NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

RADAR & CAR RADAR DEVICES

Graduation Project
EE- 400

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ABSTRACT

This project provides a summary of the USA position on the use of the 21 –27 GHz band and its use for car radars. The USA reviewed its position on the use of car radars systems operating in the 21 – 27 GHz band. The 24 GHz band is an exclusive and unique band for sensing characteristics of the atmosphere needed to forecast weather and climate throughout the world. Accordingly this band has been granted additional protection from Radio Frequency Interference (RFI) as stated in international ITU-R Regulation Number 5.340 ("all emissions are prohibited in the following bands:..."). The critical importance of this band for accurate and early weather forecasting has resulted in NOAA studies of the proposed use of this band for UWB devices and services, especially automotive radars. These studies resulted in a NOAA determination that the extensive proliferation of automotive radars in high density areas (e.g., metropolitan or urban areas) could seriously and permanently compromise the availability of weather data from this critical band. Most meteorological agencies, including NOAA, have also noted that the automotive radar functions could be performed in the 77 MHz band instead of the 24 GHz band, thereby ensuring that this unique 24 GHz resource would not be irreparably contaminated and remain available for its natural weather forecasting potential.

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INTRODUCTION

After the Second World War, the Federal Communications Commission standardized radio procedures, and in the process allocated certain frequency bands for different uses. The result, radar frequencies, 'X' Band and 'K' Band were adopted for commercial use, the rest for the military and aviation industries. Most Police traffic radar falls into these frequency bands, therefore we can design and build detectors to pick up signals in this range of frequencies used for traffic radar systems both moving and stationary. Further to this, a third frequency has been allocated, 'Ka" Band. This high frequency suffers from substantial attenuation, and therefore is a short distance radar frequency.

Police departments use a variety of equipment to check vehicle speed, amphometers, digitectors, (Timing device) and of course the point of all this, radar! To further complicate things Police departments use various types of radar equipment made by different manufacturers, most of U.S origin. The problem is that most radar detectors are built either in the USA or Asia for use against the US radar, on long straight 12 lane highways, and operating on their own unique frequencies. What this means, is that if you purchase a detector from overseas, it may not work well in New Zealand, or at all. Some imported detectors won't give you protection against the latest "Ka" Band camera radars currently in New Zealand because their "Ka" band performance is very poor, or they have software (firmware) problems.

The problems don't stop there. Detectors made for the U.S market have a much lower acceptable sensitivity level (range) than that which is needed for the effective long range detection of our local radars. The latest wideband detectors pick up substantially more interference from alarm systems, shops traffic lights and even other detectors. This increased false alarming is due to the wider range of frequencies needed for the U.S radars, but not needed for New Zealand. The wider radar band coverage results in lower performance, the more frequencies you try to cover, the lower the sensitivity. (Range) U.S radar detectors are produced on an assembly line, like cars there are some real lemons out there. The performance of these production units varies from good to bad. We filter out all the bad eggs, duds and lemons in our own test labs, to offer you the best of each manufacturer.

The actual process involved in determining a vehicle's speed is basically a simple one. It involves directing a beam of microwave energy at an approaching (or receding) target vehicle.. A portion of this beam is reflected by the target vehicle and is received by the radar unit that is originally transmitted the signal. The reflected signal is shifted in frequency by an amount proportional to the speed of the target vehicle. This phenomenon is known as the Doppler Effect. The radar unit determines the target vehicle speed from the difference in frequency between the reflected signal and the original signal.

Chapter one is devoted for the general use and mechanism or radars as they operate by radiating a narrow beam of electromagnetic energy into space from an antenna.

Chapter two deals with cars equipped with the radar devices that operates in the band frequency of 21-27 GHZ. And that the 24 GHZ automotive radars cause harmful interference to the EESS sensors.

Chapter three is about the police traffic radars, how do they work? , tracking, targeting, and the errors that might occur during the process of radiating. And its also shows the calculations for the frequency shift to determine the target speed.

CHAPTER ONE
FUNDAMENTALS OF RADAR

1.1 Basic Principle

Typical radar operates by radiating a narrow beam of electromagnetic energy into space from an antenna as in figure 1.1.

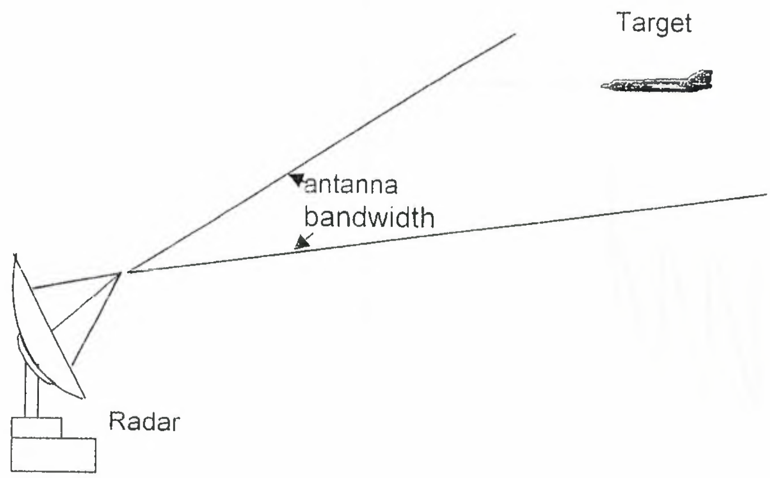

Figure 1.1 Principle of Radar Operation.

The transmitted pulse which has already passed the target, has reflected a portion of the radiated energy back toward the narrow antenna beam is scanned to search a region where targets are expected.

When a target is illuminated by the beam, it intercepts some of the radiated energy and reflects a portion back toward the radar system. Since most radar systems do not transmit and receive at the same time, a single antenna can be used on a time-shared basis for both transmitting and receiving.

A receiver attached to the output element of the antenna extracts the desired reflected signals and (ideally) rejects those that are of no interest. For example, a signal of interest might be the echo from an aircraft signals that are not of interest might be echoes from the ground or rain, which can mask and interfere with the detection of the desired echo from the aircraft. The radar measures the location of the target in range and angular direction. Range is detennined by measuring the total time it takes for the radar signal to make the round trip to the target and back figure 1.2. The angular direction of a target is usually found from the direction in which the antenna points at the time the echo signal is received. Through measurement of the location of a target at successive instants of time, its track can be deteımined. Once this information has been established, the target's location at a time in the future can be predicted, in many surveillance radar a plications, the target is not considered to be "detected" until its track has been established.

1.1.1 Radar Pulse

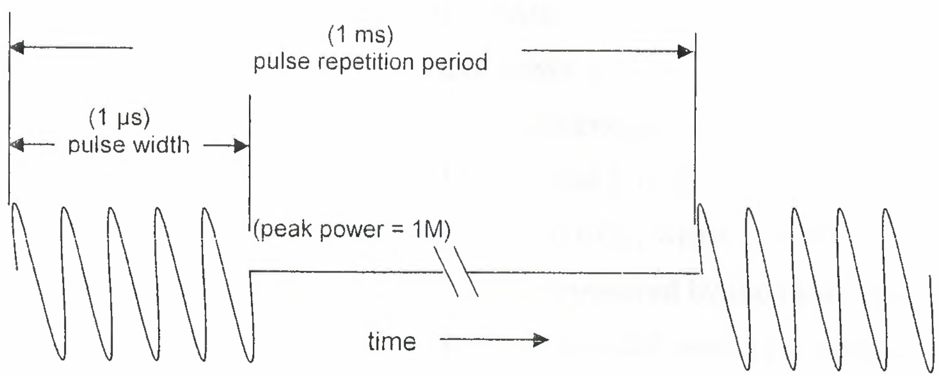

Figure 1.2 *A* typical pulse waveform transmitted by radar.

The most common type of radar signal consists of a repetitive train of short-duration pulses. Figure 1.2 is a simple representation of a sine-wave pulse that might be generated by the transmitter of medium-range radar designed for aircraft detection. This sine wave in the figure represents the variation with time of the output voltage of the transmitter. The numbers given in brackets in the figure are only meant to be illustrative and are not necessarily those of any particular radar. They are anumbers however, similar to what might be expected for a ground-based radar system with a range of about 50 to 60 nautical miles (or 90 to 110 kilometers), such as the kind used for air traffic control at airports. The pulse width is given in the figure as one millionth of a second (one microsecond). it should be noted that the pulse is shown as containing only a few cycles of the sine wave; however, in a radar system.having the values indicated, there would be 1,000 cycles within the pulse. in figure 1.2 the time between successive pulses is given as one thousandth of a second (one millisecond), which corresponds to a pulse repetition frequency of 1,000 hertz. The power of the pulse, called the peak power, is taken here to be 1,000,000 watts. Since pulse radar does not radiate continually, the average power us much less than the peak power. In this example, the average power is 1,000 watts. The average power, rather than the peak power, is the measure of the capability of a radar system. Radars have average powers from a few milliwatts to as much as one or more megawatts, depending on the application.

A weak echo signal from a target might be as low as one trillionth of a watt (10^{-12} watt). In short, the power levels in a radar system can be very large (at the transmitter) and very small (at the receiver).

Another example of the extremes encountered in a radar system is the timing. An air-surveillance radar one that is used to search for aircraft) might scan its antenna 360 degrees in azimuth in a few seconds, but ,the pulse width might be about one microsecond in duration.

The range to a target is determined by measuring the time that a radar signal takes to travel out to the target and back. The range to the target is equal to cT/2, where *c* is the velocity of propagation of radar energy, and T is the round-trip time as measured by the radar. From this expression, the round-trip travel of the radar signal is at a rate of 150 meters per microsecond. For example, if the time that it takes the signal to travel out to the target and back were measured by the radar to be 600 microseconds, then the range of the target would be 90 kilometers.

1.1.2 Components of radar

Figure 1.3 shows the basic parts of a typical radar system. The transmitter generates the high-power signal that is radiated by the antenna. The antenna is often in the shape of a parabolic reflector, similar in concept to an automobile headlight but much different in construction and size. It also might consist of a collection of individual antennas operating together as a phased-array antenna.

The duplexer permits ultemate transmission and reception with the same antenna, it is a fast-acting switch that protects the sensitive receiver from the high power of the transmitter. The receiver selects and amplifies the weak radar echoes so that they can be displayed on a television-like screen for the human operator or be processed by a computer. The signal processor separates the signals reflected by the target (e.g., echoes from an aircraft) and from unwanted echo signals (the clutter from land, sea, rain, etc).

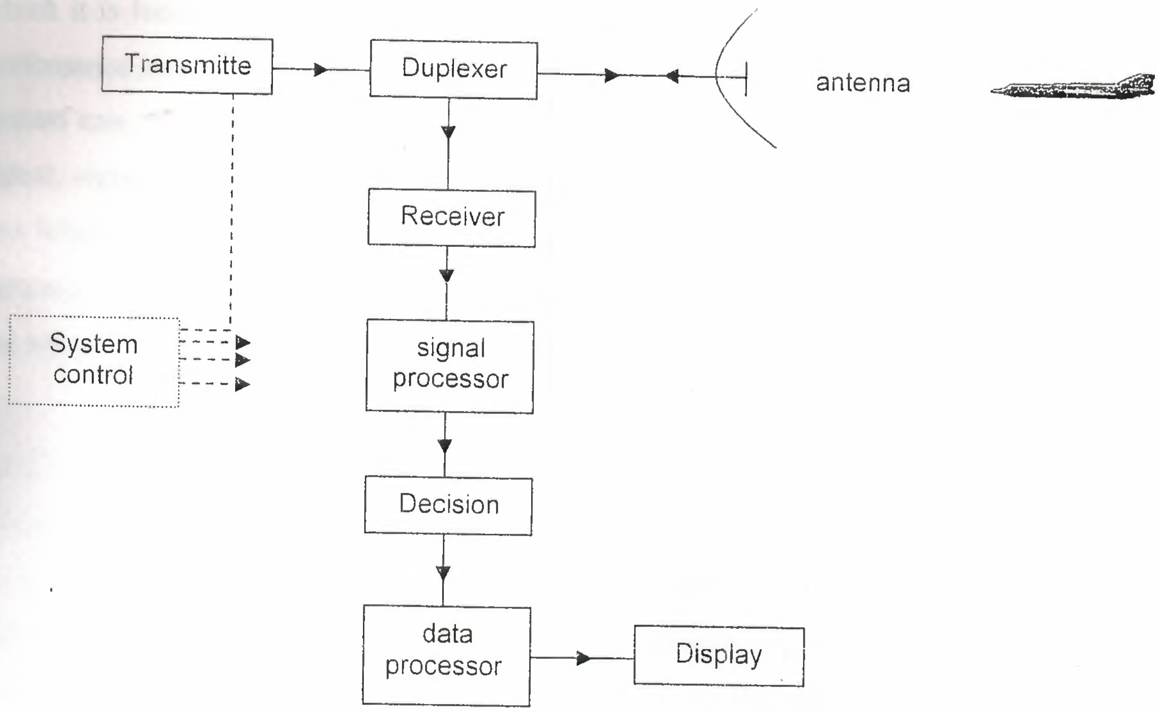

Figure 1.3 Basic Parts of a Radar System

It is not unusual for these undesired reflections to be much larger than desired target echoes, in some cases more than one miiion times Iarger. Large clutter echoes from stationary objects can be differentiated from small echoes from a moving target by noting the shift in the observed frequency produced by the moving target. This phenomenon is called the Doppler frequency shift (Figure 1.3) At the output of the receiver a decision is made as to whether or not a target echo is present. If the output of the receiver is larger than a predetermined value, a target is assumed to be present. Once it has been decided that a target is present and its location has been determined, the track of the target can be obtained by measuring the target location at different times. During the early days of radar, target tracking was performed by an operator marking the location of the target "blip" on the face of a cathode-ray tube (CRT) display with a grease pencil. Manual tracking has been largely replaced by automatic electronic tracking, which can process a much greater number of target tracks than can an operator who can handle only a few simultaneous tracks. Automatic tracking is an example of an operation performed by a data processor. The type of signal waveform transmitted and the associated received-signal processing in a radar system might be different depending on the type of target invoived and the environment in which it is located. An operator can select the parameters of the radar to maximize perfomance in a particular environment. Altrnatively, electronic circuitry in the radar system can automatically analyze the.environmet and select the proper transmitted signal, signal processing, and other radar parameters to optimize performance. The box labeled "system control" in figure 1.3 is intended to represent this function. The system control also can provide the timing and reference signals needed .to permit the various parts of the radar to operate effectively as an integrated system.

1.1.3 Target Information

The ability to measure the range to a target accurately at long distances and to operate under adverse weather conditions are radar's most distinctive attributes. There are no other devices that can compete with radar in the measurement of range The range accuracy of a simple pulse radar depends on the width of the pulse, the shorter pulse, the better accuracy. Short pulses, require wide bandwidths in the receiver and transmitter. A radar with a pulse width of one microsecond can measure the range to an accuracy of a few tens of meters or better. Some special radars can measure to an accuracy of a few centimeters. The ultimate range accuracy of the best radars is limited not by the radar system itself, but rather by the known accuracy of the velocity at which electromagnetic waves travel.

Almost all radars use a directive antenna-i.e, one that directs its energy in a narrow. The direction of a target can be found from the direction in which the antenna is beam pointing when the received echo is at a maximum. A dedicated tracking radar-one that follows automatically a single target so as determine its trajectory-generally has a narrow symmetrical "pencil" beam. Such a radar system can detennine the location of the target in both azimuth angle and elevation angle. An aircraft-surveillance radar generally employs an antenna that radiates a "fan" beam, one that is narrow in azimuth (about 1 or 2 degrees) and broad in elevation. A fan beam allows only the measurement of the azimuth angle.

Radar can extract the Doppler frequency shift of the echo produced by a moving target .by noting how much the trequency of the received signal diflers from the frequency of the signal that was transmitted. A moving target will cause the frequency of the echo signal to increase if it is approaching the radar or to decrease if it is receding from the radar. For example, if a radar system operates at a frequency of 3,000 megahertz and an aircraft is moving toward it at a speed of 400 knots (740 kilometers per hour), the frequency of the received echo signal will be greater than that of the transmitted signal by about 4.1 kilo hertz. The Doppler frequency shift in hertz is equal to 3.4 $f_0 v_r$, where f_0 is the radar frequency in gigahertz and vr is the radial velocity in knots.

Since the Doppler frequency shift is proportional to radial velocity, a radar system that measures such a shift in frequency can provide the radial velocity of a target. The Doppleı frequency shift also is used to separate moving targets from stationary ones (land or sea clutter) even when the undesired clutter power might be much greater than the power of the echo from the targets. A form of pulse radar that uses the Doppler frequency shift to eliminate stationaıy clutter is called either a moving target indication (MTI) radar or a pulse Doppler radar, depending on the particular parameters of the signal wavefom.

The above measurements of range, angle, and radial velocity assume that the target is like a point. Actual targets, however, are of finite size and can have distinctive shapes. The range profile of a finite-sized target can be deterrnined if the range resolution of the radar is small compared to the target's size in the range dimension. Some radars can have resolutions smaller than one meter, which is quite suitable for deterrnining the radiai. size and profile of many targets of interest.

The resolution in angle that can be obtained with conventional antennas is poor compared to that which can be obtained in range. It is possible, however, to achieve good resolution in angle, or cross range, by resolving in Doppler frequency if the radar is moving relative to the target, the Doppler frequency shift will be different for different parts of the target. Thus the Doppler frequency shift can allow the various parts of the target to be resolved. The resolution in cross range delived from the Doppler frequency shift is far better than that achieved with a narrow-beam antenna. It is not unusual for the cross-range resolution obtained from Doppler frequency to be comparable to that obtained in the range dimension.

Cross-range resolution obtained from Doppler frequency, along with range resolution, is the basis for synthetic aperture radar (SAR). SAR produces an image of a scene that is similar to, but not identical with, an optical photograph. One should not expect the image seen by radar "eyes" to be the same as that obseıved by optical ones. Each provides different information. Radar and optical images differ because of the large difference in the frequencies involved, optical frequencies are approximately 100,000 times higher than radar frequencies.

The SAR can operate from long range and through clouds of other atmospheric effects that limit optical and infrared imaging sensors. The resolution of a SAR image can be made independent of range, an advantage over passive optical imaging, where the resolution worsens with increasing range. Synthetic aperture radars that map areas of the Earth's surface with resolutions of a few meters can provide information about the nature of the terrain and what is on the surface.

A SAR operates on a moving vehicle, such as an aircraft or spacecraft, to image stationary object or planetary surfaces. Since relative motion is the basis for the Doppler resolution, high resolution (in cross range) also can be accomplished if the radar is stationary and the target is moving. This is called inverse synthetic aperture radar (ISAR). Both the target and the radar can be in motion with ISAR.

1.1.4 Target Recognition

Radar can distinguish one kind oftarget from another (such as a bird from an aircraft), and some systems are able to recognoze specific classes of targets. Target recognition is accomplished by measuring the size and speed of the target and by observing the target with high resolution in one or more dimensions. Propeller or jet engines modify the radar echo from aircraft and can assist in target recognition. The flapping of the wings of a bird in flight produces a characteristic modulation, which can be used to recogize that a bird is present or even to identify one type of bird from another.

1.2 Developments

1.2.1 Early Experiments

Serious developmental work on radar began in the 1930s, but the basic idea of radar had its origins n the classical experiments on electromagnetic radiation conducted by the Gennan physicist Heinrich Hertz during the late 1880s. Hertz set out to verify experimentally the earlier theoretical work of the Scottish physicist James Clerk Maxwell. Maxwell had formulated the general equations of the electromagnetic field, detennining that both light and radio waves are examples of electromagnetic waves gove.med by the same fundamental laws but having widely different frequencies. Maxwell's work led to the conclusion that radio waves can be reflected from metallic objects and refracted by a dielectric medium just like light waves. Hertz demonstrated these properties in 1888, using radio waves at a wavelength of 66 centimeters (which corresponds to a frequency of about 455 MHz).

The potential utility of Hertz's work as the basis for the detection of targets of practical interest did not go unnoticed at the time. in 1904 a patent for "an obstacle detect of and ship navigation device," based on the principles demonstrated by Hertz, was issued in several countries to Christian Hulsmeyer, a German engineer. Hulsmeyer built his invention and demonstrated it to the German navy, but failed to arouse any interest. There was simply no economic, societal, or military need for radar until the early 1930s when a long-range military bomber capable of carrying large payloads was developed. This prompted the major countries of the world to look tor a means with which to detect the approach of hostile aircraft.

Most of the countries that developed radar prior to World War II first experimented with other methods of aircraft detection, These, included listening for the acoustic noise of aircraft engines and detecting the electrical noise from their ignition. Researchers also experimented with infrared sensors. None of these, however, proved effective.

1.2.2 First Military Radars

During the 1930s, efforts to use radio echo for aircraft detection were initiated independently and almost simultaneously in several countries that were concemed with the prevaiting militaıy situation and that already had practical experience with

radio technoiogy. The United States, Great Britain, Gennany, France, the Soviet Union, Italy, and Japan all began experimentIng with radar within about two years of one another and embarked, with vaiying degrees of motivation and success, on its development for militaiy purposes. Most of these countries had some fonn of operational radar equipment in military service at the start of World War II in 1939.
The first observation of the radar effect at the U.S. Naval Research Laboratoiy (NRL) in Washington, D.C., was made in 1922. NRL researchers positioned a radio transmitter on one shore of the Potomac River and a receiver on the other. A ship sailing on the river caused fluctuations in the intensity of the received signals when it passed between the transmitter and receiver. (Today, such a configuration would be called bistatic radar.) in spite of the promising results of this experiment, U.S. Navy officials were unwilling to sponsor further work.

1.3 Radar Subsystems

Figure 1.3 shows the major subsystems that make up a typical radar system. These subsystems are described in greater detail here.

1.3.1 Antennas

A widely used from of radar antenna is the parabolic retlector, the principle of which is shown in cross section in figure 1.4(A). A horn antenna or other small antenna is Placed at the focus of the parabola to illuminate the parabolic surface of the reflector. After being reflected by this surface, the electromagnetic energy is radiated as a narrowbeam. A paraboloid, which is generated by rotating a parabola about its axis, forms a symmetrical beam called a pencil beam. A fan beam, one with a narrow beam width in azimuth and a broad beam width in elevation, can be obtained by illuminating an asymmetrical section of the paraboloid. An example of an antenna that produces a fan beam is shown in the photograph.

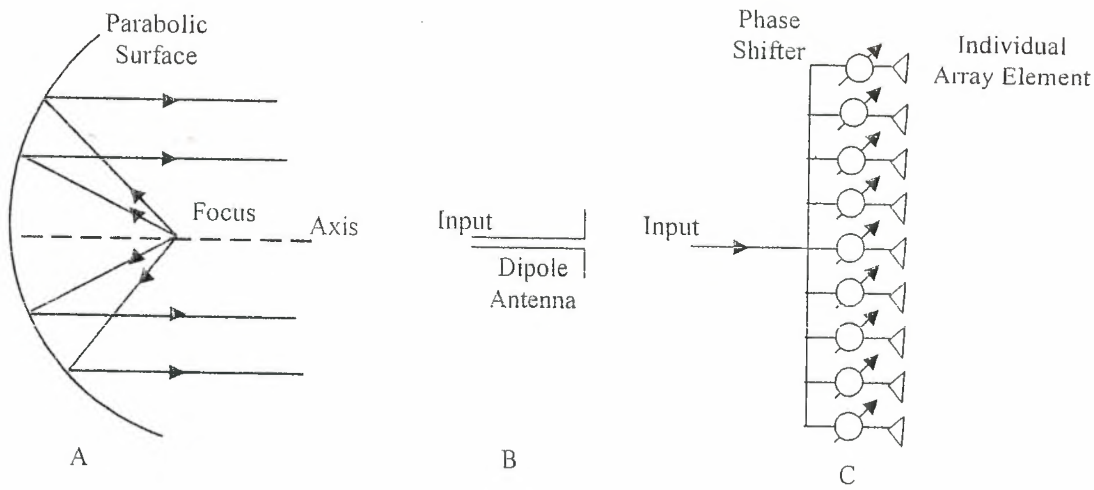

Figure 1.4 Radar amennas. (A) A parabolic reflector antenna in which the energy radiated from the focus is reflected from the parabolic surface as a narrow beam. (B) A dipole antenna. (C) A phased-array antenna composed of many individual radiating elements.

The half-wave dipole figure 1.4(B), whose dimension is one-half of the radar wave length, is the classic type of electromagnetic antenna. A single dipole is not of much use tor radar, since it produces a beam width too wide for most applications. Radar requires a narrow beam (a beam width of only a few degrees) in order to concentrate its energy on the target and to detemine the target location with accuracy. Combining many individual dipole antennas so that the signals radiated or received by each elemental dipole are in unison, or in step can forrn such narrow beams.

The phase shifters at each radiating antenna-element shift the phase of the signal, so that all signals received from a particular direction will be in step with one another. Similarly, all signals radiated by the individual elements of the antenna will be in step with one another in some specific direction. Changing the phase shift at each element alters the direction of the antenna beam. An antenna of this kind is called an electronically steered phased-array. It allows rapid changes in the position of the beam without moving large mechanical structures. in some systems, the beam can be changed from one direction to another within microseconds.

The individual radiating elements of a phased-array antenna need not be dipoles; various other types of antenna elements also can be used. For example, slots cut in the side of a waveguide are common, especially at the higher microwave frequencies. in a radar that requires a one-degree, pencil-beam antenna, there might be about 5,000 individual radiating elements. The phased-array radar is more complex than radar systems that employ reflector antennas, but it provides capabilities not otherwise available. Since there are many control points in a phased-array, the radiated beam can be shaped to give a desired pattern to the beam. Controlling the shape of the radiated beam is important when the beam has to illuminate the air space where aircraft are found but not illuminate the ground, where clutter echoes are produced Another example is when the stray radiation (called antenna side lobes) outside the main beam of the antenna pattern must be minimized.

The electronically steered phased-array is attractive for applications that require large antennas or when the beam must be rapidly changed from one direction to another Satellite surveillance radars and ballistic missile detection radars are examples that usually require phased-arrays The U.S. Army's Patriot battlefield air-defense system and the U.S. Navy's Aegis system for ship air-defense also depend on the electronically steered phased-array antenna

The phased-array antenna is also used without the phase shifters in figure 1.4(C). The beam is steered by the mechanical movement of the entire antenna. Antennas of this sort are preferred over the parabolic reflector for airborne applications, in land-based air-surveillance radars requiring multiple beams, and in applications that require ultra antenna side lobe radiation.

1.3.2 Transmitters

The transmitter of a radar system must be efficient, reliable, not too large in size and weight, and easily maintained, as well as have the wide bandwidths and high power that are characteristic of radar applications. In MT, pulse Doppler, and CW applications, the transmitter must generate noise-free, stable transmissions so that extraneous (unwanted) signals from the transmitter do not interfere with the detection of the small Doppler frequency shift produced by weak moving targets.

It was observed earlier that the invention of the magnetron transmitter in the lasted 1930s resulted in radar systems that could operate at the higher frequencies known as microwaves. The magnetron transmitter has certain limitations, but it continues to be widely used-generally in low-average-power applications such as ship navigation radar and airbome weather-avoidance radar. The magnetron is a power oscillator in that it self-osciilates when voltage is applied. Other radar transmitters usually are power amplifiers in that they take low-power signals at the input and amplify them to high power at the output. This provides stable high-power signals, as the signals to be radiated can be generated with precision at low power.

The klystron amplifier is capable of some of the highest power levels used in radar. It has good efficiency and good stability. The disadvantages of the klystron are that it is usually large and it requires high voltages (e.g. about 90 kilovolts for one megawatt of peak power). At low power the instantaneous bandwidth of the klystron is small, but the k1ystron is capable of larg.e bandwidth at high peak powers of a few megawatts.
The traveling-wave tube (TWT) is related to the klystron. It has veiy wide bandwidths at low peak power, but, as the peak power Ievels are increased to those needed for radar, its bandwidth decreases. As peak power increases, the bandwidths of the TWT and the klystron approach one another.
Solid-state transmitters, such as the silicon bipolar transistor, are attractive because of their potential for long life, ease of maintenance, and relatively wide bandwidth. An individual solid-state device generates relatively low power and can be used only when the radar application can be accomplished with low power (as in short-range applications or in the radar altimeter). High power can be achieved, however, by combining the outputs of many individual solid-state devices.
While the solid-state transmitter is easy to maintain and is capable of wide-band operation, it has certain disadvantages. It is much better suited for long pulses (milliseconds) than for the short pulses (microseconds). Long pulses can complicate radar operation because signal processing (such as pulse compression) is needed to achieve the desired range resolution. Furtherrnore, a long-pulse radar generally requires several different pulse widths: a long pulse for long range and one or more shorter pulses to observe targets at the ranges masked when the long pulse is transmitting. Every kind of transmitter has its disadvantages as well as advantages. in any particular application, the radar engineer must continually search for compromises that give the results desired without too many negative effects that cannot be adequately accommodated.

1.3.3 Receivers

Like most other receivers, the radar receiver is a classic superheterodyne. It has to filter the desired echo signals from unwanted clutter signals and receiver noise that interfere with detection. It also must amplify the weak received signals to a level where the receiver output is large enough to actuate a display or a computer. The technology of the radar receiver is well established and seldom sets a limit on radar performance.

The receiver must have a large dynamic range in situations where it is necessary to detect weak signals in the presence of very large. clutter echoes by recognizing the Doppler frequency shift of the desired moving targets. Dynamic range can be loosely described as the ratio of the largest to the smallest signals that can be handled adequately by a receiver without distortiofi. A radar receiver might be required to detect signals that vaiy in power by a million to one-and sometimes much more.

In most cases, the sensitivity of a radar receiver is determined by the noise generated internally at its input. Because it does not generate much noise of its own, a transistor is usually used as the first stage of a receiver.

1.3.4 Signal and Data Processors

The; signal processor is the part of the receiver that extracts the desired signal and rejects clutter. Doppler filtering in an MTI radar or in a pulse Doppler systym is an example. Most signal processing is performed digitally with computer technology. Digital processing has significant capabilities in signal processing not previously available with analog methods. Without digital methods many of the signal processing techniques found in today's high performance radars would not be possible. Digital processing also has made practical data processing, such as required for automatic tracking. Pulse compression (described below in Pulse-compression radar) is sometimes included under signal processing. It too benefits from digital technology, but analog processors (e.g. surface acoustic wave delay-lines) are used rather than digital methods when pulse compression must achieve resoiutions of a few meters or less.

1.3.5 Display

The cathode-ray tube has been the traditional means of displaying the output of a radar system.. Although it has its limitations, the CRT has been the preterred technology ever since the early days of radar. The CRT has undergone contInual improvement that has made it even more versatile.

Plan position indicator, or PPI is a maplike presentation in polar coordinates of range and angle. The CRT screen is dark (other than for slight noise background) except when echo signals are present. The PPI is called an intenşity-modulated display because the intensity of the electron beam of the CRT is increased sufficiently to excite the phosphor of the screen whenever an echo signal is present. The PPI is the most common form of display in use with radar. Another variety, the B-scope, is also an intensity-modulated display that presents the same infomıation and the same coordinates as the PPl but in rectangular rather than polar format. ln still another format, the A-scope, the received signal amplitude is displayed as the vertical coordinate and the range as the horizontal coordinate. The A-scope is called an amplitude-modulated display because echo signals are indicated by the increased amplitude (the vertical coordinate) on the CRT. The A-scope is not a suitable display for a surveillance radar that must search 360 degrees in azimuth, but it is used for tracking radars and in experimental radars when examining the nature of the echo signal is important.

Practical radar displays have been two dimensional, yet most radars provide more information than can be displayed on the two coordinates of a flat screen. Colour coding of the intensity-modulated signal on the PPI is sometimes used to provide additional information about the echo signal. Colour has been employed, for example, to indicate the strength of the echo. Doppler weather radars good use of colour coding to indicate on a two-dimensional display the rain intensity associated with each echo shown. They also utilize colour to indicate the radial speed of the wind, the wind shear, and other information relating to severe storms. The PPI displays targets as if seen in a horizontal plane. On the other hand, a range-height indicator, or RHI, is an intensity-modulated display that presents the echoes that appear in a vertical plane, e.g., a vertical cut through the cloud of a severe storm.

The radar display has benefited from the availability of digital technology. Digital memory allows the radar to store data from an entire scan period (usually one rotation of the radar antenna) and present the information to the operate of all at once (as in the case of a television-type monitor) rather than display targets only when they are actually within the antenna beam. This allows the operator to view the entire scene all the time and to manipulate the output to display the type of target information of most interest.

Modem surveillance radars rarely display the output of a radar receiver without further processing (raw video). When automatic detection of targets is employed in a radar system, the rejection of unwanted echoes such as land or sea clutter, the addition of the radar pulses received from a target, and the decision as to whether a target is present or not are all performed electronically without assistance from a human operator. The display then shows only detected targets without the background noise. This has been called a "cleaned-up" display or processed video. When automatic traclang is performed electronically (in a digital data processor), only processed target tracks are displayed and no individual target detections are indicated. The speed of a target and its direction of travel can be indicated on the CRT by the length of the line defining the track and its orientation. Near each target track on the display, alphanumeric information can be entered automatically to indicate information that is known about the target. For example, when the air-traffic-control radar-beacon system (ATCRBS) is used in conjunction with an air-surveillance radar, the alphanumeric data on the display can indicate the flight number of the aircraft and its altitude.

1.4 Factors Affecting Radar Performance

The performance of a radar system can be judged by the following: (1) the maximum range at which it can see a target of a specified size, (2) the accuracy of its measurement of target location in range and angle, (3) its ability to distinguish one target from another, (4) its ability to detect the desired target echo when masked by large clutter echoes, unintentional interfering signals from other "friendly" transmitters, or intentional radiation from hostile jamming (if a military radar), (5) its ability to recognize the type of target, and (6) its availability (ability to operate when needed), reliability, and maintainability Some of the major factors that affect performance are discussed in this section.

1.4.1 Transmitter Power and Antenna Size

The maximum range of a radar system depends in large part on the average power of its transmitter and the physical size of its antenna. (In technical terms, this is the power-aperture product.) There are practical limits to each. As noted before, some radar systems have an average power of roughly one megawatt. Phased-array radars about 100 feet in diameter are not uncommon, some are much larger. Likewise, mechanically scanned reflector antennas about 100 feet or larger in size can be found. There are specialized radars with (fixed) antennas, such as some HF over-the-horizon radars and the U.S. Space Surveillance System (SPASUR), that extend more than one mile.

1.4.2 Receiver Noise

The sensitivity of a radar receiver is detennined by the unavoidable noise that appears at its input. At microwave radar frequencies, the noise that limits detectability is usually generated by the receiver itself *(i.e.* by the random motion of electrons at the input of the receiver) rather than by external noise that enters the receiver via the antenna. The radar engineer often employs a transistor amplifier as the first stage of the receiver even though Iower noise can be obtained with more sophisticated devices. This is an example Of the application of the basic engineering principle that the "best" peıforrnance that can be obtained might not necessarily be the solution that best meets the needs of the user.

The receiver is designed to enhance the desired signals and to reduce the noise and other undesired signals that inteıfere with detection. The designer attempts to maximize the detectability of weak signals by using what radar engineers call a "matched filter which is a filter that maximizes the signal-to-noise ratio at the receiver output. The rnatched filter has a precise rnathernatical torrnulation that depends on the shape of the input signal and the character of the receiver noise. A suitable approximation to the matched filter for the ordinary pulse radar, however, is one whose bandwidth in hertz is the reciprocal of the pulse width in seconds.

1.4.3 Target Size

The size of a target as "seen" by radar is not always related to the physical size of the object. The measure of the target size as observed by radar is called the radar cross section and is given in units of area (square meters). It is possible for two targets with the same physical cross sectional area to differ considerably in radar size, or radar cross section. For example, a flat plate one square meter in area will produce a radar cross section of about 1,000 square meters at a frequency of 3,000 megahertz (S band; see below) when viewed perpendicular to the surface. A cone-sphere (an object resembling an ice-cream cone) when viewed in the direction of the cone rather than the sphere could have a radar cross section one thousandth of a square meter even though its projected area is also one square meter. in theory, thls value does not depend to a great extent on the size of the cone or the cone angle. Thus the flat plate and the cone-sphere can have radar cross sections that differ by a million to one even though their physical projected areas are the same.

The sphere is an unusual target in that its radar cross section is the same as its physical cross section area (when its circumference is large compared to the radar wavelength). That is to say, a sphere w.ith a projected area of one square meter has a radar cross section of one square meter.

Commercial aircraft might have radar cross sections from about 10 to 100 square meters, except when viewed broadside, where it is much larger. (This is an aspect that is seldom of interest, however.) Most air-traffic-controi radars are required to detect aircraft with a radar cross section as low as two square meters, since some small general-aviation aircraft can be of this value. For comparison, the radar cross section of a man has been measured at microwave frequencies to be about one square meter .A bird can have a cross section of 0.01 square meter. Although this is a small value, a bird can be readily detected at ranges of several tens of miles by long-range radar. In general, many birds can be picked up by radar so that special measures must usually be taken to insure that echoes from birds do not interfere with the detection of desired target:

The radar cross section of an aircraft and most other targets of practical interest is not a constant but, rather, fluctuates rapidly as the aspect of the target changes with respect to the radar unit. It would not be unusual for a slight change in aspect to cause the radar cross section to change by a factor of 10 to 1,000. (Radar engineers have to take this fluctuation in the radar cross section oftargets into account in their design.)

1.4.4 Clutter

Echoes from land, sea, rain, snow, hail, birds, insects, auroras, and meteors are of interest to those who observe and study the environment, but they are a nuisance to those who want to detect and follow aircraft, ships, missiles, or other similar targets. Clutter echoes can seriously limit the capability of a radar system; thus a significant part of radar design is devoted to minimizing the effects of clutter without reducing the echoes from desired targets. The Doppler frequency shift is the usual means by which moving targets are distinguished from the clutter of stationary objects. Detection of targets in rain is less of a problem at the lower frequencies, since the radar echo from rain decreases rapidly with decreasing frequency and the average cross section of aircraft is relatively independent of frequency in the microwave region. Because raindrops are more or less spherical (symmetrical) and aircraft are asymmetrical, the use of circular po1arization can enhance the detection of aircraft in rain. With circular polarization the electric field rotates at the radar frequency. Because of this, the electromagnetic energy reflected by the rain and the aircraft will be affected differently, thereby making it easier to distinguish between the two. (in air weather, most radars use 1inear polarization, i.e.. the direction of the field is fixed).

1.4.5 Atmospheric Effects

As was mentioned, rain and other forms of precipitation can cause echo signals that mask the desired target echoes There are other atmospheric phenomena that can affect radar pertormance as well. the decrease in density of the Earth's atmosphere with increasing altitude causes radar waves to bend. as they propagate through the atmosphere this usually increases the detection range at iow angles to a slight extent. The atmosphere can torm !"ducts" that trap and guide radar energy around the curvature of the Earth and allow detection at ranges beyond the normal horizon. Ducting over water is more likely to occur in tropical climates than in coider regions. Ducts can sometimes extend the range of an airborne radar, but on other occasions they may cause the radar energy to be diverted and not illuminate regions below the ducts. This results in the formation of what are called radar holes in the coverage. Since it is not predictable or reliable, ducting can in some instances be more of a nuisance than a help. Loss of radar energy, when propagation is through the clear atmosphere or rain, is usually in significant for systems operating at microwave frequencies.

1.4.6 Interference

Signals from nearby radars and other transmitters can be strong enough to enter a radar when propagation is through the clear atmosphere or rain, is usually insignificant for systems operating at microwave frequencies receiver and produce spurious responses. Well-trained operators are not often deceived by interference, though they may find it a nuisance. Interference is not as easily ignored by automatic detection and tracking systems, however, and so some method is usually needed to recognize and remove interference pulses before they enter the automatic detector and tracker of a radar.

1.4.7 Electronic Countermeasures

The purpose of hostile electronic countenneasures (ECM) is to deliberately degrade the effectiveness of military radar. ECM can consist of (1) noise jamming that enters the receiver via the antenna and increases the noise level at the input of the receiver , (2) false target generation, or repeater jamming, by which hostile jammers introduce additional signals into the radar receiver in an attempt to confuse the receiver into thinking they are real target echoes, (3) chaff, which is an artificial cloud consisting of a large number of tiny metallic ret1ecting strips that create strong echoes over a large area to mask the presence of real target echoes or to create confusion, and (4) decays, which are small, inexpensive air vehicles or other objects designed to appear to the radar as if they were real targets. Military radars are also subject to direct attack by conventional weapons or by antiradiation missiles (ARMs) that use radar transmissions to find the target and home on it.

Military radar engineers have developed various ways of countering hostile ECM and maintaining the ability of a radar system to perform its mission. It might be noted that a military radar system can often accomplish its mission satistactorily even though its perfonnance in the presence of ECM is not what it would be if such measures were absent.

1.5 Antenna

The radar antenna function is to first provide spatial directivity to the transmitted EM wave and then to intercept the scattering of that wave from a target. Most radar antennas may be categorized as mechanically scanning or electronically scanning.

Mechanically scanned reflector antennas are used in applications where rapid beam scanning is not required. Electronic scanning antennas include phased arrays and frequency scanned antennas.

Phased array beams can be steered to any point in their field-of-view, typically within 10 to 100 ms, depending on the latency of the beam steering subsystem and the switching time of the phase shifters. Phased arrays are desirable in multiple function radars since they can interleave search operations with multiple target tracks.

There is a Fourier transform relationship between the antenna illumination function and the far-field antenna pattern. Hence, tapering the illumination to concentrate power near the center of the antenna suppresses side lobes while reducing the effective antenna aperture area. The phase and amplitude control of the antenna illumination determines the achievable side lobe suppression and angle measurement accuracy.

Perturbations in the illumination due to the mechanical and electrical sources distort the illumination function and constrain performance in these areas. Mechanical illumination error sources include antenna shape deformation due to sag and thermal effects as well as manufacturing defects.

Electrical illumination error is of particular concern in phased arrays where sources include beam steering computational error and phase shifter quantization. Control of both the mechanical and electrical perturbation errors is the key to both low side lobes and highly accurate angle measurements. Control denotes that either tolerance are closely held and maintained or that there must be some means for monitoring and correction.

Phased arrays are attractive for low side lobe applications since they can provide element-level phase and amplitude control.

1.5.1 Transmitter

The transmitter function is to amplify waveforms to a power level sufficient for target detection and estimation.

There is a general trend away from tube-based transmitters toward solid-state transmitters. In particular, solid-state transmit/receive modules appear attractive for constructing phased array radar systems. In this case, each radiating element is driven by a module that contains a solid-state transmitter, phase shifter, low-noise amplifier, and associated control components. Active arrays built from such modules appear to offer significant reliability advantages over radar systems driven from a single transmitter. However, microwave tube technology continues to offer substantial advantages in power output over solid-state technology. Transmitter technologies are summarized in Table 1.1.

1.5.2 Receiver and Exciter

This subsystem contains the precision timing and frequency reference source or sources used to derive the master oscillator and local oscillator reference frequencies. These reference frequencies are used to down convert received signals in a multiple-stage super heterodyne architecture to accommodate signal amplification and interference rejection. The receiver front end is typically protected from overload during transmission through the combination of a circulator and a transmit/receive switch.

The exciter generates the waveforms for subsequent transmission. As in signal processing, the trend is toward programmable digital signal synthesis because of the associated flexibility and performance stability.

1.5.3 Antenna Directivity and Aperture Area

The directivity of the antenna is

$$D = \frac{4\pi A\eta}{\lambda^2} \tag{1.1}$$

where η . is aperture efficiency and λ . is radar carrier wavelength. Aperture inefficiency is due to the antenna illumination factor.

The common form of the radar range equation uses power gain rather than directivity. Antenna gain is equal to the directivity divided by the antenna losses. In the design and analysis of modern radars, directivity is a more convenient measure of performance because it permits designs with distributed active elements, such as solid-state phased arrays, to be assessed to permit direct comparison with passive antenna systems.

Beam-width and directivity are inversely related; a highly directive antenna will have a narrow beam-width. For typical design parameters,

$$D = \frac{10^7}{\theta_{az}\theta cl}$$

(1.2)

where θ_{az} and θ_{cl} are the radar azimuth and elevation beam-widths, respectively, in mill radians.

CHAPTER TWO

CAR RADAR DEVICES OPERATING IN THE FREQUENCY BAND 21 – 27 GHZ

A group of car manufacturers have organized themselves under the name SARA (Short Range Automotive Radar) and have recently published plans to introduce Short Range Radar (SRR) equipment on cars using Ultra Wide Band (UWB) technology.

The target frequency range for this application is 22.625 – 25.625 GHz, which includes the band used for very important measurements from passive sensors at 23.6 – 24 GHz. This band is a unique natural resource allowing to correct "windows" between 1 –40 GHz from the water vapor attenuation bands and giving the necessary correction for using the 50 – 60 GHz band for vertical temperature profiling. Due to the importance of this band for passive sensor measurements, the band is protected in the ITU Radio Regulations by FN 5.340 stating "No emissions allowed in this band".

The SARA group has started activities to achieve licenses for their equipment. Several workshops have been conducted under the responsibility of the European Radio communication Office (ERO) and European frequency regulatory administrations involving SARA and representatives of so-called "victim services" including the Earth Exploration Satellite Service (EESS).

The discussion process in Europe has resulted in a situation where a draft standard for SRR devices proposed by the European Telecommunications Standards Institute (ETSI) has been put on hold until compatibility between the new service and the existing protected services in the band has been proofed. CNES, ESA, and EUMETSAT have submitted compatibility studies. These studies were based on actual ITU Recommendations and input parameters received from SARA as well as parameters quoted in the draft ETSI standard. Present and future instruments were included into the study (conical scanned, cross-track nadir, and push broom sensors). The studies clearly indicate that operation of the new service is not compatible to EESS applications. Several mitigation techniques have been proposed but so far, these have not resulted in acceptable sharing conditions.

The study was discussed at the CEPT special working group SE-24 in Bern (Switzerland). The conclusion of this group was that sharing between the car radars and EESS (passive) is not feasible. Activities are concentrated to find an alternative frequency band. Nevertheless SARA claims that they would need to start implementation of the service in the band 21 – 27 GHz. This is due to the availability of sensors, which were designed for this band. SARA representatives have proposed to develop a new type of sensor which will operate in a different band and that they intend to depart from the band covering the EESS (passive) allocation. It will now be necessary to find and agree on an alternative band and to develop a committing schedule for introduction and termination of the service. It is foreseen to fix a date after which no new equipment will be installed. Such a committing schedule could be made part of the licensing agreement issued by the frequency regulators. The EESS community could agree on this regulation recognizing that:

- In the first years of service implementation there would be only small numbers of cars equipped with these radars
- EESS sensors of a new, more sensitive type (as included in the compatibility study) would only be implemented in a few years.

The FCC in the USA has issued a "First Report and Order" (ET Docket 98-153) on 22 April 2002 regarding the use of Ultra-Wideband transmissions including the use of this technology for "Vehicular Radar systems". Although this document concludes that no harmful interference will be caused to meteorological satellite measurements, it is expected that the associated spectrum masks and operation values used in this document are not giving the required protection to EESS usage in the band. It has therefore to be expected that the introduction of the new service will invalidate measurements of instruments operated on meteorological satellites. Wrong measurement values will be achieved and will invalidate not only the measurements in the 24 GHz band but also all other measurements of these instruments. This could result in a major degradation in meteorological processing based on these measurements.

A phased approach for the introduction of the Vehicle Radar System has been proposed by reducing the output power of SRR equipment after certain dates to compensate for the growing number of operating devices and the related cumulative interference from serious high numbers of equipment. Although this could improve the sharing situation,

There are still doubts whether this will give the required protection. It is also noted that the equipment will be operated under part 15 of FCC rules, i.e. as unlicensed equipment.

ITU has discussed the issue of UWB and has decided that a Task Group (TG 1/8) be established in Study Group 1 in order to urgently address the compatibility between UWB devices and radio communication services (Q.227/1), the spectrum management framework related to the introduction of UWB devices (Q.226/1), and appropriate measurement techniques for UWB devices. Considering the criticality of this issue to the space-component of the Global Observing System and to its all weather sounding capability CGMS is invited to discuss this issue and to elaborate on possible solutions to the problem. The attached study provides the necessary background for these discussions. An update of developments in Europe will be given verbally at CGMS XXX.

2.1 EXECUTIVE SUMMARY

This chapter is a compatibility analysis between the short range automotive radars which are planned to operate in the 21-27 GHz band and the EESS (passive) meteorological sensors operating in the purely passive band 23.6-24 GHz band. The parameters for these studies are derived from:

- the draft ETSI System Reference Document for short range radars in the 24 GHz band (ETSI TR 101 982R1 v1.1.3a (2002-05)),
- the characteristics of the EESS passive sensors operating in the band 23.6-24 GHz, provided by the EESS representatives,
- the protection criteria for EESS passive sensors contained in the ITU-R recommendation SA.1029-1 and those updated by ITU-R WP 7C in February 2002.
- the protection criteria for EESS passive sensors which are envisaged by the Space and the meteorological Agencies in the far future around the year 2020.
- additional technical information provided by the SARA group as mitigation factors.
- figures from the SARA group about foreseen vehicle density scenarios. The results show that sharing with all types of EESS sensors would result in a sizable negative margin (up to 20 dB for current requirements and up to -27 dB in the very long term

for future instruments), corresponding to the loss of the required meteorological information. This report also contains a ground scattering model that leads to margins up to – 25 dB (instead of – 20 dB that took into account the direct path only) for current

2.1.1 Requirements of passive sensors:

It is to be noted that ITU-R footnote 5.340 does not allow any emission in the band 23.6-24 GHz and that, according to the Rules of Procedures of the ITU-R Radio Regulation Board, it is impossible to notify any system in the bands listed in footnote 5.340. Therefore, the use of the bands covered by footnote 5.340 must be avoided by any type of UWB device. All the above reasons come to the conclusion that the short range radars cannot share the band with the EESS (passive) in the band 23.6-24 GHz. Given the importance of the use of these meteorological parameters for weather forecast, SE-24 suggests exploring the possibility to shift the UWB band to avoid entering the 23.6-24 GHz band.

The report also contains elements concerning the use of the adopted FCC regulation and also for a proposal from ETSI to introduce lower eirp and improved antenna pattern. Those two regulations are quite similar and lead to the same conclusion: the Short Range Radars using these new lower figures cannot share the band with the EESS (passive) in the band 23.6-24 GHz.

2.2 PASSIVE SERVICE

The EESS (passive) currently operates two types of passive sensors:

- Conically scanned sensors around the nadir direction, which are designed to measure two dimensional surface (land and ocean) parameters;
- Cross-track nadir sensors which are designed to measure three-dimensional atmospheric parameters.

2.2.1 EESS (passive) frequency allocation status

2.2.1.1 General

In recognition of:

- The extreme vulnerability to interference of microwave passive sensors which are designed to measure very faint natural emissions.

- and the catastrophic consequences that interference may have on operational and scientific applications which rely on microwave passive measurements, Exclusive Status has been granted to most passive allocations, in particular to those which are used for 3D atmospheric measurements, to the exception of frequency bands where the natural atmospheric attenuation provides sufficient shielding to prevent interference (for instance, in the O_2 absorption spectrum around 60 GHz).

2.2.1.2 The 23.6-24 GHz frequency band

- The 23.6-24 GHz frequency band is allocated to the EESS (passive) with an exclusive status where the footnote 5.340 is applicable.

- The footnote 5.340 stipulates that all emissions are prohibited in these frequency bands.

- According the Rules of Procedures of the Radio Regulation Board, it is impossible to notify any system in the bands listed in footnote 5.340.

The table 1 summarizes the frequency allocation around 24 GHz.

Table 2.1 Adjacent band allocations

Services in lower allocated bands		Passive band	Service in upper allocated band
22.55-23.55 GHz	23-23.6 GHz	23.6-24 GHz	24-24.05 GHz
FIXED INTER-SATELLITE MOBILE	FIXED MOBILE	EARTH EXPLORATION-SATELLITE (Passive) RADIO ASTRONOMY SPACE RESEARCH (Passive) S5.340	AMATEUR AMATEUR-SATELLITE S5.150

NOTE – The Inter-satellite allocation could be used for GSO and non-GSO systems.

It should be emphasized that, despite the fact that interference may be suffered by the passive sensor, near the lower and upper edges of the allocated passive band, due to out-of-band emissions from active services allocated in adjacent bands, the exclusive status of the allocation essentially guarantees the cleanliness of the passive band, thus preserving the potential improvement of this sensing technique.

2.2.2 Service

2.2.2.1 General interest of the band 23.6-24 GHz

The band 23.6-24 GHz is of primary interest by itself to measure water vapor and liquid water. It is used by both conically scanned and cross-track nadir sensors. The total water vapor content from the ground to the satellite is best measured in this frequency band and, it is not possible to find any equivalent frequency band having this same characteristic in the whole electromagnetic spectrum.

2.2.2.2 Auxiliary parameter for 3D vertical atmospheric temperature sensing

Three dimensional atmospheric temperature measurements of utmost importance for operational meteorology (numerical weather forecasting models) and climate studies and monitoring are performed in the oxygen absorption spectrum around 60 GHz. Temperature is also essential to retrieve passive measurements of other atmospheric gases which play a major role in energy transport (water vapor) and photo-chemistry processes (o3, CH4, No2…).

Besides these primary measurements, auxiliary parameters are simultaneously measured because they are mandatory to decontaminate the primary measurements from unwanted effects due to atmospheric moisture (water vapor and liquid water).

Auxiliary parameters are obtained in three radiometric channels:

- Around 23.8 GHz for the total water vapor content;
- Around 90 GHz for the liquid water (precipitation);
- Around 31.5 GHz, which is the optimum « window » in the « valley » resulting from the combination of the oxygen and water-vapor absorption curves (see the channel 2 (A) on the figure 1 below), and which serves as a reference for all other measurements.

These auxiliary measurements must have radiometric and geometric performances consistent with those of the primary measurements, and must receive similar

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These auxiliary measurements must have radiometric and geometric performances consistent with those of the primary measurements, and must receive similar protection against interference. It is noted that the non-availability of only one auxiliary channel totally invalidates the complete data set.

These frequencies are indicated on the atmospheric O_2 and H_2O absorption curves presented on figure 1, where « channels 1(A) and (B), 2(A) and (B), 3(A) and (B)… » refer to the AMSU-A and B vertical sounders which are currently deployed on operational meteorological satellites.

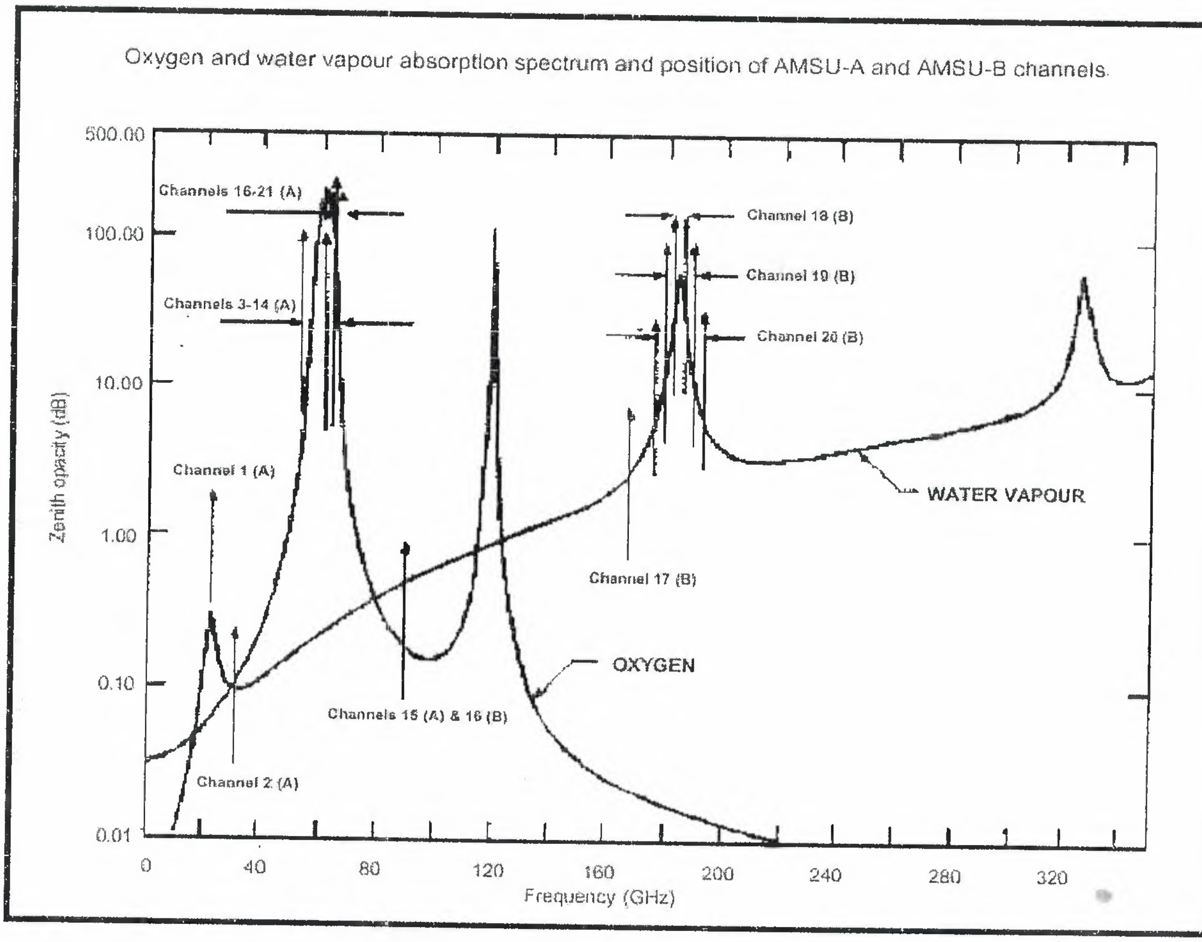


Figure 2.1 Frequencies for three dimensional passive atmospheric sounding

It must be emphasized that besides the numerical weather prediction, many applications relying on these measurements are strongly life and property-safety related. It was demonstrated that they can be severely hampered by any interference exceeding the internationally agreed threshold. These applications are in particular:

- Detection and signalization of potentially hazardous meteorological events. The augmentation of these hazardous events, even at mid latitudes, raises serious concerns in the scientific community;

- Air and sea traffic routing and safety in the vicinity of airports;
- Off-shore activities and in general out-door industrial activities.

Concerning the band 23.6-24 GHz, it is important to note that this is the unique band in the whole electromagnetic spectrum where it is possible to retrieve with a good quality the total vertical water vapor content. Therefore, it is essential to preserve such a frequency band.

2.2.3 Required protection criteria

The following three documents establish the interference criteria for passive sensors.

1) Recommendation ITU-R SA.513-3, Frequency bands and bandwidths used for satellite passive services

2) Recommendation ITU-R SA.1028-1, Performance criteria for satellite passive remote sensing.

3) Recommendation ITU-R SA.1029-1, Interference criteria for satellite remote sensing.

The interference criteria are the following:

- The interference threshold of the passive sensor is -163 dBW in a reference bandwidth of 100 MHz. This is a maximum interference level from all sources. Such a threshold corresponds to a measurement sensitivity of 0.2 K.
- For conical scan instruments, the number of measurement cells lost due to the threshold being exceeded must not exceed 5% in cases where the interference events are random and 1% when the interference events are systematic. For three dimensional measurements of atmospheric temperature or gas concentration, the number of measurement cells lost due to the threshold must not exceed 0.01%.

It should be emphasized that operational applications which are routinely operating microwave passive sensors rely heavily on background scientific activities aiming at a better understanding and knowledge of the complex land/ocean-atmosphere machinery.

For that reason, the required performance parameters and interference criteria which are contained in the recommendations ITU-R SA.1028 and 1029 must be regularly updated to reflect such improvements, and to take advantage of the technological advances. These recommendations were recently revised (WP7C, February 2002).

The revised interference criteria are the following.

- The interference threshold of the passive sensor is -166 dBW in a reference bandwidth of 200 MHz. This is a maximum interference level from all sources. Such a threshold corresponds to a measurement sensitivity of 0.05 K.
- The number of measurement cells where the interference threshold can be exceeded must not be more than 0.01% of pixels in all service areas for any kind of instrument.

2.2.4 Operational characteristics

Operational characteristics of conically scanned instruments

The following table provides characteristics of conically scanned sensors.

Table 2.2 Preliminary specifications for microwave radiometric applications using conically scanned sensors

Channel 23.6 – 24 GHz	MEGHA-TROPIC	**EOS-AMSR-E**
Channel bandwidth	400 MHz	400 MHz
Pixel size across track	35.4 km	17.6 km
Beam efficiency	96 %	97%
Incidence angle i at footprint centre	52.3°	55°
Half cone offset angle	44.5°	47.5°
Useful scan angle	130°	122°
Altitude of the satellite	817 km	705 km
Maximum antenna gain	40 dBi	46 dBi
Reflector diameter	650 mm	1.6 m
Half power antenna beamwidth ?$_{3dB}$	1.65°	0.9°

The pixel size across track is computed from the –3 dB contour of the antenna pattern taking into account the satellite altitude and the incidence angle of the beam bore sight.

It is important to note that this kind of EESS sensor is not a nadir satellite, but an EESS sensor having a conical scan configuration centered on the nadir direction. It is important for the interpretation of surface measurements to maintain a constant ground incidence angle along the entire scan lines. The in orbit configuration of conically scanned instruments is described in the figure 2. The rotation speed of the instrument (and not the satellite) is w = 20 revolutions per minute (rpm) for MEGHA-TROPIC and 40 rpm for EOS AMSR-E. At its altitude, the conical scan radiometer measures the upwelling scene brightness temperatures over an angular sector (useful scan angle in Figure 2).

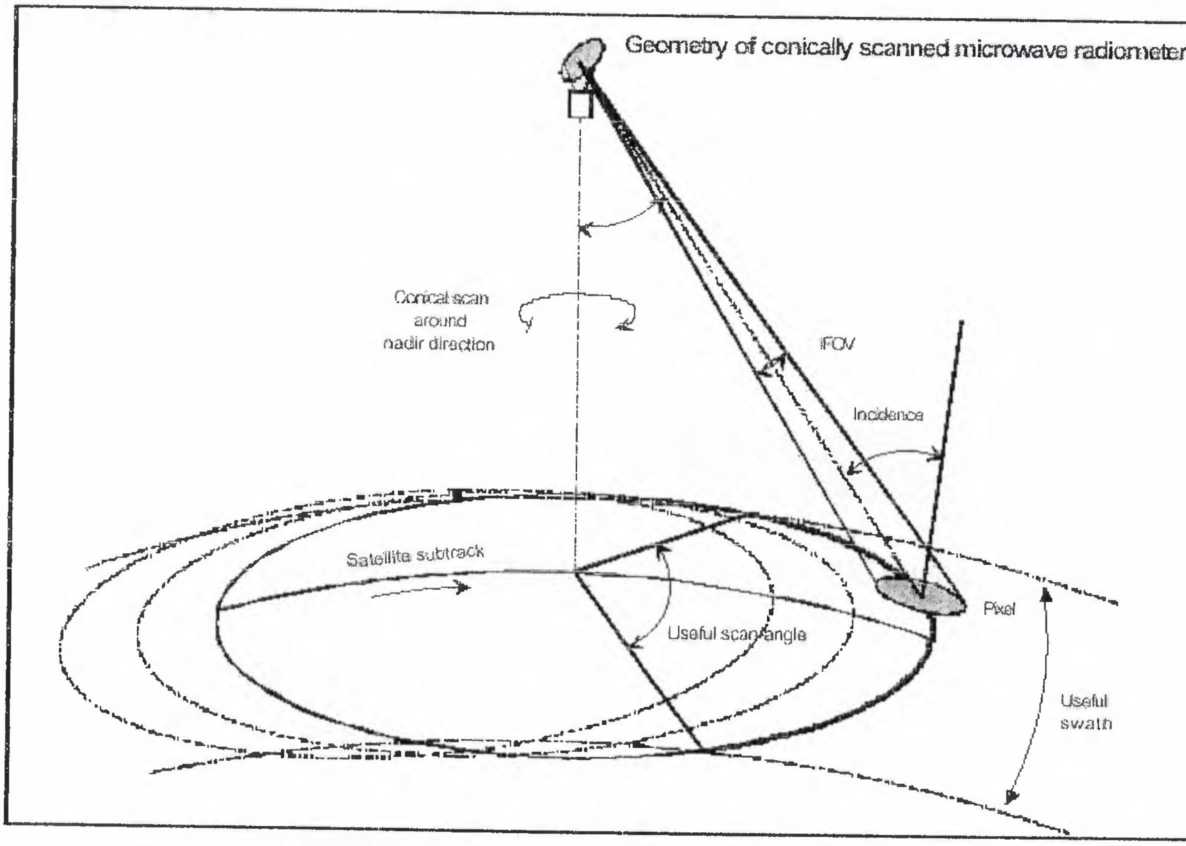


Figure 2.2 Configuration of conically-scanned passive microwave radiometers

The typical geometrical parameters of this kind of instruments are the following (for an altitude of about 850 km).

– Ground incidence angle I at footprint centre: around 50°.

– EESS offset angle to the nadir or half cone angle a to the nadir direction: about 44°.

– Useful swath of about 1600 km.

– The scanning period is chosen in order to ensure full coverage and optimum integration time (radiometric resolution).

The hereunder figure shows the relative antenna gain pattern of the MEGHA-TROPIC satellite below the maximum gain.

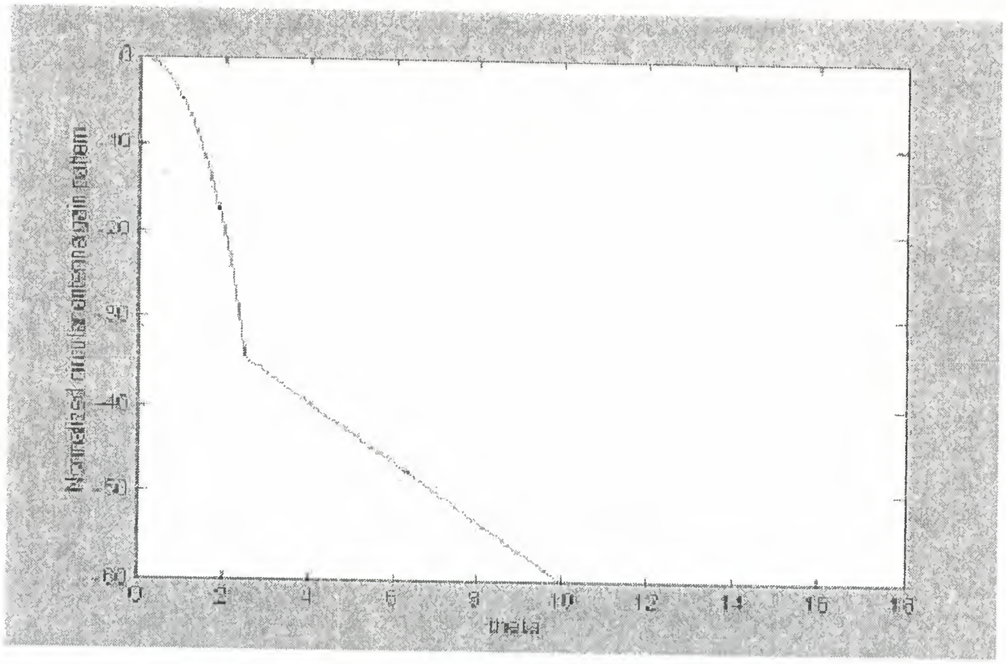


Figure 2.3 Antenna gain pattern of the MEGHA-TROPIC satellite

The hereunder figure shows the relative antenna gain pattern of the EOS AMSR-E satellite below the maximum gain.

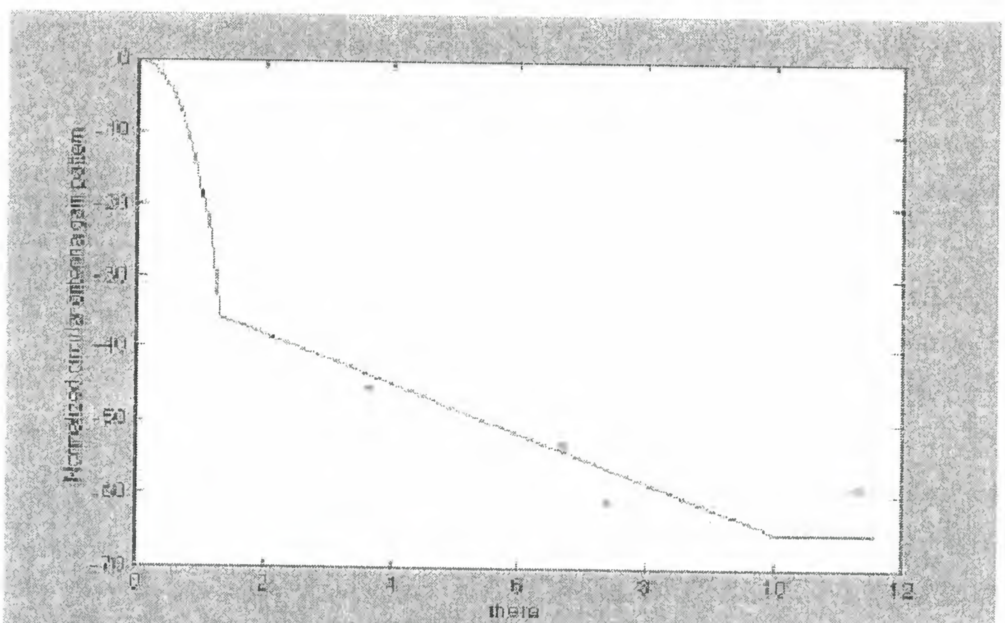


Figure 2.4 Antenna gain pattern of the EOS AMSR-E satellite

2.2.5 Operational characteristics of cross-track nadir sensors

The cross-track nadir sensors retained for this analysis are the AMSU and the "push-broom". They both scan in a vertical plane containing the nadir direction, normal to the velocity vector of the satellite.

The AMSU (Advanced Microwave Sounding Unit) is a mechanically scanned instrument, where the pixels are acquired sequentially. The cold-space calibration is implemented once per scan revolution by the main antenna, when looking in the cold space direction. The AMSU instrument contains 20 channels and is comprised of two major components, AMSU A and AMSU-B. The 23.6-24 GHz band is contained within the AMSU-A instrument (module AMSU A2).

The « push-broom » is a purely static instrument with no moving parts, where all pixels in a scan-line are acquired simultaneously, enabling to significantly increase the integration time and the achievable radiometric resolution. The push-broom incorporates one fixed data acquisition antenna pointing in direction of nadir and one dedicated cold space calibration antenna.

The main characteristics of these sensors are given in Table 3.

Table 2.3 Cross-track nadir sensors characteristics

Parameter	**AMSU**	**Push-broom**
Main antenna gain (dBi)	36	45
Antenna Back Lobe Gain (dBi)	-12	−12
IFOV (Instantaneous Field Of View) at -3 dB in °	3.3	1.1
Total FOV (Field Of View) cross/along-track (°)	96.66/3.3	100/1.1
Pixel size (km)	48	16
Number of pixels per line	30	90
Sensor Altitude (km)	850	850
Cold calibration antenna gain (dBi)	36	35
Cold Calibration Angle (re.satellite track)	90	90
Cold Calibration Angle (re. nadir direction)	83	83
Type of Scan	Mechanical	Electronic

The in-orbit configurations of the AMSU and the "push-broom" sensors are described on the figures 5 and 6 respectively.

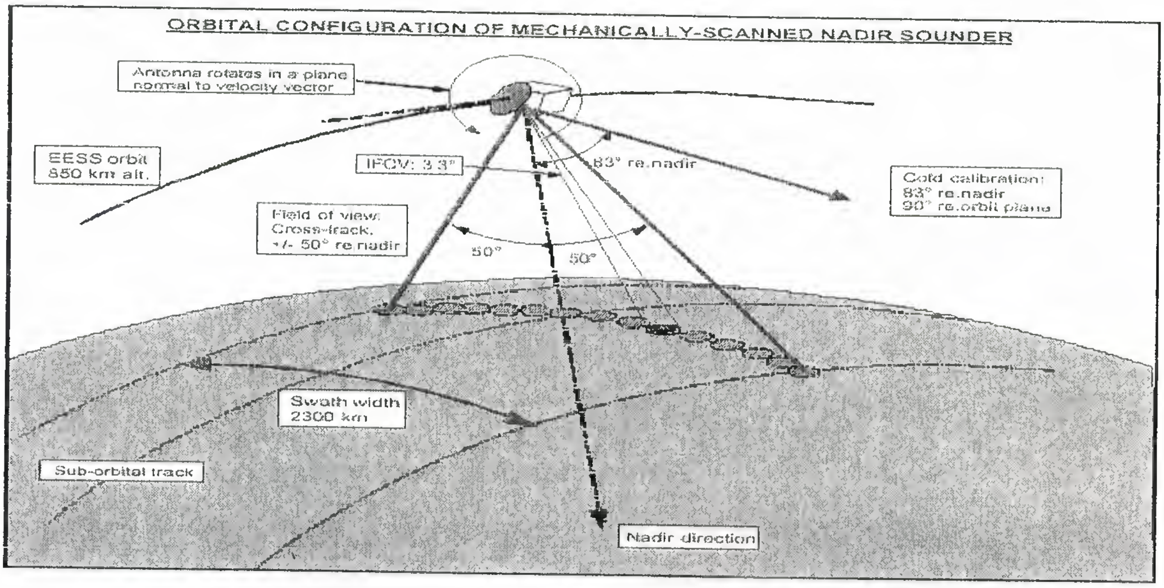


Figure2.5 Geometry of a nadir scanpas

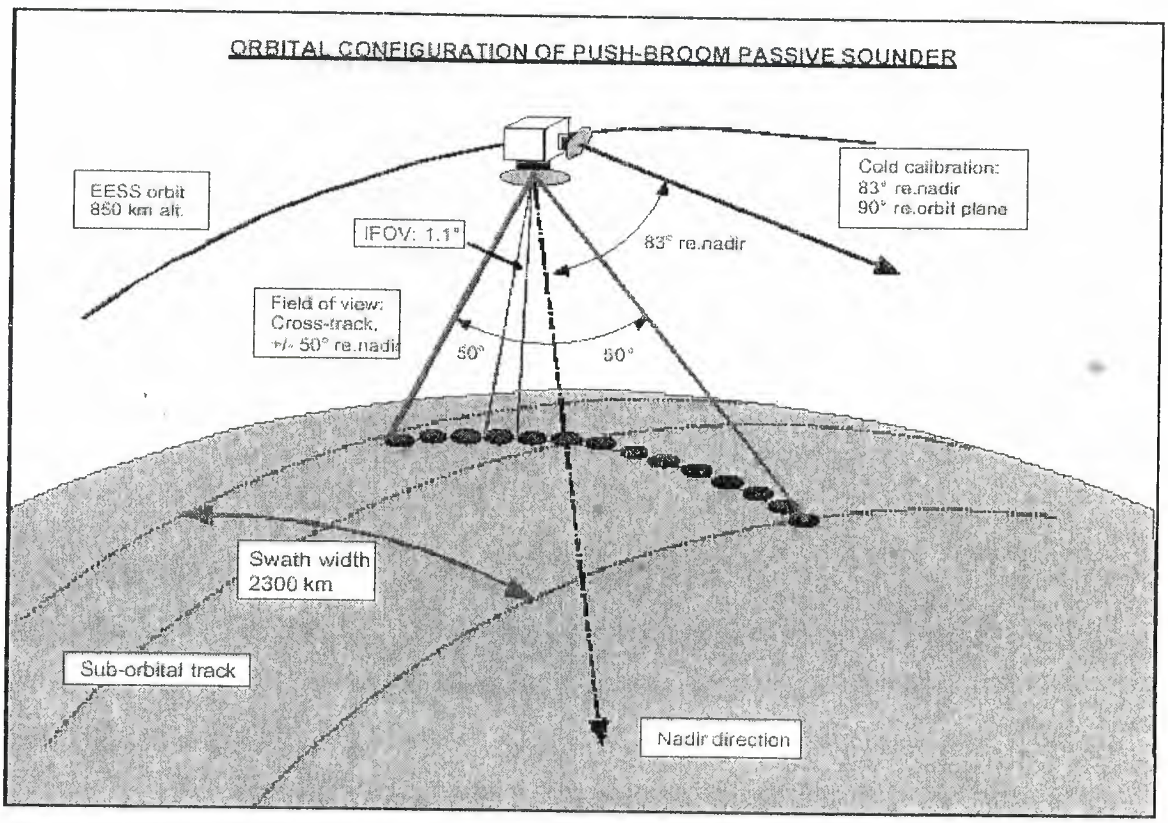


Figure 2.6 Orbital configuration of the push-broom sensor

2.2.6 Characteristics of the 24 GHz automotive radar

2.2.6.1 Transmit carrier frequency

The carrier transmitted frequency is within the range 24.05-24.25 GHz.

The band 24-24.25 GHz (centre frequency 24.125 GHz) is designated for industrial, scientific and medical (ISM) applications.

Administrations shall take all practical and necessary steps to ensure that radiation from equipment used for industrial and medial applications is minimal and that, outside the bands designated for use by this equipment, radiation from such equipment is at level that does not cause harmful interference to a radio communication service.

2.2.6.2 Limitation of vertical antenna characteristic

The applicable ETSI document gives the limitations of vertical antenna pattern for the car radars. The following table gives the spatial antenna gain for a vertical antenna angle θ in o. Antenna gains of about 15 dBi are typical for automotive short range radars.

Table 2.4 Limitation of vertical antenna pattern

Vertical antenna angle θ in °	Spatial antenna gain in dBi
$\theta < -70°$ and $\theta > 40°$	G_max - 26.66
$-70° < \theta < -30°$	G_max + 0.66(θ + 30)
$-30° < \theta < 0°$	G_max
$0° < \theta < 40°$	G_max - 0.66 θ

2.2.6.3 Bumper loss

According to the applicable ETSI document, the mounting of 24 GHz SRR devices behind metallic colored vehicle bumpers do not pose problems due to size and attenuation by the bumper material. However, this is highly critical for devices working at 77 GHz. In addition to that, concerning the application capability, it is stated that simulation and experiments tell that devices at 24 GHz can live with these application requirements while 77 GHz devices suffer from significant attenuation in excess of 20 dB. According to information provided by ETSI, the following compatibility analysis will take into account a loss of 3 dB due to bumper attenuation.

2.3 INTERFERENCE ASSESSMENT

The general methodology applicable to this document is to compute the margin given a certain expected vehicles density, as they are provided in §2.2. According to the applicable ETSI document, several automotive radars are planned for each car, but they are not all operated simultaneously. According to information provided by ETSI, the basis is 4 SRR per car that are supposed to be in operation simultaneously. However, for the specific case of the conical scan instruments due to their geometry, it is assumed a mitigation of factor of 25% due to random car directions.

2.3.1Conically scanned instruments

The hereunder table provides the results of the compatibility analysis for conical scan instruments.

Table 2.5 Compatibility analyses between automotive radars at 24 GHz and MEGHA-TROPIC, EOS AMSR-E

Parameter	MEGHA-TROPIC	EOS AMSR-E
Maximum EIRP (power spectral density)	-30 dBm / MHz	-30 dBm / MHz
Bumper attenuation	-3 dB	-3 dB
Elevation angle in order to reach the maximum EESS antenna gain	37.7°	35°
Radar antenna gain at the above elevation angle (0° ideal elevation)	15 – 0.66*37.7 = -9.8 dBi	15 – 0.66*35 = -8.1 dBi
Radar antenna gain to be substracted	Gmax (15) – (-9.8) = 24.8 dBi	Gmax (15) – (-8.1) = 23.1 dBi
Direct power component	-87.8 dBW/MHz	-86.1 dBW/MHz
Distance radar - EESS sensor in km	1336	1229
Space attenuation in dB	182.5 dB	181.7
EESS antenna gain in dBi	40	46
Atmospherical loss (ITU-R P.676)	-1.0 dB	-1.0 dB
Received power at the EESS in a 1 MHz bandwidth in dBW	-231.3	-222.8
Corresponding received power at the EESS in a bandwidth of 100 MHz in dBW for one single radar.	-211.3	-202.8

EESS interference threshold in a reference bandwidth of 100 MHz: application of ITU-R SA 1029-1	-163 dBW	-163 dBW
Number of radars in order to reach the EESS threshold	48.3 dB (67608 radars)	39.8 dB (9549 radars)
Number of active radars per car	4	4
Mitigation factor due to random car directions (25%)	- 6 dB	- 6 dB
Size of the EESS pixel: diameter in km	35.4	17.6
Maximum car density per km^2 corresponding to the above number of cars in the EESS pixel	$67608 / \pi\left(35.4/2\right)^2 = 68.6$ or 18.3 dB (cars) per km^2	$9549 / \pi\left(17.6/2\right)^2 = 39.2$ or 15.9 dB (cars) per km^2
Expected car density per km^2	123/ Km^2 (Highway) (20.9dB) 330/Km^2 (Urban/suburb.) (25.2dB)	123/ Km^2 (Highway) (20.9 dB) 330/ Km^2(Urban/suburb.) (25.2 dB)
Margin in highway scenario	**-2.6 dB**	**-5 dB**
Margin in urban/suburban scenario	**-6.9 dB**	**-9.3 dB**

The margin for both instruments and for both car density scenarios is negative.

A more realistic computation is to take into account the revised version of ITU-R SA. 1029-1. therefore, the above margins become.

Table 2.6 Resulting margins of the compatibility analysis between automotive radars at 24 GHz and MEGHA-TROPIC, EOS AMSR-E using the revised version of ITU-R recommendation SA.1029-1

Parameter	**MEGHA-TROPIC**	**EOS AMSR-E**
EESS interference threshold in a reference bandwidth of 200 MHz: revised ITU-R SA 1029-1	-166 dBW	-166 dBW
Margin in highway scenario	**-8.6 dB**	**-11 dB**
Margin in urban/suburban scenario	**-12.9 dB**	**-15.3 dB**

2.3.2 Cross-track nadir sensors

The compatibility between cross-track nadir sensors and automotive radars is evaluated in the table 7 below.

Table 2.7 Compatibility analyses between automotive radars at 24 GHz and nadir sensors

Parameter	Push-Broom	AMSU-A
Radar EIRP density in main lobe	-30 (dBm/MHz)	-30 (dBm/MHz)
Bumper attenuation	*-3dB*	*-3dB*
Direction of interfering path	Zenith	Zenith
Radar antenna gain to be substracted	-26.6	-26.6
Radar EIRP density to zenith :direct power component	-89.6 dBW/MHz	-89.6 dBW/MHz
Distance radar - passive sensor (km):	850	850
Space loss at 23.8 GHz in dB	178.6	178.6
Atmospherical loss (ITU-R P.676)	-1.0 dB	-1.0 dB
EESS antenna gain in dBi	45	36
Power density received by the sensor from one single radar (dBW/MHz)	-224.2	-233.2
Corresponding received power at the EESS in a bandwidth of 100 MHz in dBW for one single radar.	-204.2	-213.2
EESS interference threshold in a reference bandwidth of 100 MHz: application of ITU-R SA 1029-1	-163 dBW	-163 dBW
Number of radars in order to reach the EESS threshold	41.2 dB (13182 radars)	50.2 dB (104712 radars)
Number of radars active per car	4	4
Size of the EESS pixel: diameter in km	16	48
Maximum car density per km^2 corresponding to the above number of cars in the EESS pixel	$3295 / \pi\left(16/2\right)^2 = 16.3$ or 12.1 dB (cars) per km^2	$26178 / \pi\left(48/2\right)^2 = 14.4$ or 11.6 dB (cars) per km^2
Expected car density per km^2 (as from SARA forecast)	123/ Km^2 (Highway) (20.9dB) 330/Km^2 (Urban/suburb.) (25.2dB)	123/ Km^2 (Highway) (20.9 dB) 330/Km^2(Urban/suburb) (25.2dB)
Margin in highway scenario	**- 8.8 dB**	**- 9.3 dB**
Margin in	**- 13.1 dB**	**- 13.6 dB**

The margin for both instruments and for both car density scenarios is heavily negative, even taking into account the ITU-R SA. 1029-1.

A more realistic computation is to take into account the revised version of ITU-R SA. 1029-1. therefore, the above margins become.

Table 2.8 Resulting margins of the compatibility analysis between automotive radars at 24 GHz and push-broom, AMSU-A using the revised version of ITU-R recommendation SA.1029-1

Parameter	Push-broom	AMSU-A
EESS interference threshold in a reference bandwidth of 200 MHz: revised ITU-R SA 1029-1	-166 dBW	-166 dBW
Margin in highway scenario	**- 14.8 dB**	**- 15.3 dB**
Margin in urban/suburban scenario	**- 19.1 dB**	**- 19.6 dB**

2.3.3 Effect on EESS passive sensors of the calculated interference from SRR

The following table gives the temperature error corresponding to the interference calculated for the various sensors in the two scenarios. The required protection threshold is 0.01 K, corresponding to a radiometric sensitivity of 0.05 K.

Table 2.9 Resulting radiometric temperatures of the EESS (passive) sensors due to the interference caused by the automotive radars at 24 GHz

EESS Sensor	Equiv.ΔT (K) highway	Equiv.ΔT (K) Urban/suburban
3 MEGH A-TROPIC	0.36	0.98
AMSR-E	0.63	1.7
Pushbroom	1.51	4
AMSU-A	1.7	4.5

The sensor's performance requirements are very significantly degraded, and are brought back to the situation of the seventies. Such a step backward would negate the efforts cumulated during three decades by the public services that rely on passive measurements, and ruin their results.

2.4 FUTURE PROTECTION CRITERIA

Permissible interference based on operational weather forecast and climate monitoring today, the required delta T is 0.05 K which is needed for surface remote sensing and assimilation in the numerical weather forecasts (NWP). It is to be noted that, at the time of completion of the ETSI scenario for the SARA group, the required radiometric sensitivity of the passive sensor will be well below 0.05 K. A reasonable hypothesis by the year 2020 for this value is 0.01 K, which will be needed for global climatic change monitoring and global change survey. It is therefore to be expected that a future revision of Recommendation 1029 will have a –173 dBW/200 MHz threshold value for this band around the year 2020. The sharing analysis conducted in this document uses the official figures contained in Recommendation SA.1029 and its revised version, but the sensor evolution should be kept in mind when analyzing the results. These expected requirements explain why this band is designated as "purely passive" in the ITU regulations. It is of utmost importance that the « cleanliness » of the exclusive passive sensor allocations is preserved, in order not to unduly limit the improvement potential of the applications that rely on these passive measurements.

2.4.1 Permissible interference based on the technological evolution of the passive 2.4.1.1 sensors

Taking into account the technological evolution of the on space borne passive sensors, it is expected that the cross track nadir sensors will be able to reach a sensitivity measurement of 0.01K.

2.4.1.2 Review of the margins

The following table provides the updated margins taking into account the above future threshold requirements of –173 dBW/200 MHz.

Table 2.10 Resulting margins of the EESS (passive) sensors due to the interference caused by the automotive radars at 24 GHz using an initial measurement sensitivity requirement of K (future evolutions of cross track nadir sensors)

Type of EESS sensor	Highway scenario	Urban/suburban scenario
Pushbroom	Margin = - 21.8 dB	Margin = - 26.1 dB
AMSU-A	Margin = - 22.3 dB	Margin = - 26.6 dB

2.5 OTHER ASPECTS IN THE SHARING ANALYSIS

Although the above compatibility analysis can be used to draw conclusions on the sharing feasibility, the following factors have not been yet considered. Noting that each of the following effect is able to create additional negative margins, resulting into a compatibility situation even worse, it may not be necessary to examine in depth all the following effects.

2.5.1 Scattering effects

The US meteorological administration (NOAA) has made a study that analyses the impact of the radar signal scattering. One of the most probable coupling scattering mechanisms between mobile vehicle radar and a satellite radiometer is a reflection of the main lobe of the radar by another directly-illuminated vehicle toward the main lobe of the radiometer. This study has shown that the reflection generated by the rear part of the car in front of the transmitting radar would create a coupling ranging from –10 to –30 dB with respect to the EESS radiometers within the range of look angles. This study considers reflections from other cars only and takes into account the reflections due to the curvature of the window (characterized by an effective radius of curvature), the glass thickness and the distance between the two cars. Assuming that the short range radars will use horizontal polarization to minimize ambiguous signals from roadway backscattering, the figures are the following for a glass thickness of 0.5 cm and for a radius of curvature of 10 m.

⇨ Cars with a separation distance of less than 10 m: about 5% of cars and a scatter gain of – 15 dB.

⇨ Cars with a separation distance of less than 30 m and more than 10 m: about 45% of cars and a scatter gain of – 18 dB.

⇨ Cars with a separation distance of more than 30 m: about 50% of cars and a scatter gain of – 25 dB.

In addition to the above scattering gains, we take a hemispherical averaging factor of -6 dB and a -1 dB factor due to the gain due to the scattering from asphalt.

Therefore, the averaged car scattering gain becomes:

$$\overline{car\_scattering\_gain} = -6 + 10 * \log 10\left[0.05 * 10^{-1.5} + 0.45 * 10^{-1.8} + 0.5 * 10^{-2.5}\right] = -25.8\,\text{dB}$$

2.5.2 Compatibility analysis

According to §3, the cross-track nadir sensors are more sensitive than conical scan sensors.

Therefore, it is possible to compute the resulting averaged attenuation of the horizontal eirp of the short range radar in the EESS direction (at the nadir) taking into account the following parameters:

⇨ the above car scattering gain,

⇨ the current ETSI attenuation of the horizontal eirp of the SRR (-26.6 dB) in the EESS direction (nadir),

⇨ an additional attenuation of 1 dB due to the asphalt.

$$averaged\_eirp\_attenuation = 10 * \log 10\left[10^{-2.58} + 10^{-2.66} + 10^{\frac{-26.6-1}{10}}\right] = -21.8\,\text{dB}$$

The conclusion of the calculation shows that the scattering effect brings an additional negative margin of 4.8 dB. The resulting margins of table 8 become.

Table 2.11 Resulting margins of the compatibility analysis between automotive radars at 24 GHz and push-broom, AMSU-A using the revised version of ITU-R recommendation SA.1029-1 and a ground scattering model

Parameter	Push-broom	AMSU-A
Margin in highway scenario	**- 19.6 dB**	**- 20.1 dB**
Margin in urban/suburban scenario	**- 23.9 dB**	**- 24.4 dB**

2.5.3 Residual carrier component in the sensor band

A residual carrier component is generated by the SRR radars due to the finite phase shift precision. The current draft specification for automotive radars does not guarantee the absence of residual carrier components in the nearby sensor band. The low-cost characteristics of these radars do not guarantee a proper filtering capability. This could imply much higher power levels than the ones currently assumed in the calculations, in particular when combined with the effects of clock ageing.

2.5.4 Effects of clock ageing

The current draft specification does not give indications about the required short-term and long-term stability of the clock. Here again the low-cost concept of the radars can play a role.

A drift with time of the central frequency would generate much higher interference levels than the ones considered so far in the ideal case.

2.5.5 Radar misalignment

The effect of the radar elevation with respect to the elevation angle has not been taken into consideration. These misalignments can be caused by two factors:

- The car is moving uphill.
- The radar is not mounted properly and presents max gain above 0 o. This improper mounting is likely to happen frequently, due to the fact that the optimal configuration for the radar does not correspond to the down-tilted mask in the ETSI document but rather to a more symmetrical configuration similar to what was presented by ETSI (BOSCH) at the first CEPT UWB workshop in 2001 in Mainz.

2.5.6 Apportionment

Since this band is exclusively allocated to the EESS (passive), interferences near the lower and upper limits of the allocated band are to be expected only due to unwanted emissions from active services allocated in the adjacent bands (see table 1 for the current allocated services). The concept of "apportioning" the interference threshold among the various interferers (which are actually the adjacent services) has not been agreed yet within ITU-R (TG1/7).

2.6 USE OF THE US FCC REGULATION

2.6.1 Description of the adopted FCC rules concerning the 24 GHz automotive radars

The US Federal Communications Commission has released a revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems. It has been adopted February 14, 2002 and released April 22, 2002.

Concerning Vehicular Radar Systems, the FCC rules state the following:

-These devices are able to detect the location and movement of objects near a vehicle, enabling features such as near collision avoidance, improved airbag activation, and suspension systems that better respond to road conditions. Attenuation of the emissions below 24 GHz is required above the horizontal plane in order to protect space borne passive *sensors operating in the 23.6-24 GHz band. (...)*

-Our primary interference concern with vehicular radar systems is cumulative interference to passive sensing systems operating in the 23.6-24 GHz band on low earth orbiting satellites, including meteorological satellites. (…)

-NTIA based its analysis on 22 to 23 dB antenna discrimination at elevation angles above 30 degrees above the horizon. It concluded that the emissions from vehicular radar systems in the 23.6-24 GHz must be 35 dB below the Part 15 general emission limits at elevation angles greater than 30° above the horizon. (…)

-It agreed to permit UWB vehicular radar systems provided these systems attenuate emissions appearing within the 23.6-24 GHz band at greater than 30 dB elevations above the horizontal plane by the following amounts below the Part 15 general emission limits:

25 dB by January 1, 2005

30 dB by January 1, 2010

35 dB by January 1, 2014"

The FCC Part 15 general emission limits are –41.3 dBm/MHz.

2.6.2Resulting margins using these limits

The results contained in tables 6, 8 and 10 are reviewed taking into account the above FCC figures.

2.6.3 Conical scan instruments

Table 2.12 Resulting margins of the compatibility analysis between automotive radars at 24 GHz and MEGHA-TROPIC, EOS AMSR-E using the revised version of ITU-R recommendation SA.1029-1 and the FCC regulation

Parameter	MEGHA-TROPIC	EOS AMSR-E
EESS interference threshold in a reference bandwidth of 200 MHz: revised ITU-R SA 1029-1	-166 dBW	-166 dBW
Margin in highway scenario using a 25 dB antenna pattern attenuation by the year 2005	**+ 7.1 dB**	**+ 4.7 dB**
Margin in urban/suburban scenario using a 25 dB antenna pattern attenuation by the year 2005	**-3.2 dB**	**- 5.6 dB**
Margin in highway scenario using a 30 dB antenna pattern attenuation by the year 2010	**+ 12.1 dB**	**+ 9.7 dB**
Margin in urban/suburban scenario using a 30 dB antenna pattern attenuation by the year 2010	**+ 1.8 dB**	**- 0.6 dB**
Margin in highway scenario using a 35 dB antenna pattern attenuation by the year 2014	**+ 17.1 dB**	**+ 14.7 dB**
Margin in urban/suburban scenario using a 35 dB antenna pattern attenuation by the year 2014	**+ 6.8 dB**	**+ 4.4 dB**

The above table shows that positive margins are expected using the FCC figures, but those figures don't take into account the fact that, for example by the year 2014, when the antennas having an attenuation of 35 dB instead of 30 dB or 25 dB are introduced in the automotive market, we have to keep in mind that there will be already a significant number of cars equipped with the previous antenna patterns. Therefore, all the figures contained in the above table must be decreased by several factors depending on the number of cars already in use and having several types of antenna patterns.

The situation might be highly critical for EOS AMSR-E in urban/suburban areas.

2.6.4 Cross nadir instruments

Table 2.13 Resulting margins of the compatibility analysis between automotive radars at 24 GHz and push-broom, AMSU-A using the revised version of ITU-R recommendation SA.1029-1 and the FCC regulation

Parameter	Push-broom	AMSU-A
EESS interference threshold in a reference bandwidth of 200 MHz: revised ITU-R SA 1029-1	-166 dBW	-166 dBW
Margin in highway scenario using a 25 dB antenna pattern attenuation by the year 2005	**- 5.1 dB**	**- 5.6 dB**
Margin in urban/suburban scenario using a 25 dB antenna pattern attenuation by the year 2005	**- 9.4 dB**	**- 9.9 dB**
Margin in highway scenario scenario using a 30 dB antenna pattern attenuation by the year 2010	**- 0.1 dB**	**- 0.6 dB**
Margin in urban/suburban scenario scenario using a 30 dB antenna pattern attenuation by the year 2010	**- 4.4 dB**	**- 4.9 dB**
Margin in highway scenario scenario using a 35 dB antenna pattern attenuation by the year 2014	**+ 4.9 dB**	**+ 4.4 dB**
Margin in urban/suburban scenario scenario using a 35 dB antenna pattern attenuation by the year 2014	**+ 0.6 dB**	**+ 0.1 dB**

The same comments as those noted in §6.2.1 are valid for the above table. The situation is even much more critical for cross nadir instruments, because the positive margins are quite small by the year 2014. In addition to that, it is expected that in the meantime, the passive sensor requirements would have been modified, so that the above margins envisaged for 2014 would become negative. Therefore, the use of the FCC regulation won't solve the compatibility issue, even in the long term for cross nadir sensors.

In addition to that, if we both consider very long term protection criteria in §4 and the ground scattering effect in §5.1, all the margins contained in table 13 become largely negative. The ground scattering effect will provide an additional negative margin of:

⇨ -4.2 dB for an attenuation of 25 dB of the antenna pattern in the direction of the nadir,

⇨ -6.5 dB for an attenuation of 30 dB of the antenna pattern in the direction of the nadir,

⇨ -10 dB for an attenuation of 35 dB of the antenna pattern in the direction of the nadir.

⇨ In 2020, it is expected that the cross nadir instruments will reach a radiometric sensitivity of 10 mK, so that it will result into an additional negative margin of – 7 dB.

2.7 PROPOSED MODIFICATIONS OF THE CURRENT ETSI STANDARD

2.7.1 Description of the modifications proposed by ETSI

In view of the above adopted rules by the US Federal Communications Commission, ETSI has proposed some modifications concerning the current SRD for automotive collision warning Short Range Radar. These modifications have not been yet adopted by ETSI and are still under discussion.

The proposed changes are the following.

⇨ Attenuation of the short range radar horizontal eirp down to:

– 40 dBm/MHz up to 2010,

– 45 dBm/MHz between 2010 and 2014,

– 50 dBm/MHz after 2014.

⇨ The short range radar antenna gain is attenuated to -30 dB (instead of -26.6 dB) in the direction of the nadir.

2.7.2 Resulting margins using these limits

The results contained in tables 6, 8 and 10 are reviewed taking into account the new above ETSI figures.

The use of the ground scattering model explained in §5.1 provides an averaged eirp attenuation of -23.5 dB (instead of -30 dB) in the nadir direction, which provides an additional negative margin of -6.5 dB.

Due to the fact that the cross nadir sensors are the most sensitive, the resulting margins will only address this specific type of passive sensor. The margins quoted in parenthesis are those obtained using the ground scattering model.

Table 2.14 Resulting margins of the compatibility analysis between automotive radars at 24 GHz and the cross nadir sensors using the revised version of ITU-R recommendation SA.1029-1 and the new ETSI figures

Parameter	Push-Broom	AMSU-A
EESS interference threshold in a reference bandwidth of 200 MHz: revised ITU-R SA 1029-1	-166 dBW	-166 dBW
Margin in highway scenario using an eirp of -40 dBm/MHz	**- 1.4 dB (-7.9)**	**- 1.9 dB (-8.4)**
Margin in urban/suburban scenario using an eirp of -40 dBm/MHz	**- 5.7 dB (-12.2)**	**- 6.2 dB (-12.7)**
Margin in highway scenario using an eirp of -45 dBm/MHz by the year 2010	**+ 3.6 dB (-2.9)**	**+ 3.1 dB (-3.4)**
Margin in urban/suburban scenario using an eirp of -45 dBm/MHz by the year 2010	**- 0.7 dB (-7.2)**	**- 1.2 dB (-7.7)**
Margin in highway scenario using an eirp of -50 dBm/MHz by the year 2014	**+ 8.6 dB (+2.1)**	**+ 8.1 dB (+1.6)**
Margin in urban/suburban scenario using an eirp of -50 dBm/MHz by the year 2014	**+ 4.3 dB (-2.2)**	**+ 3.8 dB (-2.7)**

The above table shows that positive margins are expected using the FCC figures and the direct path model, but those figures don't take into account the fact that, for example by the year 2014, when the radars having an eirp of - 40 dBm instead of -35 dBm or -30 dBm are introduced in the automotive market, we have to keep in mind that there will be already a significant number of cars equipped with the previous eirp. Therefore, all the figures contained in the above table must be decreased by several factors depending on the number of cars already in use and having several types of radars.

As it is explained in 6.2.2, it is expected that in the meantime, the passive sensor requirements would have been modified, so that the above margins envisaged for 2014 would become negative for the direct path model for the urban/suburban scenario.

If we consider very long term protection criteria in §4 (additional margin of – 7 dB) and the ground scattering effect in §5.1 (see the figures in parenthesis), all the margins contained in table 14 become largely negative.

2.8 Problems Caused by Car Radios in the 21 – 27 GHz Range

The FCC in the USA issued a "First Report and Order" (ET Docket 98-153) on April 22, 2002 regarding the use of ultra-wideband transmissions including the use of this technology for "Vehicular Radar systems". Although this document concludes that no harmful interference will be caused to meteorological satellite measurements, it is expected that the associated spectrum masks and operation values used in this document are not giving the required protection to EESS usage in the band. It has, therefore, to be expected that the introduction of the new service will invalidate measurements of instruments operated on meteorological satellites. Wrong measurement values will be achieved and will invalidate not only the measurements in the 24 GHz band but also all other measurements of these instruments. This could result in a major degradation in meteorological processing based on these measurements. A phased approach for the introduction of the Vehicle Radar System (VRS) has been proposed by reducing the output power of SRR equipment after certain dates to compensate for the growing number of operating devices and the related cumulative interference from serious high numbers of equipment. Although this could improve the sharing situation, there are still doubts whether this will give the required protection. It is also noted that the equipment will be operated under part 15 of FCC rules, i.e. as unlicensed equipment.

ITU has discussed the issue of UWB and has decided that a Task Group (TG 1/8) be established in Study Group 1 in order to urgently address the compatibility between UWB devices and radio communication services (Q.227/1), the spectrum management framework related to the introduction of UWB devices (Q.226/1), and appropriate measurement techniques for UWB devices. Considering the criticality of this issue to the space-component of the GOS and to its all weather sounding capability, CGMS members are invited to express their concerns to their national frequency administrations.

2.8.1 USA Response and Recommendation

The USA reviewed its position on the use of car radars systems operating in the 21 – 27 GHz band. The 24 GHz band is an exclusive and unique band for sensing characteristics of the atmosphere needed to forecast weather and climate throughout the world. Accordingly this band has been granted additional protection from Radio Frequency Interference (RFI) as stated in international ITU-R Regulation Number 5.340 ("all emissions are prohibited in the following bands:..."). The critical importance of this band for accurate and early weather forecasting has resulted in NOAA studies of the proposed use of this band for UWB devices and services, especially automotive radars. These studies resulted in a NOAA determination that the extensive proliferation of automotive radars in high density areas (e.g., metropolitan or urban areas) could seriously and permanently compromise the availability of weather data from this critical band. Most meteorological agencies, including NOAA, have also noted that the automotive radar functions could be performed in the 77 MHz band instead of the 24 GHz band, thereby ensuring that this unique 24 GHz resource would not be irreparably contaminated and remain available for its natural weather forecasting potential.

2.8.2 Communications and Measurement

One administration has approved regulations, including operating restrictions, authorizing the use of UWB devices on an unlicensed basis for communications and measurement applications. The characteristics given in Table 1 provide an example of two products that are being designed to operate under those regulations.

Table 1 Characteristics of some UWB communications devices

	Device A	**Device B**	**Device C**
Max. ave. eirp (dBm/1 MHz)	−41.3	−41.3	-41.3
Lower −20 dB and −10 dB emission limits (GHz)	3.1, 3.6	≥ 3.1 (−10 dB down)	3.1, 3.6
Upper −10 dB and −20 dB emission limit (GHz)	9.6, 10.1	≤ 10.6 (−10 dB down)	9.6, 10.1
Antenna pattern	Omni	Omni	Omni
Pulse rate (Mpps)	> 500	≥1	>1000
Bit rate (Mbps)	≤ 100	≤ 40	≤ 500
Range (m)	~10	< 100	4-10
Max. ave. eirp (dBm/1 kHz) in 960-1 610 MHz	≤−90	≤−85.3	≤-90
Max. ave. eirp (dBm/1 MHz) in 960-1 610 MHz	<−90	≤−75.3	≤-90
Max. ave. eirp (dBm/1 MHz) in 1 610-3 100 MHz	<−63.3	≤−53.3	≤-63.3

Device A is intended for operation within an office or home applications for transmission of data up to 100 Mbps. It is also intended for operation between hand held devices that may be outside and that do not employ a fixed infrastructure. Such applications include links among personal digital assistants (PDA) or lap top computers. Within a LAN, it may carry multiple digital video signals among components of a video system such as between a video camera and a computer, between a cable set-top box and a TV, or between a high-end plasma display and a DVD player. Device B is a multi-purpose device intended for use indoors for industrial, commercial, and consumer applications where communications, precision positioning or radar sensing is required. The device can be configured to operate over a range of data rates. The operating range depends upon the data rate.

Device C is intended for operation within an office or home applications for transmission of data up to 500 Mbps. These higher data rate devices are intended to provide wireless connectivity for many of the same applications as Device A, but also serve to provide wireless cable replacement for high-speed wired connections such as USB or IEEE 1394.

CHAPTER THREE
POLICE TRAFFIC RADAR

3.1 How does police radar works?

You're driving down the highway, and you're passed by a little red sports car. Two miles down the road, you see blue lights on a car parked just behind the red car. Have you wondered how the officer knew how fast they were going? How does the police radar work? Is there anything that I can do to avoid police radar?

3.2 Doppler radar

Police radar is a Doppler radar. It measures speed by looking for a red shift or blue shift in light, similar to the way astronomers measure the velocity and distance of stars.

The radar antenna emits a beam of light in the radio frequency range. The light bounces off of the target, and then returns to the police radar antenna. The velocity of the target will change the frequency of the radar signal. That change in frequency is interpreted by the radar unit and shown to the officer as the target's speed.

3.3 Radar Case

In order for the officer to make a speeding case he needs to establish the following:

- Jurisdiction
- Date and time of the offence
- Roadway on which the offence occurred
- Posted Speed
- Identify the vehicle and the operator
- Tracking History
- Radar Reading

It's often helpful for the officer to include other information such as weather and traffic conditions, and any statements made by the violator.

The officer testimony will typically be something like this:

On 30 December 2001 at about 8:27pm, I was operating stationary radar on Highway 1 near Main Street, in the city of Centre, Georgia. The area is posted as 45 mile per hour zone. I noticed a red Saturn SL1 traveling east on Highway 1 at a high rate of speed. I activated my radar. It gave a high-pitched clear tone, and it indicated a speed of 62 miles per hour. I stopped the Saturn and made contact with the driver, Ms. Blank.

Some jurisdictions may require additional information, such as the calibration information on the radar, the officer's certification to operate the radar, information establishing why the violator's speed was unsafe, etc.

3.4 Tracking

The most important part of a radar case is a tracking history. The radar unit will display a number, and that's all. It doesn't tell the officer which vehicle it is, or if there's even a vehicle there. The officer has to track the vehicle to make sure that his observations match what the radar is showing him. Otherwise, the officer might stop the wrong vehicle or a common radar error might give an incorrect speed. In some jurisdictions, the officer has to visually estimate the violator's speed within 5 miles per hour.

The radar beam is a cone. It doesn't pick out individual vehicles. It can't even pick out individual lanes. The radar shows a speed based on three factors:

- Reflectivity
- Position
- Speed

This is generally referred to as biggest, closest, and fastest. The radar usually picks up target that is the largest in its view. Therefore, it might pick up a motorcycle that was very close to it before a tractor-trailer a mile down the road. Many times the radar will display different speeds of different vehicles that are close together. The officer has to determine if he's getting a good reading and if so which vehicles' speed is being displayed.

This isn't as hard as it might sound. Radars are equipped with a speaker which gives a tone reflecting the Doppler signal it's receiving. If it's a clear high pitched tone, then it's getting a good solid reading from a vehicle. It will give a low raspy tone if it's not getting a clear signal. This happens when there's something in between the radar and the target or when the vehicle is entering or leaving the beam.

Once you have a solid tone, you look at how the traffic is moving. If there is a clump of vehicles that is moving at 65mph then a vehicle overtakes them at a high rate of speed, and the radar shows 85mph, it's easy to figure out who was going that fast. Alternatively, if a group of vehicles is traveling together in a clump, where no one is overtaking or falling behind, all the vehicles in that clump will be at about the same speed.

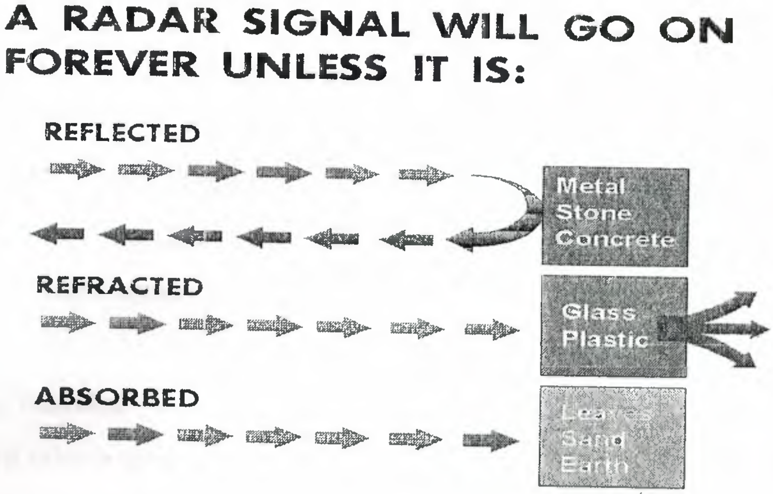
Some radars have a fastest vehicle button that will display the fastest vehicle in its cone. This is very useful for when there are large targets such as tractor-trailers in between the radar and a fast moving small vehicle.

3.5 Reflection, refraction and absorption

Radar depends on a reflected signal. If no signal is reflected, there is nothing for the radar's internal computer to compute. Cars make excellent reflectors. Radar reflects very nicely off metal and hard, opaque plastics. Radar's return signal comes mainly from the body of the car but in the case of those vehicles with fiberglass bodies, it may get a return from the engine. Fiberglass is essentially transparent to radar. Unless, of course, you have a metallic paint on the outside.

Radar signals can be absorbed. Trees, bushes, snow, earth, all absorb a radar signal. A good example of radar signal absorption is a microwave oven. The oven generates radio waves, like radar, and it is absorbed by the liquids in the food and the energy of the radio wave is converted to heat. The food gets hot from the radio waves being absorbed.

A radar signal can be refracted. An example of refraction is the multi-colored band of light passing through a crystal prism. The light enters a prism, bends while passing through and goes out the other end broken into different colors. Military jets, such as the F117 Stealth Fighter, use absorption and refraction to avoid detection by enemy radar. The aircraft body is coated with materials that resist reflecting radar signals by sending it off in various directions. The airplane has few broad, flat, distinctive surfaces to reflect a signal. The aircraft was designed with radar avoidance as the primary goal.



Some auto accessory firms make nose covers and front license plate covers for cars that they claim will prevent traffic radar from receiving a return signal. This is all hype. To effectively prevent your car from reflecting radar signals, you would have to remove all the glass, headlights and turn signals and cover every exposed part with a non-reflective coating. According to my friends in the Defense Department, the coating used on the Stealth Fighter would cost you about $250,000. If you could get it. They do not sell it at your local auto parts store. And don't forget to change the entire body style to present as small a surface as possible front and rear. For considerably less you could cover the entire car, from the ground up, with foam rubber one foot thick. Then you would have a stealthy car. Foam rubber absorbs radar signals. Pretty good insulation, too.

While a basic knowledge of the physics of radar is necessary to operate it correctly, you cannot use any of this information to fight a traffic ticket. In June, 1955, the New Jersey Supreme Court took judicial notice of the Doppler Principle. Every other state quickly followed suit. The courts have decided the Doppler Principle is a scientific fact that you cannot argue about.

The Kentucky Court of Appeals, in the case of Honeycutt v. Commonwealth, ruled a radar operator need not be able to explain the internal workings of a radar unit; that knowledge of the Doppler Principle is irrelevant to radar operation; that the defense cannot question the operator's knowledge of the Doppler Principle or other scientific principles and the operator will not be allowed to describe or explain these principles in court.

Since you cannot defend a traffic ticket based on the physics, or challenge the operator on how the radar unit works, what's left? Plenty. Most people drive a car but not many know how it works, let alone the physics involved. There are rules in driving they obey even if they do not know exactly why. They know they have to step on the brake pedal to slow down but do not know how the brakes work. The same is true with radar operators. Some know they have to do certain things, but do not know why. Because they do not know the "why," they tend to bend the rules for convenience or forget some of the procedures. Therein lays the defense.

3.6 Targeting vehicles

This is the area where most citations can be challenged. A radar beam cannot be seen so how is the officer to know which vehicle he is tracking? How is he to know he is not getting a false return?

Police traffic radar does not operate like airport radar. There is no screen showing the positions of vehicles, it does not rotate or sweep an area. There is no screen showing a number of blips with data beside each one. It is single point radar that only displays a speed reading, a number, from a target within a fairly narrow area.

The radar beam goes out in a fan pattern. The further away from the transmitter the radar beam travels, the wider it gets. Generally, radar guns send out a beam at an initial angle of between 11 and 18 degrees. At 12 degrees, a K band beam becomes 420 feet wide at 2000 feet away. Any vehicle moving within the beam can reflect the signal. The radar gun can only display one speed at a time and does not show the operator which vehicle is being tracked. Traffic radar, unlike airport radar, does not give the location of the target, just a speed.

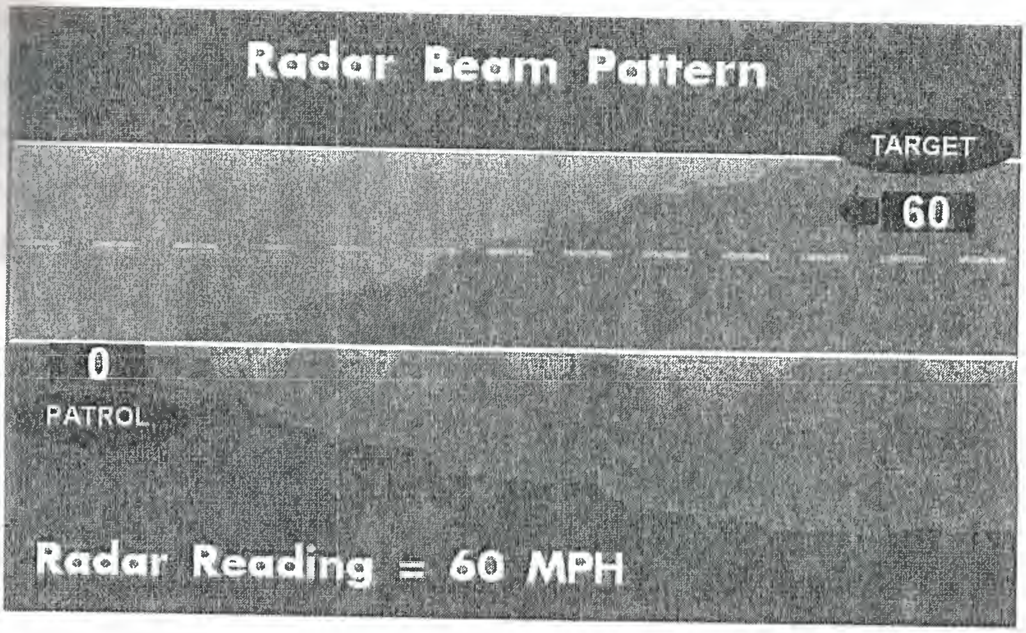


Figure 1 he radar beam goes out in a "fan" pattern from the radar transmitter. The signal is reflected from an oncoming car and the Doppler Shift in the signal is computed and converted to miles per hour by the radar unit. The speed of the vehicle is displayed on the radar unit for the officer to see.

To help ascertain a good track, traffic radar provides audio Doppler. This is a whistling sound or tone from the radar unit for the officer to hear. The pitch of the tone corresponds with the speed calculated by the radar receiver. The higher the pitch of the tone, the higher the speed. If the sound is clear and steady, then the radar unit has a good track (on something, not necessarily the intended target) and is receiving a strong return signal. If the sound is fuzzy, noisy or broken, then the track is not strong and the displayed speed, if any, is questionable. Some officers turn the audio Doppler tone volume down so low it cannot be heard. After a few hours this noise can become annoying so they just turn it off. An audio Doppler tone is required for a traffic radar track. Having just the visual display is not sufficient as the unit will display speeds without a good track. If the audio Doppler was not on and had a corresponding pitch to the speed reading, a ticket could be dismissed for lack of evidence.

Outside interference can produce false radar readings. Outdoor moving signs, motion detectors on burglar alarms, airport radar, radio transmitters, telephone lines moving in the wind, can all produce false, momentary, readings but they will not send back a clear steady tone. The interpretation of the audio Doppler is required to confirm the speed displayed on the radar unit.

A maker of radar detectors once ran an ad that pictured a radar gun aimed at a group of trees and the unit was displaying a speed of 65 m.p.h. The not-too-subtle suggestion was radar makes mistakes and you can protect yourself from being invited to appear in court by buying one of his radar detectors. What the advertiser did not show in the picture was the hand held radio being keyed right next to the radar receiver. The radar receiver was picking up interference from the radio transmitter and displaying the interference as speed. It was not producing an acceptable audio tone. Radar detectors will not "protect" you from being tracked by radar. They will only give you a warning when a radio signal, in a certain radio bandwidth, is present with sufficient strength to be police radar.

One of the first things shown to a radar operator in training is the 35 m.p.h. defroster. Radar units, when mounted on the dash of a patrol car, will pick up the movement of a windshield defroster fan running on high and display a speed. The audio tone will be fuzzy and broken. Solid returns will override this interference; a clear audio tone will be heard.

For the officer to confirm he has a good radar track, a strong, clear, steady tone is required. If the tone changes in pitch, then the displayed speed reading must also change accordingly. This is something that takes practice but a competent operator can estimate the speed of a tracked vehicle just by the tone. Fortunately, this is not enough to get a conviction.

Now that we know how to determine a false signal from a good return using the audio Doppler, the only question remaining is which vehicle is being tracked? Traffic radar only displays numerical speed readings, not which vehicle is being tracked.

For the officer to issue a citation, he has to see the vehicle speeding. He must make a visual estimate of the car's speed in addition to the speed displayed on the radar gun and the audio tone. They all have to match. Some police officers are very good at estimating speeds and others not so good. If you go to court, they will all say they estimated your speed at the same speed displayed on the radar unit. It would be very difficult to challenge someone on their ability to visually estimate vehicle speeds. Most state certification courses require at least 20 hours of hands on training during which the trainee is required to accurately estimate vehicle speeds before being shown the radar reading.

When the officer makes the visual speed estimate, he also has to make sure the vehicle he is observing is within the radar's operational beam, that there is no interference that would produce a false return in the area and that the vehicle is out front and by itself. Large vehicles and faster vehicles return stronger signals than smaller or slower vehicles. If any other cars or trucks are in the immediate vicinity of the car the officer visually estimates to be speeding, then an argument can be made that he cannot be certain which vehicle was being tracked by the radar. Radar cannot pick out a single vehicle in a tight group.

Shadowing is an aspect that can result in undeserved citations. Large vehicles will return a stronger radar signal than small vehicles. Tractor trailer rigs, with their large, flat forward surfaces send back very strong signals. A car, in front, behind or to the side of a tractor trailer rig can be moving along faster than the truck but will not be detected by a radar unit until it gets well in front of the truck. On the other hand, a speeding truck coming up from behind a slower moving car will cause a strong signal to be returned, overshadowing the car's speed which could be much lower. Even though the car is out front, the truck's larger surface area and speed returns a stronger signal than is reflected from the car. The radar operator has to be aware of all traffic in the immediate vicinity of the targeted vehicle. Sudden shifts or changes in the audio Doppler tone indicate the radar unit is processing numerous signals. The return of numerous short, differentiated signals in the audio tone makes the radar readings questionable.

3.7 Modes of Radar

3.7.1 Stationary

Stationary radar is radar at its simplest. The officer sits on the side of the road, and watches traffic. When he observes a vehicle moving at high speed, he activates the radar. The radar goes through its basic decision factors (Reflectivity, Position, and Speed) then it displays that speed. The radar will give a tone. If the tone is clear and the displayed speed matches the officer observations, the officer can make the stop.

3.7.2 Moving

Moving radar is very similar stationary radar, but it's looking for two different speeds. The radar looks for the largest object in its field, and it assumes that this is the passing background. Then it looks for the second most significant object that it assumes is the target. The radar actually measures the closing speed or separation speed between the target and the patrol vehicle. The radar's counting unit will then use the following formulas.

Target Speed (TS) = Closing Speed (CS) - Patrol Speed (PS)

or

Target Speed (TS) = Separation Speed (CS) - Patrol Speed (PS)

The radar unit will then display two speeds. It will show the target speed and the patrol speed. The officer must compare the patrol speed displayed on the radar with that displayed on the car's speedometer. This is an essential element of the radar case. The radar speed will be more accurate, but there are certain errors that this will detect. The speeds must be consistent.

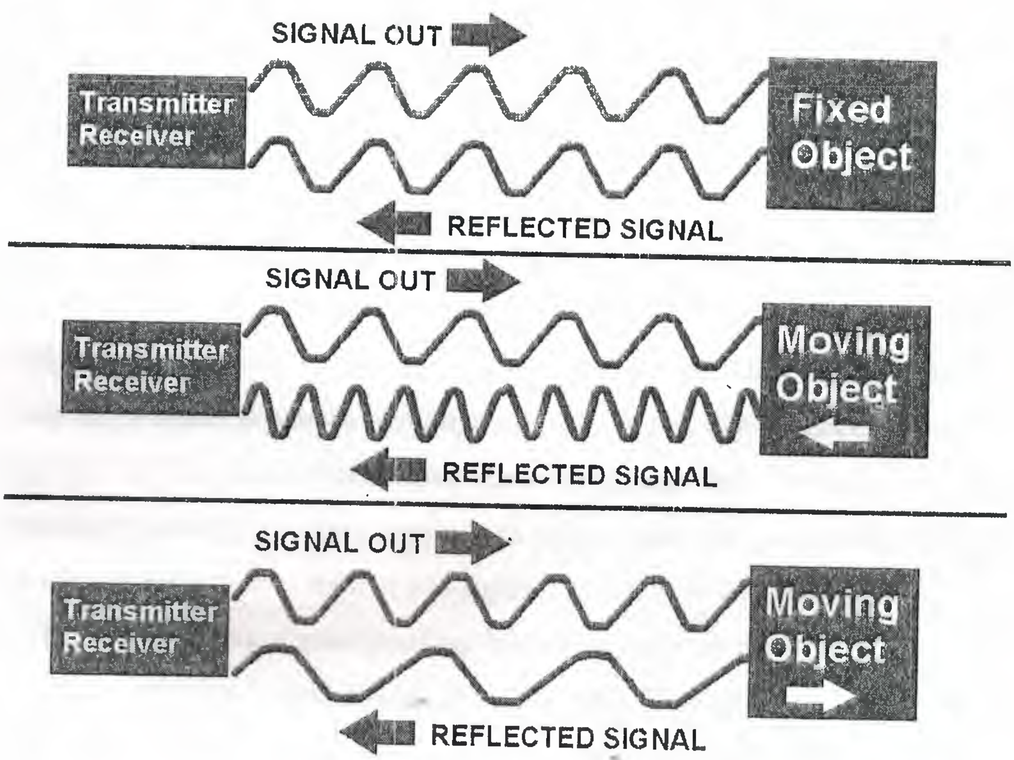


Figure 2 The top image shows radar signal going out and reflecting with no change in the wave length. The radar unit would read a target speed of 0 mph. The second image shows a radar return with the object moving towards the radar. The radar display will show the speed of the object due to the increase in the frequency (rate) of return of the waves; more waves coming back in a set time frame than were sent out. The last image shows how the waves would change if the object were moving away, a lower rate (frequency) of return, and fewer waves coming back in a given time frame.

3.7.3 Same Direction

Same direction radar was developed when engineers were examining the shadowing error. Same direction radar uses very different logic than moving or stationary radar. It also requires more a complicated tracking history.

Basically, it figures out the patrol speed. Then it looks for the bounced reflection off of the other vehicle and measures the relative speed between them. This makes things more complicated because the officer must decide to activate the radar, let the radar know if the officer or the target is moving faster.

3.8 Radar Errors

There are several things that will affect a police radar unit. There's a famous example of a lawyer aiming a radar at the courtroom wall and clocking it at 19 miles per hour. Radars will pick up interference from things other than vehicles. Power lines and the patrol car's air conditioner are the most common things that a radar will register. This is why training and experience is important. Officers will learn where the power lines are, and how the radar will react to them.

3.8.1 Interference

Police radar uses part of the electromagnetic spectrum. They can be influenced by any number of electromagnetic and physical phenomena. For instance, targeting radars on fighters use the same frequencies. Air conditioning units in patrol cars can create a reading (generally 32 mph). Some high power lines can also set off radars (generally in the around either 92 mph or 101 mph).

Officers must have a good tracking history in order to confirm that his observations are matched by the speed displayed by the radar. If an officer is traveling along a road with a 35 mph limit, and sees a vehicle traveling at around 50 mph, and the radar displays 100 mph, he knows that the result is bogus. An officer should know his beat well enough that he's aware of the common sources of interferences.

Some forms of interference, such as the air conditioning units, will disappear when the radar detects an actual moving object. Its decision factors will ignore any signal as weak from the air conditioner unit.

3.8.3 Masking

Masking is a rarely observed error where the radar antenna is pointed at the counting unit (the part of the radar that shows the speed).

3.8.4 Shadowing

Shadowing is when an officer is behind another moving object. Usually it will be something large like a tractor-trailer. The radar will interpret the tractor-trailer as the background instead of the actual background. Therefore, when an officer is running moving radar, he has to check the patrol speed showed by the radar unit against his speedometer. If they don't match then he may have a shadowing error.

3.8.5 Batching

Batching is when an officer is accelerating and activates the radar. Most modern radars have internal error checking that prevent this from being an issue.

3.8.6 Scanning

Scanning is when you swing a radar antenna across a background. It's possible to get the radar to show a speed this way, but it is hard.

3.9 Other Potential Issues with Radar

3.9.1 Officer Training

An officer must be trained to operate the radar. It doesn't take much to figure out how the radar works, but it does take some training and experience. In many states, the officer will have to be licensed to operate the radar. It will be an element of the case that the officer will make in court. Asking the officer for this permit on the side of the road is probably a waste of time.

3.9.2 Two Officer Teams

On some occasions, officers will act in teams. One officer will operate the speed detection equipment, and another officer will issue citations. This is particularly common when the police use airplanes to find speeders.

In order to obtain a conviction, the officer who identifies the violation must be in court to identify the violation. The officer who issues the citation must come to court to identify the driver. The officers must also be able to say how they were to pass the information about the violation between them.

3.10 Radar Detectors

A radar detector is just a radio receiver that flashes a light and makes a noise whenever it receives a signal in a certain frequency range. That's very useful right? The answer is maybe.

Just as there are numerous things that a radar picks up as interference, there are a number of things that will activate a radar detector. Furthermore, most police radars are equipped with an instant on feature. The officer will activate a radar whenever he identifies a potential speeder. Therefore, there may be no signal for the detector to pick up until it's too late.

That's not to say that radar detectors don't have value. If you're traveling across level ground, then you may pick up the radar signal when the officer checks a driver in front of you.

3.11 Calibration

Radars should be checked for accuracy occasionally. Under Georgia law, the officer has to check it at the beginning and end of each shift. The check for accuracy consists of the following:

A light check. The officer presses a button on the radar, and all the LED lights light up.

An internal circuit check, which is accomplished by pressing a button on the radar unit.

Tuning fork check. Tuning forks that are tuned to vibrate at a certain frequency are put in front of the radar antenna. The radar unit will display a certain speed.

If the radar doesn't perform within the manufacturer's specifications, it has to be removed from service until the radar can be repaired.

Radars also have to be calibrated by specially trained technicians occasionally, usually once a year.

3.12 Other Methods of Speed Detection

There are other methods to detect speed. The most common are LIDAR (Laser) and pacing.

One of the most accurate and easy to use technologies is Laser (LIDAR). A laser is similar to a radar, but it is aimed like a rifle. The officer can specify a particular vehicle whose speed the officer wants to determine. The officer just aims it, pulls the trigger, and the unit displays the speed and distance to the target. Some newer models also take a digital picture of the target.

Officers can also pace speeders using their speedometers. The officer maintains a constant distance from the violator. He watches his speed over a certain distance. The violator is then cited with the lowest speed that the officer observed. This method depends on the accuracy of the officer's speedometer. Officers must be able to testify that the accuracy of their speedometer has been checked or use a radar to confirm the officer's speed when following the violator.

3.13 Frequency shift to calculate target speed

Consider a single photon from the police radar. The photon must interact with the approaching car for a finite time while it is being reflected. Call this time, Δt. Let an interaction force, $\pm f$, exist between the photon and the car for the time, Δt. The force exerted by the photon on the car, $+f$, acts to remove energy from the car. The force exerted by the car on the photon, $-f$, acts to add energy to the photon. Therefore, we expect the photon frequency to increase. During the time Δt, the car travels a distance $\Delta s = V \Delta t$. We may now write two equations, one for a change in momentum, Δp, and one for a change in energy, ΔE:

Momentum: $\Delta p = f \Delta t$ 1.

Energy: $\Delta E = f \Delta s = fV \Delta t$ 2.

Since the photon energy, E, is equal to hn, where h = Planck's constant = 6.63×10^{-34} j sec, then

$\Delta E = h \Delta v$ 3.

Also, since photon momentum equals $h\nu/c$, where c is the speed of light, then

$$\Delta p = 2h\nu/c + h\Delta\nu/c \qquad 4.$$

Where the first term on the RHS represents Δp for an elastic reflection (i.e., one for which $\Delta E = 0$), and the second term takes into account the change in frequency due to the change in energy.

Dividing eq. 1 by eq. 2, and substituting for ΔE and Δp from eqs. 3 and 4, we find

$$(2h\nu/c + h\Delta\nu/c)/(h\Delta\nu) = 1/V \qquad 5.$$

This equation may be simplified to read

$$\Delta\nu/\nu = 2V/(c-V) \approx 2V/c \qquad 6.$$

Where the final step results from $V << c$. Now, let $V = 60$ mph $= 27$ m/sec, and let $\nu = 5 \times 10^{8}$ Hz. Then,

$$\Delta\nu = 90 \text{ Hz} \qquad 7.$$

The police radar detector easily detects this frequency shift.

CONCLUSION

This analysis shows that the EESS interference threshold is reached as soon as a very small density of cars equipped with 24 GHz automotive radars, is located within an EESS pixel. Scenarios with negative margins in the order of -20 dB (up to – 27 dB in the very long term) have been identified. This result is obtained from current and foreseen EESS sensors, from ETSI documentation for the SRR part and from SARA inputs regarding mitigation factors and expected car density. If a ground scattering model is used, the above figures will be decreased by an additional negative margin of – 4.8 dB.

The conclusion is that the 24 GHz automotive radars will cause harmful interference to the EESS sensors and, therefore, all the data derived from those measurements will be totally corrupted. The corresponding EESS observations will be systematically lost over cities (even small cities), roads or motorways.

It is to be noted that the criticality of the potential interference is of course growing with time, since it is linked to the car radars market penetration and to the appearance of high resolution EESS sensors in a few years time (for which the Recommendation SA 1029 has been recently revised).

In addition to the above considerations, the use of the FCC regulation or the proposed new ETSI figures won't be able to protect the passive sensors, especially the cross nadir instruments which are the most sensitive, even considering in the long term the improvement of the short range radar antenna pattern and the decrease of the horizontal eirp. It is therefore proposed that the band 23.6-24 GHz be avoided by any kind of automotive short range radar and CEPT should consider shifting this application to another frequency band where the compatibility conditions are much more favorable.

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