABRAS CLAVE

FMCW	Frequency Modulated Continuous Wave Radar
RADAR	Radio and Ranging
RCS	Radar Cross Section
MRR	Medium-Range Radar
LRR	Long-Range Radar
SRR	Short Range Radar

ÍNDICE GENERAL

1. INTRODUCCIÓN

La implementación de un enfoque de prueba para la prueba y calibración del radar es necesaria desde que ADAS se hizo popular en el sistema de seguridad de los vehículos. Dependiendo del OEM (Fabricante de Equipo Original), se requiere calibrar algún sistema de radar después de que algún otro sistema ha sido removido del vehículo, reemplazo del parabrisas (sólo para la cámara) o incluso después de que ocurra una colisión menor en el vehículo.

Debido al complicado principio de funcionamiento entre los sensores en ADAS, el instrumento de calibración proporcionado por el OEM es extremadamente inteligente y costoso. Por lo tanto, no todos los centros de servicio de vehículos y talleres se permiten tener el instrumento de calibración respectivo. Aunque hay una prueba de calibración estándar que se adapta a cada tipo de vehículo, fabricantes de automóviles, tipo de radar y la posición del mismo, fue diseñado y no está disponible para el exceso libre debido a cuestiónes de legalidad.

Dado que los sensores de radar trabajan con ondas electromagnéticas invisibles en un rango específico de frecuencia, se requiere una configuración y un equipo de prueba especial para el enfoque de la prueba. Como ya se sabe que el radar se reflejará en cualquier pieza metálica y que el radar automotor funciona mientras el vehículo está en movimiento, es necesario establecer el método científico para llevar a cabo la prueba estática en la sala de pruebas cercana. Es necesario definir la definición adecuada para obtener una calibración perfecta.

1.1. Motivation

El vehículo defectuoso que sufrió un accidente, incluso por un accidente menor, debe someterse a una prueba de calibración para asegurar que todos los sistemas funcionan correctamente. Los sensores montados en el exterior son sensibles debido a las enormes vibraciones y movimientos repentinos que se pueden crear durante el choque. En ciertos casos, debido a un contrato de seguro, el usuario del vehículo sólo ha podido enviar su vehículo al taller más cercano que es el proveedor de seguros que quería evadir el costo del transporte. Sin embargo, no todos los talleres pueden proporcionar un instrumento para la calibración del radar porque es demasiado costoso, y no pueden hacer una nueva instalación del sensor de radar debido a que no se dispone de un método de calibración estándar que pueda utilizarse como guía.

La prueba en campo abierto lleva tiempo y requiere que un mecánico conduzca el vehículo en la calle mientras se realiza la prueba. La prueba a campo abierto tiene una desventaja debido a que las condiciones de la calle no son fijas (atascos o mala respiración) y el vehículo sometido a prueba también puede tener la posibilidad de sufrir un accidente. Por lo tanto, no se puede definir una normalización y una directriz para la prueba de radar en el campo de pruebas abierto que sea adecuada para cada condición de la calle.

Por otra parte, es sumamente importante contar con un enfoque de prueba práctico y fiable para el sistema de radar, a fin de evitar la lectura errónea y la mala alineación del radar montado en el vehículo, ya que este problema de mala alineación puede provocar un accidente. Un accidente puede ocurrir cuando el radar calculó mal el alcance, la velocidad y el ángulo del objetivo que se aproxima.

El consumo de tiempo para la calibración también contribuye a la eficacia de la prueba. Además de que puede acortar el tiempo de espera para que los clientes recuperen su vehículo, también puede maximizar el número de trabajos de calibración que puede realizar el taller y finalmente puede reducir el costo del servicio.

1.2. Objetivo

El objetivo de estos estudios es el siguiente:

a) Introducir un enfoque de prueba para el radar automotriz en una sala de pruebas cercana que cumpla con el requisito de la Seguridad Funcional Automotriz, ISO 26262.
b) Implementar un método de prueba y calibración del radar que sea capaz de detectar el blanco así como de medir el alcance.
c) Implementar un enfoque de prueba que sea fiable y práctico para cada tipo de radar y posición.
d) Implementar una prueba de radar automotriz que sea adecuada para cada país.
e) Implementar el equipo apropiado para la prueba.
f) Planificar la configuración de la disposición y el entorno de la prueba.
g) Introducir un enfoque de prueba que ahorre tiempo, sea asequible y fácil de manejar.

2. REVISIÓN DE LA LITERATURA

En este capítulo se ofrece un breve resumen del principio general de funcionamiento del radar. La teoría matemática detrás del principio de funcionamiento y la relación con la sección transversal del radar (RCS), por lo que se aplica el RCS a este enfoque de pruebas. Además de eso, este capítulo también describe brevemente cómo determinar el alcance y el ángulo del objetivo desde el radar, adecuado para esta prueba. El enfoque estará abierto al factor que afecta al RCS y a la relación para elegir el objetivo para esta metodología de prueba. Además, una breve introducción sobre la aplicación se proporciona un radar en un vehículo autónomo.

2.1. El radar y su principio de funcionamiento

El Radar (Radio Detección y Alcance) fue originalmente adaptado del sistema de sonar (Navegación Sonora y Alcance) que fue naturalmente usado por animales como los murciélagos para la navegación y la determinación de distancias. Los murciélagos emiten ondas de sonido entre 30 y 120 kHz de rango de ultrasonido. Entonces los murciélagos captarán el eco del obstáculo o de su presa usando sus oídos. El principio de funcionamiento de Radar también aplicó la misma teoría, sin embargo, utilizando la señal de radio. El radar emitirá una señal de radio desde la antena transmisora y se reflejará cuando golpee el objeto hecho de material de conductividad eléctrica (por ejemplo, la carrocería del vehículo) como un eco a la antena receptora [1].

2.1.1. *MEDICIÓN DEL RANGO*

Para todos los métodos de radar, la medición del alcance se basa en el tiempo de propagación directo o indirecto, como el tiempo entre el momento en que se emite la señal de radar y el momento en que se recibe el eco de la señal. Tiempo de propagación indirecta, el período es igual al doble de la distancia recorrida hasta el reflector dividido por la velocidad de la luz, como se muestra en la siguiente ecuación: [1]

$$\tau = 2r/c \qquad (2.1)$$

Donde $\tau = tiempo$
$r = rango$
$c = velocidad\ de\ Luz$idad de Luz

de propagación indirecta utiliza un método conocido como FMCW (Frequency Modulated Continuous Wave) que es mucho más simple que el tiempo de propagación indirecta. En el FMCW, las ondas de radar se modulan linealmente en su frecuencia durante una duración y se comparan las frecuencias de la señal transmitida (chips TX) y del eco de la señal recibida (chips RX). Como se muestra en la Figura 1, la señal recibida (chirrido RX) es la versión de retardo de la señal transmitida (chirrido TX) por la que el retardo es directamente proporcional al alcance del objetivo. Estas señales de transmisión y recepción se mezclan y producirán una señal de frecuencia resultante, que se llama frecuencia intermedia. (IF) [2].

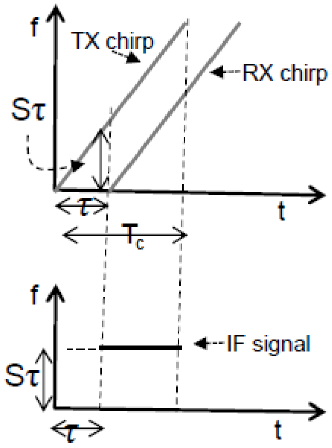


Figura 1: FMCW [3]

Utilizando la relación de los chirridos de tiempo, el inicio del período, T_c y la diferencia de tiempo, τ y la relación de la diferencia de frecuencia, IF al ancho de banda, B se puede formar la ecuación 2.2 [2].

$$\tau = \frac{IF\ T_c}{B} \tag{0-2}$$

Al sustituir τ por 2-1, se puede calcular el alcance del radar al objetivo [2]

$$d = c\ \frac{IF\ T_c}{2B} \tag{0-3}$$

Además de eso, la señal de FI puede ser expresada en la señal sinusoidal como se indica en la ecuación 2-4 y puede ser transformada en Transformada rápida de Fourier (FFT). La FFT se aplica en la señal de FI para encontrar el pequeño cambio en el desplazamiento del objetivo. Nótese que, el pequeño movimiento del objetivo no dará mucho cambio en la frecuencia, pero sí dará un gran cambio de fase en la FFT, por lo que el cambio de fase, Δϕ se utiliza para encontrar la estimación del ángulo del objetivo. El cambio de fase puede verse desde el pico del rango en FFT y puede expresarse como sigue [3] .

$$X_{out} = A\, sin(\omega t\ +\ \Delta\phi) \tag{0-4}$$

Basado en la ecuación general de la onda sinusoidal, ω=2πf mientras que la frecuencia de la IF es $S2d/c$ y IF >1/T_c . Por otro lado, ω en IF la señal sinusoidal puede ser simplificada en la ecuación 2-5 [3].

$$\omega = \frac{4\pi\Delta d}{\lambda} \qquad 0\text{-}5$$

Donde S=Pendiente
d=distancia
T_c =inicio del período
Δϕ = cambio de fase

λ=longitud de onda

2.1.2. *ÁNGULO DE ESTIMACIÓN*

El ángulo de estimación del objeto único frente al radar requería al menos 2 antenas RX y el ángulo puede determinarse calculando la distancia diferencial del objeto a cada una de las antenas como se muestra en la Figura 2. [3]

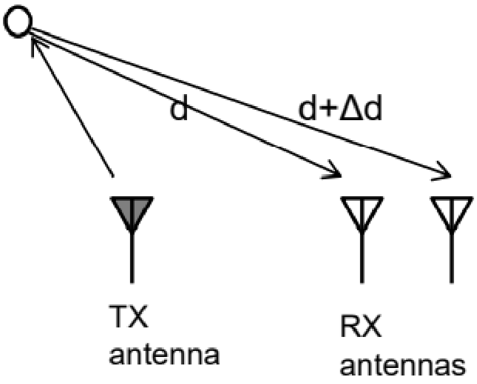


Figura 2: Estimación del ángulo de 2 antenas RX [3]

Refiriéndose a la Figura 3, $\boldsymbol{d}\ \mathbf{sin}\,\boldsymbol{\theta}$ es la distancia entre dos antenas. Dado que el cambio en ω también equivale al cambio de fase, Δϕ y después de sustituir Δd=d sinθ en la ecuación 2-5, **Δϕ** puede expresarse como en la ecuación 2-6. Dado que la onda de la señal se desplaza hasta el objetivo y vuelve a la antena receptora, **Δϕ** se expresará simplemente por el factor 2. [3]

La portada del TFM seguirá el modelo indicado como ejemplo en los Anexos [3].

$$\Delta\phi = \frac{2\pi\ d\ \ sin(\theta)}{\lambda} \tag{0-6}$$

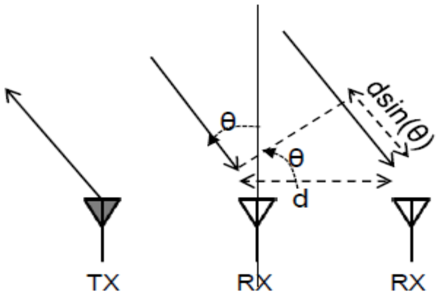


Figura 3: Distancia entre 2 antenas de RX [3]

A partir de esto, la estimación del ángulo, θ del objeto único en FMCW puede ser definido como en la siguiente relación.

$$\theta = \ sin^{-1}(\frac{\lambda\omega}{2\pi d}) \tag{0-7}$$

2.2 *Sección transversal del radar general (RCS)*

Teóricamente, la sección transversal del radar (RCS, o σ) puede definirse como la relación entre la densidad de potencia radiada que golpea el objetivo y la potencia por unidad de ángulo sólido retrodispersada a la antena receptora por el objetivo. En otras palabras, la RCS es la eficiencia en la que un objetivo hace eco de la energía del radar de vuelta al receptor del mismo.[4] Matemáticamente, el RCS puede presentarse como la siguiente ecuación: [5]

$$\sigma = 4\pi\,\frac{P_s}{P_i} \qquad \text{0-8}$$

Donde σ = Sección transversal del radar
P_s = potencia por unidad de ángulo sólido reflejado por el objetivo, (W⁄sr=W)
P_i = la densidad de potencia de una onda plana que golpea el objetivo, (W/m^2)

El RCS tiene un amplio rango de 10^{-5} para los pequeños insectos a 10^{6} para los grandes barcos. Por lo tanto, el RCS se expresa a menudo en la escala de decibelios logarítmicos: [5]

$$\sigma_{dBSqm} = 10.log\,(\frac{\sigma}{1.m^2}) \qquad \text{0-9}$$

2.2.1 FACTOR QUE AFECTA AL RCS

Según [6], el RCS es el producto de 3 factores que son el área transversal proyectada, la reflectividad, y la directividad donde la reflectividad es usualmente más pequeña, y dependiente del material mientras que la directividad puede ser mucho más grande y depende de la forma del objeto [5].

$$RCS = A_P \times R \times D \qquad \text{0-10}$$

Que A_p = área transversal proyectada
R = reflectividad, fracción re-radiada de la potencia interceptada
D = directividad

Además de la forma, la composición del material también afectará al RCS del objetivo. El eco del radar está influenciado por los movimientos de carga inducidos en el objetivo y el RCS se calcula como una relación de la eficiencia de la esfera perfectamente conductora. Sin embargo, no todos los tipos de objetos en el aire son perfectamente conductores o incluso no son conductores en absoluto. Generalmente, una esfera sólida no conductora tendrá un RCS de aproximadamente cero. [5]

Como se indica en la definición de RCS general en 2.2 Sección transversal de radar general (RCS), RCS es la relación entre la densidad de potencia radiada que golpea el blanco y la potencia por unidad de ángulo sólido retrodispersada a la antena receptora por el blanco. Por lo tanto, el blanco esférico será perfectamente sólido. Sin embargo, según [5] , los

globos con tejidos metalizados se utilizan a veces para la calibración del radar con el mismo propósito y devolverían un eco eficiente. Sin embargo, hay que prestar especial atención a la suavidad de la superficie, la reflectividad del tejido metalizado y la posibilidad de que el tejido o la pintura que se desprenda después de cierto tiempo.
Por lo tanto, el RCS varía dependiendo de estos 3 factores. El RCS del vehículo es influenciado por todos los reflectores en el vehículo como; cuerpo del vehículo, radiador/rejilla, parachoques, placa de matrícula, espejo y antenas. El Corvette, por ejemplo, tiene un bajo RCS debido a su cuerpo de fibra de vidrio que tiene menos reflectores que un cuerpo de metal. Por otro lado, el Mustang convertible tiene un bajo RCS en gran parte debido a que no tiene un techo de metal. [7]

2.3 RCS del objeto y su determinación

Para la calibración y prueba del radar, objetos simples pueden actuar como el objetivo del radar. Se utilizan comúnmente dos tipos de formas geométricas que son la esfera y los reflectores de esquina. La Figura 4 muestra un objeto simple con la dimensión principal de 1m y su RCS. La esfera, sin embargo, se elige a menudo porque devolverá la misma potencia al mismo receptor debido a su perfecta área de sección transversal proyectada. [4].

Si el diámetro de la esfera es lo suficientemente grande en comparación con la longitud de onda operativa, entonces el RCS del objetivo es constante e independiente de la longitud de onda e independientemente de cualquier polarización lineal donde el RCS es igual a su área geométrica proyectada $\sigma=\pi r^2$ bajo la cierta condición que se describirá más adelante en el siguiente subcapítulo [4].

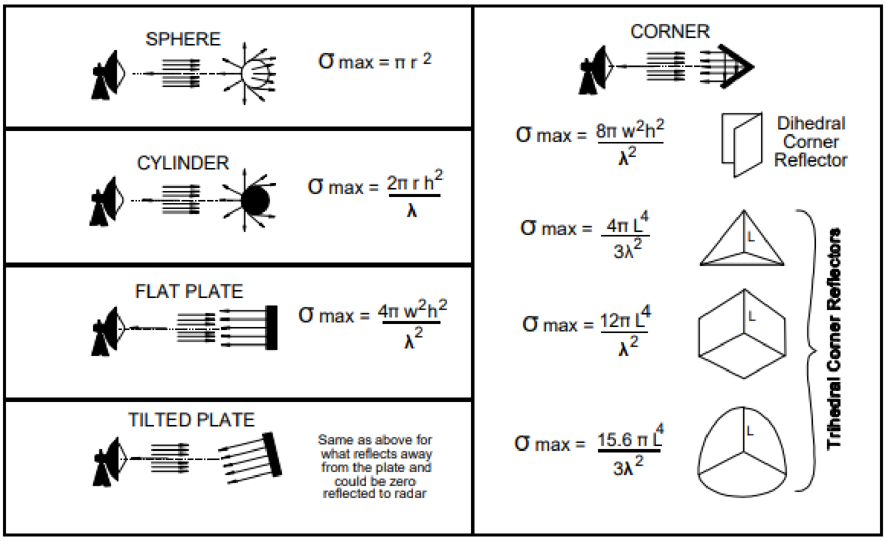


Figura 4: RCS para un tipo diferente de geometría [4]

En la aplicación real del radar, el objetivo actuará como la segunda antena, lo que significa que volverá a irradiar la potencia interceptada a las antenas receptoras. Esta salida del radar, sin embargo, tiene sus propias propiedades de campo cercano y lejano y su patrón de radiación debido a su tamaño y forma. Por lo tanto, para desplazar el centroide de fase del centro geométrico del objetivo grande y complejo, las diferencias de fase entre los frentes de onda que provienen de diferentes partes del objetivo deben ser sumadas o restadas de maneras complicadas. Este fenómeno se conoce como error de centelleo o error de seguimiento y este error puede ser despreciado para el objetivo esférico debido a que el centroide de fase de la esfera siempre coincide con el centro geométrico [8].

Otra ventaja del objetivo esférico es su magnitud relativa. La Figura 5 muestra que, los patrones de RCS como objeto se giran alrededor de su eje vertical (las flechas demuestran la dirección del reflejo del radar). De esta cartografía, se ve claramente que, la esfera tiene el mismo reflejo en todas las direcciones mientras que la placa plana casi no tiene RCS excepto cuando se posiciona directamente hacia el radar. Por otra parte, el RCS para el reflector de la esquina es alto como la placa plana pero sobre un ángulo más amplio, es decir, ±60°. [4]

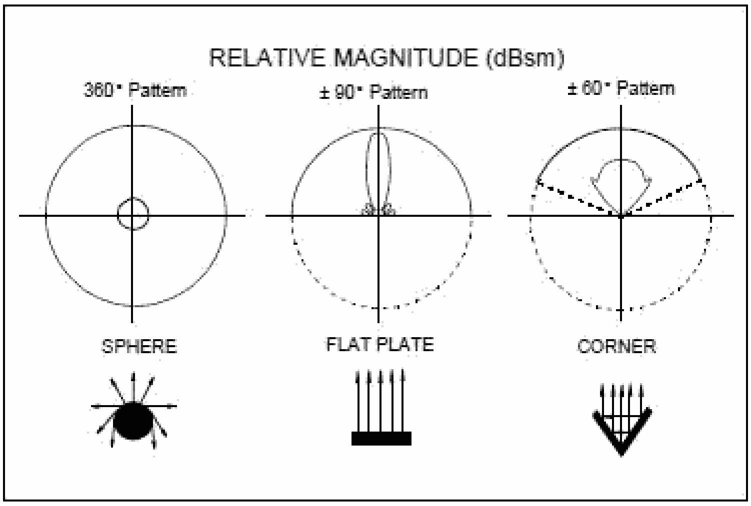


Figura 5: Magnitud relativa de los objetivos [4]

Por consiguiente, la polarización del objetivo esférico es la misma que la polarización de una onda de radio simple, que está definida por la orientación del plano del vector eléctrico, que está girado 90° con respecto al plano del vector magnético.[4]

2.3.1.OBJETIVO ESFÉRICO Y RCS

El campo lejano o región óptica para la calibración y prueba del radar significa donde $\lambda <<$ rango y $\lambda <<$ radio. En este caso, el RCS del objetivo esférico es constante y no depende de la longitud de onda operativa como ya se mencionó en el subcapítulo anterior. Con referencia a la Figura 6, para estar en el campo lejano o en la región óptica, la circunferencia del círculo debe ser al menos 10 veces la longitud de onda de funcionamiento o, en cambio, el diámetro del círculo será aproximadamente 3,2 veces la longitud de onda del radar. [4]

Sin embargo, si la circunferencia de la esfera cae por debajo de 10λ, entonces el RCS del objetivo esférico estará situado en la región de resonancia de Mie, donde el RCS fluctuará cada vez más a medida que la circunferencia se aproxime a la longitud de onda. Finalmente, el RCS del objetivo es fuerte y linealmente dependiente de la longitud de onda cuando entra en la región de Rayleigh u otras palabras $2\pi r/\lambda$ cae por debajo de 1.0. Esta es la parte del diagrama que normalmente es apropiada para la detección de gotas de lluvia y granizo por el radar meteorológico. [4]

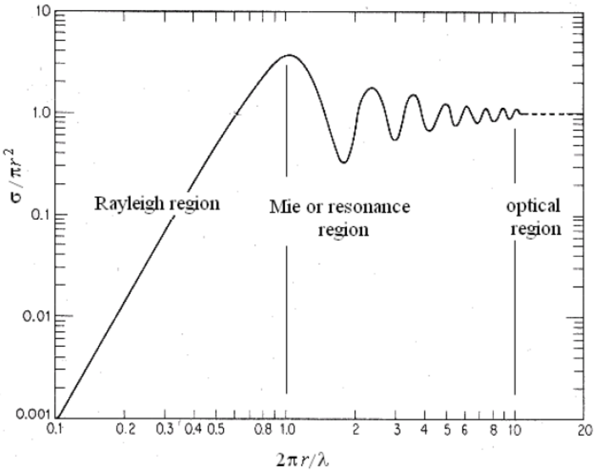


Figura 6: El diagrama de la sección transversal del radar [4]

Experimentalmente, el eco de radar del objetivo real se compara con el eco de radar de una esfera que tiene un área frontal o proyectada de un metro cuadrado o 44. pulgadas de diámetro respectivamente [9]. Con la ayuda del objetivo de forma esférica para la medición en el campo o en el laboratorio, la orientación o posicionamiento de la esfera no afectará la intensidad de la reflexión del radar en comparación con la que tendría la placa plana. Como se indica en [9] la prueba de radar debe llevarse a cabo con 44. pulgadas de diámetro del objetivo de la esfera como se muestra en la Figura 7. Sin embargo, para reducir la resistencia durante la prueba, el diámetro de la esfera puede ser adaptado a tu6, 14 o 22 pulgadas y el tamaño de referencia es de 0,018, 0,099 o 0,245 m respectivamente en lugar de 1 m. [4]

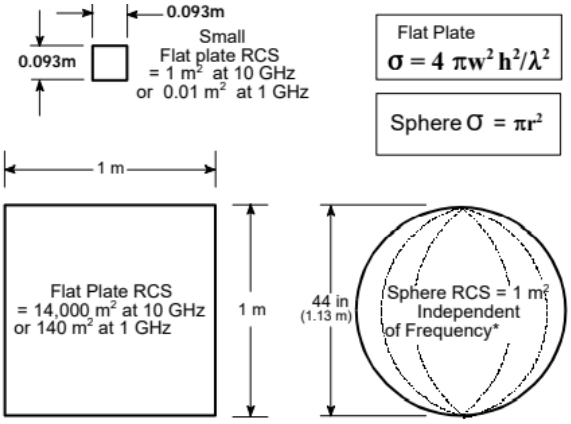


Figura 7: RCS contra la geometría física [4]

3. EL ENFOQUE DE LAS PRUEBAS DE RADAR

Este capítulo se centra particularmente en el proceso de desarrollo desde la etapa de planificación hasta la finalización del diseño de todo el equipo establecido. En la etapa de planificación, la necesidad del método de ensayo se ha enumerado en la lista de necesidades en consecuencia. A continuación, los estudios prosiguen con la redacción de posibles soluciones que coincidan con la lista de requisitos, en la que se identifican todas las ventajas y desventajas de cada diseño. Las soluciones se analizaron más a fondo utilizando la tabla de clasificación y el análisis de beneficios cruzados, en el que los diseños se ponderaron analíticamente. Una vez finalizada la solución de ambos análisis, la solución de diseño elegida se visualizó utilizando el modelo tridimensional.

3.1. Objetivo del enfoque de la prueba

Sobre la base del estudio descrito en el capítulo anterior, se ha elegido como objetivo de este enfoque de ensayo la esfera según la simplificación que se indica a continuación:

1. El RCS de la esfera es independiente de la frecuencia de radar en determinadas condiciones.
2. El error de seguimiento es insignificante debido al centroide ya
3. Que el centro de masa de la esfera siempre coincide con el centro geométrico.
4. Magnitud relativa constante del RCS para la rotación en el eje vertical.
5. Simplificación en la polarización debido a la magnitud relativa constante

3.1.1. *DETERMINAR EL TAMAÑO DEL OBJETIVO*

Teóricamente, la relación entre la frecuencia y la longitud de onda puede estar presente en la siguiente fórmula: [9]

$$f = \frac{c}{\lambda} \qquad 3\text{-}1$$

Que f = frecuencia
C = velocidad de la luz (3×10^{10} cm/sec)
λ = longitud de onda

para f = 24 GHz ; $\lambda = \frac{3\times10^{10}\ cm/sec}{24\ GHz} = 1.25\ cm$

para f = 76 GHz ; $\lambda = \frac{3\times10^{10}\ cm/sec}{76\ GHz} = 0.394 cm$

para f = 77 GHz ; $\lambda = \frac{3\times10^{10}\ cm/sec}{77\ GHz} = 0.389\ cm$

Teniendo en cuenta que a partir de 2022 ya no se permitirán 24 GHz en Europa, es más práctico tomar el rango de frecuencia entre 76 y 77 GHz para este estudio. Como se indicó en el capítulo anterior, el diámetro del círculo debe ser al menos 3,2 veces la longitud de onda de funcionamiento, por lo que se tomó la longitud de onda de 76 GHz para un cálculo más detallado, ya que tiene la longitud de onda más larga.

$$0.394\ cm\ \times 3.2 = 1.26\ cm \qquad 0\text{-}2$$

Por lo tanto, el tamaño de la esfera de metal debe tener al menos un diámetro de 1,26 cm. Teóricamente, el diámetro de la misma debe ser de 44 pulgadas o respectivamente 113 cm. Sin embargo, para el propósito de la prueba, el diámetro del blanco puede reducirse a 22, 14 o 6 pulgadas. [4] Teniendo en cuenta que el peso de la esfera de metal sólido podría ser pesado y difícil de fabricar y manipular, se eligió el diámetro más pequeño que 6 pulgadas o respectivamente a los 15 cm.
Como se ha indicado dos veces en el capítulo anterior, esa definición del SCR es la relación entre la densidad de potencia radiada que incide en el blanco y la potencia por unidad de ángulo sólido retrodispersada a la antena receptora por el blanco y debido al inconveniente de utilizar una esfera hueca, como se ha descrito en Factor que afecta al RCS , se decide que el blanco para este enfoque de prueba utilice una esfera metálica sólida.

3.1.2. *DETERMINAR EL RANGO REQUERIDO DEL OBJETIVO*

Para que el objetivo pueda ser detectado, es necesario colocarlo en el campo de visión del radar operado. Asegurarse de que el objetivo esté en el campo de visión del radar es de vital importancia para evitar el resultado analítico engañoso y para obtener un SCR perfecto. Si se colocó demasiado cerca del radar, éste no podrá escanear toda la geometría del objetivo. Por lo tanto, es importante aquí definir el rango requerido para que el objetivo sea colocado antes de que comience la prueba.
Para encontrar la solución a este requisito, se utiliza el ángulo de acimut del radar operado. El ancho del ángulo de apertura (X) se define aquí libremente para tener al menos ± 15 cm de tolerancia de espacio libre excluyendo el blanco. Por este medio, refiriéndose al tamaño del blanco de 15 cm, el ancho del ángulo de apertura es de 30 cm y puede simplificarse con la siguiente relación

$$X = objetivo\ de\ diámetro + 15\ cm\ cm \qquad 0\text{-}3$$

El teorema de Pitágoras y la teoría de la trigonometría se aplican aquí. Tomando el ángulo de acimut del radar como α y dividiendo simétricamente el triángulo equilátero como se muestra en la Figura 8, donde la longitud de a es la mitad de X. El alcance requerido del objetivo que debe colocarse se denota aquí con b puede conocerse utilizando la siguiente fórmula:

$$b = \frac{\mathrm{a}}{\tan(\alpha/2)} \qquad 0\text{-}4$$

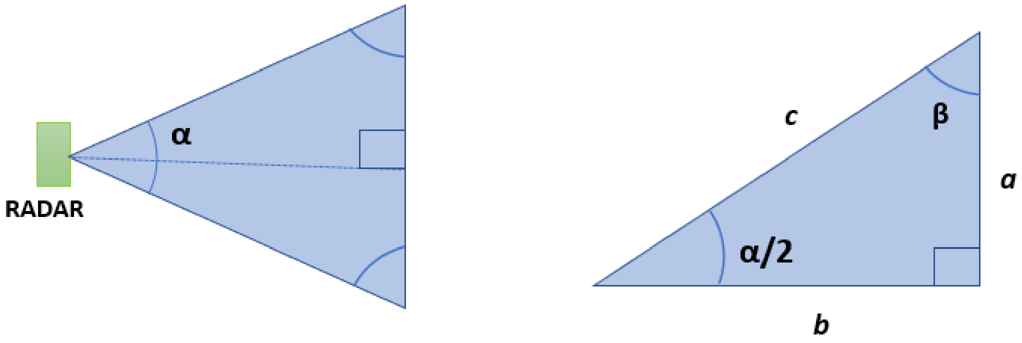


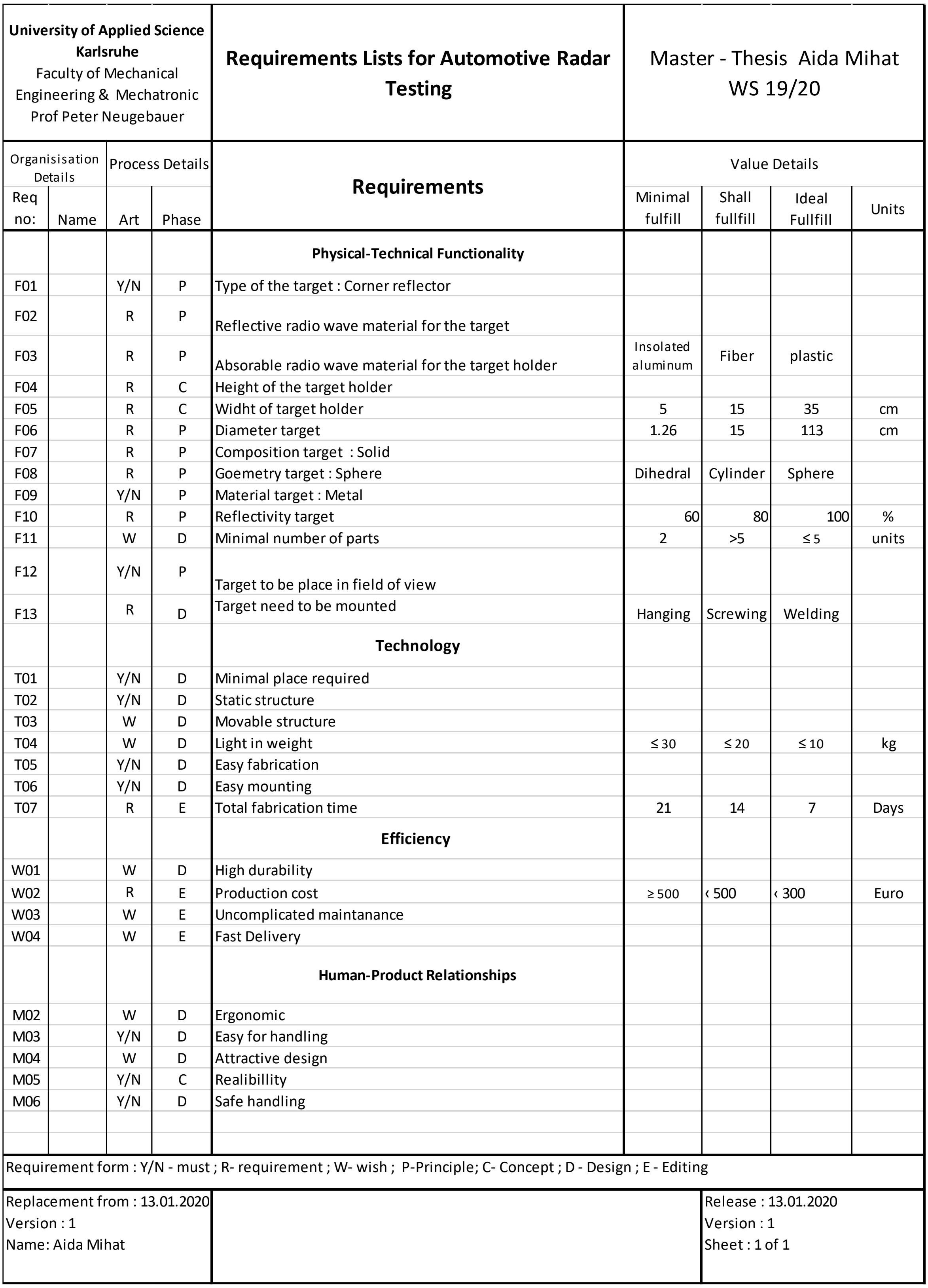
Figura 8: El campo de visión del Radar

3.2. *Lista de requisitos*

Una vez que se hayan definido el objetivo y las condiciones generales de los estudios, se podrán especificar con más detall
e las especificaciones de contenido. Esto puede describirse utilizando la lista de requisitos que contiene los requisitos básicos para el ensayo. En la marcha de los trabajos, es necesario prestar atención constante para garantizar que el enfoque del ensayo cumpla el requisito enumerado en cada etapa. [10] De todos modos, la lista de requisitos se utilizará para seleccionar el tipo de reflector y su tamaño. Después de eso, esta lista indicará el proceso de fabricación requerido, desde la selección del material hasta el proceso de montaje. El cuadro 2 a continuación muestra la lista de requisitos para el enfoque de la prueba de radar automotriz.

Según [10] al principio del proceso de diseño, el requisito debe ser aclarado para tener una idea de la necesidad del ensamblaje y de las condiciones existentes. En este estudio, el dispositivo de prueba debe ser diseñado de acuerdo con el objetivo del enfoque de prueba.

Tabla 1: Lista de requisitos



University of Applied Science Karlsruhe Faculty of Mechanical Engineering & Mechatronic Prof Peter Neugebauer				**Requirements Lists for Automotive Radar Testing**	Master - Thesis Aida Mihat WS 19/20			
Organisisation Details		Process Details		**Requirements**	Value Details			
Req no:	Name	Art	Phase		Minimal fulfill	Shall fullfill	Ideal Fullfill	Units
				Physical-Technical Functionality				
F01		Y/N	P	Type of the target : Corner reflector				
F02		R	P	Reflective radio wave material for the target				
F03		R	P	Absorable radio wave material for the target holder	Insolated aluminum	Fiber	plastic	
F04		R	C	Height of the target holder				
F05		R	C	Widht of target holder	5	15	35	cm
F06		R	P	Diameter target	1.26	15	113	cm
F07		R	P	Composition target : Solid				
F08		R	P	Goemetry target : Sphere	Dihedral	Cylinder	Sphere	
F09		Y/N	P	Material target : Metal				
F10		R	P	Reflectivity target	60	80	100	%
F11		W	D	Minimal number of parts	2	>5	≤ 5	units
F12		Y/N	P	Target to be place in field of view				
F13		R	D	Target need to be mounted	Hanging	Screwing	Welding	
				Technology				
T01		Y/N	D	Minimal place required				
T02		Y/N	D	Static structure				
T03		W	D	Movable structure				
T04		W	D	Light in weight	≤ 30	≤ 20	≤ 10	kg
T05		Y/N	D	Easy fabrication				
T06		Y/N	D	Easy mounting				
T07		R	E	Total fabrication time	21	14	7	Days
				Efficiency				
W01		W	D	High durability				
W02		R	E	Production cost	≥ 500	‹ 500	‹ 300	Euro
W03		W	E	Uncomplicated maintanance				
W04		W	E	Fast Delivery				
				Human-Product Relationships				
M02		W	D	Ergonomic				
M03		Y/N	D	Easy for handling				
M04		W	D	Attractive design				
M05		Y/N	C	Realibillity				
M06		Y/N	D	Safe handling				
Requirement form : Y/N - must ; R- requirement ; W- wish ; P-Principle; C- Concept ; D - Design ; E - Editing								
Replacement from : 13.01.2020 Version : 1 Name: Aida Mihat						Release : 13.01.2020 Version : 1 Sheet : 1 of 1		

3.3. Enfoque de diseño

Refiriéndonos a la lista de requisitos, aquí hay 3 sugerencias para la posición de montaje y el equipo de prueba como se muestra en la Figura 9, la Figura 10 y la Figura 11. El desafío en este diseño de equipo de prueba es crear un equipo práctico y movible, que pueda moverse en el eje y y en el eje x. Esto se debe a que el objetivo necesita ser ajustado de acuerdo a la altura del radar montado en el vehículo y práctico para probar cada lado del radar montado. Además de eso, el reflector se colocará dentro del campo de visión del radar durante la prueba, ya sea montado o colgado en el soporte. Teniendo en cuenta que la esfera metálica sólida es pesada, es necesario definir claramente el método de montaje para evitar que la esfera metálica se caiga y se pueda utilizar con seguridad durante el ensayo. Aparte de eso, la esfera de metal necesita ser montada simétricamente para obtener el equilibrio de la estructura del equipo. En el cuadro 3 se muestra el resumen de la comparación entre las 3 soluciones y se describirá brevemente en el siguiente subcapítulo.

Tabla 2: Comparación resumida entre la solución de tres alternativas

	Solución 1	Solución 2	Solución 3
Estabilidad	• Más estable	• Menos estable	• Estable
Complejidad	• Más complejo para la fabricación	• Simple	• Simple
Practicidad	• No se puede mover en un área estrecha, no es adecuado para la prueba de radar tresero	• Posible para la prueba de radar trasero y lateral	• Posible para la prueba de radar trasero y lateral
Manejabilidad	• Equipo autónomo	• Se requiere que una persona sostenga el soporte	• Equipo autónomo
Método de montaje	• Atornillando alrededor del anillo	• Soldadura	• Soldadura

3.3.1. SOLUCIÓN ALTERNATIVA 1

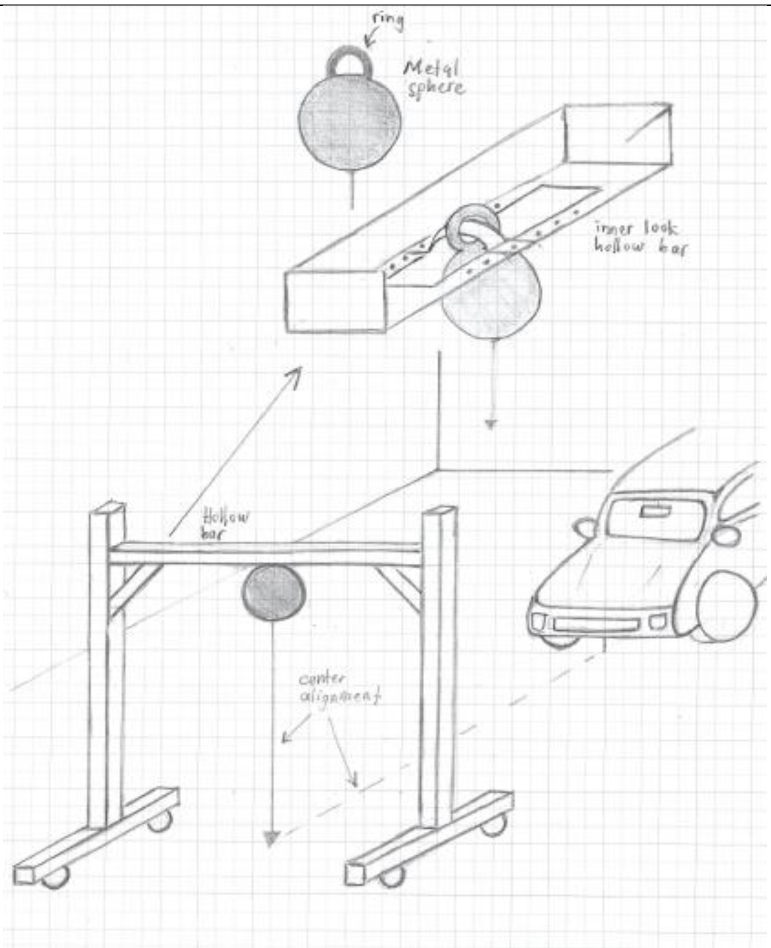


Figura 9: Solución alternativa 1

Esta estructura contiene las 3 partes principales, que son una barra horizontal hueca y cuadrada, un par de patas y un blanco. Como se puede ver en el dibujo a mano, el blanco fue diseñado para tener un anillo en la parte superior. La función del anillo es proporcionar un agujero para que el gancho cuelgue el blanco. El gancho se atornillará dentro de la barra cuadrada horizontal, por lo que la posición es ajustable en el eje x de acuerdo con la posición central del radar durante la prueba se lleva a cabo.
Después de eso, la barra horizontal se fijará a la pierna de la estructura, por lo que su altura también es ajustable en el eje y. Se planificaron dos ruedas para cada pata para que la estructura sea fácil de mover.

Ventajas:
- Movible para el eje x y el eje y
- Buena estabilidad

Desventaja
- No es práctico para aplicar para la prueba de radar trasero o en el área de prueba estrecha
- Requiere muchas partes que necesitan ser ensambladas
- Difícil de fabricar debido a un gran número de piezas
- Difícil de montar el objetivo
- Diseño complicado

3.3.2. *SOLUCIÓN ALTERNATIVA 2*

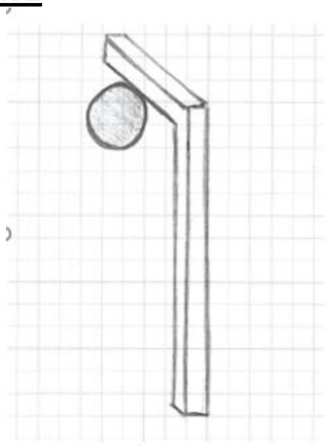


Figura 10: Solución alternativa 2

Esta estructura contiene 2 partes, que son el brazo y la pierna. El objetivo se soldará directamente a la parte inferior del brazo, mientras que el brazo y la pierna se montarán con un sujetador. La pierna está diseñada para ser ajustable en altura. Por lo tanto, el objetivo puede ser apalancado en el campo del área del radar operativo. Dado que no hay base para esta estructura, se requiere que un operador sostenga la estructura durante toda la prueba que se lleve a cabo.

Ventaja:
- Diseño simple
- Fabricación y montaje sencillos
- Requiere un número mínimo de piezas

Desventajas:
- Conducen a resultados erróneos debido a que no se fijan la pierna y el SCR del operador
- Menos estabilidad debido a la falta de base
- No es ergonómico
- Difícil de mover

3.3.3. *SOLUCIÓN ALTERNATIVA 3*

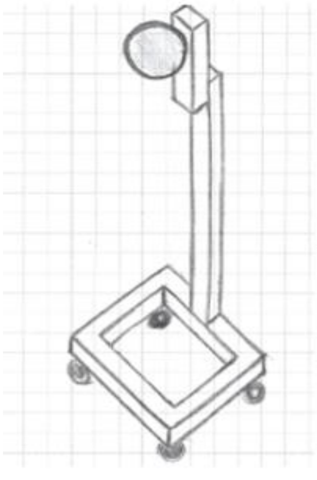


Figura 11: Solución alternativa 3

Esta estructura contiene 4 partes principales, que son el nivelador ajustable, el soporte, la base y el adaptador. Especial con la forma del semi-cilindro hueco fue diseñado para actuar como un adaptador entre la superficie curva del objetivo a la superficie plana del nivelador. La base cuadrada tiene una funcionalidad para hacer esta estructura más estable que la estructura en la solución alternativa 2. Debido a la mejor estabilidad de esta estructura, no es necesario que un operador la sostenga durante la prueba. La rueda con bloqueo se añade para hacer esta estructura fácil de mover y se bloquea cuando se requiere. Por lo tanto, esta estructura es capaz de mantenerse sola y estática durante toda la prueba.

Ventajas:

- Ajustable en el eje Y de acuerdo a la altura del radar operado
- Fácil de fabricar
- Práctico para probar el radar trasero
- Se requiere un número mínimo de piezas
- Bueno en estabilidad
- Capaz de moverse y permanecer estático cuando es necesario.

Desventajas:

- Dificultad de fijación y montaje para el objetivo y el adaptador.
- Difícil de montar el objetivo simétricamente

3.4. *Clasificación y análisis de costo-beneficio*

Para evaluar el rango, los criterios deben ser ponderados porque no es igualmente relevante. Para ello, se enumeran los criterios individuales unos contra otros y esto conducirá al cálculo de la clasificación. El cuadro 4 muestra los criterios ponderados y clasificados para el equipo de prueba. Del análisis se desprende que los criterios más importantes fueron la seguridad y la estabilidad, mientras que los dos últimos criterios fueron el bajo costo y el número de piezas. De acuerdo con el [27], los dos últimos criterios con menos del 5% ponderado se pueden clasificar y el resto de los criterios son con una cobertura de riesgo de más del 80% del valor límite.

Basándose en el análisis de clasificación de la Tabla 3, se creó un análisis de coste-beneficio en el que sólo se analizarán más a fondo los criterios restantes con las 3 soluciones de diseño alternativas. Como se muestra en la Tabla 4 la solución 3 tenía el porcentaje más alto, lo que significa que la solución 3 cumple casi todos los criterios enumerados.

Tabla 3: Criterios de clasificación y evaluación

	Safety	Stability	Practibility	No. Of parts	Easy fabrication	Easy mounting	Ergonomic	Low cost		Number	Weight factor	Ranking
Safety		+	+	+	+	+	+	+		7	0.25	1
Stability	-		+	+	+	+	+	+		6	0.21	2
Practibility	-	0		+	+	+	+	+		5	0.18	3
No of parts	-	-	-		-	-	-	-		0	0.00	8
Easy fabrication	-	-	-	+		0	+	0		2	0.07	6
Easy mounting	-	-	-	+	+		+	0		3	0.11	5
Ergonomic	-	0	0	+	+	+		+		4	0.14	4
Low cost	-	-	-	+	0	0	-			1	0.04	7
Limit at :	**Risk coverage**				**Number of remaining**					28	1.00	
0.04	0.96				6							

Tabla 4: Análisis de costo-beneficio

Evuluation criteria	Criteria weight	S1		S2		S3		Ideal solution	
		unweighted	weight	unweighted	weight	unweighted	weight	unweighted	weight
Safety	0.3	6	1.8	3	0.9	8	2.4	10	3
Stability	0.2	8	1.6	2	0.4	6	1.2	10	2
Practibility	0.2	4	0.8	10	2	10	2	10	2
Easy fabrication	0.1	4	0.4	8	0.8	7	0.7	10	1
Easy mounting	0.1	3	0.3	6	0.6	6	0.6	10	1
Ergonomic	0.1	6	0.6	3	0.3	8	0.8	10	1
Sum	1	31	5.5	32	5	45	7.7	60	10
Value		52%	55%	53%	50%	75%	77%	100	100

3.5. *Finalización del diseño*

Una vez que se ha definido la solución alternativa a partir del análisis de costo-beneficio, la solución se visualiza con mayor detalle. El boceto a mano dibujará y modelará correctamente utilizando el modelo 3D. El dibujo se hizo utilizando CREO 4.0 donde este software permite a los usuarios dibujar piezas en vista 3D, esbozar y ensamblar piezas. La Figura 12 muestra el aspecto final de la solución 3. El dimensionamiento adecuado se adjunta en el apéndice.

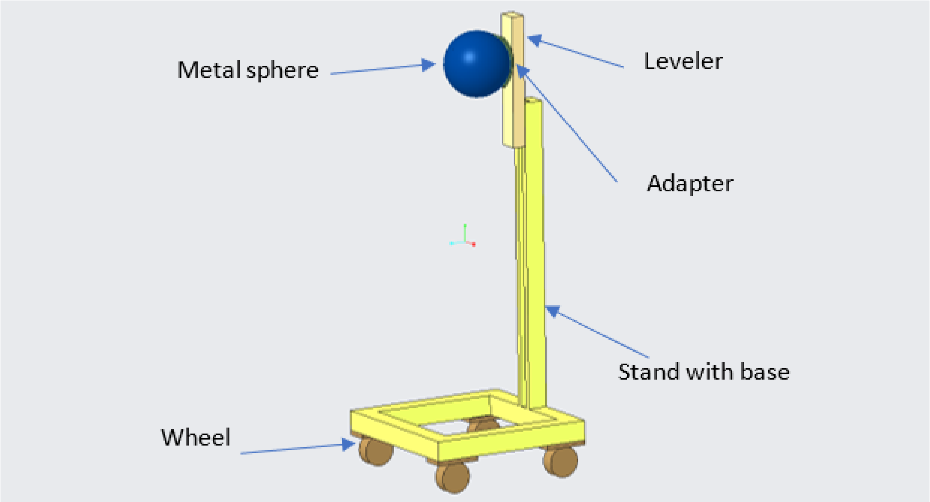


Figura 12 : El modelo 3D final para el equipo de pruebas

Este equipo de pruebas consta de las 4 partes principales, que son la esfera metálica, el soporte ajustable con la base y el adaptador. La esfera metálica de 15 cm de diámetro puede ser soldada con el adaptador, por lo que el adaptador se fija al soporte del nivelador. Para que este equipo sea fácil de fabricar, se sugirió que se utilizara la forma cuadrada para el soporte ajustable y la base. La rueda se añade en la parte inferior de la base para que sea fácil de mover de una posición a otra. Además, para que el equipo se quede estático durante la prueba, se recomienda utilizar la rueda con el bloqueo.

Teniendo en cuenta que el radar reflejará el metal y la aleación, el material para el soporte y la base debe ser de un material absorbente de microondas como la fibra y el plástico. Sin embargo, dado que la fibra y el plástico son relativamente ligeros y existe la posibilidad de que se caigan debido a la esfera de metal sólido y pesado que se fija con el soporte, el material para el soporte puede utilizar metal o aleación, pero debe cubrirse con el material que pueda absorber la energía de las microondas (por ejemplo, el absorbedor de hojas piramidales).

3.6. ***Probando el diseño***

Como se ha descrito anteriormente, las pruebas se planificaron para ser realizadas en una sala cerrada. El objetivo puede ser usado para probar el RCS para cada radar delantero y trasero. La Figura 13 muestra la disposición del ambiente de prueba. La configuración de la prueba debe ser hecha manualmente y por separado para ambos radares, el delantero y el trasero. Refiérase al subcapítulo anterior para estimar la distancia mínima requerida del objetivo desde el extremo delantero y trasero.

Para el radar trasero, la rueda trasera del vehículo necesita ser fijada horizontalmente. Tomando la carrocería del extremo trasero del vehículo como una coordenada 0 en el eje y, la alfombrilla a escala puede ser una superposición a ambos lados de la carrocería del vehículo como se muestra en la Figura 13.

Es similar a la prueba realizada para el radar frontal. Tomando el extremo delantero del cuerpo del vehículo como el 0 en el eje y, se puede medir la distancia mínima requerida para la colocación del objetivo.

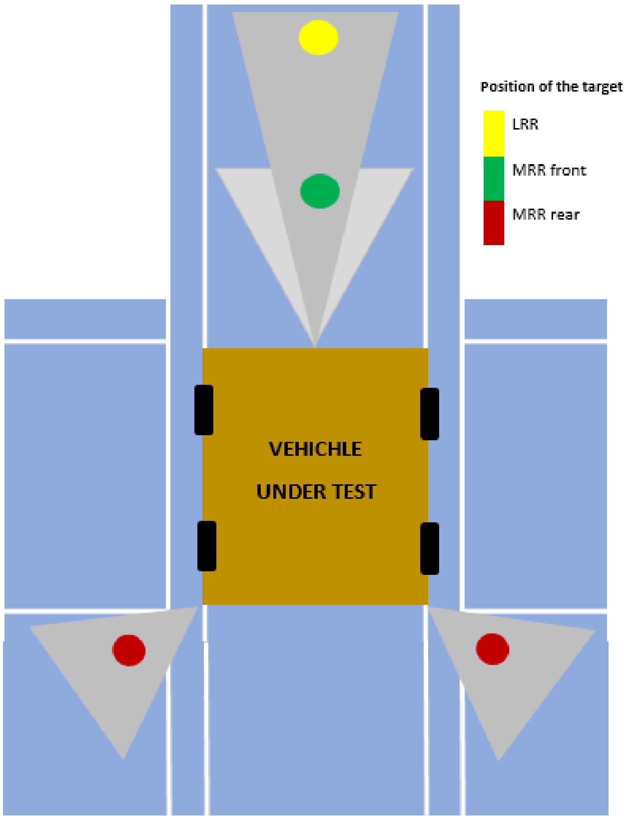


Figura 13: Probando el diseño

La alineación central del vehículo se puede hacer sujetando una cuerda desde el centro del extremo delantero o trasero del vehículo al suelo, como se muestra en la Figura 14, por lo que esta proyección formará una intersección con la línea horizontal en la alfombra de la escala. Esta intersección debe ser perpendicular entre sí o, en otras palabras, crear un ángulo recto. Basándose en esta intersección, se puede determinar un ángulo de acimut en el suelo de prueba.

Si un vehículo de prueba tiene ambos radares LRR y MRR instalados en la parte delantera del vehículo, entonces el desplazamiento del objetivo debe hacerse para la prueba MRR. Esto se debe a que el campo de visión del radar MRR se superpone al campo de visión del radar LRR. El desplazamiento del objetivo aquí significa que el objetivo del MRR no se supone que esté en la misma área del campo de visión del LRR. Este desplazamiento es importante para evitar que las múltiples señales penetren en el objetivo simultáneamente. La prueba del LRR tiene menos complejidad ya que tiene un campo de visión más largo. Por lo tanto, el objetivo del LRR puede colocarse en cualquier lugar dentro de su campo de visión.

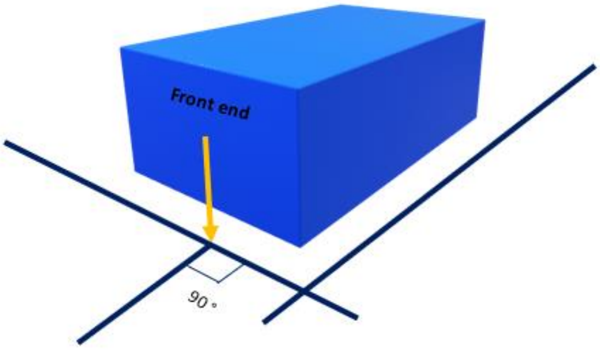


Figura 14: Alineación del centro del vehículo

Aquí está la restricción y la pauta para el enfoque de la prueba:

- El objetivo debe colocarse en el área del campo de visión del radar, de lo contrario, el objetivo no puede ser detectado. Es necesario prestar atención al campo de visión superpuesto para probar diferentes radares instalados.
- Deben evitarse las piezas metálicas u otras piezas fuertes del instrumento reflector del radar cerca de la zona de prueba.
- La pared de la sala de pruebas puede cubrirse con una alfombra absorbente de microondas (por ejemplo, una lámina piramidal)
- Piso de prueba plano

3.7. Resultado esperado

Los resultados analíticos esperados de este enfoque de prueba son la detección del radar, el alcance y la estimación del ángulo para el objetivo. Mediante la emisión de señales de radio del radar operado al blanco metálico esférico en una determinada condición, como se indica en el capítulo anterior, se puede examinar la funcionalidad del radar. El blanco actuará como la segunda antena y reflejará el eco y dará el valor de RCS. Para este enfoque de prueba, el RCS del blanco es igual al área del círculo de la esfera. Utilizando la fórmula siguiente, se puede obtener el RCS.

$$\sigma = \pi r^2 \tag{3-5}$$

Donde σ=RCS (Radar Cross Section)

r=círculo de radio

Dado que la potencia que penetra en el objetivo y la potencia de eco son constantes debido a la constante geometría del objetivo, el alcance del objetivo no puede definirse a partir de la fórmula general del SCR como se indica en la ecuación 2-8. Sin embargo, como el radar de automóviles utiliza el radar de FMCW, el alcance del blanco puede determinarse reformulando la ecuación 2.3 según la cual $d = c\frac{IF\,T}{2B}$.

Que d=distancia
IF=Frecuencia de intermieadate
T=tiempo
B=Ancho de banda
c=velocidad de la luz

Hay que hacer pruebas previas para obtener el valor umbral del SCR no deseado. De acuerdo con [7], el RCS para el suelo y el desorden varía de unos 1000-100000 m2.

Por otra parte, la estimación del ángulo, θ del objetivo esférico en FMCW puede ser determinado usando la ecuación matemática en 2-7. (se refiere a Ángulo de estimación)

$$\theta = \sin^{-1}\left(\frac{\lambda\omega}{2\pi d}\right)$$

Donde ω =fase
$d = distanc$ia entre dos antenas
λ =longitud de inde de IF

4. CONCLUSIÓN

Las ideas eran implementar una metodología de prueba apropiada y una guía para el radar automotor en la sala de pruebas cercana. Al principio del estudio, se dedicó mucho tiempo a comprender el funcionamiento del radar, a investigar la tecnología actual de las pruebas de radar y a intercambiar ideas.

Sabiendo que hoy en día se montan más de un radar en el vehículo con fines de seguridad, la idea del concepto de diseño también debe cumplir el requisito de la regulación de frecuencia y la posición actual del radar montado. A lo largo del proceso, continúa la discusión con el supervisor y el colega se hizo para cambiar las ideas y evitar malentendidos. El cálculo erróneo hará que el enfoque de la prueba no sea fiable y producirá errores mientras el equipo se utiliza para la prueba.

La esfera metálica esférica fue elegida para este enfoque de prueba debido a su simplificación en el RCS. Sin embargo, el objetivo de la esfera también tiene algunas restricciones para evitar la fluctuación de la lectura del RCS, en la que el diámetro de la esfera necesita ser al menos 3,2 veces la longitud de onda operativa en la condición de prueba de campo lejano donde λ<< rango y λ<< radio. Desafortunadamente, la esfera de metal con diámetro de 15 cm no es adecuada para la determinar el RCS de una persona porque el diámetro del objetivo es muy pequeño en comparación con el RCS de una persona. De acuerdo a [9] y como está estipulado en [3], el rango del RCS de una hombre adulto está entre 0.4 y 1.2 m2, dependiendo de la frecuencia del radar. Tomando el menor rango para un hombre adulto 0.4m2, y además, calculando el radio requerido para un objetivo esférico, el cual equivale a un hombre adulto usando la fórmula del área de la esfera se obtiene:

$$r = \sqrt{\frac{0.4}{\pi}} = 0.36\,m = 36cm \tag{3.1}$$

Por lo tanto, para tener un blanco esférico que tenga un RCS equivalente a un hombre adulto con RCS de 0.4m2, el radio del blanco esférico debe tener un radio de 36cm o un diámetro de 72cm.

El dibujo que se ha hecho se basa en el concepto de diseño seleccionado. El cálculo adecuado del tamaño del reflector necesario para asegurar que la prueba dará los resultados esperados. Además de la fiabilidad del equipo, también debe ser práctico en su manejo y desplazamiento. Por lo tanto, las características como la superficie del material, el material, el proceso de fabricación y el método de unión de todo el equipo deben considerarse durante el diseño. Además, esta normalización y directriz de este equipo se ha estudiado para que se adapte a las pruebas de radar de cada país y cada modelo de vehículo, especialmente en Europa.

El equipo de prueba fue diseñado para la prueba de los sensores de radar delanteros y traseros. Originalmente sólo la solución alternativa 1 (ver. Solución alternativa 1) fue diseñada para sostener el blanco de la esfera y tener un soporte de estabilidad. Después de que se hiciera un estudio más detallado del aparato de prueba existente de Texa, (https://www.texa.com/products/radar-camera-calibration-kit) se implementó la solución alternativa 2, que es este diseño es casi similar al aparato de prueba de radar para el sistema de punto ciego, pero el blanco fue reemplazado por el blanco esférico. Esta solución, desafortunadamente, es menos estable y requirió que una persona sostuviera el equipo durante toda la prueba. Conducirá a la perturbación del sistema de adquisición de datos del sensor porque el radar se reflejará en el operador también como el blanco. Finalmente, se ha hecho alguna mejora y se creó la solución alternativa 3, y este diseño obtuvo el mayor porcentaje en el análisis de costo-beneficio.

4.1. Recommendation

Basándose en la solución seleccionada para este enfoque de prueba, aquí está la lista que se puede hacer para mejorar la fiabilidad y la eficiencia de la prueba:

1. En lugar de usar metal o aluminio para el soporte y la base del equipo de prueba, puede ser reemplazado por madera, fibra o plástico. Sin embargo, hay que prestar atención a la estabilidad, la posibilidad de fabricación. Además de eso, el soporte de metal o aluminio también puede ser cubierto con una hoja de energía absorbible de microondas.

2. En otra solución para reducir la perturbación de la energía de microondas de los alrededores durante las pruebas, la cámara de desecho se puede implementar para la sala de pruebas, que es la pared, se puede cubrir con espuma piramidal Cuming que esta cámara de desecho se aplica en las pruebas de aviones (por ejemplo; Cámaras Anecoicas: https://www.cumingmicrowave.com/anechoic-chambers-application.html)

3. La reflectividad del metal esférico puede ser probada usando un espectrómetro como parte de la guía de pruebas de Euro NCAP.

4. La estabilidad del diseño seleccionado puede ser analizada más a fondo usando el software del Método de Elementos Finitos (MEF) como Abaqus ANSYS.

5. La centralización y la medición de ángulos para el posicionamiento del objetivo pueden realizarse con la ayuda de una plantilla de goniómetro como la que se utiliza en TEXA (https://www.texa.com/products/radar-camera-calibration-kit) o en un autocolimador.

4.2. El trabajo future

Este enfoque de prueba puede aplicarse para examinar si el radar funciona en consecuencia, así como para determinar su alcance y ángulo. De acuerdo con el resultado de este estudio, aquí hay algunas sugerencias para el trabajo futuro en el área de las pruebas de radar. Sin embargo, todas estas sugerencias de pruebas deben ser discutidas e investigadas más a fondo.

1. Prueba de radar para detectar la desalineación. Se puede hacer predeterminando la posición fija del objetivo e instalarlo en el sistema de adquisición de datos. Después de eso, al mover el objetivo en una cierta distancia y ángulo, el sistema de adquisición de datos debería dar el mensaje de error si la distancia y el ángulo actuales siguen teniendo el mismo valor que antes de que se haya movido.

2. Para validar la distancia del objetivo al radar añadiendo un sensor ultrasónico. A partir de este estudio, la distancia ya se puede obtener a partir de la relación entre el tiempo y la frecuencia intermedia. Sin embargo, esta distancia calculada puede volver a determinarse con la ayuda del sensor ultrasónico como se indica en la patente. (Numero de patente : US7620518B2)
3. Para medir la velocidad relativa. Para implementar este enfoque de prueba, el vehículo u objetivo debe estar en movimiento durante la prueba. La velocidad relativa se puede determinar a partir de la relación del efecto doppler. Sin embargo, este tipo de pruebas requiere una sala de pruebas más grande.
4. Usar el reflector de esquina triédrica como objetivo para la prueba de calibración. Hay que prestar atención a la polarización de la onda.

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UNIVERSIDAD DE OVIEDO

In cooperation with

INSTITUTE OF ENERGY EFFICIENT MOBILITY (IEEM),
HOCHSCHULE KARLSRUHE (HSKA)

Approaches to Testing Highly Automated Driving Systems in Production and Field

Radar System

Master Thesis

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STUDENT DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citation which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other institution and has not been published.

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LIST OF ABBREVIATIONS

ACC	Adaptive Cruise Control
AEB	Automatic Emergency Braking
ADAS	Advanced Driver Assistance System
FMCW	Frequency Modulated Continuous Wave Radar
OEM	Original Equipment Manufacturer
PTI	Periodic Technical Inspection
RADAR	Radio and Ranging
RCS	Radar Cross Section
MRR	Medium-Range Radar
LRR	Long-Range Radar
SRR	Short Range Radar

LIST OF SYMBOLS

φ	Phase	rad/sec
ω	Omega	rad/sec
τ	Time	sec
f	Frequency	Hz
λ	Wavelength	cm
c	Speed of light	cm/sec
σ	RCS	m^2

ABSTRACT

Autonomous driving becomes a hot topic for decades. Many types of research have been carried out to improve the security, safety, and efficiency of this technology. The reliability of the sensing technology also not left behind from this discussion.

Within the scope of a master thesis, the testing approach for automotive radar is described. The focus will be open on how mounted automotive radar unit at the vehicle can be tested. This paper elaborates about the selected target, testing concept, testing equipment, testing set up as well as the methodology for the automotive radar testing in a closed room. The methodology of this test approach is applying for far-field radar testing whereby $\lambda <<$ range and $\lambda <<$ radius and target were defined to be static. Appropriate equipment was designed to hold the target throughout the testing and the design was finalized after considered all the testing's requirement and the respective analytical test has been carried out. This testing approach can examine the functionality of the radar as well to determine the range and the angle of the target from the mounted radar. The limitation of this study is not able to calculate the relative velocity since the target and vehicle are arranged to be static. Furthermore, testing set up is also briefly described in this paper.

Besides using the trihedral corner reflector, solid spherical metal is used as the target for this approach. The metal sphere has advantages over the reflectors due to the simplification of the radar cross-section under the specific condition and negligible tracking error. Also, magnetic polarization can be neglected due to the symmetry shape and smooth surface of the sphere.

KURZFASSUNG

Autonomes Fahren wird für Jahrzehnte ein hochaktuelles Thema sein. Viele Arten von Forschung wurden durchgeführt, um die Sicherheit und Effizienz dieser Technologie zu verbessern. Auch die Zuverlässigkeit der Sensortechnologie bleibt in dieser Diskussion nicht außen vor

Im Rahmen einer Masterarbeit wird der Testansatz für das Automobilradar beschrieben. Dabei wird der Fokus darauf liegen, wie die am Fahrzeug montierte Kfz-Radaranlage getestet werden kann. In dieser Arbeit werden das ausgewählte Ziel, das Testkonzept, die Testausrüstung, der Testaufbau sowie die Methodik für die Prüfung des Kfz-Radars in einem geschlossenen Raum erläutert. Die Methodik dieses Testansatzes gilt für Fernfeld-Radartests, wobei $\lambda <<$ Reichweite und $\lambda <<$ Radius und Ziel als statisch definiert werden. Eine geeignete Ausrüstung wird entwickelt, um das Zielobjekt während des gesamten Tests zu fixieren, und das Design wird nach Berücksichtigung aller Testanforderungen und der entsprechenden analytischen Tests abgeschlossen. Mit diesem Testansatz kann auch die Funktionalität des Radars untersucht werden, um die Reichweite und den Winkel des Ziels vom montierten Radar aus zu bestimmen. Die Grenzen der Studie liegen darin, dass sie nicht in der Lage ist, die relative Geschwindigkeit zu berechnen, da das Zielobjekt und das Fahrzeug statisch angeordnet sind. Darüber hinaus wird auch der Versuchsaufbau in dieser Ausarbeitung kurz beschrieben.

Neben der Verwendung des tetraedrischen Eckreflektors wird bei diesem Ansatz massives kugelförmiges Metall als Zielobjekt eingesetzt. Die Metallkugel hat gegenüber den Reflektoren Vorteile durch die Festlegung einer spezifischen Bedingung zur Vereinfachung des Radarquerschnitts und eines vernachlässigbaren Nachführungsfehlers. Außerdem kann die magnetische Polarität aufgrund der Symmetrieform und der glatten Oberfläche der Kugel vernachlässigt werden.

Contents

1.0 Introduction

According [1] in ITS Forum 2009, 90% from the 1.2 Million road accident in Europe was caused by human error. [1] The increasing number of killed people during a fatal accident due to driver carelessness and many kinds of research has been carried out over the years to save the living. This awareness has led the automakers to improve sensing technology at the vehicle. Depending on the capability and of the sensors, every sensor has a different application, advantage, and limitation. For example, the performance of the camera will become worse when there is rain, snow, fog, and low lighting. Due to this disadvantage in the camera, radar is used to overcome these limitations which are has been proven over decades that reliable in all wheatear conditions.

Radar calibration by using the reflector is not a new approach in radar technology. Reflectors are the passive equipment that commonly used for years to calibrate radar to weather radar, ship radar and another type of radar and can be found in few geometrical shapes. The most used for radar calibration are the dihedral, trihedral and sphere shape. Every type of reflector has its advantages and drawback suitable for different applications. From this reflector, depending on the target's geometrical shape, the Radar Cross Section (RCS) can be defined and the functionality of the radar can be examined.

Research has been carried out by National Institute for Occupational Safety and Health (NIOSH) to detect the object, small vehicles, and pedestrian works that may be in the blind areas of haulage that used at the mining construction side. [2] The test was carried out the open parking area by using two different radar system which is from different manufacture and has been done by using corner reflector and metallic sphere for the target because these two targets are commonly used in radar testing as well as using test manikin to represent the actual person as suggested by the Society of Automotive Engineer (SAE) [2]

In this study, they were trying to find the best target for radar testing and to test the effectiveness of each radar system in detecting objects and people. Besides that, NIOSH also tried to find the best practice for the radar's installation. According to [2], the detection zone of radar is depending on 3 main factors which are (1) radar type and configuration of the radar antenna, (2) the size, geometrical shape, and composition of the target, (3) mounting height and tilt angle of the radar antenna.

During the test, the reflector was attached to the plastic pole and let the reflector to be hung inside the field of view of the radar. For this test approach, a person is required to hold the plastic pole while this person can remain outside the radar’s beam. In [2] stated that the testing approach by using a corner reflector is easy to construct and available in many sizes. However, the drawback of this approach is the amount of echoing signal is depending on radar's orientation and possibility the echoing signal may be reflected from the person, who's holding the plastic pole. [2]

Another approach was done by using a metallic sphere. For this test approach, the expected value of RCS of the metal sphere must be equivalent to the RCS of a person. According to (Skolnik)[3], adult man has a range of RCS between 0.4 to 1.2 m^{2,} depending on radar frequency. For this test, [2]used 0.8 m^2 which represents a man in standing position. For the test set up, the sphere must also be attached to a holder and required a person to hold it from outside of the radar's beam. A sphere can be a very good target for radar testing since the magnitude of the echoing signal does not depend on orientation. Even though the sphere target is available in the market for radar calibration, but this testing set up is not practical due to the heavyweight of the metal sphere where the sphere weights 26 kg.

Consequently, two different reflective spheres were created as the target. The first sphere was using 36-cm (14-in) in diameter of the playground ball and covered with aluminum foil and secured with foil tape. However, the RCS for this target is too small in comparison to the RCS of a person and the unsmooth sphere's surface. Due to this limitation, another larger sphere target from the weather balloon sprayed painted with conductive paint was used as the alternative. This balloon has a final diameter of 91 cm (36 in) which is this diameter has the closest to the RCS of the person, however, the reflectivity of the conductive paint was undefined. Extra attention needs to be paid to the paint that might be peeled off because of deflation or rough treatment during the test. Both sphere targets were placed at a height of 2.1 meters from the ground to ensure accurate recording to be detected.

Finally, the two different manikins were tested to examine the effect of manikin composition on the radar detection range. The first model was used crash test dummy which composed of a steel and aluminum frame with a vinyl skin (heavy manikin) whereas the second model of manikin was an accident reconstruction, composed of a wireframe surrounded by a foam body (light manikin).

The manikins were let to be in sitting position during the test because (1) the standard manikin testing as released from SAE, (2) it is impossible to put the manikin in a kneeling position and, (3) only the height for sitting manikin is specified in the standard. Therefore, both manikins have a height of 81 cm (32 in) from the head of the manikins to the ground.

The procedure was beginning by finding the detection zone of a person. It was done by letting a person walking within the area of interest and the position where the person starts to be detected from the radar was marked. The person has 190 cm (6 ft, 3 in) tall and weighed 84 kg. The test was continuing by replacing those targets at the marked position.

The results show that the person had the largest detection zone meanwhile detection zone for the reflector is smaller and the for the sphere was even the smallest. There are few difficulties were encountered during the test with reflected is carried. It was impossible for the person to stay outside of the detection zone. Due to sporadic and reflector is on orientation depended on the reflector, the test needs to repeat many times and it took a long time to complete it. Therefore, reflector needs to be moved, tilted and turned several times at each to verify the detection throughout the test.

As expected, the RCS of the playground ball is too small and not comparable to the RCS of a person. Therefore, playground ball is not suitable to use for this test purpose. The detection zone of the balloon was slightly the same as the detection zone for the person for both radar systems. The difficulty of the balloon was identified when the temperature rose as the day progressing, then the conductive paint was started to crack and peel off. Besides that, the balloon target also depending on the height.

The use of the manikins as the target for this approach was to find the manikin’s distance that can be detected by the radar. The result shows that manikins cannot be well detected by the radar at the height of the first radar's mounting. This may happen because the manikins were sitting underneath the radar's beam. Then the height of radar's mounting was lowered, and manikins can be detected. The result shows only heavy manikins gave the best detection meanwhile the light manikin gave very bad detection even the height of radar's mounting was changed. However, (Todd M. Ruff) concluded that manikin can be the good target to represent a person because the manikins were seated during the test is carried out meanwhile the person was in standing position. [2]

(Todd. M. Ruff) [2]added, to determine a reliable radar system's detection zone for a person, only an actual person should be used as the test target. However, this assumption had raised a question if the size of a person will affect the person's RCS. After that, an extra experiment was done by using a different size, height, and weight of the persons as the target to analyze if these variables will influence the result. The result shows that the height of the person is not affecting the maximum range or outer dimension zone. [2]

1.1 Stage in the Development of the Automotive Radar

In the 1980s, the self-driving car with a digital processor onboard was invented by Ernst Dickmanns after Watson Watt had invented radar in 1935. In 1992, Vorad from the USA had introduced first operational busses and trucks with commercial radar for collision avoidance and Adaptive Cruise Control (ACC) that works with 24GHz and successfully reduced 21 % accidents in 1993 compared to the year before. In 1995, ACC was commercialized in Japan and this technology was further improved by Mercedes in 1998/1999 by introducing the first commercial radar for passenger car of S class model in which working with 76-77 GHz. While European car manufacture only producing 77 GHz cars with the ACC system, Toyota was already introduced to their active brake assist for collision mitigation (additional for ACC) based on 77 GHz Long Range Radar (LRR) in 2003. [4]

Since a few years back, a lot of improvement has been done regarding the frequency regulation for automotive radar. The 76-77 GHz band was regulated already in the ‘90s and has no restriction limit time as well as quantity and followed by standardization in Europe (ETSI EN 301 091). Nowadays, this frequency band is allocated for Intelligent Transport Service (ITS) in Europe, North America and Japan. However, the short-range radar (SRR) application with Ultra- Wide Band (UWB) is preferable since it is less expensive and high in resolution in range cm. In 2002 Federal Communication Commission (FCC) regulated UWB short-range radar system for the North American market (NAFTA) with 22-29 GHz. [5]

However, due to the strong objection of the telecom industry and earth observation institutions, a lot of effort has been done to deal and to enable the automotive UWB radar system. Finally, on 17 January 2005, the FCC of the European decided to designate the range 21.65 – 26.65 GHz for UWB short-range radar. This marketing of this system is only allowed between 07/2005 until 06/2013. This regulation is expected with the time frame of eight years is to be enough to develop an inexpensive short-range radar that operating with a new frequency. In other words, the application of the 24GHz UWB radar in Europe is prohibited starting from the year 2022. [5]

Consequently, the European Commission allocated in March 2004 the frequency range between 71-81 GHz for UWB SRR with permitted application from 2005 onwards. Expecting this allocation also will be applied in Japan and North America, the SRR supplier will probably shift their UWB development from 24 GHz to 79GHz. [5]

77 GHz ACC system will be further improved to be operational low speed including full stop capability. Besides that, the 77GHz sensor will be keep implemented not only for (ACC stop & go) but also for predictive and active safety systems. [5]

1.2 Problem Statement

Implementing a testing approach for radar testing and calibration is needed since ADAS becoming popular in the vehicle safety system. Depending on the OEM (Original Equipment Manufacturer), some radar system is required to be calibrated after some other system has been removed from the vehicle, windshield replacement or even after a minor collision occurs at the vehicle.

Due to the complicated working principle between sensors in ADAS, the calibration instrument provided from the OEM is extremely smart and expensive. Therefore, not every vehicle service center and workshop afford to have the respective calibration instrument. Even though there is a standard calibration test that suits every type of vehicle, automakers, type of radar and the position of radar, it was patterned and not available for freely excess due to legality issue.

Since radar sensors work with invisible electromagnetic waves under a specific range of frequency, special testing set up and equipment are required for the testing approach. As already known that radar will reflect to any metal parts and the automotive radar is functioning while the vehicle is moving, the scientific method needs to establish to carry out the static test in the close testing room. The proper definition needs to be defined to obtain perfect calibration.

1.3 Motivation

The defected vehicle that experienced crash even for a minor accident needs to undergo a calibration test to ensure all the systems are working correctly. Exterior mounted sensors are sensitive due to sudden huge vibration and movement that may create during the crash. In certain case, due to insurance contract, vehicle user only has been allowed to send their vehicle to the nearest workshop which is the insurance provider wanted to cut off the transportation cost. However not every workshop able to provide an instrument for radar calibration because it is too expensive to buy, and they are not able to do a new installation of the radar sensor due to no standard calibration method that can be used as a guideline provided.

Open field test takes time and required a mechanic to drive the vehicle on the street while testing is carried out. Open field test has a disadvantage due to unfixed street condition (traffic jam or bad wheatear) and vehicle under test may also have the possibility to involve in accident. Therefore, standardization and guideline for radar testing at the open testing field that suitable for every street condition cannot be defined.

On the other hand, to have a practical and reliable testing approach for the radar system is extremely important to avoid the misreading and misalignment of the mounted radar on the vehicle because this misalignment issue may lead to an accident. An accident may happen when the radar miscalculated the range, speed, and angle of the approaching target.

Time consumption for the calibration also contributes to the effectiveness of the testing. Besides it can shorten waiting time for the customers to get back their vehicle, it may also maximize the number of calibrations works that can be achieved by the workshop and finally can reduce the service cost.

1.4 Objective

Following are the objective of these studies:

a) To introduce a testing approach for automotive radar in a close testing room that meets the requirement of the Automotive Functional Safety, ISO 26262.
b) To implement a method for radar testing and calibration that able to detect the target as well as to measure the range.
c) To implement a testing approach that reliable and practical for every type of radar and position.
d) To implement automotive radar testing that suitable for every country.
e) To implement the appropriate equipment for the testing.
f) To plan the set up for the testing layout and environment.
g) To introduce a testing approach that good in time-saving, affordable and easy to handle.

2.0 Literature Review

This chapter gives a brief overview of the general working principle of the radar. The mathematical theory behind the working principle and the relation to the Radar Cross Section (RCS) is explained, whereby RCS is applied to this testing approach. Besides that, this chapter also describes briefly how to determine the range and angle of the target from the radar, that suitable for this test set up. The focus will be open to the factor affecting RCS and the relation to target choose for this testing methodology. Also, a short introduction regarding application radar in an autonomous vehicle is provided.

2.2 Radar and It's Working Principle

Radar (Radio Detecting and Ranging) was originally adapted from the sonar system (Sound Navigation and Ranging) that was naturally used by animals such as bats for navigating and distance determination. The bats will emit sound waves between 30 to 120 kHz ultrasound range. Then the bats will catch the echo from the obstacle or their prey by using their ears. The working principle of Radar also applied the same theory however by using the radio signal. The radar will emit radio signal from the transmitting antenna and will reflect when it hit the object made of electric conductivity material (e.g. vehicle body) as an echo to the receiving antenna. [6]

2.2.1 Range Measurement

For all radar methods, the range measurement is based on the direct or indirect propagation time for the time between when the radar signal is emitted and when the signal echo is received. Indirect propagation time, the period is equal to double of the distance travel to the reflector divided by the speed of the light as shown in the following formula: [6]

$$\tau = 2r/c \tag{2-1}$$

Where $\tau = time$

$r = range$

$c = speed\ of\ light$

The direct propagation time is using a method known as FMCW (Frequency Modulated Continuous Wave) which is much simpler than indirect propagation time. In FMCW, radar waves are linearly modulated in their frequency for a duration and it compares the frequencies of the transmitted signal (TX chips) and received signal (RX chips) echo. As shown in Figure 1 , the received signal (RX chirp) is the delay version of the transmitted signal (TX chirp) whereby the delay is directly proportional to the range of the target. These transmitting and receiving signals then are mix and will produce resulting frequency signal, called Intermediate Frequency. (IF) [7]

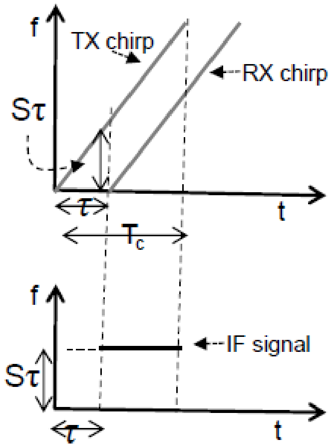


Figure 1: FMCW method [8]

By using the ratio of the time chirps, period start, T_c and the time difference, τ and the ratio of the frequency difference, IF to the bandwidth, B the equation 2.2 can be formed. [7]

$$\tau = \frac{IF\ T_c}{B} \tag{2-2}$$

By substituting τ into *2-1*, the range from the radar to the target can be calculated. [7]

$$d = c\,\frac{IF\ T_c}{2B} \qquad \textit{2-3}$$

Besides that, the IF signal can be express in the sinusoid signal as stated in equation 2-4 and can be transformed into Fast Fourier Transform (FFT). FFT is applied in the IF signal to find the small change in the displacement of the target. Note that, the small motion of the target will not give much change in frequency, but it will give a big change in phase in FFT whereby the phase change, $\Delta\phi$ is used to find the estimation of the angle of the target. The change in phase can be seen from the peak of the range in FFT and can be express as follow. [8]

$$X_{out} = A\,sin(\omega t\ +\ \Delta\phi) \qquad \textit{2-4}$$

Based on the general sinusoidal wave equation, $\omega = 2\pi f$ meanwhile frequency of the IF is $S2d/c$ and $IF\ > \frac{1}{T_C}$. On the other hand, ω in IF sinusoidal signal can be simplified in equation 2-5. [8]

$$\omega = \frac{4\pi\Delta d}{\lambda} \qquad \textit{2-5}$$

where $S = Slope$

$d = distance$

$T_C\ = period\ start$

$\Delta\phi = phase\ change$

$\lambda = wavelength$

2.1.2 Angle of Estimation

The angle of estimation of the single object in front of radar required at least 2 RX antennas and the angle can be determined by calculating the differential distance from the object to each of the antennas as shown in Figure 2. [8]

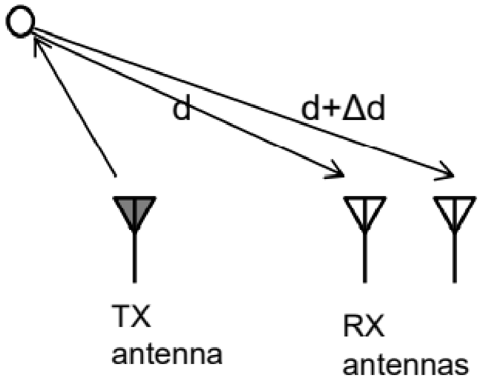


Figure 2: Angle estimation from 2 RX antennas [8]

Referring to figure 3, $\boldsymbol{d}\ \mathbf{sin}(\boldsymbol{\theta})$ is the distance between two antennas. Since the change in ω is also equivalent to the change in phase, Δφ and after substituting $\Delta d = d \sin\theta$ in equation 2-5, $\boldsymbol{\Delta\phi}$ can be express as in equation 2-6. Since the signal wave is travel to the target and back to the receiving antenna, $\boldsymbol{\Delta\phi}$ be simply by the factor of 2. [8]

$$\Delta\phi = \frac{2\pi\ d\ sin(\theta)}{\lambda} \qquad \text{2-6}$$

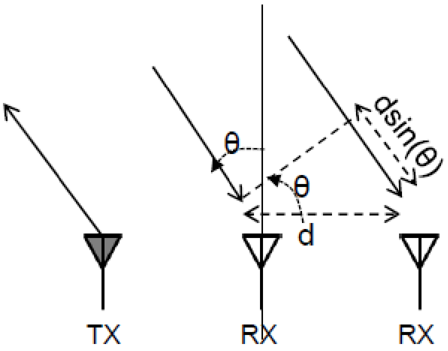


Figure 3: Distance between 2 RX antennas [8]

From this, estimation of angle, $\boldsymbol{\theta}$ of the single object in FMCW can be defined as in the following relation. [8]

$$\theta = sin^{-1}(\frac{\lambda\omega}{2\pi d}) \tag{2-7}$$

2.2 General Radar Cross Section (RCS)

Theoretically, Radar Cross Section (RCS, or σ) can be defined as the ratio of the radiated power density that hit by the target to the power per unit solid angle backscattered to the receiving antenna by the target. In other words, RCS is efficiency in which a target echoes radar energy back to the radar receiver. [9] Mathematically, RCS can present as the following formula: [10]

$$\sigma = 4\pi \frac{P_s}{P_i} \tag{2-8}$$

Where σ = Radar Cross Section
P_s = power per unit solid angle reflected by the target, $(W/sr = W)$
P_i = power density, or intensity, of a plane wave striking the target, (W/m^2)

RCS has a wide-ranging from 10^{-5} for small insects to 10^{6} for large ships. Therefore RCS is often expressed in the logarithmic decibel scale: [10]

$$\sigma_{dBSqm} = 10.log\,(\frac{\sigma}{1.m^2}) \tag{2-9}$$

2.2.1 Factor Effecting RCS

According [3], RCS is the product of 3 factors which are projected cross area, reflectivity, and directivity where reflectivity is usually smaller, and material-dependent meanwhile directivity can be much larger and depends on the shape of the object.[10]

$$RCS = A_P \times R \times D \qquad 2\text{-}10$$

Where $A_p =$ projected cross area

R = reflectivity, re-radiated fraction of intercepted power

D = directivity

Besides shape, the material composition also will affect the RCS of the target. The radar's echo is influenced by induced charge motions in the target and RCS is calculated as a ratio of the efficiency of the perfectly conducting sphere. However, not all types of objects in the air are perfectly conducting or even not conducting at all. Generally, a non-conductive solid sphere will have RCS of approximately zero. [11]

As stated in the definition of general RCS in **2.2 General Radar Cross Section (RCS)**, RCS is the ratio of the radiated power density that hit by the target to the power per unit solid angle backscattered to the receiving antenna by the target. Hence, the spherical target shall be perfectly solid. However according to [11], balloons with metallized fabrics are sometimes used for radar calibration with the similar purpose and would return an efficient echo. However, extra attention needs to be paid to the smoothness of the surface, the reflectivity of the metallized fabric and possibility that fabric or painting that might be peeled off after certain period.

Therefore, RCS is varying depending on these 3 factors. RCS of the vehicle is influenced by all the reflectors on the vehicle such as; vehicle body, radiator/grill, bumper, license plate, mirror, and antennas. Corvette, for example, has a low RCS because of its fiberglass body which has less reflective than a metal body. On the other hand, Mustang convertible has a low RCS in large part due to not having a metal roof. [12]

2.3 RCS of the Object and its Determination

For radar calibration and testing, simple objects can act as the target for the radar. Two types of geometry shapes commonly use which are the sphere and corner reflectors. Figure 4 shows a simple object with the principle dimension of 1m and their RCS. Sphere, however, is often to be chosen because it will return the same power to the same receiver due to its perfect projected cross-sectional area. [9]

If the diameter of the sphere is large enough compared to the operating wavelength, then the RCS of the target is constant and independent from the wavelength and regardless to any linear polarization where the RCS is equal to its projected geometrical area $\sigma = \pi r^2$ under the certain condition that will be described further in the following subchapter. [9]

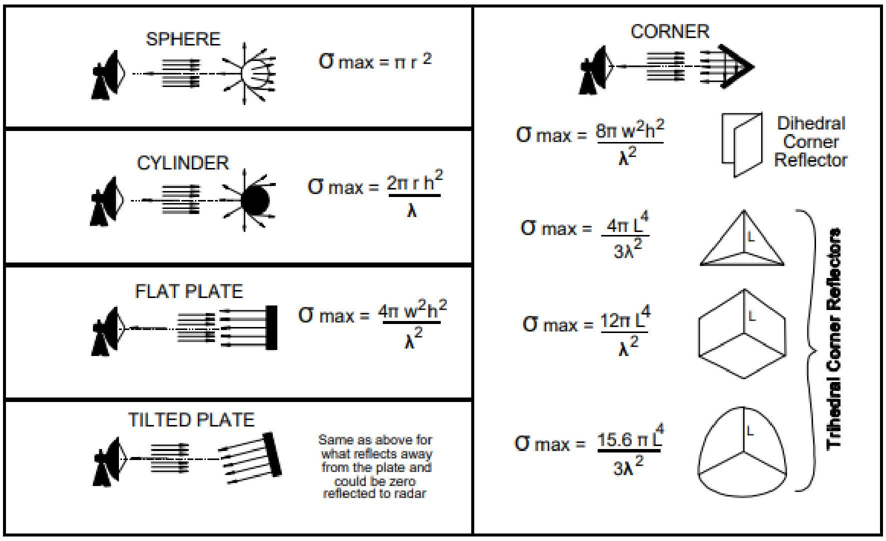


Figure 4: RCS for a different type of geometry [9]

In the actual application of the radar, the target will act as the second antenna which means it will re-radiate back the intercepted power back to the receiving antennas. This radar output, however, has its own near- and far-field properties and radiations pattern due to its size and shape. Therefore, to shift the phase centroid away from the geometric center of the large and complex target, the phase differences between wavefronts that coming from different parts of the target need to be added or subtracted in complicated ways. This phenomenon is known as glint error or tracking error and this error can be neglected for the spherical target due to the phase centroid of the sphere is always coinciding with the geometric center. [11]

Another advantage of the spherical target is its relative magnitude. Figure 5 shows that, RCS patterns as object are rotated about their vertical axis (the arrows demonstrate the direction of the radar reflection). From this mapping, its clearly seen that, sphere has the same reflection in all directions meanwhile the flat plate has almost no RCS except when positioned directly toward the radar. In other hand, the RCS for the corner reflector is high as the fat plate but over a wider angle, i.e. ±60°. [9]

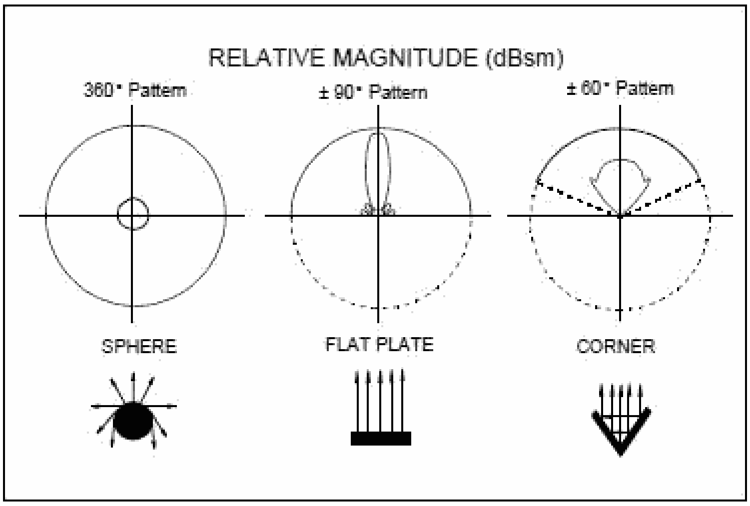


Figure 5 : Relative magnitude of targets [9]

Consequently, the polarization of the spherical target is same where the polarization of a simple radio wave is defined by the orientation of the plane of the electric vector, which is rotated 90° relative to the plane of the magnetic vector.[11]

2.3.1 Spherical Target and RCS

The far-field or optical region for the radar calibration and testing means where $\lambda <<$ range and $\lambda <<$ radius. In this case, the RCS of the spherical target is constant and not dependent on the operating wavelength as already mentioned in the previous subchapter. Referring to Figure 6, to be in the far-field or optical region, the circumference of the circle needs to be at least 10 times the operating wavelength or in the other hand, the diameter of the circle shall be about 3.2 times the radar wavelength. [11]

However, if the circumference of the sphere falls below than 10λ, then the RCS of the spherical target will be lying on the Mie resonance region where the RCS will fluctuate increasingly as the circumference approaches the wavelength. Finally, the RCS of the target is strongly and linearly dependent on the wavelength when it enters the Rayleigh region or other words $2\pi r/\lambda$

falls below 1.0. This is the part of the diagram usually appropriate to weather radar detection of raindrops and hail.[11]

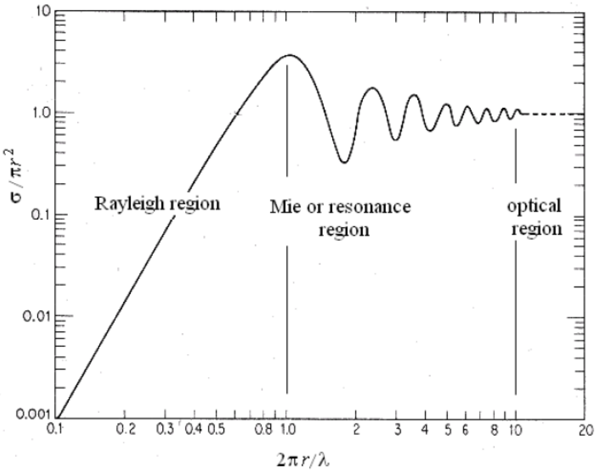


Figure 6: The Radar Cross Section diagram [11]

Experimentally, the radar echo from the actual target is compared to the radar echo from a sphere which has a frontal or projected area of one square meter or 44. inch diameter respectively.[9] With the help from the spherical shape target for in the field or laboratory measurement, the orientation or positioning of the sphere will not affect radar reflection intensity compared to the flat plate would. As stated in [9] the radar testing should be carried out with 44. inch diameter of the sphere target as shown in Figure 7. However, to reduce drag during the test, the diameter of the sphere can be towed into 6-inch, 14-inch or 22-inch and the reference size is 0.018, 0.099 or 0.245 m respectively instead of 1 m. [9]

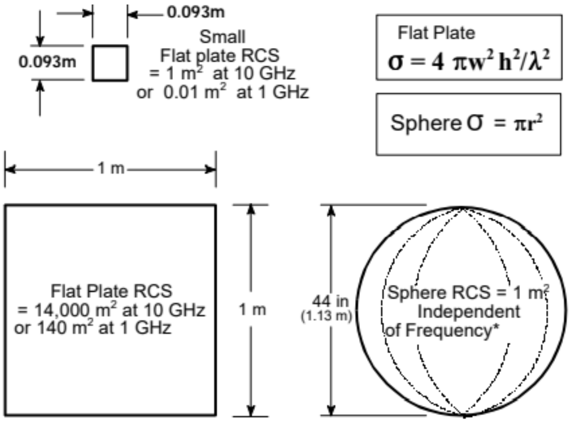


Figure 7: RCS versus physical geometry [9]

2.4 Automotive Radar

As already known, radars are used in the automotive field is to improve safety for the road user by alarming the dangers. The radar emits a frequency-modulated radar range between 76 to 77 GHz from the transmitter and the waves will hit the object in front or behind the vehicle depending on the position of the radar to be mounted. By calculating the doppler effect and delay, range and relative velocity can be determined.

There are 3 main types of automotive radar that widely used by the automaker, which are Short-Range Radar (SRR), Mid-Range Radar (MRR) and Long-Range Radar (LRR). For every type of radar, there is a different application based on the limited field of view of the radar. Table 1 shows a summary of the type of radar and its application meanwhile the functionality for every will be further described in the following subchapter.

Table 1: Type of current automotive radar

	SRR	MRR	LRR
Range of view	• Min – 0.2 m [13] • Max- 90 m	• Front - 160 m [14] Rear – 80 m	• 250 m [15]
Operated Frequency	• 24 GHz [13]	• 76 to 77 GHz [14]	• 76 to 77 GHz [15]
Applications	• Parking assistance with range 0.2 m range of view [13] • Lane change alert with 90 m range of view) [13]	• ACC with a maximum speed of 150 km/h, • AEB • MRR rear for lane change assist • MRR rear for rear traffic assist	• ACC with a maximum speed of 200 km/h • Traffic jam assist

2.3 Radar Application and ADAS

Advanced Driver Assistance System or also known as ADAS has introduced a few smart systems. ADAS (Advanced Driver Assistance Systems) are designed to ensure driving safety and comfort. ADAS is becoming increasingly common in latest-generation vehicles, even in the utility segment. ADAS offers smart functionality in the vehicle which are; Adaptive cruise control, emergency braking, lane keep assist, pedestrian and traffic sign recognition, steering assist driver, collision avoiding, etc.

2.3.1 Adaptive Cruise Control (ACC)

A cruise control unit has the functionality to maintain the desired speed that has been set from the driver by allowing the vehicle to accelerate the vehicle or decelerated when an obstacle is detected by closing the throttle. ACC is using Long-range radar or Mid-range radar as the main sensor and can measure a range up to 250 m (depending on the radar; 160 m for MRR or 250 m for LRR) in front of it. By collecting the data from the reflected radio waves, information such as amplitude ratio, Doppler shift and timing can be obtained. This information will be further analyzed in the Electronic Control Unit (ECU) to calculate distance, relative speed and angle position relative to the vehicle in front. However, ACC has a limitation which is it has no permit to operate in the city and only can be activated at the speed of more than 30 km/h. [15]

2.3.2 Automatic Emergency Braking (AEB)

Automatic Emergency Braking System, on the other hand, is regulated with the ESP (Electronic Stability Program) sensor inside the vehicle and with the information from the radar. The function of the AEB is to avoid rear-end collision and to reduce the severity of the crash. This system will be activated once the vehicle is started regardless of the days and nights. [15]

The system then begins to apply partial braking to reduce the speed and give enough time to the driver to react. Once the driver starts to brake, the system will provide braking support.

To do this, the system continuously calculating the required vehicle deceleration to avoid the collision. Finally, when the system detects that the driver has failed to apply sufficient braking force, it increases the braking pressure until the driver can bring the vehicle standstill before the collision occurs. [15]

2.3.3 Blind Spot Detection

Two MRR radar sensors are concealed in the rear bumper, one on the left side and one on the right side of the vehicle. These two radars work together to detect other vehicles in the driver's blind spot as well as traffic that approaching from behind. [15]

Blindspot detection can be used for lane change assist and rear traffic cross-functionality. By the lane change assist, blind-spot detection helps the driver to prevent critical situations that occur when changing lane. The system will warn the driver by displaying an illuminated symbol around the side mirror when another vehicle in the driver's blind spot or when there is another vehicle approaching quickly from behind. [15]

Rear cross-traffic alert, on the other hand, helps the driver when the driver reversing out of transverse parking space. If there are other vehicles are detected crossing behind within 50 meters, the system will alert the driver by audible and/or visual warning to prevent the risk of an accident. [15]

2.3.4 Traffic Jam Assist

With the help from a video camera, the longitudinal and lateral movements of the vehicle of the partially automated driver comfort function can be control. If the driver assistance system detects crowded or slow-moving traffic at speed below 60 km/h, the push of a button can be activated by the driver. The vehicle then will automatically follow the vehicle in front, accelerating, braking, take over starting and steering in its lane. The vehicle adapts accordingly to the in which the vehicle in front is driving and it necessary to change the lanes or if uneven obstacles are detected in the lane, the system will return control to the driver. [15]

Besides this traffic jam assist can control the vehicle permit a certain range to the vehicle in front of it, this radar also able to detect the surrounding vehicle, enabling the system to calculate a driving corridor and to detect the absence of lane markings. However, the driver muss monitors the system be ready to take control of the vehicle at any time. [15]

3.0 State of Art

It is compulsory in Germany, where every road vehicle needs to go through a periodical technical inspection (PTI) either by TÜV (*Teschnischer Überwachungsverein,),* GTÜ (Gesellschaft für Technische Überwachung), KÜS *(Kraftfahrzeug-Überwachungsorganisation freiberuflicher Kfz-Sachverständiger e.V), or* DEKRA *(Deutsche Kraftfahrzeug-Überwachungs-Verein)* for every to 2 years. This inspection aims to ensure that every system at the vehicle working correctly. By optimizing the system function, the road accident can be minimized. Besides these organizations, there are other types of inspection of the car, which is the inspection of the new car to achieve certain security standard and necessary inspection that normally need to be done to ensure the system of the car can be well functioning after a minor accident happened.

Most of the vehicle inspection at the PTI is carried out in static mode with the specific test except for the test drive. In contrast to the radar testing that is carried out from Euro NCAP and ACEA, where the testing is done at the open places. Depending on the approaches of the test from different organization, some of the test required big testing area. The following subchapter describes test for radar calibration that currently used by the related organization and company in closed testing room and at the open place.

3.1 Automotive Radar Testing by Euro NCAP and ACEA

In Europe, two responsible organizations are conducting the test for the new car on the market according to the respective standard. The organizations are Euro NCAP (European New Car Assessment Program) and ACEA (European Automobile Manufacturer Association). Focusing on testing for radar systems and functioning, these organizations come out with specific testing methodologies that suit every type of vehicle. The testing is carried out on the open parking area by using a 3-dimensional dummy target depending on which type of target is going to be tested. [16]

Before the test begins, the radar reflectivity of the dummy target will be determined by using a spectrometer whereby it was the average across the three measurement for wavelengths in the range of 850 to 910 nm. These radar reflectivity for every dummy target shall be like the actual target of the same size on the road and must be detectable by following automotive sensors technologies: RADAR, video, LiDAR, PMD (Photonix Mixer Device) and IR (infrared). In the following subchapter, the radar testing for every type of target on the road will be briefly explained.

3.1.1 Radar Testing with GVT

According to several Global Harmonization Workshops organized by Euro NCAP and attending by National Highway Traffic Safety Administration (NHTSA), Insurance Institute for Highway Safety (IIHS) as well as pre-studies from Dynamic Research, Euro NCAP is come out with Global Vehicle Target (GVT) as shown in Figure 8. This GVT is used to test the functionality of the radar towards a vehicle where this GVT has equivalent RCS of the actual vehicle on the road. [16]

Figure 8: GVT from Euro NCAP [16]

3.1.2 Radar Testing with Pedestrian

The Pedestrian Target (PT) must be able to represent as a human which consists of articulated legs, a pair of static arms and torso. Besides that, it shall be clothing with a long-sleeved, t-shirt and trousers in different colors, whereby t-shirt in black and jeans in blue. The clothing must be made from water resistance and tear-proofed material while the skin surface parts must cover with a non-reflective flesh-color texture. During the test, these PTs are let moving on the conveyor to the created walking mechanism. [17]

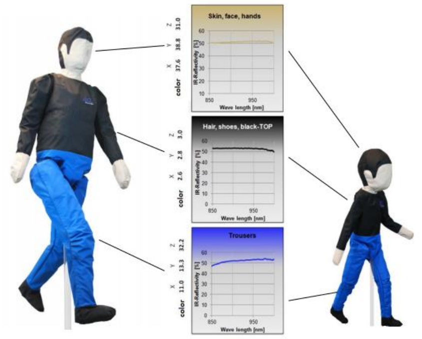


Figure 9: PT for adult and children from ACEA [17]

3.1.3 Radar Testing with Cyclist

The Bicyclist Target (BT) must be able to represent as a natural human in cycling position which means the posture of the BT should facing forward, both hands on the steering wheel, with right foot down and left foot up. Similar to the adult pedestrian target specified in (3.1.2 Radar Testing with Pedestrian), BT shall be clothing with long-sleeved, t-shirt and trousers in a different color. The radar reflectivity of the bicyclist and Bicycle Target (BT) should be comparable to a human being cycling of the same size. This BT is also will let it be moved on the conveyer to the created moving mechanism of a person cycling a bike. [18]

Figure 10: Standard posture of BT[18]

The RCS for every target is varied dependent on the angle of observation. Based on the theory, there is no difference in RCS with the distance, however, according to these organizations, due to the field of view of the radar sensor, the RCS of the dummy target is slightly different depending on the distance. For example, for the short distance, the radar not able to scan over the complete height of the target. Besides that, RCS also influenced by the geometry and surface of the target. [16][17][18]

These reports added, measuring RCS at a fixed range may produce misleading results due to cancellation or amplification of the multi-path effect from the sensor. Therefore, it is necessary to measure RCS by moving the sensor towards the target, where throughout the process the sensors will be moving into and out of the cancellation and amplification regions. [16]

3.2 Calibration by BOSCH

As the ADAS becoming popular in the vehicle safety system, the automaker needs to be aware of what to keep the system effectively and how often the system needs to be calibrated. Depending on the OEM (Original Equipment Manufacturer), some radar system is required to be calibrated after a part has been removed from the vehicle, for example, windshield replacement or even after minor collision occur at the vehicle.[19]

Figure 11: ADAS sensor calibration at the Bosch Workshop [19]

As Bosch estimated that more than half of all cars first registered in 2017 came with at least one driver assistance system, Bosch introduced the DAS 1000 calibration set with the ADAS workshop. This workshop is powered by high technology tooling for accurate adjustment of radar sensor as well as cameras of driver assistance systems whereby this workshop was supplied with data and training methods for the sensor adjustment on the vehicle models from Volkswagen Group (Volkswagen, Audi, Skoda and Seat). Figure 11 shows that the vehicle is placed on the test bay to undergo a calibration process with the DAS 1000 calibration. [19]

3.3 Calibration by TEXA

Besides Bosch, TEXA also offers a variety of vehicle diagnosis services in sensor fusion for ADAS. Focusing on radar calibration, TEXA has almost similar calibration as Bosch has for ADAS calibration. As shown in Figure 12, laser technology is applied to calibrated front radar on the vehicle. By centralizing the reflected plate and central laser, calibration for the front radar can be done.

Figure 12: Front radar calibration by using laser technology [20]

This laser technology for radar calibration also used by HELLA , where HELLA has a calibration kit named CSC Tool System (CSC = Camera and Sensor Calibration) from Hella Gutmann Solution. This tool allows workshops to the professionally calibrated camera and radar on vehicles from multi-vehicle brands with mega macs diagnostic units. [21]

Figure 13: Rear radar calibration by using corner reflector [20]

As shown in Figure 13, an operator is holding the trihedral target and he is doing the radar calibration for rear MRR. This test set up composed of a metal reflector cone, a laser, and a goniometer jig to help the operator position the reflector correctly. A scale mat is overlay at the rear end of the vehicle body and centralized apparatus is used and was put directly under the center of the rear end vehicle body to have the central alignment. The metal reflector implemented by TEXA is suitable for the front, side and rear radars. The calibration for rear radar needs to be done to test the functionality of the blind spot detection of the vehicle. The target is being leveled to be positioned inside the field of view of the mounted radar.

3.4 Patent for Radar Calibration

3.4.1 Distance Measuring Device

A distance measuring device and method for testing the operation of a distance measuring system was patterned in from Robert Bosch USA in 2005 under patent number US7620518B2. [22] This patent introduced a distance measuring device for measuring the distance of a vehicle to an obstacle and method for testing the operation of a distance measurement system. There are two measurement systems in this invention, where each operating has different physical principles according to the measuring method, for example; ultrasonic distance measurement is using acoustic distance measurement whereas radar distance measurement or infrared light distance measurement (LIDAR) is using electromagnetic distance measurement. The reliability of the second measuring system can be proved when second measuring systems detect an obstacle which has already been detected previously by the measuring system.

A distance measuring device was built up with 4 units of the ultrasonic sensor (numbered with 3) on a front end of the vehicle, which is connected via a data bus to an analyzed device in the vehicle. These ultrasonic sensors are controlled by the analyzer device and emit ultrasound waves into the area in front of the vehicle. Besides that, the same analyzer also connected to the radar sensor (numbered with 7), which emits a radar signal in a signal cone (numbered with 14) in a beam angle of approximately 7° to 15° as shown in Figure 14. This signal cone can detect an obstacle up to a distance of approximately 80 m. The analyzer is then processing the received data from the ultrasonic sensor and radar sensor, in which these data represent the distance of the obstacle in the vehicle's surroundings.

It is a profitable invention by having the first measuring system having long-range meanwhile the second measuring system that having a short-range with a maximum possible angular coverage. The overlapping coverage area from both systems may occur in close range. This method is practically tested if the operation of one another works. In other words, the short-range system may be tested if the long-range system detects an obstacle in the closer surrounding of the vehicle within the range of the short-range system. If there is an obstacle that exists and detected by the long-range system, the short-range system should also be able to detect this obstacle in the short-range.

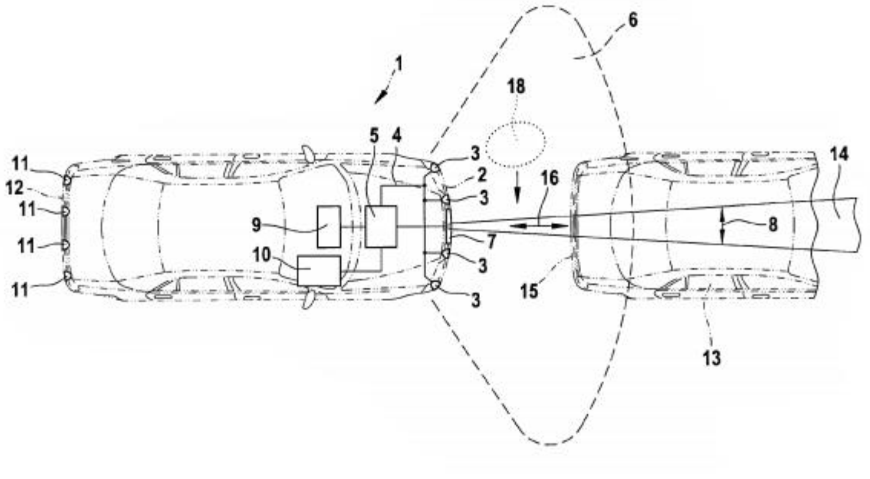


Figure 14: Distance measurement [22]

3.4.2 Calibration Apparatus

A patent of Automotive Radar Alignment was published by Raphael Hellinger and Oliver F. Schwindt in from Robert Bosch in Jul. 27, 2017 under patent number US 2017/0212215 A1. [23] This patent had introduced a method and apparatus to determine the misalignment of a radar sensor unit mounted to a vehicle including targets on an alignment apparatus and it is suitable for a radar sensor unit that mounted behind the vehicle's bumper.

In this calibration set up, a vehicle is placed at a predetermined position on a test station. The exact position and distance of the targets from each other and the radar sensor of the vehicle at the test station are known and pre-stored, whereby at least one target should be having greater distance from the vehicle compared to other targets. Then, the alignment of the radar sensor is carried out with at least three corner reflectors even if the height of the radar's mounting and its lateral position is unknown as shown in Figure 15.

A calibration program will automatically calibrate azimuth and elevation to adjust for misalignment whereby the radar sensor than will determine the distance of the targets and compares with the given or actual position and distance of the targets to determine the misalignment of the radar sensor. This calibration method is normally used in the production line where there is a various variant of the vehicle and the height of mounted radar is highly dependent on the type of the suspension of the vehicle.

The inventors stated that the better signal to noise ratio results (SNR) from higher radar cross-section (RCS) can be obtained and it is independent of radar's mounting position. The interference between reflected radar waves from the multiple reflectors can be minimized during calibration by providing multiple reflectors at a different distance from the mounted radar sensor at the test station.

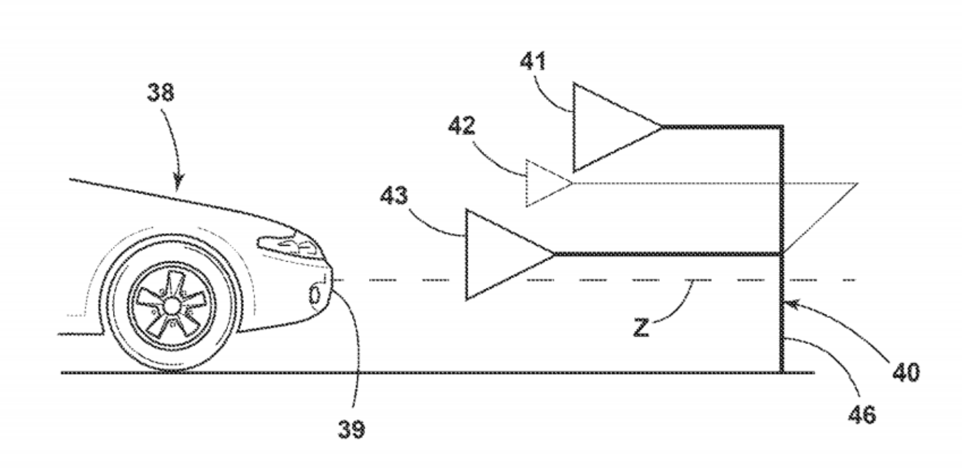


Figure 15: Apparatus for determining Radar misalignment [23]

3.4.3 Method for Correcting Radar Misalignment

A method for correcting radar misalignment was published by Farooq A. Ibrahim and Gerald L. Sielagoski, from Visteon Global Technologies, Inc. on November 17, 2009, under patter number US6,714,156 B1. [24] This patent introduced a method to identify if the radar required alignment and adjusting the alignment of the radar fixed to a mounting assembly. This method is suitable to be used in the service workshop. This method composes of the steps of determining a misalignment threshold, determining the misalignment angle of the radar, and creating an alignment notice if the misalignment angle exceeds the threshold.

The threshold misalignment angle for radar can be determined by using the mathematical relation as describe is equation 3-1, whereas the actual misalignment angle (M_A) is determined by conventional alignment determination software. Then, the (M_A) will be compared with the value of the threshold misalignment angle (M_{th}). If the value of (M_A) is greater than (M_{th}), the radar needs to be adjusted, meanwhile when (M_A) is smaller than (M_{th}), the radar did not require any adjustment. [24]

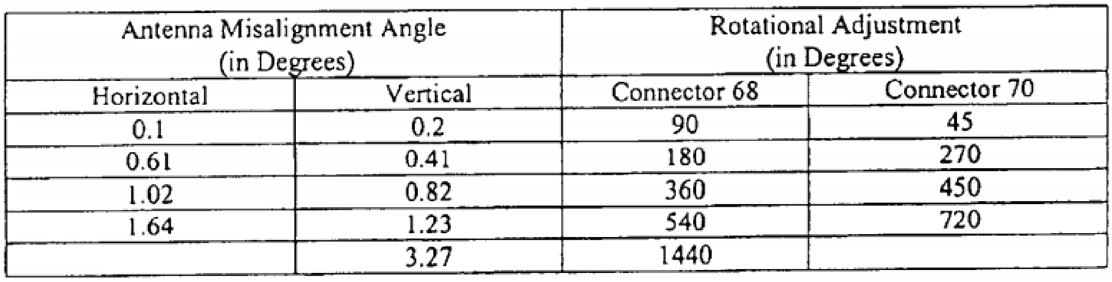
$$M_{th} = F - \left[\frac{2}{ROC} + \frac{R}{2ROC}\right] \tag{3-1}$$

Where $F = field\ of\ view\ in\ radians$

$R = range\ of\ view\ the\ radar\ is\ expected\ to\ be\ observed\ along\ ROC$

$ROC = predetermined\ radius\ of\ curvature$

In some vehicle systems, the misalignment is already stored in the controller and the system will warn the driver if the radar exceeding the allowable misalignment angle. As a car arrived at the workshop for realignment, the technician can extract the stored misalignment angle from the system. The technician then will refer to the mapping table for the radar and mount to determine the appropriate adjustment whereby the mapping table composed a plurality of incremental misalignment values correlated to and appropriate adjustment of the mounting assembly as shown in Figure 16. [24] Therefore, this invention was claimed to provide a low-cost misalignment adjustment method for a vehicle-mounted radar system.



Antenna Misalignment Angle (in Degrees)		Rotational Adjustment (in Degrees)	
Horizontal	Vertical	Connector 68	Connector 70
0.1	0.2	90	45
0.61	0.41	180	270
1.02	0.82	360	450
1.64	1.23	540	720
	3.27	1440	

Figure 16: Mapping table for the angle adjustment [24]

4.0 The approach of Radar Testing

This chapter focuses particularly on the development process from the planning stage until the design finalization of the entire equipment set up. In the planning stage, the requirement of the test approach has been listed in the requirement list accordingly. Then the studies were continuing by drafting possible solutions that match with the requirement list where all the advantages and disadvantages for every design are identified. The solutions were further analyzed by using the ranking table and cross benefit analysis, where the designs were analytically weighted. After the solution from both analyses has been finalized, the chosen design solution was visualized by using the 3D model.

4.1 Target for the Testing Approach

Based on the study as describe in previous chapter, target for this test approach has been chosen to be sphere according to the simplification as listed below:

1. RCS of sphere is independent from the radar frequency under certain condition.
2. Negligible tracking error due to centroid due to the phase centroid of the sphere is always coinciding with the geometric center.
3. Constant relative magnitude of RCS for the rotation at vertical axis.
4. Simplification in polarization due to constant relative magnitude.

4.1.1. Determine the size of the Target

Theoretically, the relationship between frequency and the wavelength can be present as the following formula: [25]

$$f = \frac{c}{\lambda} \quad 4\text{-}1$$

Where f = frequency

C = speed of the light ($3 \times 10^{10}\ cm/sec$)

λ = wavelength

for f = 24 GHz ; $\lambda = \frac{3\times10^{10}\ cm/sec}{24\ GHz} = 1.25\ cm$

for f = 76 GHz ; $\lambda = \frac{3\times10^{10}\ cm/sec}{76\ GHz} = 0.394cm$

for f = 77 GHz ; $\lambda = \frac{3\times10^{10}\ cm/sec}{77\ GHz} = 0.389\ cm$

Considering that 24 GHz will be not allowed anymore in Europe starting 2022, it is more practical to take the frequency range between 76 to 77 GHz for this study. As stated in the previous chapter, the diameter of the circle needs to be at least 3.2 times the operating wavelength, therefore wavelength of the 76 GHz was taken for further calculation since it has the longest wavelength.

$$0.394\ cm \times 3.2 = 1.26\ cm \qquad \textit{4-2}$$

Therefore, the size of the metal sphere should be at least having a diameter of $1.26\ cm$. Theoretically, the diameter of the should be 44 inches or respectively 113 cm. However, for the test purpose, the diameter of the target can be reduced to the 22-inch, 14 -inch or 6-inch. [9] Considering the weight of the solid metal sphere might be heavy and difficult for fabrication and handling, the smallest diameter was chosen which 6-inch or respectively to the 15 cm.

As stated twice in the previous chapter, that definition of the RCS is the ratio of the radiated power density that hit by the target to the power ***per unit solid angle*** backscattered to the receiving antenna by the target and due to the drawback using hollow sphere as has been described in **Introduction** and **2.2.1 Factor Effecting RCS**, the target for this test approach is decided to use solid metal sphere.

4.1.2 Determine the Required Range of the Target

To make the target can be detected, the target needs to be placed in the field of view of the operated radar. Ensuring target to be in the radar's field of view is critically important to avoid the misleading analytical result and to get perfect RCS. If it was placed too close to the radar, the radar will not able to scan the whole geometry of the target. Therefore, it is importance here to define the required range for the target to be placed before the testing begins.

To find the solution for this requirement, the azimuth angle of the operated radar is used. The width of the opening angle *(X)* is freely defined here to have at least ± 15 cm tolerance of free space excluding target. By this means, referring to the size of the target of 15cm, the width of the opening angle is 30 cm and can be simplified with the following relation.

$$X = diameter\ target + 15\ cm \qquad \textit{4-3}$$

The theory of Pythagoras theorem and the theory of trigonometry are applied here. Taking the azimuth angle of the radar as an **α** and dividing the equilateral triangle symmetrically as shown in Figure 17 whereby the length of ***a*** is the half of the ***X***. The required range of the target that should be placed is denoted here with the ***b*** can be known by using the following the formula:

$$b = \frac{\mathrm{a}}{\tan(\alpha/2)} \qquad \textit{4-4}$$

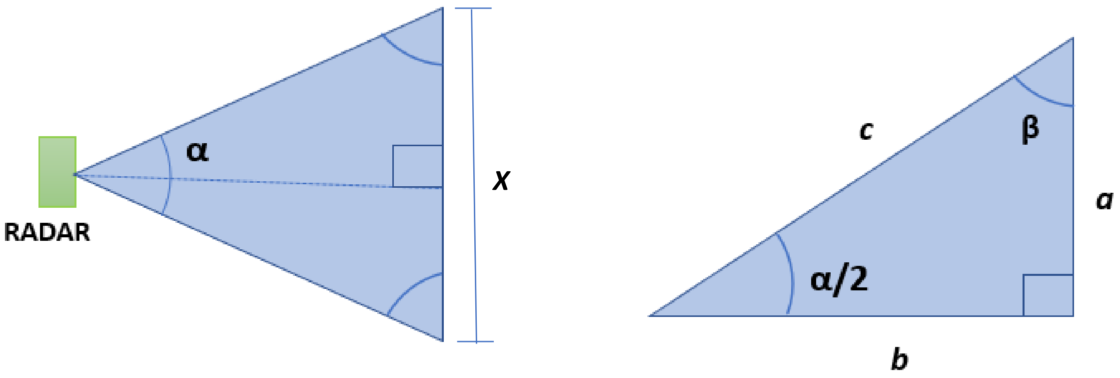


Figure 17: Field of view of the Radar

4.2 Requirement List

Once the objective and general conditions of the studies have been defined, the content specifications can be further specified. This can be described by using the requirement list which contains the basic requirement for the test. In the progress of the works, consistent attention needs to be paid on in ensuring that the test approach will meet the listed requirement at every stage. [26] For of all, the requirement list will be used to select the type of reflector and its size. After that, this list will state the required fabrication process starting from material selection until the mounting process. Table 2 below shows the requirement list for the approach of the automotive radar testing.

According to [26], at the beginning of the design process, the requirement must be clarified in order to get an idea of the requirement for the assembly and the existing conditions. In this study, the testing device needs to be designed that matches the objective of the testing approach.

Table 2: Requirement List

University of Applied Science Karlsruhe Faculty of Mechanical Engineering & Mechatronic Prof Peter Neugebauer	**Requirements Lists for Automotive Radar Testing**	Master - Thesis Aida Mihat WS 19/20

Organisisation Details		Process Details		**Requirements**	Value Details			
Req no:	Name	Art	Phase		Minimal fulfill	Shall fullfill	Ideal Fullfill	Units
				Physical-Technical Functionality				
F01		Y/N	P	Type of the target : Corner reflector				
F02		R	P	Reflective radio wave material for the target				
F03		R	P	Absorable radio wave material for the target holder	Insolated aluminum	Fiber	plastic	
F04		R	C	Height of the target holder				
F05		R	C	Widht of target holder	5	15	35	cm
F06		R	P	Diameter target	1.26	15	113	cm
F07		R	P	Composition target : Solid				
F08		R	P	Goemetry target : Sphere	Dihedral	Cylinder	Sphere	
F09		Y/N	P	Material target : Metal				
F10		R	P	Reflectivity target	60	80	100	%
F11		W	D	Minimal number of parts	2	>5	≤ 5	units
F12		Y/N	P	Target to be place in field of view				
F13		R	D	Target need to be mounted	Hanging	Screwing	Welding	
				Technology				
T01		Y/N	D	Minimal place required				
T02		Y/N	D	Static structure				
T03		W	D	Movable structure				
T04		W	D	Light in weight	≤ 30	≤ 20	≤ 10	kg
T05		Y/N	D	Easy fabrication				
T06		Y/N	D	Easy mounting				
T07		R	E	Total fabrication time	21	14	7	Days
				Efficiency				
W01		W	D	High durability				
W02		R	E	Production cost	≥ 500	‹ 500	‹ 300	Euro
W03		W	E	Uncomplicated maintanance				
W04		W	E	Fast Delivery				
				Human-Product Relationships				
M02		W	D	Ergonomic				
M03		Y/N	D	Easy for handling				
M04		W	D	Attractive design				
M05		Y/N	C	Realibillity				
M06		Y/N	D	Safe handling				

Requirement form : Y/N - must ; R- requirement ; W- wish ; P-Principle; C- Concept ; D - Design ; E - Editing

Replacement from : 13.01.2020 Version : 1 Name: Aida Mihat		Release : 13.01.2020 Version : 1 Sheet : 1 of 1

4.3 Design Approach

Referring to the listed requirement list, here there is 3 suggestion for the mounting position and testing equipment as shown in Figure 19, Figure 20, and Figure 20. The challenge in this design testing equipment is to create practical and moveable equipment, which can move in the y-axis and x-axis. This is because the target needs to be adjusted according to the height of the mounted radar at the vehicle and practical to test every side on the mounted radar. Besides that, the reflector shall be placed inside the field of vision of the radar during testing either it be mounted or hang on the holder. Noted that, the solid metal sphere is heavy, the mounting method need to clearly be defined to avoid the metal sphere is not fall and safe to use during testing is carried out. Other than that, the metal sphere needs to be mounted symmetrically to gain the balance from the structure of the equipment. Table 3 shows the summary of the comparison between the 3 solutions and it will be briefly described in the following subchapter.

Table 3: Summary comparison between the 3-alternative solution

	Solution 1	Solution 2	Solution 3
Stability	• Most stable	• Less stable	• Stable
Complexity	• Most complex for fabrication	• Simple	• Simple
Practicality	• Not able to move in a narrow area, not suitable for rear radar testing	• Possible for rear and side radar testing	• Possible for rear and side radar testing
Handleability	• Stand-alone equipment	• Required a person to hold the stand	• Stand-alone equipment

Mounting method	• Screwing around the ring	• Welding	• Welding

4.3.1 Alternative Solution 1

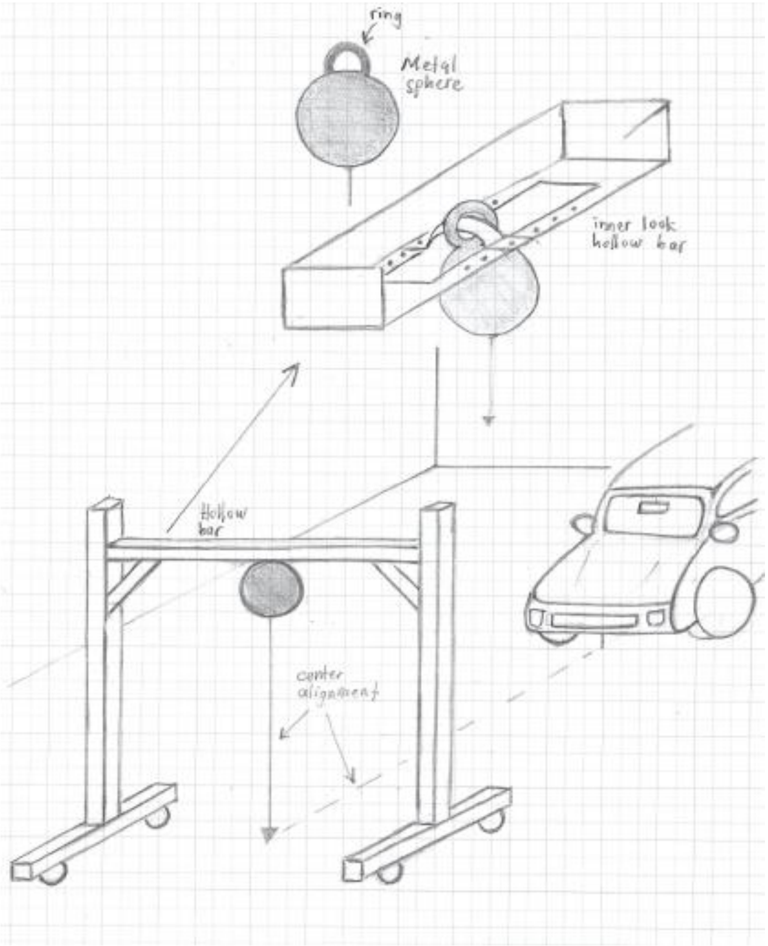


Figure 18: Solution 1

This structure contains the 3 main parts, which is a horizontal hollow and square bar, a pair of legs and a target. As can see in the hand sketch, the target was designed to have a ring at the top of it. The function of the ring is to provide a hole for the hook to hang the target. The hook will be screw inside the horizontal square bar, whereby the position is adjustable in the x-axis according to the center position of the radar during testing is carried out.

After that, the horizontal bar will be attached to both the structure's leg whereby its height also adjustable in the y-axis. Two wheels for each leg was planned to make the structure easy to move.

Advantages:

- Moveable for x-axis and y-axis
- Good in stability

Disadvantage

- Not practical to apply for the rear radar testing or in the narrow testing area
- Required many parts that need to assemble
- Difficult in fabrication due to a large number of parts
- Difficult for target mounting
- Complicated design

4.3.2 Alternative Solution 2

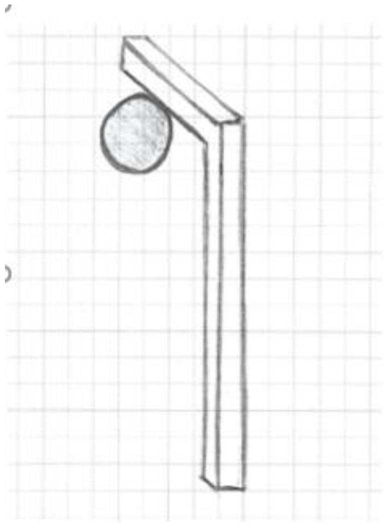


Figure 19: Solution 2

This structure contains 2 parts, which are arm and leg. The target will be weld directly to the lower part of the arm meanwhile the arm and leg will be mounted using a fastener. The leg is designed to be adjustable in height. Therefore, the target can be levered into the field of area of the operating radar. Since no base for this structure, an operator is required to hold the structure throughout the testing is carried out.

Advantage:

- Simple design
- Simple fabrication and mounting
- Required a very minimal number of parts

Disadvantages:

- Lead to misleading results due to not fixing the leg and RCS from the operator
- Less stability because of no base
- Not ergonomic
- Difficult to move
-

4.3.3 Alternative Solution 3

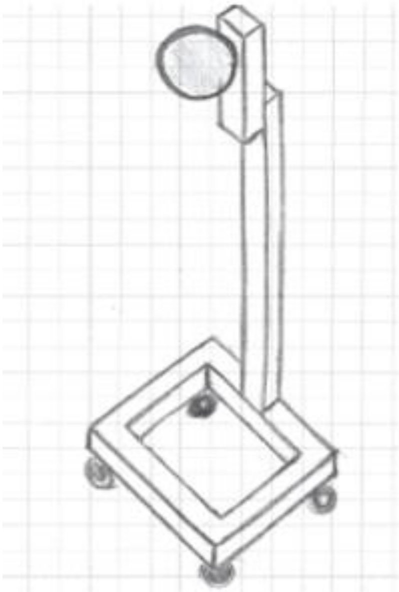


Figure 20: Solution 3

This structure contains 4 main parts, which are adjustable leveler, stand, base, and adapter. Special with the shape of the hollow semi-cylinder was designed to act as an adapter between the curved surface of the target to the flat surface of the leveler. The square base has a functionality to make this structure more stable than the structure in solution alternative 2.

Due to the better stability of this structure, it’s not required an operator to hold it during the test. Wheel with lock is added to make this structure easy to move and locked when it is required. Therefore, this structure able to stand alone and static throughout the testing.

Advantages:

- Adjustable in y-axis according to the height of the operated radar
- Easy fabrication
- Practical to test for rear radar
- Required minimal number of parts
- Good in stability
- Able to move and stay static when needed.

Disadvantages:

- Difficult attachment and mounting for the target and the adapter.
- Difficult to mounting target symmetrically

4.4 Ranking and Cost-Benefits Analysis

In order for the rank to be evaluated, the criteria must be weighted because it was not equally relevant. For this purpose, an individual criterion is listed against each other and it will lead to the ranking calculation. Table 4 shows the weighted and ranked criteria for the test equipment. From the analysis, it is seen that the most important criteria were safety and stability meanwhile the last two criteria were low cost and number of parts. According to the [27], the last two criteria with under than 5% weighted can be sorted out and the remaining criteria are with risk coverage of more than 80% of the limit value.

Based on the ranking analysis in Table 4, a cost-benefit analysis was created whereby only the remaining criteria with the 3 alternative design solutions will be further analyzed. As shown in Table 5, solution 3 had the highest percentage which means solution 3 meets almost all the listed criteria.

Table 4: Ranking and Evaluation Criteria

	Safety	Stability	Practibility	No. Of parts	Easy fabrication	Easy mounting	Ergonomic	Low cost		Number	Weight factor	Ranking
Safety		+	+	+	+	+	+	+		7	0.25	1
Stability	-		+	+	+	+	+	+		6	0.21	2
Practibility	-	0		+	+	+	+	+		5	0.18	3
No of parts	-	-	-		-	-	-	-		0	0.00	8
Easy fabrication	-	-	-	+		0	+	0		2	0.07	6
Easy mounting	-	-	-	+	+		+	0		3	0.11	5
Ergonomic	-	0	0	+	+	+		+		4	0.14	4
Low cost	-	-	-	+	0	0	-			1	0.04	7
Limit at :	**Risk coverage**				**Number of remaining**					28	1.00	
0.04	0.96				6							

Table 5: Cost-Benefit Analysis

Evuluation criteria	Criteria weight	S1		S2		S3		Ideal solution	
		unweighted	weight	unweighted	weight	unweighted	weight	unweighted	weight
Safety	0.3	6	1.8	3	0.9	8	2.4	10	3
Stability	0.2	8	1.6	2	0.4	6	1.2	10	2
Practibility	0.2	4	0.8	10	2	10	2	10	2
Easy fabrication	0.1	4	0.4	8	0.8	7	0.7	10	1
Easy mounting	0.1	3	0.3	6	0.6	6	0.6	10	1
Ergonomic	0.1	6	0.6	3	0.3	8	0.8	10	1
Sum	1	31	5.5	32	5	45	7.7	60	10
Value		52%	55%	53%	50%	75%	77%	100	100

4.5 Design Finalization

After the alternative solution has been defined from the cost-benefit analysis, the solution is further visualized. The hand sketch will properly draw and modeled by using the 3D model. The drawing was done by using CREO 4.0 where this software allows users to draw parts in 3D view, sketching and part assembling. Figure 21 shows the final look of the solution 3. Proper dimensioning is attached in the appendix.

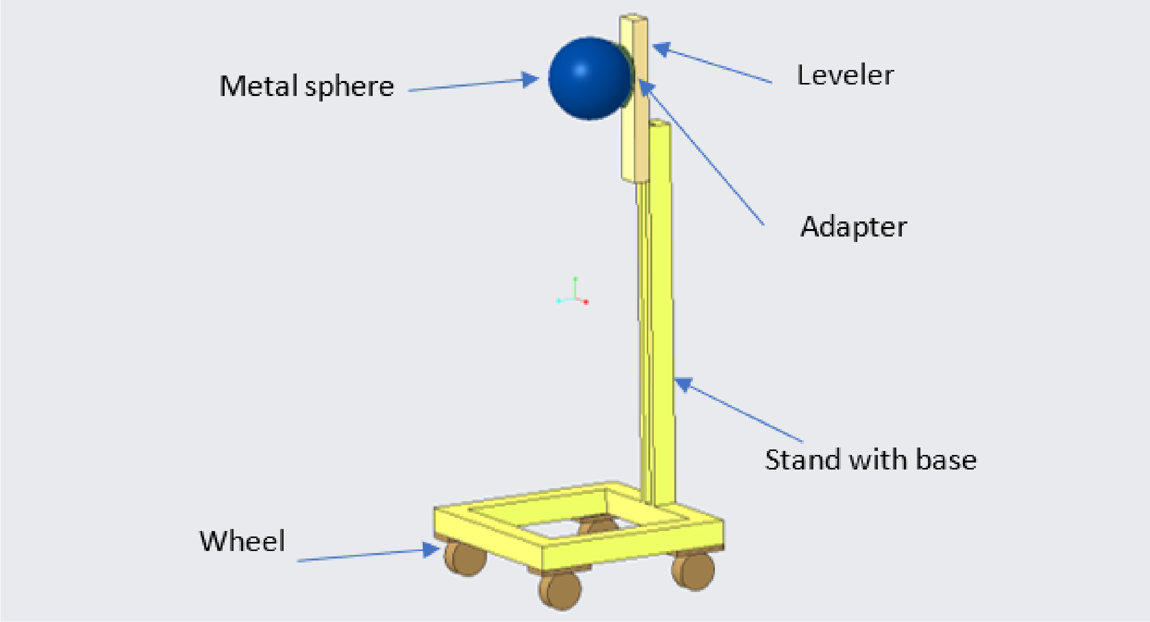


Figure 21: Final 3D model for the testing equipment

This testing equipment consists of the 4 main parts, which are metal sphere, adjustable stand with base and adapter. The metal sphere with a diameter of 15 cm can be welded together with the adapter whereby the adapter is fixed to the leveler stand. To make it this equipment easy for fabrication, the square shape was suggested to be used for the adjustable stand and base. The wheel is added at the bottom of the base to make it easy to move from one position to another. Besides that, to make the equipment static during the test is carried out, it is recommendable to use the wheel with the lock.

Considering the radar will reflect the metal and alloy, the material for stand and base should be made from microwave absorbable material like fiber and plastic. However, since fiber and plastic are relatively light and there is a possibility it can fall due to heavy solid metal sphere that attached with the stand, the material for the stand still can use metal or alloy, but it needs to be cover with the material that can absorb the microwave energy (e.g. Pyramidal sheet Absorber).

4.6 Testing Layout

As described before, the testing was planned to be carried in a closed room. The target can be used to test the RCS for every front and rear radar. Figure 22 shows the layout of the testing environment. The testing set up needs to be done manually and separately for both front and rear radar. Do refer previous subchapter above to estimate the minimum distance required of the target from the front end and back end.

For the rear radar, the rear wheel of the vehicle needs to be fixed horizontally. Taking the rear end body of the vehicle as a *0* coordinate in the y-axis, the scale floor mat can be an overlay on both sides of the vehicle's body as shown in Figure 22.

Similar to the test set up for the front radar. By taking the front end of the vehicle's body as the *0* in the y-axis, and the minimum distance required for target placement can be measured.

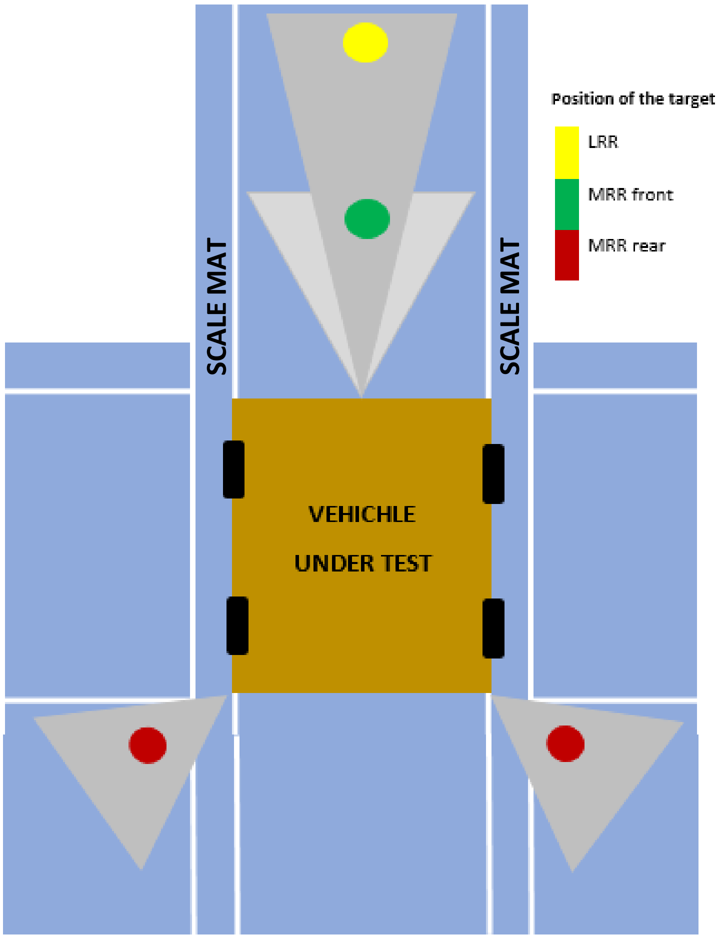


Figure 22: Testing Layout

Center alignment of the vehicle can be done by attaching a rope from the center of the front end or back end of the vehicle to the ground as shown in Figure 23, whereby this projection will form an intersection to the horizontal line at the scale mat. This intersection should be perpendicular to each other or in other words, it creates the right angle. Based on this of the intersection, an azimuth angle can be determined on the testing floor.

If a testing vehicle has both LRR and MRR radars been installed at the front end of the vehicle, then target shifting needs to be done for the MRR test. This is because the field of view of the MRR radar is overlap on the field of view of LRR radar. Target shifting here means that the MRR target is not supposed to be in the same area of the field of view for LRR. This shifting is important to avoid the multiple signals penetrating at the target simultaneously. LRR test has less complexity since it has a longer field of view. Therefore, the LRR target can be placed anywhere within its field of view.

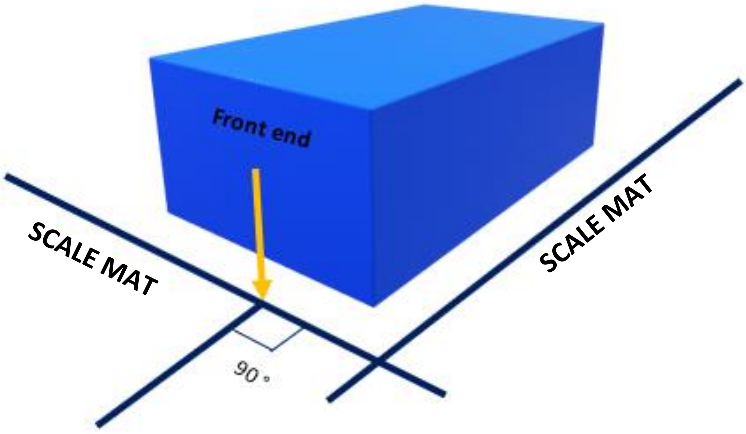


Figure 23: Vehicle center alignment

Here is the restriction and guideline for testing approach:

- The target needs to be placed in the area of the radar's field of view, otherwise, the target cannot be detected. Attention needs to be paid on the overlapping field of view to test different installed radar.
- Metallic or other strong radar-reflecting instrument parts near to the testing area should be avoided.
- Wall for the testing room can be covered with microwave absorber matt (e.g. cuming pyramidal sheet) –
- Flat testing floor

4.7 Expected Result

Expected analytical results from this testing approach are the detection of the radar, range and angle estimation for the target. By emitting radio signals from the operated radar to the spherical metal target under a certain condition as stated in the previous chapter, the functionality of the radar can be examined. The target will act as the second antenna and will reflect the echo and will give the RCS value. For this testing approach, the RCS of the target is equal to the area of the circle of the sphere. By using the formula below, RCS can be obtained.

$$\sigma = \pi r^2 \qquad 4\text{-}5$$

Where $\sigma = RCS\ (Radar\ Cross\ Section)$

$r = radius\ circle$

Since the power that penetrates the target and the echoing power are constant due to constant geometrical of the target, the target range cannot be defined from the general formula of the RCS as stated in equation 2-8. However, since automotive radar is using the FMCW radar, the target range can be determined by reformulating equation 2.3 whereby $\mathrm{d} = \mathrm{c}\,\frac{\mathrm{IF\ T}}{2\mathrm{B}}$.

where $d = distance$

$IF = Intermieadate\ frequency$

$T = time$

$B = Bandwitdth$

$c = speed\ of\ light$

Pre-testing needs to be done to get the threshold value of the unwanted RCS. According to [12], RCS for the ground and clutter varies from about 1000-100000 m^2.

On the other hand, estimation of angle, $\boldsymbol{\theta}$ of the spherical target in FMCW can be determined by using mathematical equation in 2-7. (Do refers **2.1.2 Angle of Estimation** for the brief explanation)

$$\theta = \sin^{-1}(\frac{\lambda\omega}{2\pi d})$$

Where $\omega = phase$

$d = distance\ between\ two\ antennas$

$\lambda = wavelength\ of\ the\ IF$

5.0 Conclusion

The ideas were to implement a proper testing methodology and guideline for automotive radar in the close testing room. At the beginning of the study, plenty of time was taken to understand the operation of radar, to do some research on the current technology in radar testing and to brainstorming the ideas.

Knowing that nowadays, more than one radars are mounted at the vehicle for safety purposes, the idea of design concept also needs to meet the requirement of the frequency regulation and current position of mounted radar. Throughout the process, continues the discussion with the supervisor and colleague was done to change the ideas and to avoid misunderstanding. Miscalculating will lead the test approach not reliable and will producing error while the equipment is using for testing.

The spherical metal sphere was chosen for this testing approach due to its simplification of in RCS. However, the sphere target also has some restrictions to avoid the fluctuation of RCS reading, in which the diameter of the sphere needs to be at least 3.2 times operating wavelength under the far-field testing condition where λ<< range and λ<< radius.

Unfortunately, this spherical metal target with this diameter of 15 cm is not suitable to test the RCS of the person because diameter of target was too small in comparison to the RCS of a person. According to [9] and as stated in [3], RCS for an adult male range between 0.4 and 1.2 m^2, depending on radar frequency. Taking the smallest range of RCS of adult man as $0.4m^2$, and further calculating the required radius for spherical target that equivalent to an adult man by using formula of area of sphere gives:

$$r = \sqrt{\frac{0.4}{\pi}} = 0.36\ m = 36cm \qquad \text{Equation 5-1}$$

Therefore, in order to have spherical target that has equivalent RCS to an adult man with RCS of $0.4m^2$, the radius of the spherical target needs to have radius of 36cm or diameter of 72cm.

The drawing that has been done is based on the selected design concept. The proper calculation for the size of the reflector needed to ensure the test will give results as expected. Besides the reliability of the equipment, it also needs to be practical in handling and moving.

Therefore, the features like the surface of the material, material, fabrication process and joining method for the entire equipment need to be considered during drawing. Besides, this standardization and guideline of this equipment have been studied to suit the radar testing for every country and every vehicle model, especially in Europe.

The testing equipment was designed for the front as well as rear radar sensor testing. Originally only alternative solution 1 (see. 4.3 Design Approach) was designed to hold the sphere target and to have stability stand. After the further study was done on the existing testing apparatus from Texa, (see. 3.3 Calibration by TEXA) alternative solution 2 was implemented which is this design is almost similar to the radar testing apparatus for the blind spot system, but the target was replaced by sphere target. This solution, unfortunately, is less stable and required a person to hold the equipment throughout the test. It will lead to the disturbance of the sensor data acquisition system because radar will reflect on the operator too as the target. Finally, some improvement has been done and alternative solution 3 was created and this design won the highest percentage in cost-benefit analysis.

5.2 Recommendation

Based on the selected solution for this testing approach, here is the list that can be done to improve the reliability and efficiency of the test:

1. Instead of using metal or aluminum for the stand and base for the testing equipment, it can be replaced with wood, fiber or plastic. However, attention needs to pay on the stability, fabrication possibility. Besides that, metal or aluminum stand also can be covered with an absorbable microwavable energy sheet.

2. In other solution to reduce disturbance of microwave energy from surrounding during testing, the unechoing chamber can be implemented for the testing room which is the wall can be cover with pyramidal Cuming foam which this unechoing chamber is apply in airplane testing (for example; Anechoic Chambers: https://www.cumingmicrowave.com/anechoic-chambers-application.html)

3. The reflectivity of the spherical metal can be tested using a spectrometer as part of the testing guideline from Euro NCAP. (do refer [16][17][18] for further the value of the standard reflectivity)

4. The stability of the selected design can be further analyzed by using the Finite Element Method (FEM) software like Abaqus ANSYS.

5. Centralization and angle measurement for target positioning can be done by the help of goniometer jig as used in TEXA (Figure 13) or autocollimator.

5.3 Future Work

This testing approach can be implemented to examine if the radar works accordingly as well as to determine its range and angle. According to the finding from this study, here is some suggestions for future work in the area of radar testing. However, all these testing suggestion needs to be further discussed and researched.

1. Radar testing for misalignment. It can be done by predetermined the fix position of the target and install it in the data acquisition system. After that, by moving the target in a certain distance and angle, the data acquisition system should give the error message if the current distance and angle still have the same value as before it has been moved.

2. To validate the distance of the target from the radar by adding an ultrasonic sensor. From this study, distance is already can be obtained from the relation between time and intermediate frequency. However, this calculated distance can be redetermined by help from the ultrasonic sensor as stated in the patent (3.4.1 Distance Measuring Device).

3. To measure relative velocity. To implement this testing approach, either vehicle or target needs to be moving during the test. The relative velocity can be determined from the relation of the doppler effect. However, this kind of testing required a bigger testing room.

4. To use the trihedral corner reflector as the target for calibration testing. Attention needs to be pay on the polarization of the wave.

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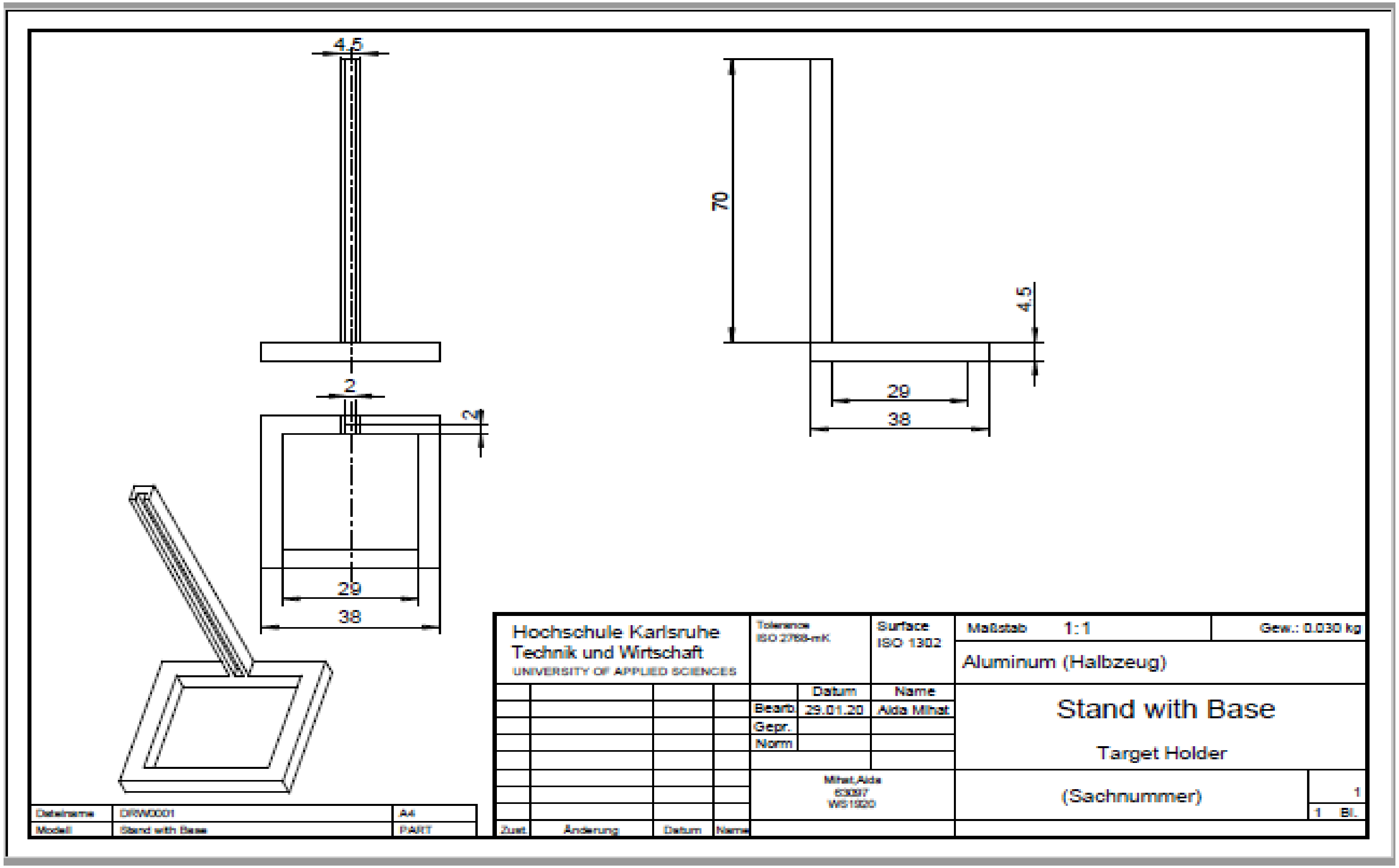
APPENDIX A



Hochschule Karlsruhe
Technik und Wirtschaft
UNIVERSITY OF APPLIED SCIENCES

Tolerance
ISO 2768-mK

Surface
ISO 1302

Maßstab 1:1

Gew.: 0.030 kg

Aluminum (Halbzeug)

	Datum	Name
Bearb.	29.01.20	Aida Mihat
Gepr.		
Norm		

Mihat,Aida
63097
WS1920

Stand with Base

Target Holder

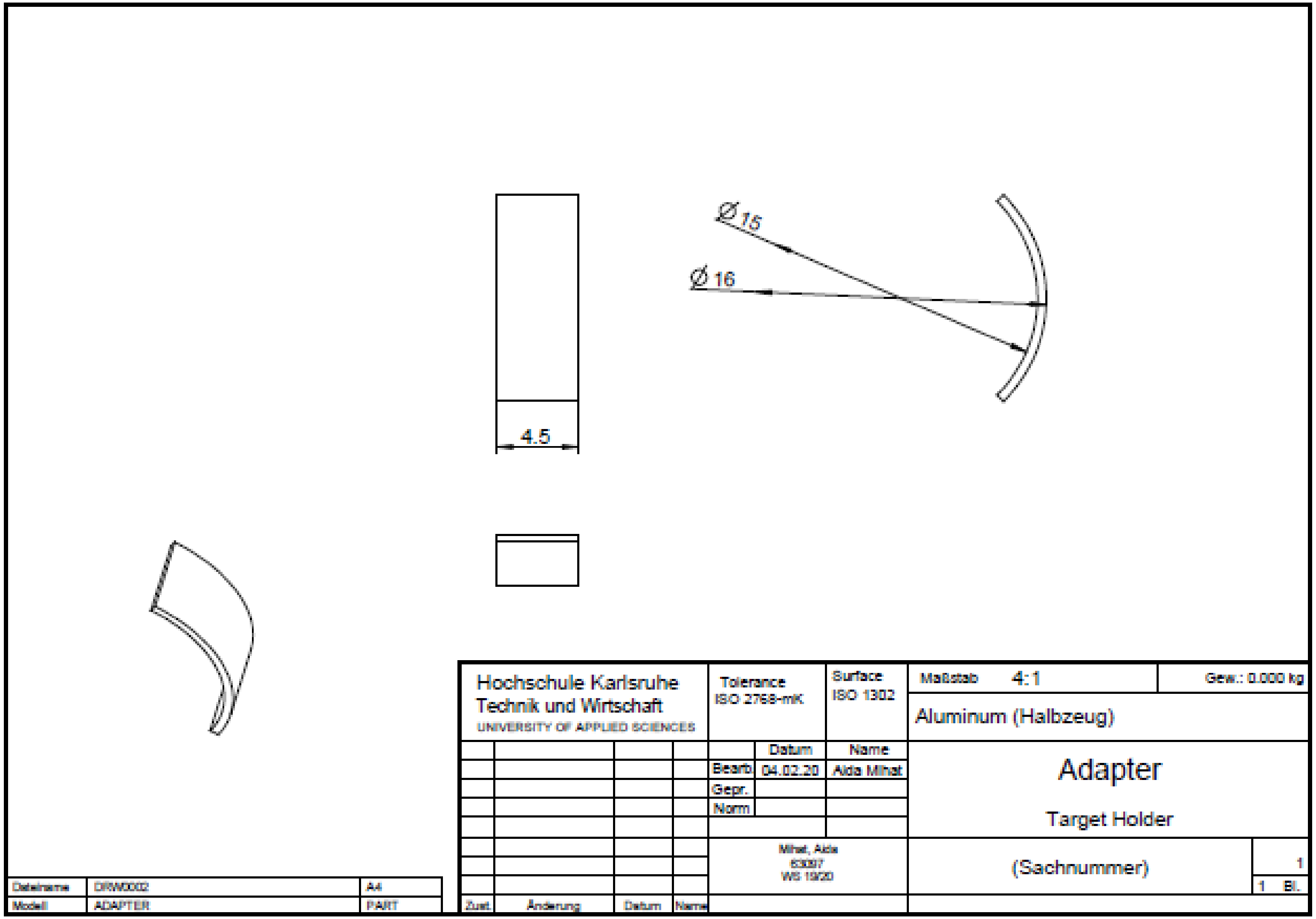
(Sachnummer)

1
1 Bl.

Zust.	Änderung	Datum	Name

Dateiname	DRW0001	A4
Modell	Stand with Base	PART

APPENDIX B


Ø15
Ø16
4.5
Hochschule Karlsruhe
Technik und Wirtschaft
UNIVERSITY OF APPLIED SCIENCES
Tolerance
ISO 2768-mK
Surface
ISO 1302
Maßstab 4:1
Gew.: 0.000 kg
Aluminum (Halbzeug)
Datum
Name
Bearb. 04.02.20 Aida Mihat
Gepr.
Norm
Adapter
Target Holder
Mihat, Aida
63097
WS 19/20
(Sachnummer)
1
1 Bl.
Zust.
Änderung
Datum
Name
Dateiname
DRW0002
A4
Modell
ADAPTER
PART