TURKISH AEROSPACE

KAAN

TURKISH COMBAT AIRCRAFT

BBM233 Logic Design Lab - Fall 2023

FINAL VERILOG PROJECT

Prepared by Selma Dilek and Alperen Çakın. The winner award sponsored by [Turkish Aerospace Industries, Inc.](#)

BACKGROUND

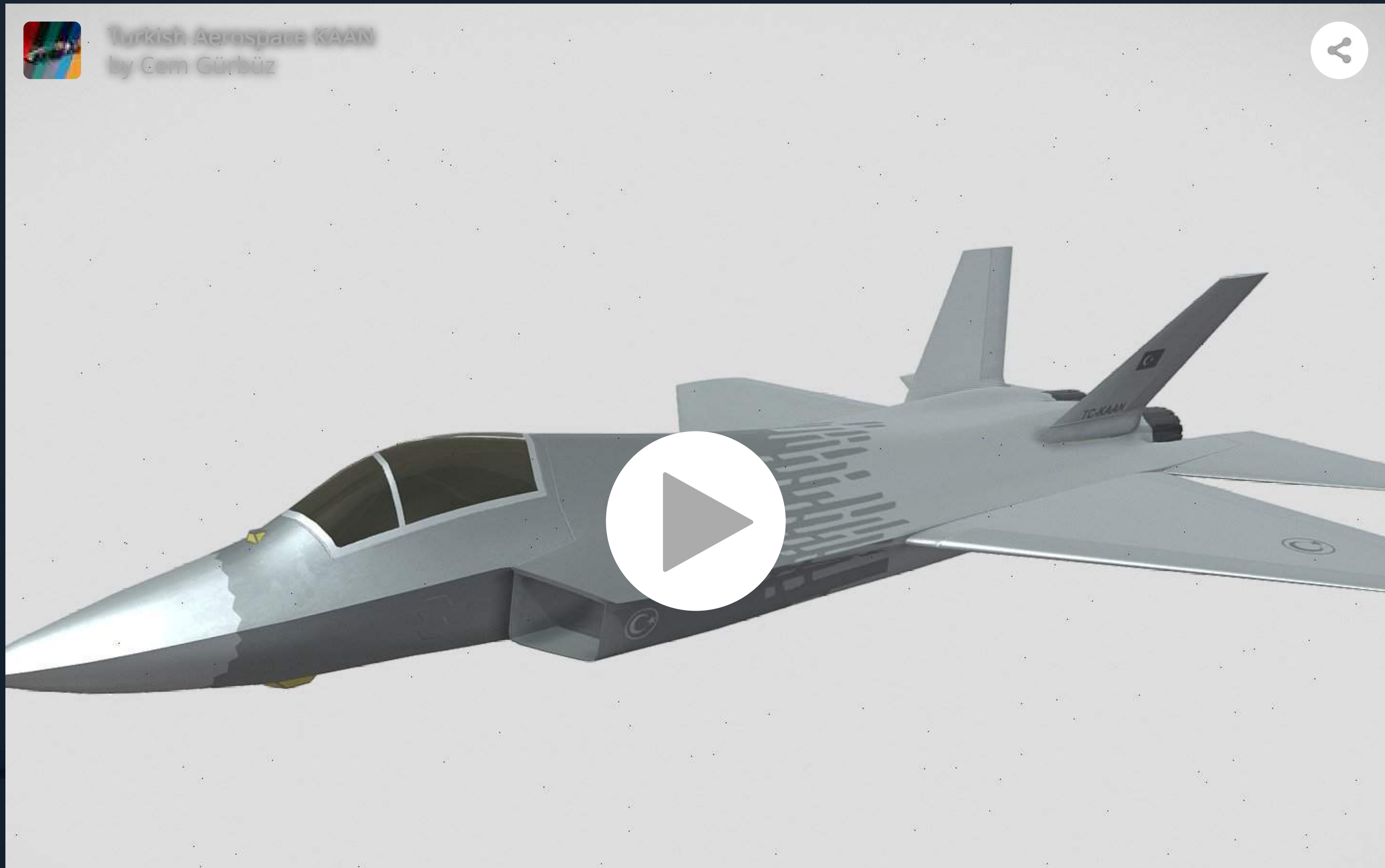
The **TAI KAAN** (formerly known as TF-X), alternatively named TF ("Turkish Fighter"), and in Turkish known as Milli Muharip Uçak (National Combat Aircraft), is a stealth, twin-engine, all-weather air superiority fighter jet in development by Turkish Aerospace Industries (TAI) and BAE Systems as its sub-contractor. **TAI KAAN** is planned to replace the F-16 Fighting Falcon aircraft of the Turkish Air Force.

The **KAAN** is a fighter jet that will feature an advanced active electronically scanned array radar which will use gallium nitride (GaN) technology, which is currently being developed by ASELSAN for the TF-X program. **KAAN** aircraft will be a multi-role aircraft, it will be designed mainly for air-to-air role with a consideration to air-to-surface roles as well.

Turkish Fighter **KAAN** will provide air dominance through: increased air-to-air engagement ranges with novel weapons, precise and accurate weapon firing from internal weapon bays at high/supersonic speed, and augmented lethality with support of Artificial Intelligence and Neural Networks.

Special Award

The first student to get the full score from the project on **Tur^{3}Bo Grader** will be awarded a 3D model of **KAAN**. The project award has been sponsored by Turkish Aerospace Industries, Inc..



Turkish Aerospace KAAN by Cem Gürbüz on Sketchfab

>> Click here to go to the Mission Directives <<

TURKISH AEROSPACE

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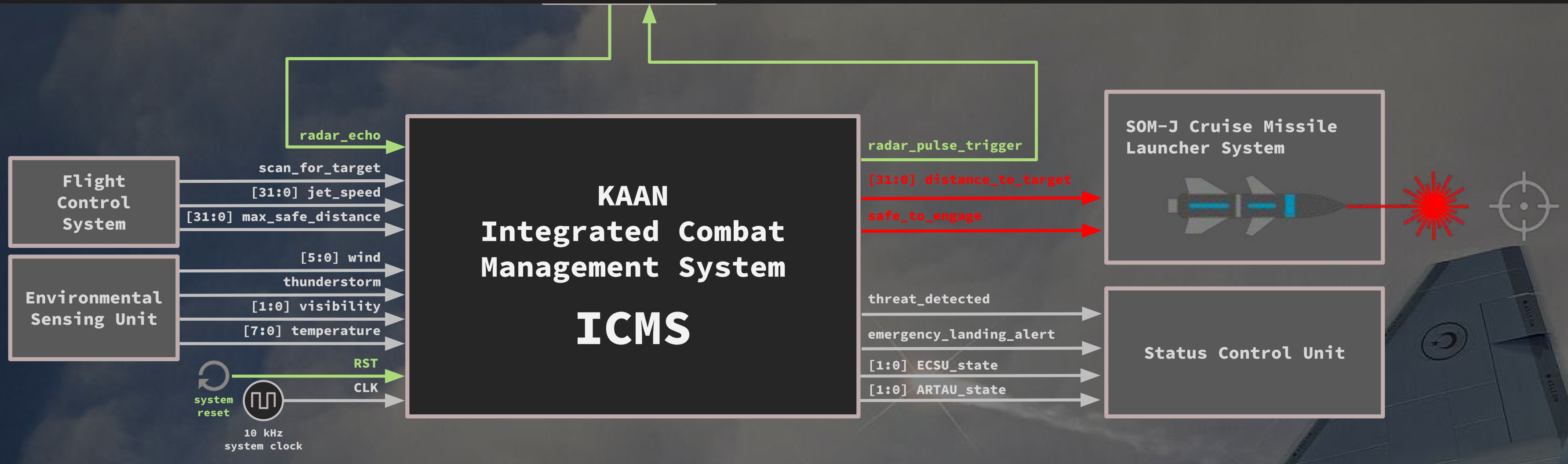
MISSION DIRECTIVES

KAAN Integrated Combat Management System

KAAN Integrated Combat Management System (ICMS) is envisioned as an embedded hardware module that manages target tracking and threat assesment, and provides environmental support in combat missions. As illustrated in the circuit diagram below, it will be connected to other system units such as **Flight Control System**, **Environmental Sensing Unit**, **Radar**, **Status Control Unit**, and **SOM-J Cruise Missile Launcher System**.



ICMS will consist of two separate units: **Advanced Radar and Threat Assessment Unit (ARTAU)** and **Environmental and Combat Support Unit (ECSU)**. These two modules must be designed first before **ICMS** can be assembled. The full functionality of **ICMS** is summarized as follows:

- It will operate on **the system clock** of 10 kilohertz (kHz).
- It should be able to reset on the high **system reset** signal.
- It will receive input signals from the **Flight Control System**, **Environmental Sensing Unit** and the **Radar**.
- It will be able to initiate the radar pulse and listen for the echo response from the radar to scan for targets, calculate the distance to the target, and assess the threat level.
- It will be able to analyze environmental conditions and provide crucial feedback to the pilot and flight control systems.
- It will be able to send status information important for target tracking, flight and combat management.

TAI has been known to trust only the best engineers to work on their next-gen defense technology, and that is why they employed the **HUBBM** students from Hacettepe Computer Engineering Department to work on this crucial mission. As the tumultuous year of 2023 was approaching its miserable end with all the wars and economic crises, **TAI** issued a mission for the **HUBBM** students that is vital for future defense operations on Turkish soil. The top-secret mission is to design the **KAAN Integrated Combat Management System (ICMS)**.

The students were oblivious to the importance of the mission. They thought it was just an ordinary final project for the Logic Design Lab course they were taking that year. **Little did they know they were actually designing a piece of the future technology**.

>> Click here to go to the instructions <<

TURKISH AEROSPACE

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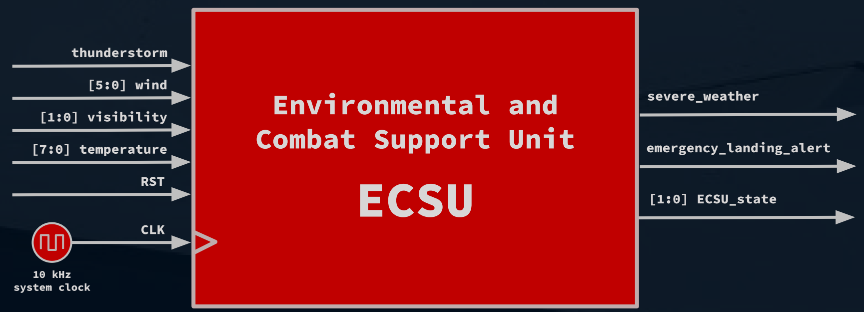
INSTRUCTIONS - PART 00

Environmental and Combat Support Unit

The first module to be designed is the **Environmental and Combat Support Unit (ECSU)**, which is essential for supporting fighter jet operations in various environmental conditions and combat scenarios. This unit processes data from external sensors, analyzing weather conditions and other environmental factors. Its primary function is to assess the safety of the environment for flight and combat operations.



Inputs	Description
CLK	This input is the system clock signal provided to the chip from the system. The clock cycle is set to 100 μs (microseconds).
RST	This input provides a reset signal (on **HIGH**) which resets the system to its default settings (**ALL_CLEAR** state).
thunderstorm	This input is supplied to the chip from the **Environmental Sensing Unit**. When this signal becomes **HIGH**, it means that thunderstorm is detected.
[5:0] wind	This 6-bit input signal also comes from the **Environmental Sensing Unit**. It specifies the wind speed in knots.
[1:0] visibility	This 2-bit input signal also comes from the **Environmental Sensing Unit**. It specifies the level of outdoor visibility. The possible levels are: completely clear (00), limited visibility (01), somewhat clear (10), and completely invisible (11).
[7:0] temperature	This 8-bit input signal also comes from the **Environmental Sensing Unit**. It specifies the outdoor temperature in Celsius.

ECSU chip has three outputs described below:

Outputs	Description
severe_weather	This 1-bit output signal triggers the severe weather alert that is crucial for flight and combat management.
emergency_landing_alert	This 1-bit output signal triggers emergency landing in severely compromising weather conditions.
[1:0] ECSU_state	This 2-bit output represents the state of the **ECSU**. **00** represents the **ALL_CLEAR** state, **01** represents the **CAUTION** state, **10** represents the **HIGH_ALERT** state, and **11** represents the **EMERGENCY** state.

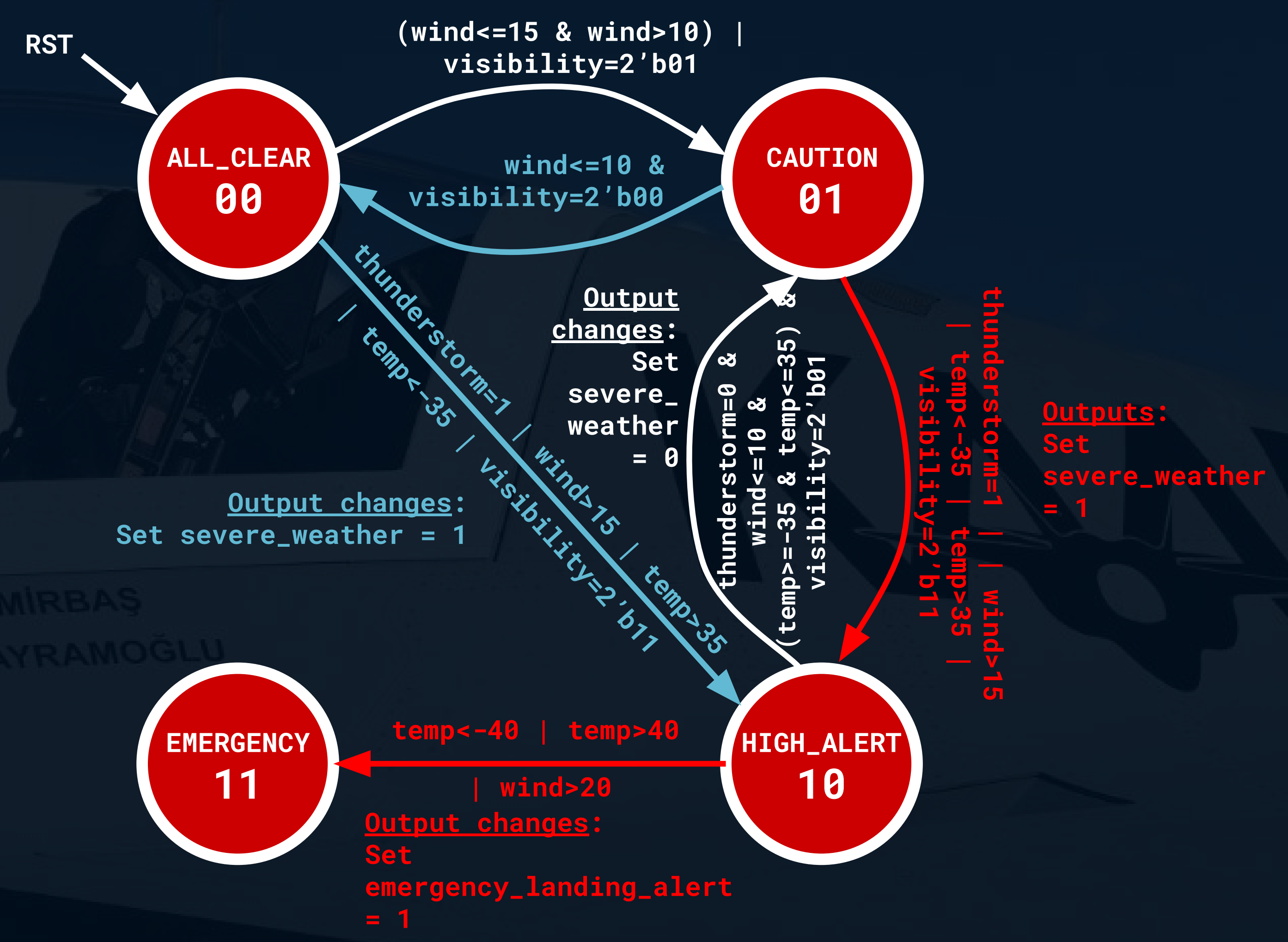
ECSU Specifications

The Environmental and Combat Support Unit operates in four states as described below:

State	Description
State 00: **ALL_CLEAR**	This is the default state indicating optimal environmental conditions for flight and combat. Here, all outputs are set to 0, signifying no severe weather or emergency conditions.
State 01: **CAUTION**	This state is activated under marginal weather conditions, where caution is advised. Specific thresholds for wind, visibility, and temperature may trigger this state.

	strong winds, extreme temperatures, or poor visibility.
State 11: EMERGENCY	This state indicates critical environmental conditions, prompting an emergency landing alert. It's triggered by extreme weather scenarios like very high winds or temperatures beyond safe operational limits.

The ECSU state transition diagram is given below.

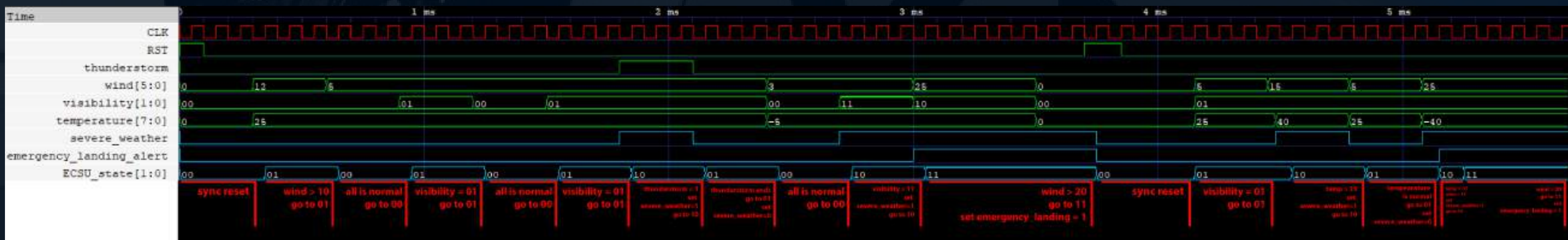


- **In the ALL_CLEAR state**, the system monitors environmental inputs for any signs that may require a heightened alert. The transition to the CAUTION state occurs if wind speeds are between 11 and 15 (inclusive) knots or if visibility drops to 01 (limited visibility). On the other hand, the transition to the HIGH_ALERT state is triggered by any of the following conditions: presence of a thunderstorm, wind speeds exceeding 15 knots, temperatures above 35°C or below -35°C, or the lowest level of visibility (11) is detected (completely invisible).
- **The CAUTION state** is entered under suboptimal but not severe environmental conditions. Here, the system will return to ALL_CLEAR if the wind speed decreases to 10 knots or below and visibility is at the highest level (00). Conversely, the state escalates to HIGH_ALERT if any of the following conditions occur: thunderstorm begins, the wind speed exceeds 15 knots, the temperature rises above 35°C or drops below -35°C, or visibility reaches the lowest level (11).
- **If the next state of the system is determined to be the HIGH_ALERT state**, the system activates the severe weather alert immediately. This state is maintained unless environmental conditions worsen to trigger an emergency or improve to justify deescalation. The transition to EMERGENCY happens when temperatures fall below -40°C or rise above 40°C, or wind speeds exceed 20 knots. To return to the CAUTION state, conditions must improve to no thunderstorm, wind speeds at 10 knots or less, temperatures between -35°C and 35°C (both included), and visibility above the lowest level. If the next state is determined to be the CAUTION state while in HIGH_ALERT state, then severe weather alert should be deactivated.
- **The EMERGENCY state** indicates extremely critical environmental conditions and triggers the emergency landing alert. This state is maintained under continuous severe conditions and is only reset when the system RST signal is triggered, typically after landing and a thorough reevaluation of environmental conditions.

Design the ECSU according to these specifications using a behavioral design approach in Verilog.

Example Tests and Waveforms

In the waveform given below, you can see the results of the given sample testbench. Click on the figure to enlarge.



>> Click here to go to the next Instructions <<

INSTRUCTIONS - PART 01

Advanced Radar and Threat Assessment Unit

The second module that needs to be designed is the **Advanced Radar and Threat Assessment Unit (ARTAU)** that uses radar data to not only calculate the distance to a target but also assess the threat level.

Inputs and Outputs

The finite state machine of the ARTAU chip depends on six inputs described below:

Inputs	Description
CLK	This input is the system clock signal provided to the chip from the system. The clock cycle is set to 100 μs (microseconds).
RST	This input provides the system reset signal that resets the unit (on HIGH) to its default settings (IDLE state).
scan_for_target	When this signal becomes HIGH, the ARTAU should trigger the radar to emit a radio pulse by setting the radar_pulse_trigger output to HIGH for 300 μs.
radar_echo	This signal comes from the radar. When the transmitted radio pulse reflects off of a target and reaches back to the radar, this signal becomes HIGH. It means a target is detected within the range.
[31:0] jet_speed	This 32-bit input comes from the Flight Control System and represents the fighter jet's current speed in meters per second.
[31:0] max_safe_distance	This 32-bit input also comes from the Flight Control System and represents the maximum distance that a target can approach the jet without being considered as a potential threat.

ARTAU chip has four outputs described below:

Outputs	Description
radar_pulse_trigger	This output signal is connected to the radar. It will trigger the radar's radio transmitter to send radio pulse to look for a target.
[31:0] distance_to_target	This 32-bit output specifies the distance to the target in meters (m).
threat_detected	This output indicates that the detected target poses a threat.
[1:0] ARTAU_state	This 2-bit output represents the current state of the ARTAU. 00 represents the IDLE state, 01 represents the EMIT state, 10 represents the LISTEN state, and 11 represents the ASSESS state.

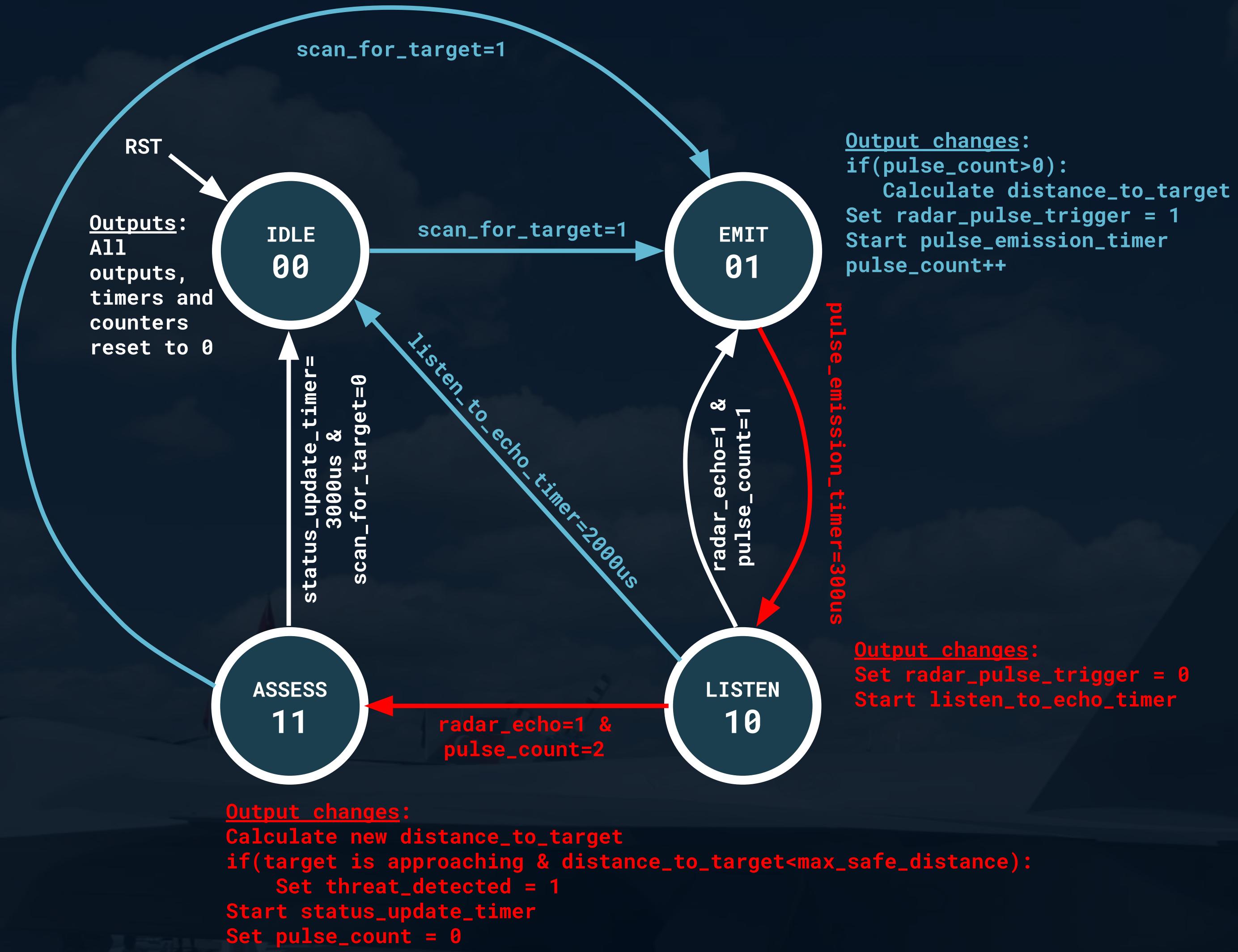
ARTAU Specifications

ARTAU has four states as described below:

States	Description

States	Description
	which the radar should transmit radio pulse to scan for possible targets.
State 10: **LISTEN**	In this state, **ARTAU** listens for the echo signal that is reflected off of a possible target. The range of the radar is 300 km, so it is sufficient to listen for at most 2000 μs or until the echo is received. When an echo is received, if this is the first reading, the distance to the target is calculated in meters when going back to the **EMIT** state.
State 11: **ASSESS**	In this state, **ARTAU** assesses the target: the new distance to the target is calculated and updated, and based on the target's trajectory and proximity to the jet, **threat_detected** is set to **HIGH** if the target poses a threat to the jet. We assume that after 3000 μs the target information becomes obsolete if not refreshed.

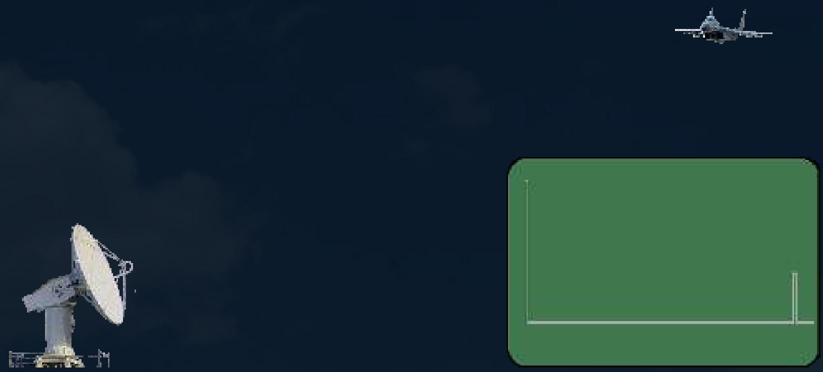
The **ARTAU** state transition diagram is given below.



System Behavior — State Transitions

The state transitions are synchronized with the rising edge of the CLK, whereas other outputs may be asynchronous for improved accuracy of the system. The system behavior is described below.

- When ARTAU is reset, it must be in its start and default state IDLE. It should stay in this state until the signal scan_for_target becomes HIGH, signaling that the a command to scan for a target is issued.
- Once the signal scan_for_target becomes HIGH, ARTAU must immediately trigger the radar's radio transmitter by making the radar_pulse_trigger signal HIGH. Moreover, ARTAU must switch to EMIT state on the next closest rising edge of the CLK. If the scan_for_target signal becomes HIGH on the rising edge of the CLK, than all these changes in outputs happen simultaneously.



- The radar transmits a short radio pulse with very high pulse power. This pulse is focused in one direction only by the directivity of the antenna, and propagates in this given direction with the speed of light. If in this direction there is an obstacle (a target), then a part of the energy of the pulse is scattered in all directions. A very small portion is also reflected back to the radar, and the radar antenna receives this energy. It is necessary to transmit the radio pulse for 300 μs. Hence, **ARTAU** must keep the **radar_pulse_trigger** signal **HIGH** and stay in the **EMIT** state for exactly 300 μs, after which, it must pull the **radar_pulse_trigger** signal to **LOW**, start listening for an echo immediately, and move to the **LISTEN** state at the next rising edge of the **CLK**.
- In the **LISTEN** state, **ARTAU** will listen for an echo signal coming from the radar. Since the propagation of radio waves happens at constant speed (the speed of light c_0) the distance to a target is determined from the echo of the high-frequency transmitted signal. The actual range of a target from the radar is known as slant range. Slant range is the line of sight distance between the radar and the illuminated object. Since the waves travel to a target and back, the round trip time is dividing by two in order to obtain the time the wave took to reach the target. Therefore we can calculate the distance using the following formula:

$$distance = \frac{c_0 \times t}{2}$$

- In the formula above, $c_0 = 3 \cdot 10^8\ ^{m}/_{s}$, is the speed of light at which all electromagnetic waves propagate and t is the round trip time of the radio pulse [s]. When the time t is known, the distance in [m] between a target and the radar can be calculated by using this equation.
- We assume the maximum range of 300 km. Therefore, **ARTAU** will listen for echo for at most 2000 μs. If the **echo** is not received within that time, it means that there is no target in range. In such case, **ARTAU** should return to the **IDLE** state, reset the outputs, and wait for the further commands. However, if an **echo** pulse is received while still in the **LISTEN** state, **ARTAU** should immediately calculate **[31:0] distance_to_target** in meters using the given formula, and move to either the **EMIT** state for the second target scan, or to the **ASSESS** state on the next rising edge of the **CLK**, if this was actually the second scanning. Upon the second scan for target, **ARTAU** will have the old and the new distance to the target. Using this information, and the **jet_speed** input, **ARTAU** must assess whether the target poses a threat or not. For the sake of simplifying the problem at hand, you may assume that the jet will always be flying towards a target, whereas the the target will either be going in one of two directions: towards the jet or away from it (or it will be stationary). We know that we can calculate the relative velocity of the target using the following formula:

$$Relative\_Target\_Velocity = \frac{|(distance_2 + jet\_speed \times t) - distance_1|}{t}$$

- From this, we may assess whether the target is approaching by checking that:

$$((distance_2 + jet\_speed \times t) - distance_1) < 0$$

- If the target is assessed to be approaching, and if the latest calculated distance to the target is less than the given **max_safe_distance**, then **ARTAU** must also set the **threat_detected** signal to **HIGH**.
- While in the **ASSESS** state, two things can happen:

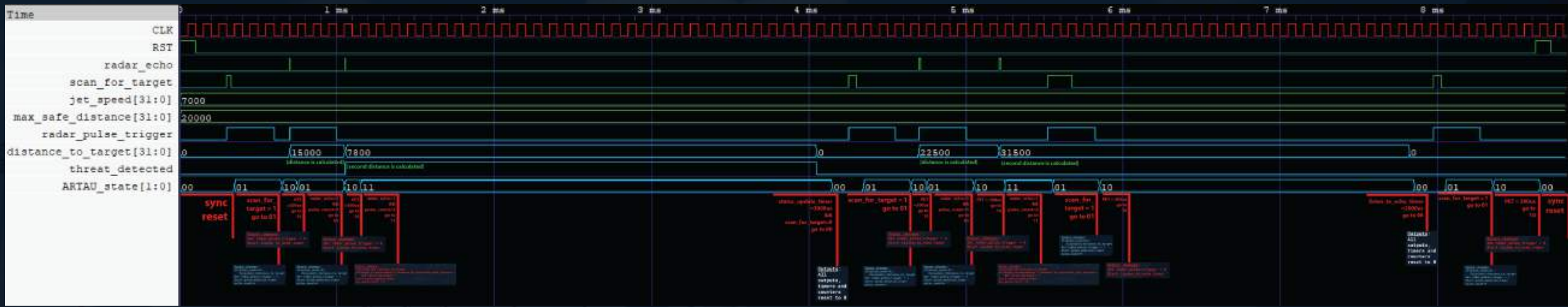
should return to the IDLE state and reset all outputs. However, if a new scan_for_target is issued while still in the ASSESS state, ARTAU should return to the EMIT state and repeat the process of scanning for a target as described above. While trying to refresh the target information in this case, ARTAU should keep the last measured distance and threat assessment as long as it does not expire or until the new information is received.

You will design the ARTAU according to the given specifications using the **behavioral design approach**.

To calculate the elapsed time from the falling edge of the **radar_pulse_trigger** signal to the rising edge of the **radar_echo** signal regardless of the clock (as this process is asynchronous), you can use a time function in Verilog (e.g., "$time"). You may learn more about these functions [here](#).

Example Tests and Waveforms

In the waveform given below, you can see the results of the given sample testbench. Click on the figure to enlarge.



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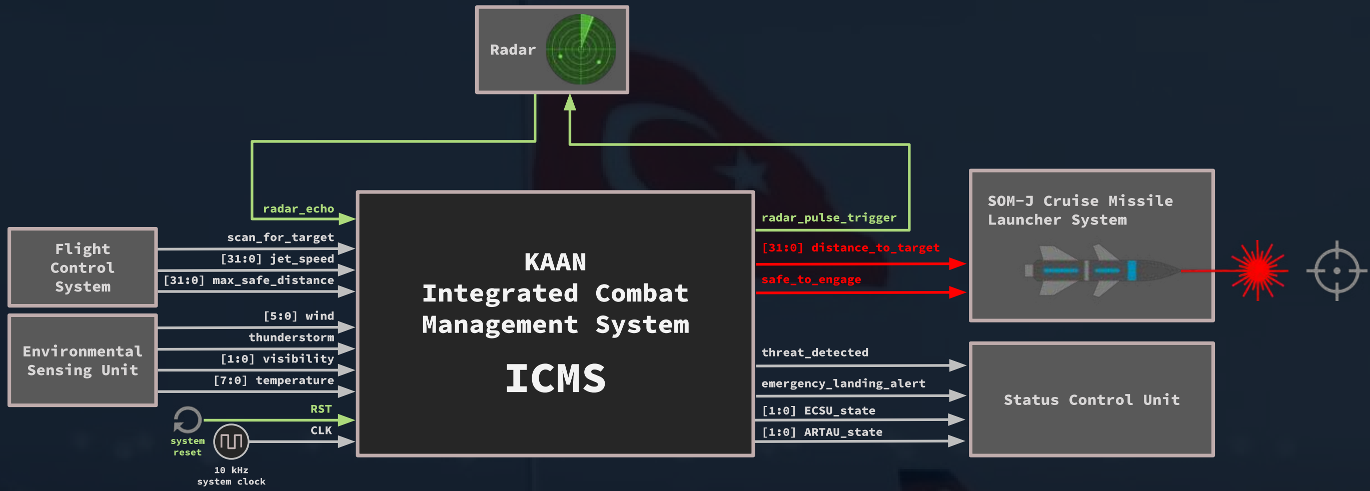
INSTRUCTIONS - PART 10

KAAN Integrated Combat Management System

The final module that needs to be designed is the **Integrated Combat Management System (ICMS)** that manages target tracking and threat assesment, and provides environmental support in combat missions.



Inputs and Outputs

The ICMS chip depends on ten inputs described below:

Inputs	Description
CLK	This input is the system clock signal provided to the chip from the system. The clock cycle is set to 100 μs (microseconds).
RST	This input provides a reset signal (on HIGH) which resets the system to its default settings.
thunderstorm	This input is supplied to the chip from the Environmental Sensing Unit. When this signal becomes HIGH, it means that thunderstorm is detected.
[5:0] wind	This 6-bit input signal also comes from the Environmental Sensing Unit. It specifies the wind speed in knots.
[1:0] visibility	This 2-bit input signal also comes from the Environmental Sensing Unit. It specifies the level of outdoor visibility. The possible levels are: completely clear (00), limited visibility (01), somewhat clear (10), and completely invisible (11).
[7:0] temperature	This 8-bit input signal also comes from the Environmental Sensing Unit. It specifies the outdoor temperature in Celsius.
scan_for_target	This input is supplied to the chip from the Flight Control System. When this signal becomes HIGH, the ARTAU should trigger the radar to emit a radio pulse by setting the radar_pulse_trigger output to HIGH for 300 μ.
radar_echo	This signal comes from the radar. When the transmitted radio pulse reflects off of a target and reaches back to the radar, this signal becomes HIGH. It means a target is detected within the range.

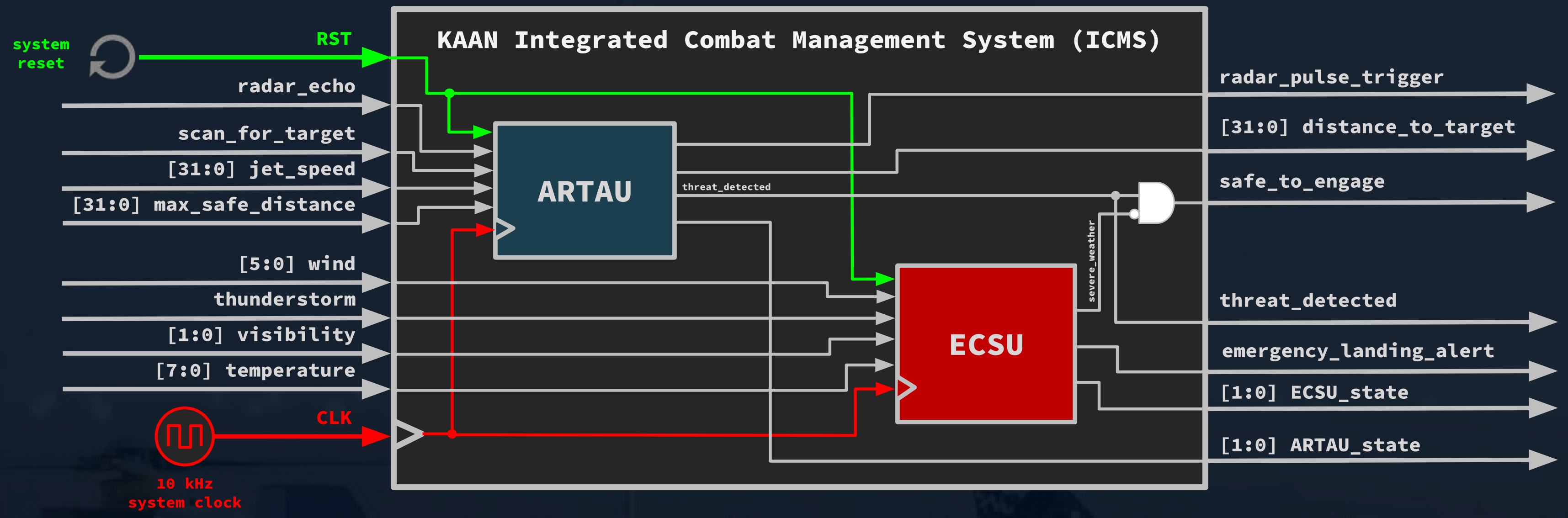
Inputs	Description
max_safe_distance	jet without being considered as a potential threat.

The **ICMS** chip has seven outputs described below:

Outputs	Description
radar_pulse_trigger	This output signal is connected to the radar. It will trigger the radar's radio transmitter to send radio pulse to scan for a target.
[31:0] distance_to_target	This 32-bit output specifies the distance to the target in meters (m).
safe_to_engage	This 1-bit output signal signalizes to the **SOM-J Cruise Missile Launcher System** that flight conditions are safe for engaging into combat.
threat_detected	This output indicates that the detected target poses a threat.
emergency_landing_alert	This 1-bit output signal signalizes to the **Status Control Unit** that emergency landing protocol is initiated in severely compromising weather conditions.
[1:0] ECSU_state	This 2-bit output represents the state of the **ECSU** chip, which is fed to the **Status Control Unit**.
[1:0] ARTAU_state	This 2-bit output represents the current state of the **ARTAU** chip, which is fed to the **Status Control Unit**.

ICMS Specifications

The circuit diagram for the **ICMS** is given below:



You will design the ICMS by following the given circuit diagram and using the structural design approach. You do not need any additional specifications as the diagram clearly shows that the ICMS chip is designed by combining ARTAU and ECSU in the depicted manner, with some additional combinational logic.

Example Tests and Waveforms

In the waveform given below, you can see the results of the entire testbench. Click on the figure to enlarge.

>> Click here to go to the final Instructions <<

KAAN

INSTRUCTIONS - PART II

MUST—USE Starter Codes

- [You must use these starter codes for your implementation.]
- Do NOT change the I/O port names, order, or width! Your submissions will be graded using an automatic grading script. If you change any of these, you will fail grading and get 0. Objections in this regard will not be accepted after the grades are announced!
- Makefile is included in the starter code for your convenience. It is not mandatory to use it, but if you do, it will speed up your testing process a lot.

Important Notes

- Your system MUST operate in microseconds and conform to the given clock cycle (100 µs) and delay instructions (see the given waveforms). Any other timescale will not be accepted!
- **Automatic grading [VERY IMPORTANT!]**: Your submissions will be graded using an automatic grading script. Therefore, You MUST download and use the provided starter code files before you start working! **Do NOT change the I/O ports (names, order, bit-width, etc.)!**

Testing via

TUR^{3}BO GRADER

- You MUST test your codes via our Tur^{3}Bo Grader before the submission to see which tests you are passing.
- Note that this is used for testing purposes only, and you still have to submit your full codes via https://submit.cs.hacettepe.edu.tr/ to get graded.

Plagiarism Control Notice

Students must implement their solutions individually. All submissions will be submitted to a plagiarism check. Any submissions that show a high level of similarity will be graded with -100 pts and reported as plagiarism attempts to the ethics committee.

Grading Policy

- Verilog codes: 100%
  - ECSU: 45%
  - ARTAU: 45%
  - ICMS: 10%

Submissions will only be accepted via https://submit.cs.hacettepe.edu.tr/. **Submissions will not be accepted via e-mail or Piazza or any other platform!**

The deadline for submissions is **Sunday, 14/01/2024 at 23:59:59**.
There will be **no extensions**!
Late submissions **will not be** accepted!

Your submission will include all Verilog codes and it must be in the following format to be accepted:

- **b<studentID>.zip**
  - ECSU.v
  - ARTAU.v
  - ICMS.v

Note that only ZIP archives are accepted!
Placing your codes in an extra folder will be graded with 0 and regraded only on request with penalty -10.

Project Counted as Final Exam

Since the final project is counted as the final exam for this course, there will be **NO EXTENSIONS** for submission. Late submission will not be accepted under any circumstances. **Make sure to submit anything if you don't want to fail the class with F2!** Resit exam will be performed face-to-face in the lab.

This assignment has been inspired by the KAAN project. The story and background materials are mostly taken from here, here, here, here, and here.

The project award has been sponsored by Turkish Aerospace Industries, Inc.. They have contributed by providing a 3D model of KAAN. We are truly thankful.

Assignment authors: Res. Asst. Alperen Çakın and Res. Asst. Dr. Selma Dilek