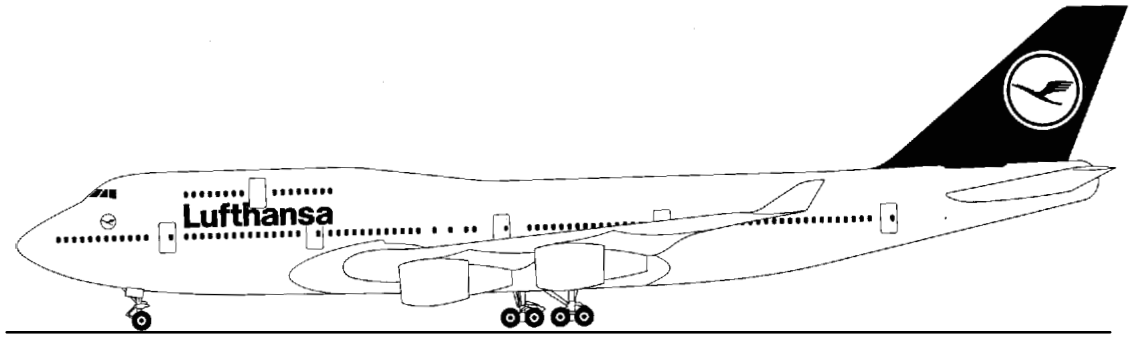
Lufthansa Technical Training

Training Manual B 747-400



ATA 22-12
AFDS CONTROL

Level III

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ATA 22-12 AFDS CONTROL

PITCH, ROLL AND YAW CONTROL

Each of the three flight control computers (FCC) receives inputs from the mode control panel (AFCS MCP) and sensors and provides the other FCC's with cross-channel inputs. Each FCC, when enabled by mode selection and A/P and F/D engagement, supplies command outputs to the electronic flight instrument system (EFIS) and to autopilot servos for stabilization and navigation of the airplane about the pitch, roll and yaw axes.

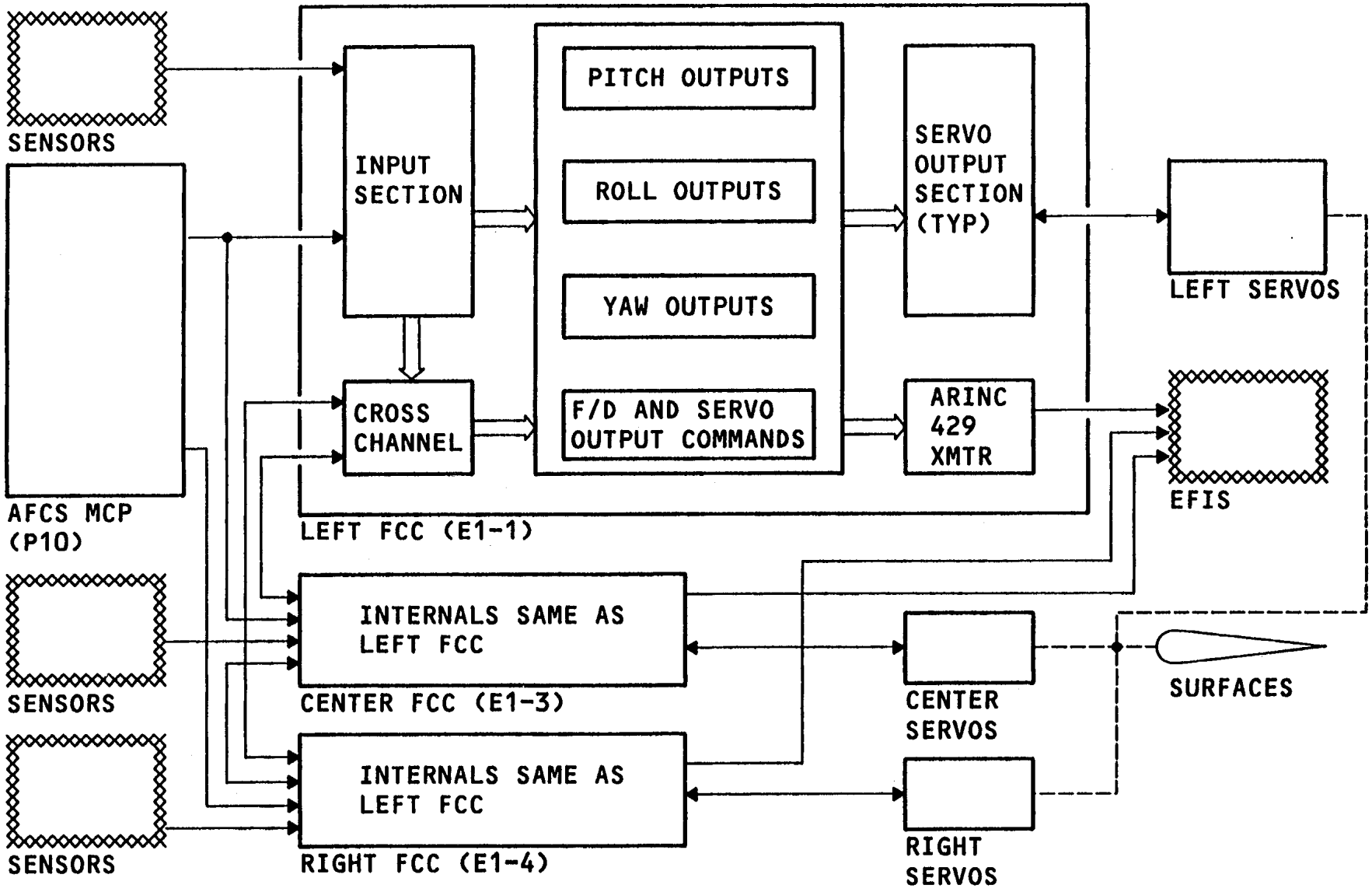

Figure 1 PITCH, ROLL AND YAW CONTROL

FCC INNER AND OUTER LOOP CONTROL

General

There are two types of control signal calculations in the FCC. These are an outer loop and an attitude, or inner, loop. The type of calculation determines signal integrity requirements and response to failure.

Outer Loop

The outer loop calculations are used to command attitude changes. These commands control the airplane to a vertical speed or heading, for example, with a desired attitude change (pitch or roll) for the airplane.

For cruise operation, outer loop signals need to be present from only one sensor to allow operation. Loss of the outer loop data results in a mode fail with reversion to attitude hold.'

Inner Loop

The inner loop compares the desired attitude with the actual attitude of the airplane. The inner loop then uses attitude error and attitude rate to develop a command for the flight control system.

Servo Loop

The servo loop compares the servo command to the servo position. This forms the feedback control loop as well as allows the performance of the servo to be monitored.

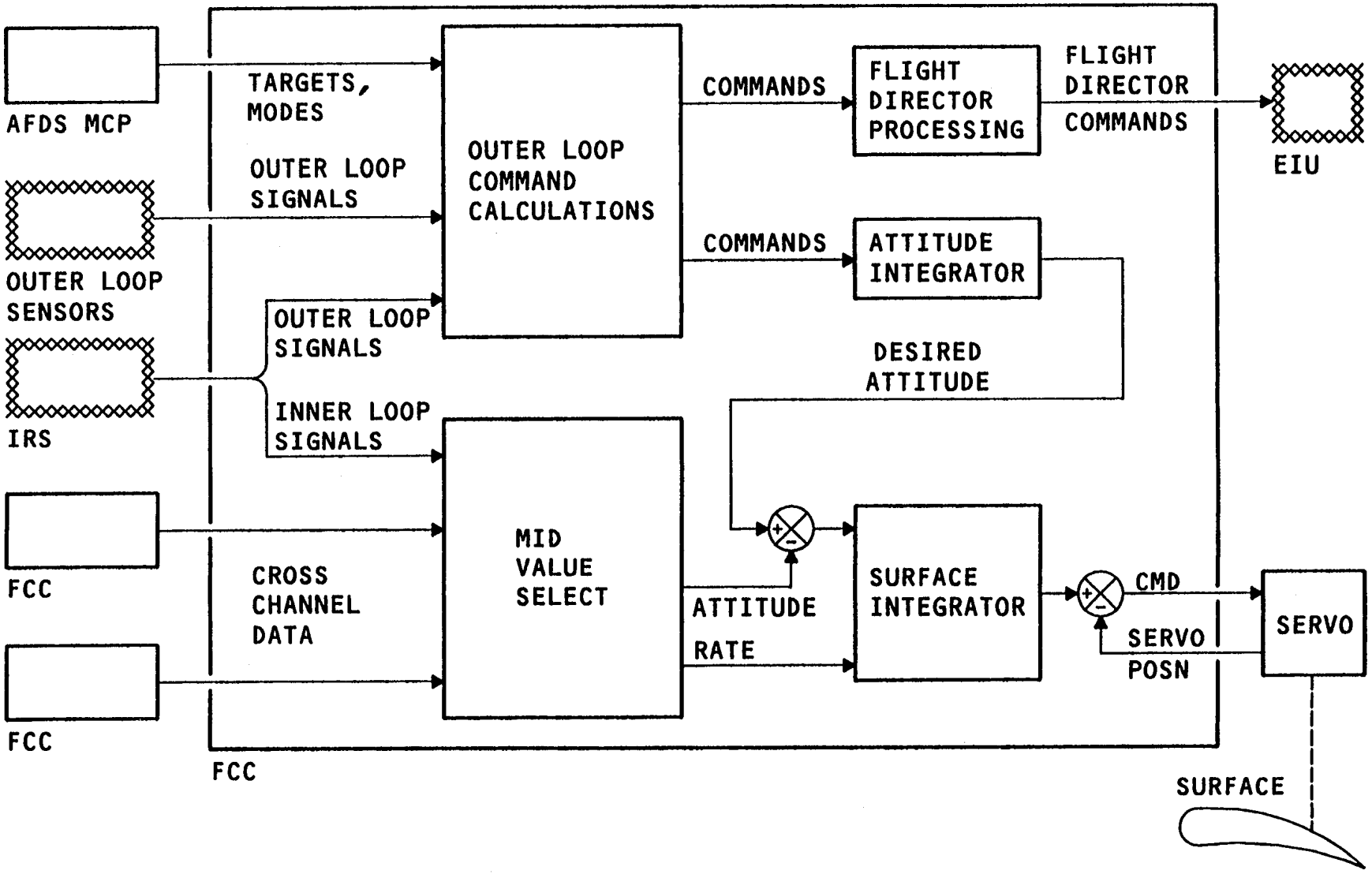

Figure 2 FCC INNER AND OUTER LOOP CONTROL

PITCH AXIS CONTROL

General

The FCC processes commands and applies these commands to the EFIS, the pitch control servos and the stabilizer trim/rudder ratio module.

Pitch Attitude

The pitch attitude integrator (PITCH ATT INTEG) synchronizes to the pitch attitude when the A/P is disengaged. When the A/P is engaged, the PITCH ATT INTEG senses command inputs and establishes the correct pitch attitude for the airplane. During multi-channel approach, the NOSE LETDOWN logic causes a pitch down command after the airplane is on the ground and less than two degrees pitch attitude.

Autopilot Command

The elevator trim integrator (ELEV TRIM INTEG) synchronizes the servo position to the surface position while the A/P is armed. When the A/P is engaged, the ELEV TRIM INTEG supplies commands to move the elevators and to trim the

stabilizer through the stabilizer trim/rudder ratio module (SRM).

Command Sections

The vertical speed section develops the command when the V/S mode is in effect. When V NAV is in effect, vertical steering commands from the FMC are used. The speed section develops the commands during takeoff, flight level change and go-around. The vertical position develops commands during the altitude modes, glide slope and flare.

Versine

Versine senses roll commands and supplies pitch commands to the F/D and to the A/P to compensate for loss of lift during roll.

F/D Command NCD

The F/D command word has an NCD status if the operating mode is invalid (sensor fail or improper operation).

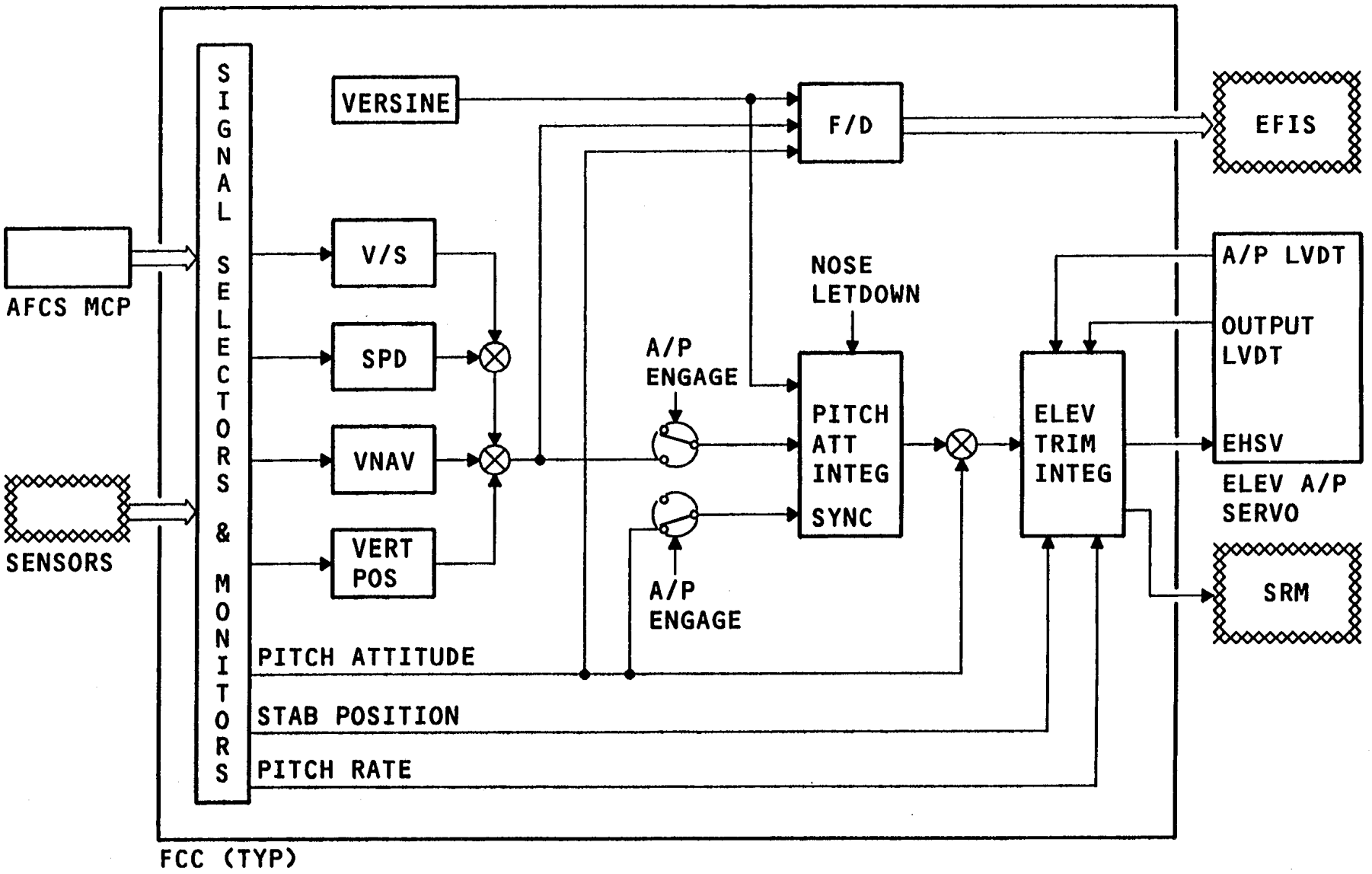

Figure 3 AFDS - PITCH AXIS CONTROL

PITCH MODE TRANSITION TABLE

The pitch mode transition table shows the ability to change either manually or automatically from one pitch mode to another. Note that some mode transitions have restrictions or conditions applied.

FROM \ TO	T/O	V/S	ALT HOLD	ALT CAPT	FL CH	VNAV	G/A	G/S	FLARE
T/O	●	YES	YES	3	YES	YES	NO	NO	NO
V/S	NO	●	YES	YES	YES	YES	YES	YES	NO
ALT HOLD	NO	YES	●	●	YES	YES	YES	YES	NO
ALT CAPT	NO	YES	●	●	YES	YES	YES	YES	NO
FL CH	NO	YES	YES	YES	●	YES	YES	YES	NO
VNAV	NO	YES	YES	YES	YES	●	YES	YES	NO
G/A	NO	1	1	3	1	YES	●	NO	NO
G/S	NO	2	2	NO	2	NO	YES	●	YES
FLARE	NO	NO	NO	NO	NO	NO	YES	NO	●

1 YES WHEN ABOVE 400 FEET RAD ALT

2 YES BEFORE LOC ACTIVE

3 YES WHEN ABOVE 800 FEET RAD ALT

Figure 4 PITCH MODE TRANSITION TABLE

TAKEOFF AND GO-AROUND PITCH MODE LOGIC

Takeoff Pitch Mode

The conditions for the takeoff mode are:

- CAPT or F/O F/D OFF to ON
- No channel in CMD
- Airplane on the ground

These conditions enable the T/O annunciation and T/O PITCH ENGA, if T/O PITCH sensors are valid. Takeoff pitch mode is exited when any of these occur:

- Any A/P to CMD if on the ground
- A new pitch mode engages
- Speed mode selected for the A/T

Go-Around

G/A is enabled by:

- G/A switch activation
- TRANS ENABLE (transition enable)
- IN AIR
- G/S active or flaps not up

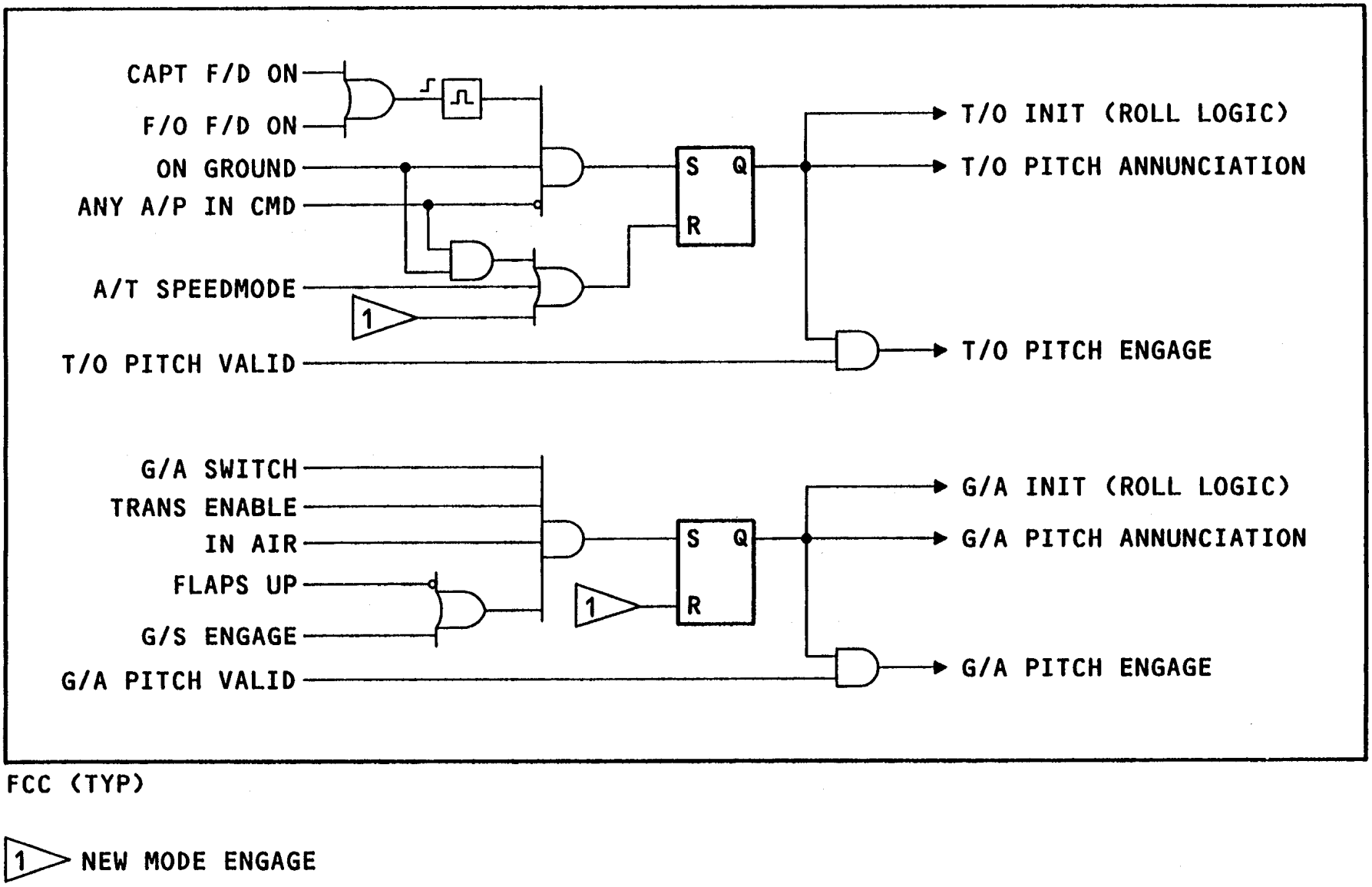

Figure 5 TAKE OFF AND GO-AROUND PITCH MODE LOGIC

VERTICAL SPEED AND ALTITUDE MODE LOGIC

Vertical Speed

vertical speed is in effect for these conditions:

- V/S Request or V/S Default
- Transition Enable

V/S Default occurs with:

- F/D to ON with A/P off in the air
- A/P to CMD with F/D's off
- A/P to CMD with F/Ds in T/O (on the ground)
- A/P to CMD with F/Ds in G/S capture
- AFDS in SPD-THROUGH-ELEV and A/T changes to the speed mode

Altitude Capture

Altitude capture occurs in climb or descent when the ALT CAPT logic is set (attempt to fly through MCP altitude).

Altitude Hold

Altitude hold is entered by:

- ALT HOLD Request
- V/S ENGAGE with Zero V/S - ALT HOLD default

The ALT HOLD default mode occurs if:

- In FLCH, and the airplane goes away from the path to capture the MCP altitude by 8000 feet.
- In VNAV, with the airplane between the FMC target altitude and the MCP altitude and the FMC target altitude changes away from the MCP altitude.
- In VNAV,, and the FMC target altitude would cause the airplane to go through or leave the MCP altitude.
- In VNAV, at the MCP altitude and the master FMC fails.

For the altitude hold or altitude capture mode, ALT shows on the FMA.

When V/S is engaged and the selected vertical speed is zero, ALT HOLD is in effect but the V/S mode annunciation shows.

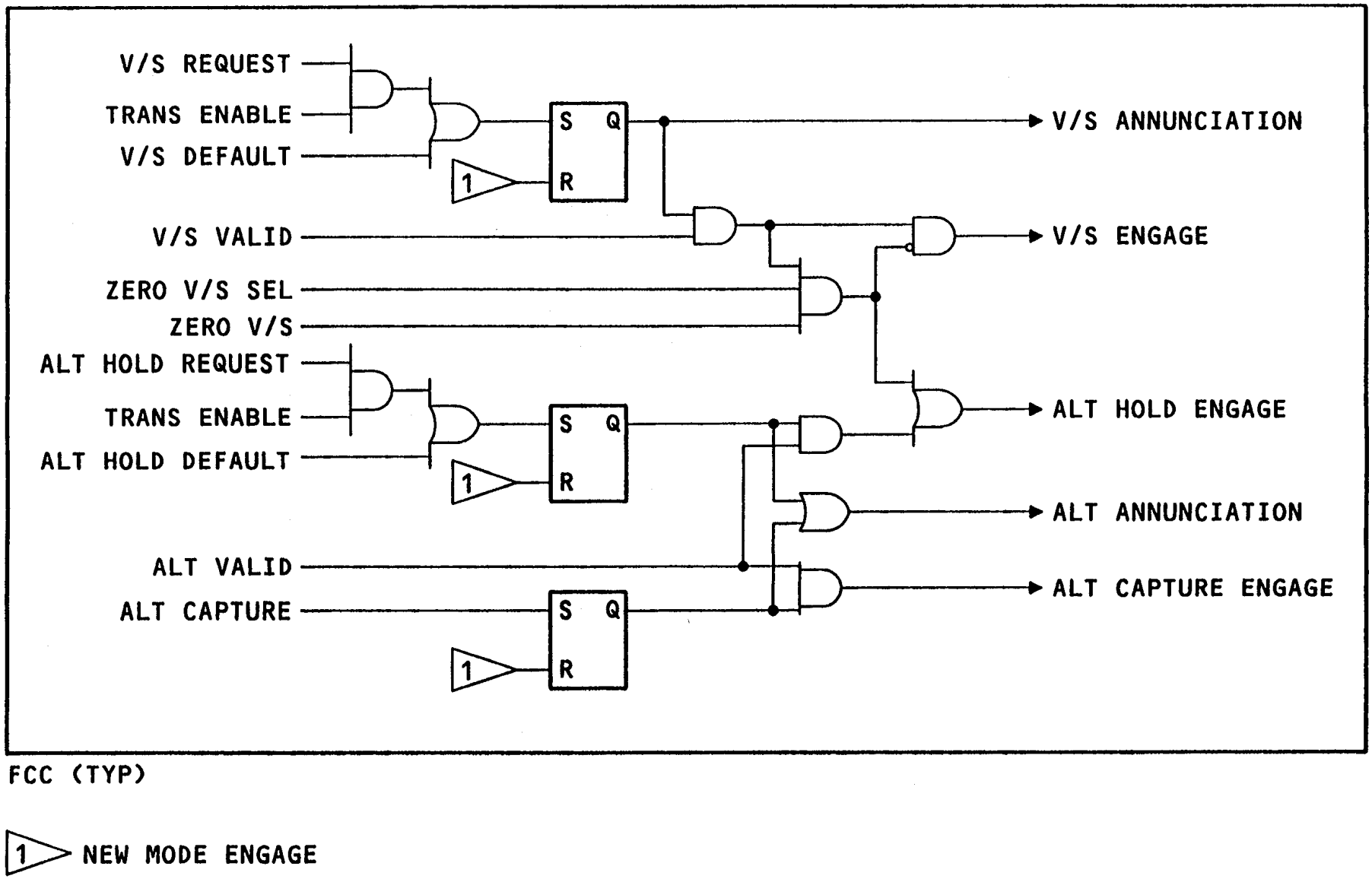

Figure 6 VERTICAL SPEED AND ALTITUDE MODE LOGIC

FLIGHT LEVEL CHANGE AND VNAV MODE LOGIC

Flight Level Change

The flight level change (FLCH) mode starts by FLCH selection on the MCP if the transition is allowed. Flight level change is cancelled by a new mode engaged. This may be selected or automatic as in the case of altitude capture.

Vertical Navigation

Vertical Navigation (VNAV) starts by VNAV selection on the MCP if the transition is allowed. This causes VNAV ARM annunciation if VNAV valid is not received from the FMC. VNAV engage occurs when the FMC sends valid VNAV commands (FMC DATA VALID). VNAV ARM is removed by a second push of the VNAV push button or by approach selection. VNAV ARM is also removed at VNAV ENGAGE. VNAV ENGAGE is cancelled by a new mode engaged.

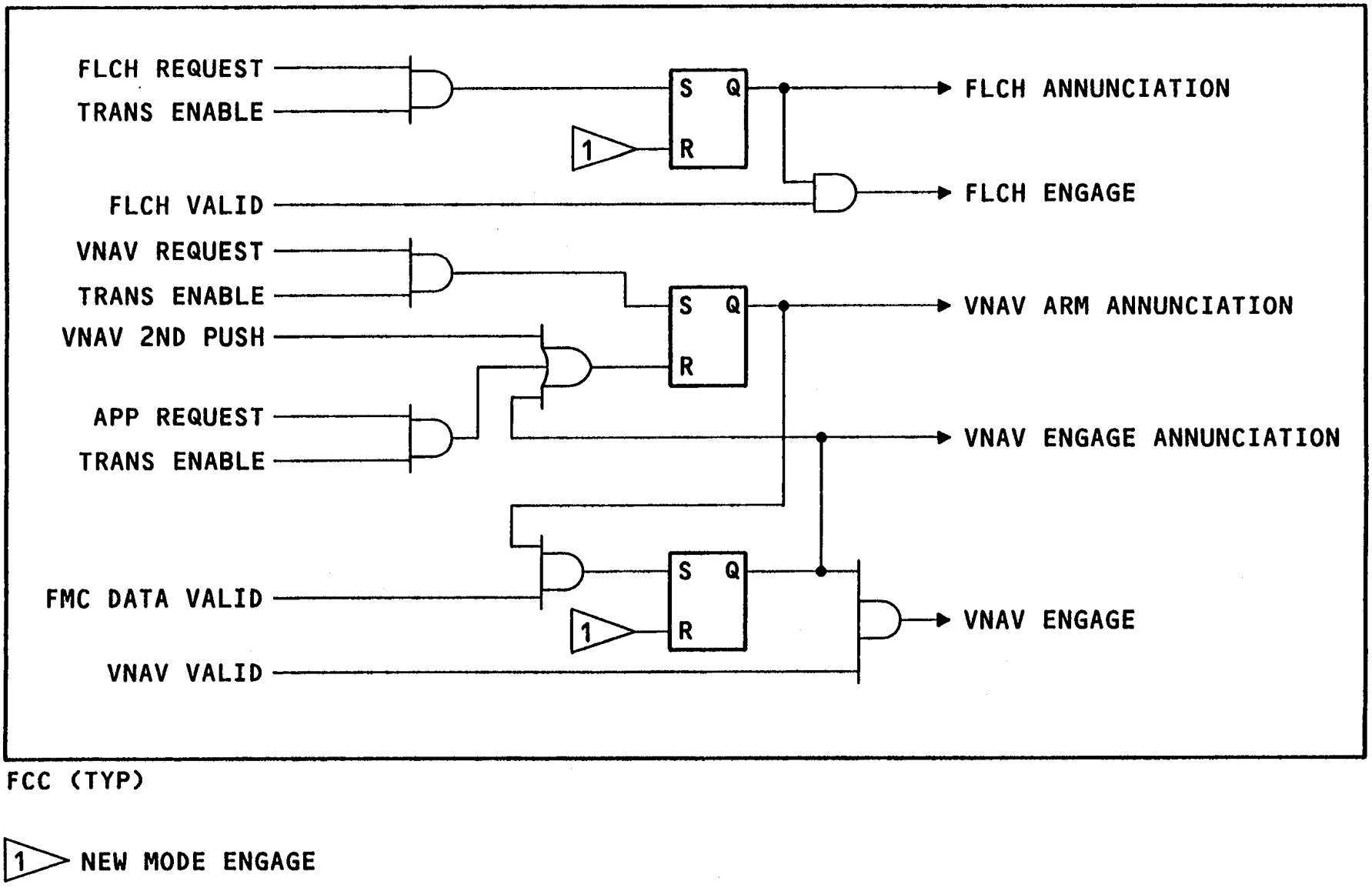

Figure 7 FLIGHT LEVEL CHANGE AND VNAV MODE LOGIC

PITCH APPROACH MODE LOGIC

Glide Slope Armed

The conditions that start G/S arm are approach request from the MCP if the transition is allowed. With LOC armed, G/S arm is cancelled by any of these:

- APP 2ND PUSH (second push of the APP button)
- LOC Request from MCP
- VNAV or LNAV Arm

With LOC engage, G/S arm is cancelled by a new roll mode.

Glide Slope Engage

G/S engage is determined by a capture detector if G/S ARM. G/S is cancelled by FLARE engage.

Flare

FLARE ARM annunciation shows at multichannel engaged. FLARE ENGAGE altitude is determined by the sink rate of the airplane. At a high sink rate (>18 ft/sec), the flare altitude is 60 feet. At a moderate sink rate (12.5 to 14.5 ft/sec), the flare altitude is 50 feet. At a low sink rate (<8.5 ft/sec), the flare altitude is 40 feet.

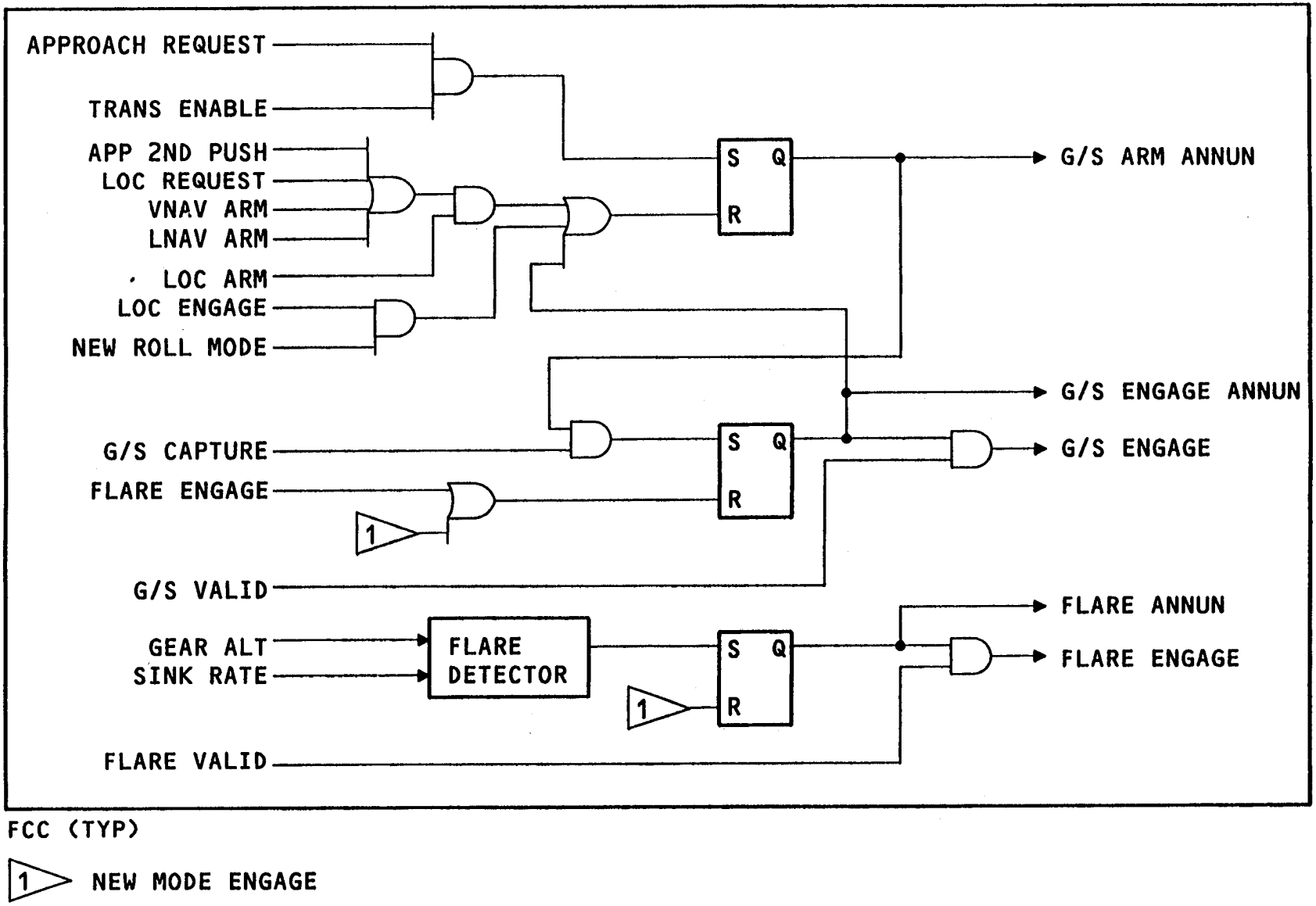

Figure 8 PITCH APPROACH MODE LOGIC

PITCH VERTICAL SPEED AND SPEED CONTROL

Vertical Speed

When the V/S mode is engaged by default or by selection, the present airplane vertical speed is the reference. The MCP vertical speed display shows the value at the start of the V/S mode. Any difference between the reference selected on the MCP and the IRU inertial V/S, is the command to the F/D and to the A/P.

Speed-Through-Elevator

The speed-through-elevator modes are takeoff, go-around and FLCH. The speed reference is compared with airspeed from the ADC. Any difference is a command to the elevators. Speed control includes stall protection through minimum safe speed calculation normally from the FMC. If the FMC fails, the FCC calculates the minimum safe speed based on angle of attack (AOA) and flap, stabilizer and speed brake positions.

If a speed is selected greater than the safe flight envelope of the airplane, the safe operational speed replaces the speed or mach selected as the reference. This is normally calculated in the FMC. If the FMC fails, the FCC calculates the maximum speed based on maximum operating schedule or flap position.

The G/A mode has full time windshear protection. The takeoff mode has windshear protection if a windshear or engine out is detected. When altitude rate is greater than 1200 feet/minute, MCP Speed is controlled. When altitude rate is less than 600 feet/minute, attitude is controlled. In between, the control is a combination of pitch attitude and speed.

When the FLCH mode is selected, the reference airspeed and MCP speed synchronize to either:

- FMC target speed if VNAV was the engaged mode before FLCH or
- The higher of MCP speed or present airspeed if VNAV was not the engaged mode before FLCH.

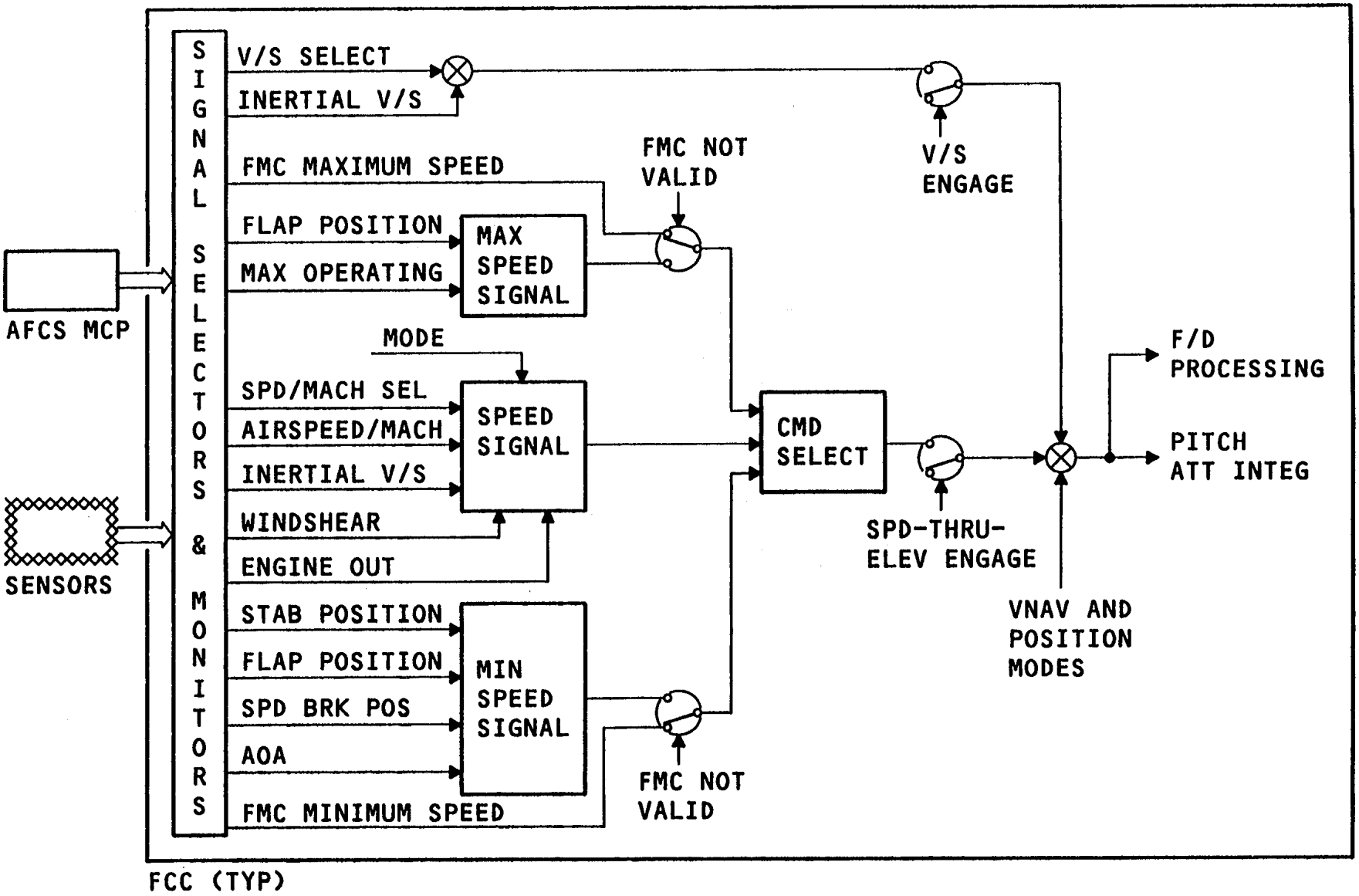

Figure 9 PITCH VERTICAL SPEED AND SPEED CONTROL

VNAV AND VERTICAL POSITION CONTROL

Vertical Navigation

VNAV commands come from the FMC and are used when VNAV is engaged.

Altitude Hold

The altitude reference for altitude hold is the barometric altitude when the ALT HOLD mode starts. The altitude hold command is the difference between this reference and the airplane altitude. The command also includes inertial vertical speed for damping.

Altitude Capture

Altitude capture occurs in all modes except glide slope. The altitude capture command is the difference between the MCP selected altitude at capture and airplane altitude. The command also includes inertial vertical speed for damping.

Glide Slope

The G/S deviation is converted to linear distance to beam center (G/S DEV ALT) by an estimate of the distance to the G/S transmitter. This is done with radio altitude. A three-degree glide slope is assumed. The command is based on G/S DEV ALT and G/S DEV ALT rate.

The glide slope command also includes an inertial path control. If the glide slope signal is lost, the inertial path control remains and the airplane holds the existing path.

Flare

Gear altitude is calculated by radio altitude, pitch angle and distance from the R/A antenna to the gear. This gear altitude is used for the flare command. The flare command calculates touchdown at 1.5 feet/second, 450 feet from the G/S transmitter.

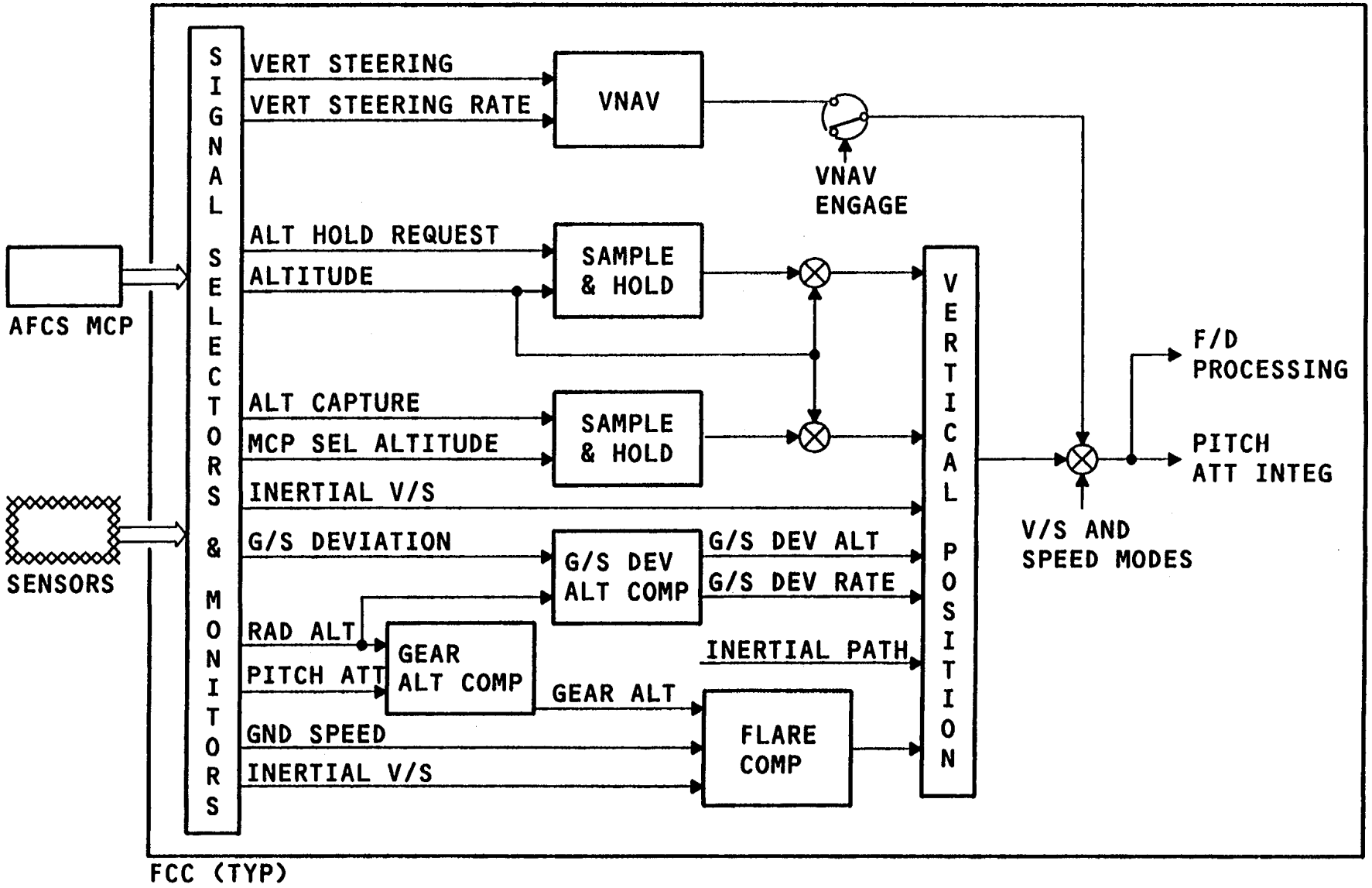

Figure 10 VNAV AND VERTICAL POSITION CONTROL

ROLL AND YAW AXIS CONTROL

Command Development

There are five sections for commands for F/D and A/P roll and yaw. These are:

- Lateral navigation (LNAV) -Heading/track (HDG/TRK) - Localizer (LOC) - Runway align (RWY ALIGN) - Rollout

Roll Attitude

The roll attitude integrator (ROLL ATT INTEG) synchronizes to roll attitude when the A/P is not engaged.

The ROLL DOWN logic causes the roll attitude integrator to remove any command input and command the airplane to go wings level. This occurs when the heading hold mode begins or when 5 feet gear altitude is reached during autoland.

Autopilot Command

The aileron trim integrator (AIL TRIM INTEG) synchronizes the servo position with the surface position while the A/P is armed and supplies all A/P commands to the aileron servo while engaged.

Command Sections

When LNAV is engaged the FMC calculates lateral steering commands. The HDG/TRK section develops the commands during heading select, heading hold and track hold modes. The LOC section is used during approach. The RWY ALIGN section uses heading and track to reduce the effects of crosswind and engine-out. The ROLLOUT section uses LOC deviation to hold runway centerline after landing. The yaw damper control operates if both yaw damper systems are invalid. These last three sections function during multichannel approach only.

F/D Command NCD

The F/D command word has an NCD status if the operating mode is invalid (sensor fail or improper operation).

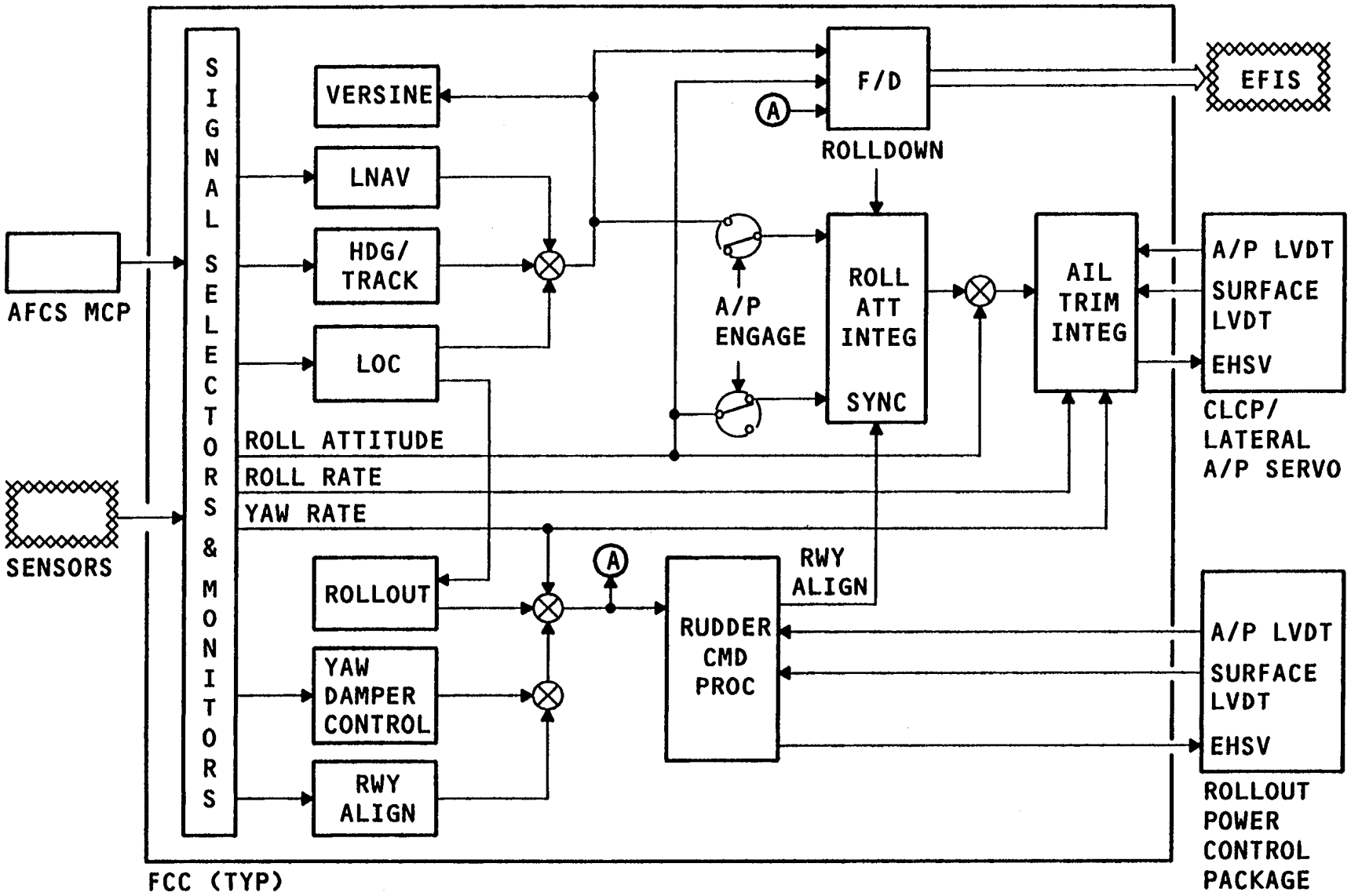

Figure 11 ROLL AND YAW AXIS CONTROL

ROLL MODE TRANSITION TABLE

The roll mode transition table shows the ability to change either manually or automatically from one roll mode to another. Note that some mode changes have restrictions or conditions applied.

FROM \ TO	T/O	HDG HOLD	HDG SEL	LNAV	LOC	G/A	ROLLOUT
T/O	●	YES	YES	YES	NO	NO	NO
HDG HOLD	NO	●	YES	YES	YES	YES	NO
HDG SEL	NO	YES	●	YES	YES	YES	NO
LNAV	NO	YES	YES	●	YES	YES	NO
LOC	NO	1	1	NO	●	YES	YES
G/A	NO	2	2	2	NO	●	NO
ROLLOUT	NO	NO	NO	NO	NO	NO	●

1 YES BEFORE G/S ACTIVE

2 YES WHEN ABOVE 400 FEET RAD ALT

Figure 12 ROLL MODE TRANSITION TABLE

TAKEOFF ROLL AND HEADING MODE LOGIC

Takeoff Roll

T/O INIT (initiate), comes from the pitch logic, with T/O Roll Valid and is used to produce T/O Roll.

Heading Hold

Heading hold starts by default or by a push of the HDG HOLD switch if transition enable. This causes the HDG HOLD is annunciation.

The heading hold default conditions are:

- Flight director on with autopilots not engaged (in the air)
- Autopilot engages with flight directors off
- Autopilot engages with flight directors in takeoff (on the ground), go-around or LOC CAPTURE
- HDG REF switch changes while in HDG SEL

The conditions for HDG HOLD ENGA are wings level (roll angle less than 3 degrees) and HDG HOLD VALID.

Heading Select

The requirements for HDG SEL are;

- HDG SEL request
- Transition enable
- HDG SEL valid

This engages and annunciates heading select (HDG SEL).

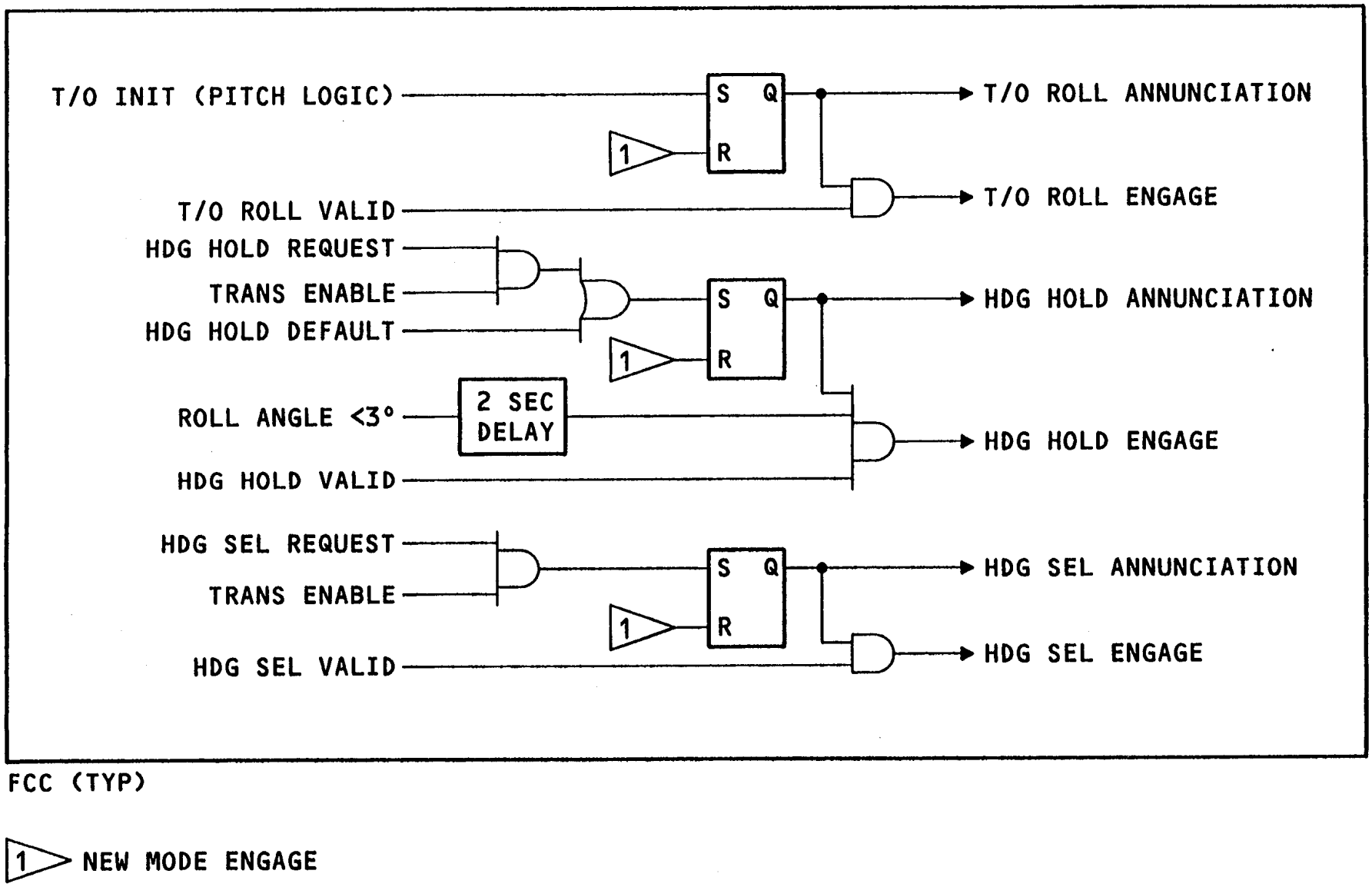

Figure 13 TAKEOFF ROLL AND HEADING MODE LOGIC

GO-AROUND ROLL AND LNAV MODE LOGIC

Go-Around

Roll G/A starts by:

G/A INIT (initiate), from the pitch logic G/A roll valid

Lateral Navigation

The conditions for LNAV are:

- LNAV request
- Transition enable
- FMC data valid
- LNAV valid

LNAV arm is cancelled by:

- LNAV button 2nd push
- Localizer or approach request if the localizer transition request is allowed.
- LNAV engage

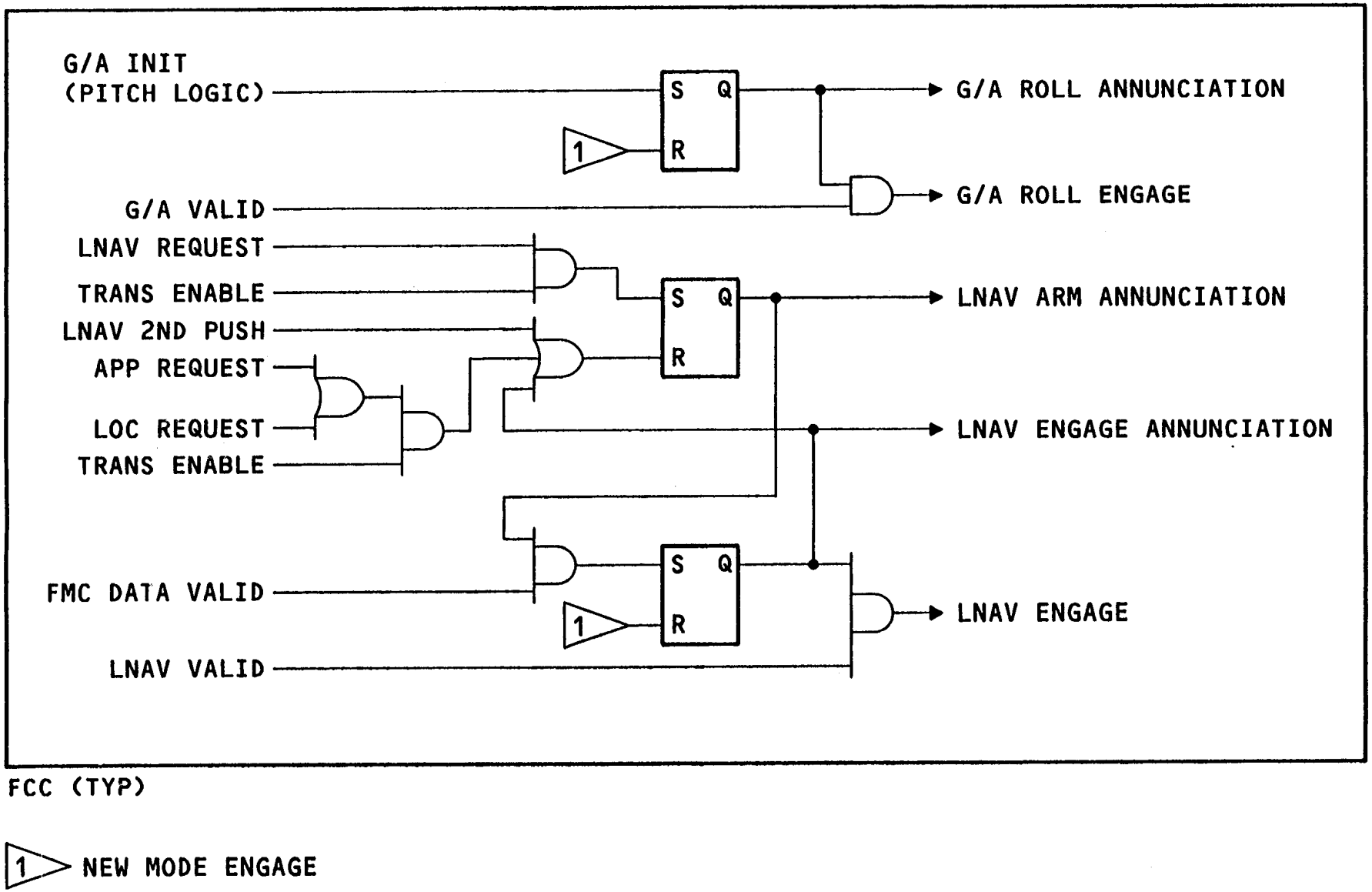

Figure 14 GO-AROUND ROLL AND LNAV MODE LOGIC

LOCALIZER MODE LOGIC

LOC arm occurs with:

- LOC request or APP request
- Transition enable

LOC engage occurs with:

- LOC arm
- LOC mode valid
- Course error less than 120 degrees
- LOC capture

If G/S is not engaged, LOC arm is cancelled by any of these:

- APP second push
- LOC second push
- LNAV or VNAV arm

If G/S is engaged, LOC arm is cancelled if a new pitch mode engages.
LOC arm is also cancelled by LOC capture.

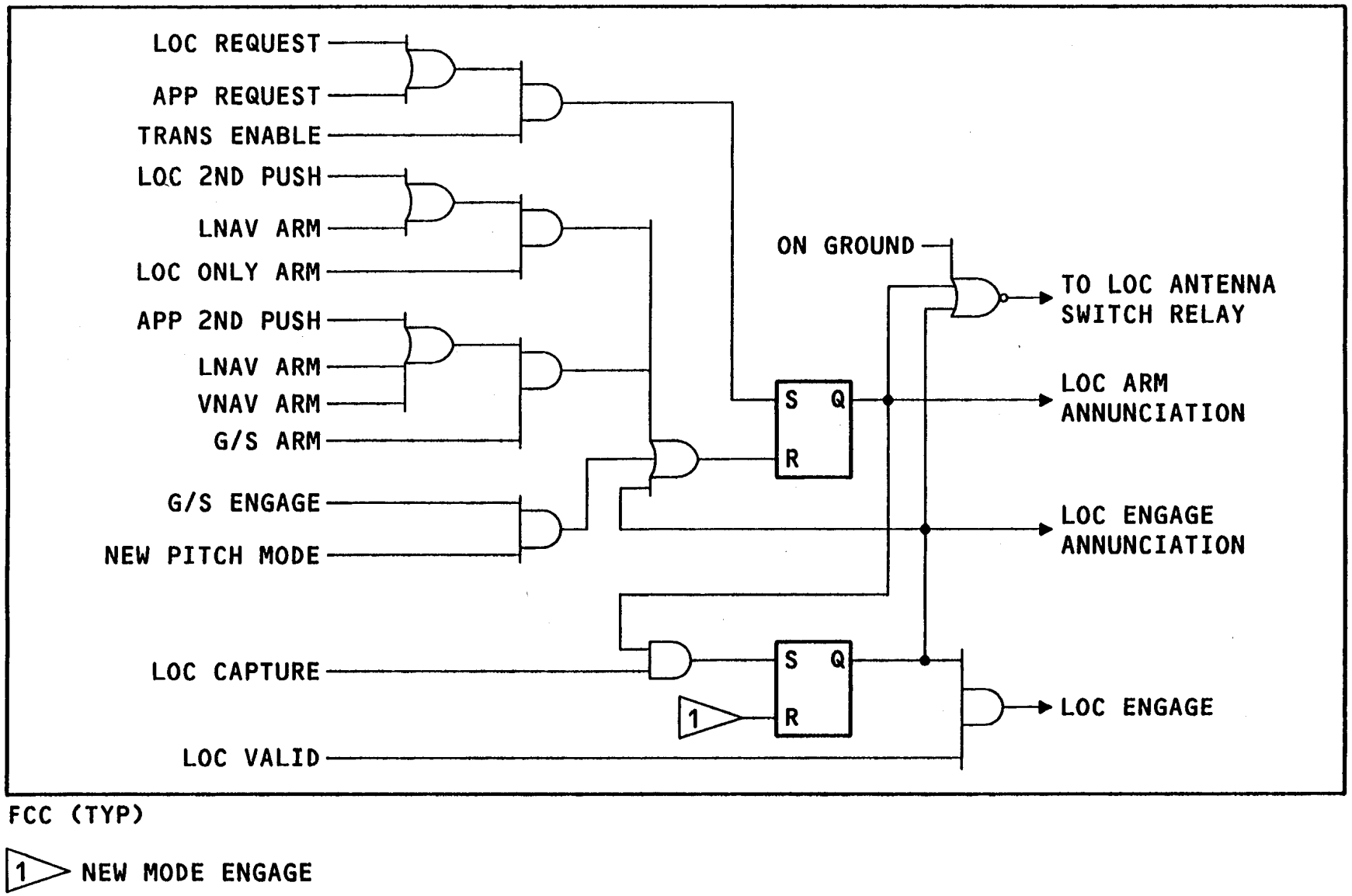

Figure 15 LOCALIZER MODE LOGIC

HEADING, LNAV AND LOC CONTROL

Heading/Track Modes

In a heading mode (HDG HOLD or HDG SEL), the command is based on a difference between a reference heading or MCP selected heading and the airplane magnetic or true heading.

In other than a heading mode (takeoff or go-around), the command is based on airplane track.

Lateral Navigation

LNAV steering commands from the FMC are applied to the F/D and to the ROLL ATT INTEG.

The commands are based on deviations from desired track.

Localizer

LOC operation is divided into capture and track.

During capture, control is based on cross runway velocity, LOC deviation and the difference between ground track and runway heading. Runway track angle must be less than 1201 for LOC capture. At LOC TRACK (final roll down on LOC centerline) the command is changed to LOC deviation distance and rate. LOC deviation is converted to linear distance to beam center by an estimate of the distance to the LOC transmitter. This is done with radio altitude. A three degree glide slope and 10,000 foot runway is assumed.

The localizer command also includes an inertial path control. If the localizer signal is lost or a localizer anomaly is detected, the inertial path control remains and the airplane holds the existing path.

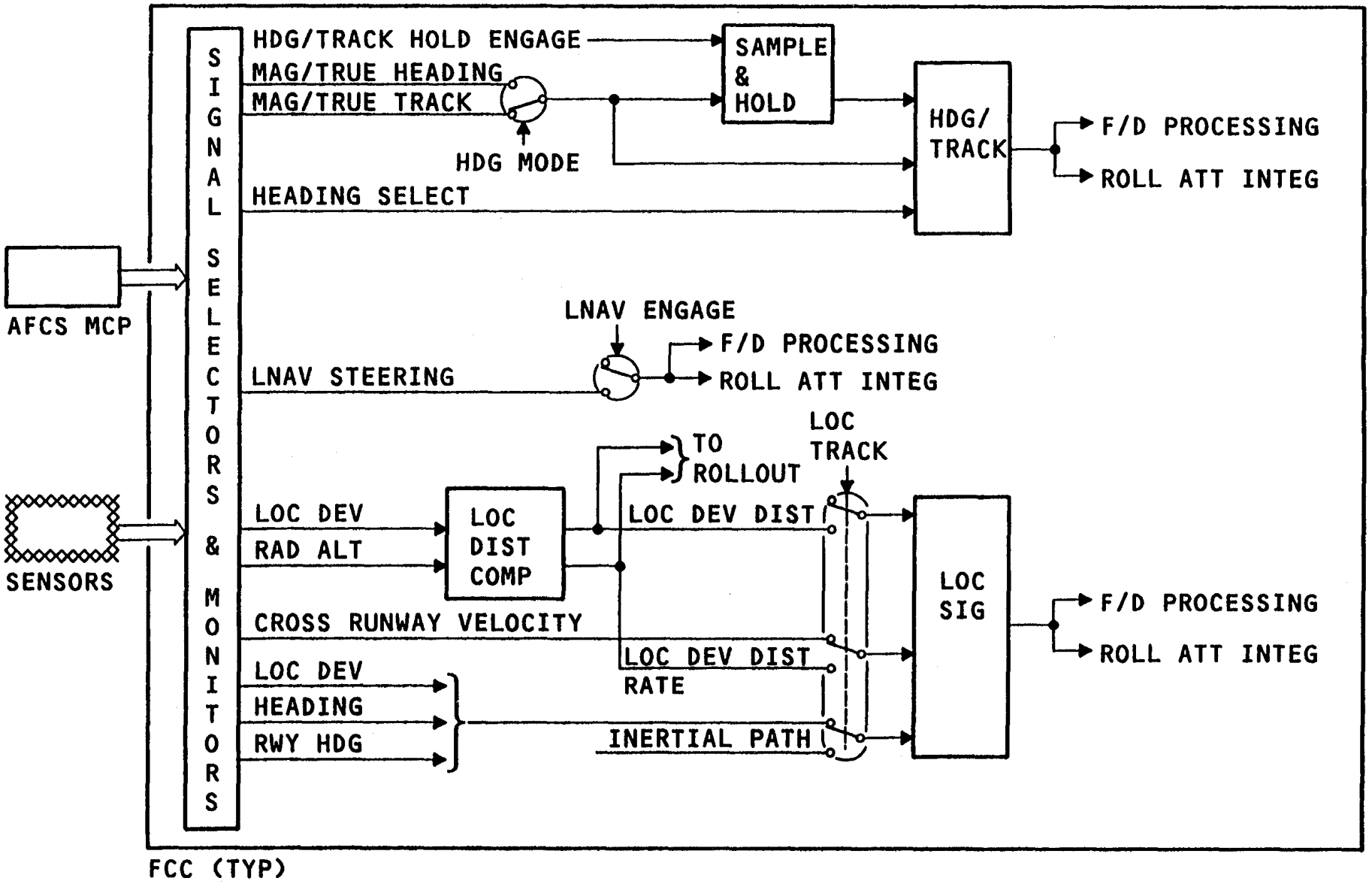

Figure 16 HEADING, LNAV AND LOC CONTROL

RUNWAY ALIGN AND ROLLOUT MODE LOGIC

Runway Align

The runway align modes are designed to reduce the effects of an engine-out and to reduce the crab angle due to cross winds. The engine-out operation is enabled at multi-channel engage. If an engine fails during the approach, aileron and rudder commands make sure a wingslevel condition or small upwind wing low condition is maintained.

The DECRAB portion begins, if multichannel engaged, at either 500 feet or 200 feet radio altitude, dependent on the magnitude of the crosswind.

There is no annunciation of runway alignment or decrab. Runway alignment and decrab are cancelled at rollout or go-around engage.

Rollout

Rollout arm is shown if multi-channel engaged.

Rollout engage occurs at 2 feet radio altitude. Rollout engage annunciation is shown if multi-channel engaged when rollout begins. If not multi-channel engaged when rollout begins, the rollout mode is engaged for flight director but the mode shown is LOC.

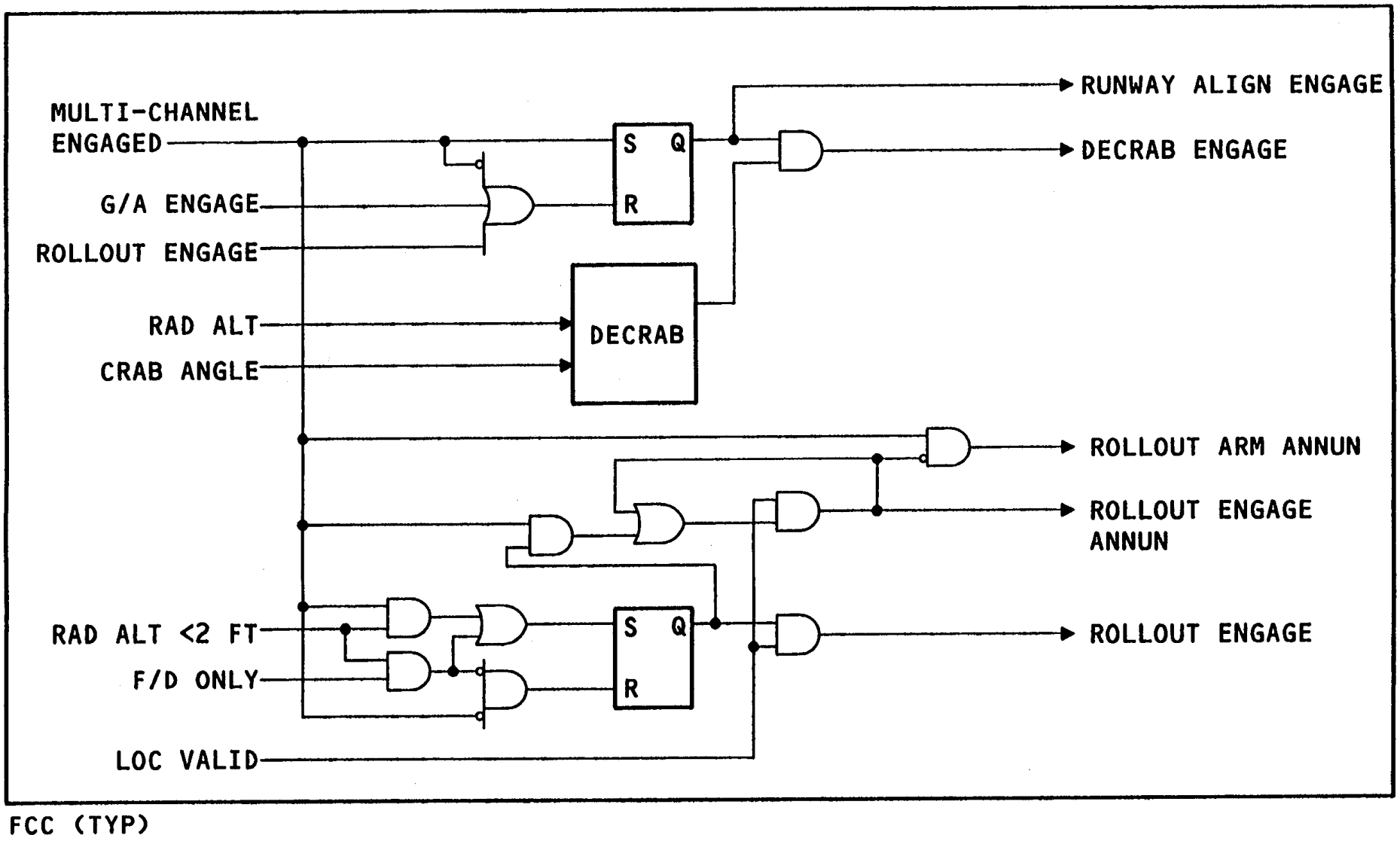

Figure 17 RUNWAY ALIGN AND ROLLOUT MODE LOGIC

RUNWAY ALIGN, ROLLOUT & YAW DAMPER CONTROL

Runway Align

The runway align command is based on magnetic heading and track. This command reduces the effect of engine loss and crosswinds. The DECRAB command uses magnetic heading and runway heading to reduce the crab angle. This command also causes a roll command to compensate for drift angle reduction.

For crab angle greater than 5 degrees, a rudder and aileron command reduces the crab angle and produces a maximum of 5 degrees sideslip. This begins at 500 feet radio altitude.

For a crab angle less than 5 degrees, the commands begin at 200 feet and the crab angle is completely eliminated.

Rollout

The rollout command uses LOC deviation distance and rate developed for localizer control. This signal controls to localizer (runway) centerline through the rudder and nose wheel steering if multichannel

engaged. If not autopilot engaged, the rollout control is used for flight director only.

Yaw Damper Command

The FCC supplies a yaw damper command during a multi-channel approach if both yaw damper modules are invalid.

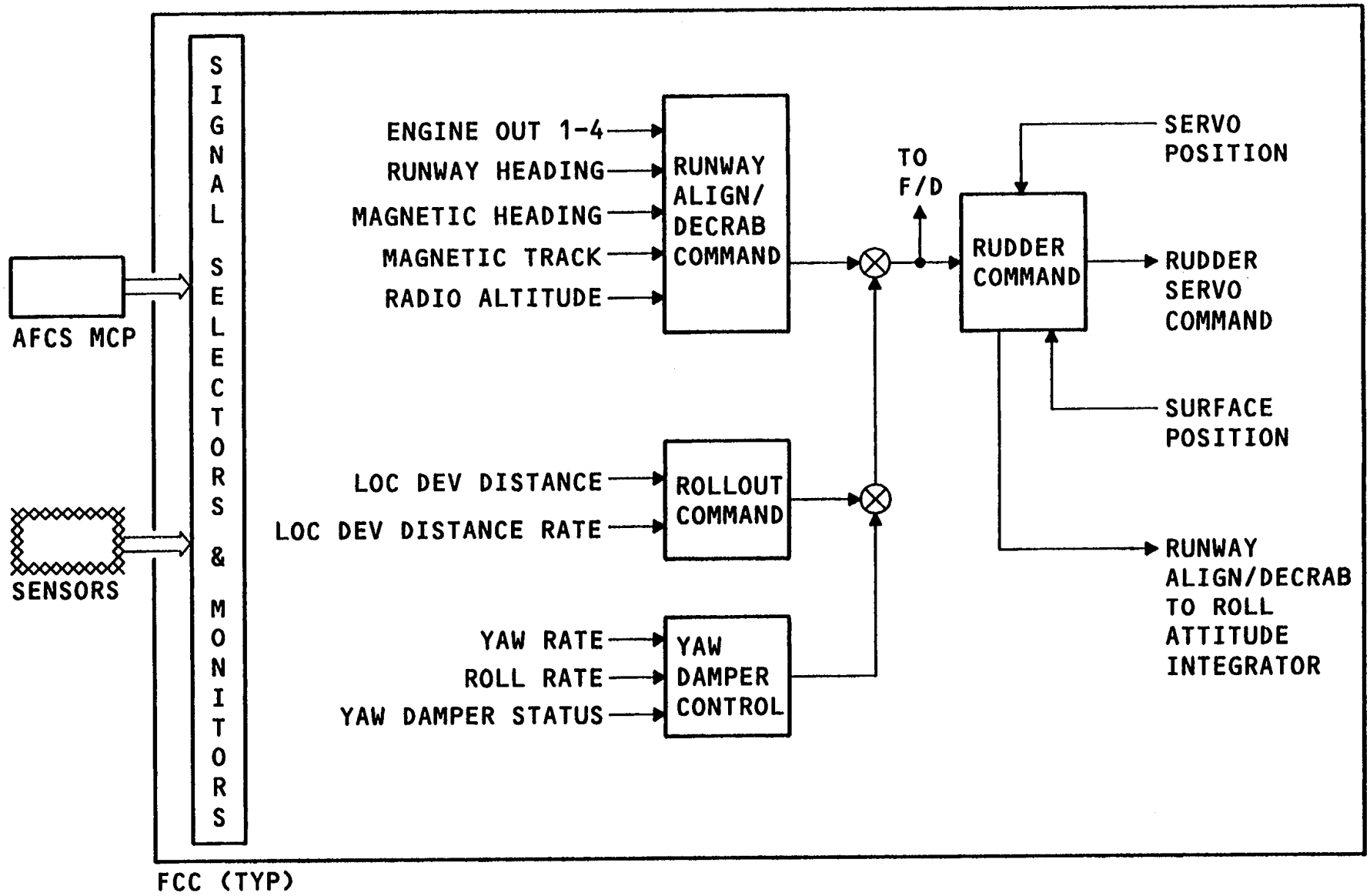

Figure 18 RUNWAY ALIGN, ROLLOUT & YAW DAMPER CONTROL

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