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Study of VHF Active Phased Array Wind Profiler Radar Control Switches

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Abstract: Wind Profiler RADARS are playing an important role in 3-D mapping of the atmospheric winds. Earlier, various RADARS are located around the globe and studied well the meteorology of their geographic locations. As Manora Peak (29.4^{o} N; 79.2^{o} E; 1958 m amsl), ARIES ST RADAR (ASTRAD) is a high altitude site in the central Himalaya and having peculiar topography. Therefore, a wind profiler is installed to study the meteorology over the central Himalaya. This profiler is a unique facility in the central Himalaya, because it is an Active Phased Array radar i.e. each transmitter and receiver (transceiver) functions are composed of numerous small solid-state transmit-receive modules (TRMs) and also each transceiver has individual power supply. It have 588 antennas with operating frequency is 206.5 MHz. It can measure the vertical profile of the wind velocity up to 20 km above ground level (AGL) in the atmosphere. It has 588 TRM connected with same array of antenna. Individual 588 TRM have different kind of switches, these switches are the heart of the VHF radar. Because without these switches the TRM cannot operates the radar. So, this paper deals with the basic description of switches and how these switches are work for VHF Active Phased Array radar which is developed at ARIES ST RADAR (ASTRAD).

Keywords: Wind Profile RADAR, 3-D MAPPING, ASTRAD, AGL, TRM.

I. Introduction

Globally, there are networks of radars available for studying Stratosphere and Troposphere regions. In India, Himalayan regions is void of such observational facility and the locations of ARIES, Nainital is best suited for this purpose [1]. The performance of ST radar systems with active phased array antennas is mainly 588-element active aperture array driven by the performance of the microwave T/R modules. The concept of active aperture array is critically dependent on the availability of compact and minimum weight, low consumption and high reliability T/R modules. The large number of individual T/R modules integrated with the respective radiating elements of the active array ensures a great degree of redundancy in case of failure of elements (graceful degradation). Due to the close connection of the T/R modules to the radiating elements, the losses in both cases, transmit and receive, are low, compared to passive array systems. This leads to a low receive noise figure and high transmit efficiency.

The Transmit & Receive module (TRM) consists of a transmit section, receiver section, calibration section and a controller and each section have different kind switches like: SPDT 1, DDC, SPDT 2, BLK 2, BLK 1, DPDT, GATE BIAS and T/R SWITCH by which TRM operates the radar. The major challenge is that choosing of these switches, because each switches characteristics and functionalities are different. So, at a time for each section each switch need to work properly otherwise TRM can't operate the radar. The transmit section is designed to amplify a nominal level of -4.0dbm RF pulsed signals with upto 13% (max) duty cycle to 400W peak level. It is tuned to the centre frequency of 206.5 MHz and has a band width of 5 MHz. Transmit and receive sections share a common path using the same input/output connector, simplifying the RF circuitry. The output drives a Yagi Antenna through a lightening protector. The same antenna is used for transmit and receive functions. In receive path, the signals are amplified through a low noise LNA section and made available in the common input/out connector. The module is capable of being networked through a distribution network for receiving RF and control signals.

Fig.1. ARIES ST RADAR, NAINITAL

II. BRIEF DESCRIPTION OF ACTIVE PHASED ARRAY RADAR

An active electronically scanned array (AESA), also known as active phased array radar is a type of phased array radar whose transmitter and receiver functions are composed of numerous small solid-state transmit/receive modules (TRMs). AESA radars aim their "beam" by emitting separate radio waves from each module that interfere constructively at certain angles in front of the antenna. Advanced AESA radars can improve on the older passive electronically scanned array (PESA) radars by spreading their signal emissions out across a band of

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frequencies, which makes it very difficult to detect over background noise.

Critical high power spare parts are getting obsolete making it difficult to sustain the radar operation. In view of these problems, an R&D project was taken up to upgrade the ARIES ST RADAR in to an active phased array system using the solid-state transmits-receive (TR) modules. For wind profiling radar system this is the best fitted phased array radar [2],[3].

Active phased array radar has so many functionalities:

i. High gain width low side lobes
ii. Ability to permit the beam to jump from one target to the next in a few microseconds
iii. Ability to provide an agile beam under computer control
iv. Arbitrarily modes of surveillance and tracking
v. Free eligible Dwell Time
vi. Multifunction operation by emitting several beams simultaneously
vii. Fault of single components reduces the capability and beam sharpness, but the system remains operational
viii. Low probability of intercept
ix. High jamming resistance

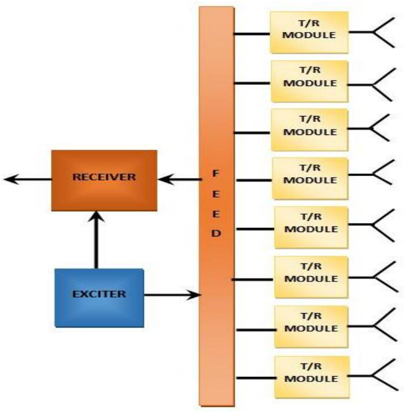

Fig.2. Block diagram of Active Phased Array Radar

III.SCHEMATIC DIAGRAM OF TRM (TRANSMIT RECEIVE MODULE)

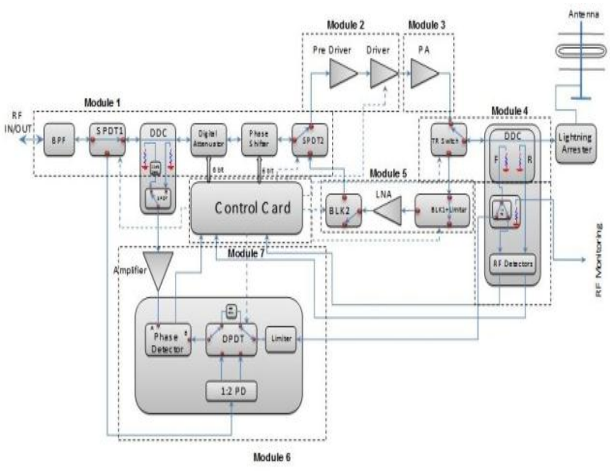

Fig.3. Block diagram of TR module

A. Brief Description of TR Module

Transmit / Receive module is one of the most important parts for VHF coherent active phased array wind profiler radar. TRM is consist of transmit path and receive path as well as it has some common path which consist of band pass filter (BPF), some SPDT switches like SPDT 1, SPDT 2; 6 bit digital attenuator, and 6 bit phase shifter. Phase shifter is one of the important blocks of TRM module because its shift the beam electronically to the south, north, east, west and azimuth direction for measures the wind speed and velocity. Total TRM module control by control card which is connect with each and every digital circuit module inside the TRM block. After the common path high power section is connected, this is basically divided into three parts i.e. pre driver, driver, and power amplifier (PA). This high power section generate the high power signal at transmit mode. This TRM input power is very low i.e. -4dBm and at the transmit time it's generate the TRM output as 56dBm which is very high i.e 400W. It has also consists of TR switch as a duplexer. It's required +5V to operates as a transmit mode and required -5V to operates as a receive mode. In receive path the most important device is low noise amplifier (LNA) which is connected with antenna to get back the receive signal with low power, before this LNA one limiter is connected to protect the device from damage. Before the LNA device one DDC is present which protect the TRM from the leakage high power if reflected back due to broken antenna probe. TRM also required 32V DC power @ 4Amps as a power supply. It has consist with 5 port like J1, J2, J3, J4, J5, as RF input/output port, Tx/Rx common port, DC power supply port, RF monitoring port and antenna port respectively.

B. Block diagram of control switchs

1. Transmit path Switch connections

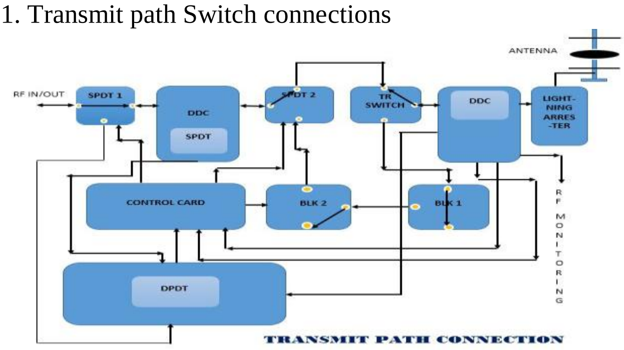

Fig.4. connection of T_X path

2. Receive path Switch connections

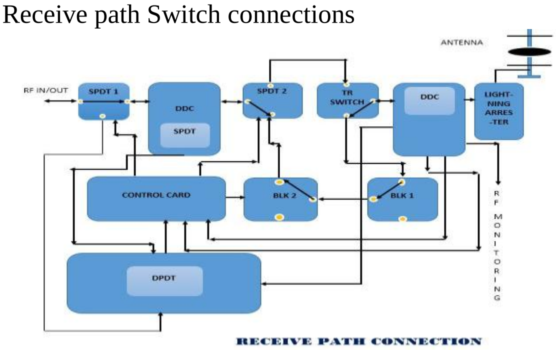

Fig.5. connection of R_X path

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IV. INTERNAL CIRCUIT OF TR MODULE

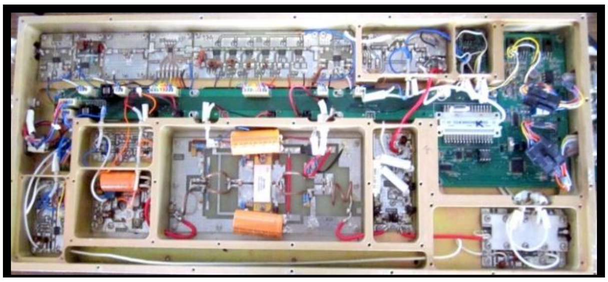

Fig.6. Internal circuit of TR module

A. Brief Description of TRM Control Switches

1. SPDT-1(Single Pole Double Through-1)

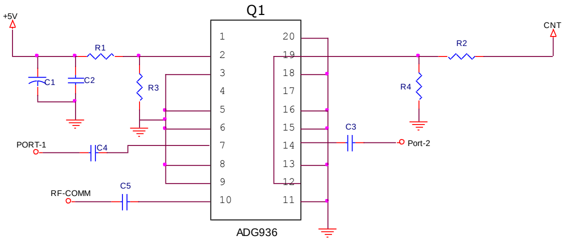

Fig.7. Schematic of SPDT-1

SPDT (Single Pole Double Through), that means its inputs is one way and its output is two way. This SPDT is the first switch of the TR module.This switch output is always need to high for TX/RX section.

The main part of this circuit is ADG936, which are wideband analog switches that comprise two independently selectable SPDT switches using a CMOS process to provide high isolation and low insertion loss to 1 GHz [4]. It has 5 ports, 2 ports of pin 7 and pin 14 is for input/output. Pin 2 used for operating the IC. Port in pin 19 and pin 12 for operating control signal of TR module. Port in pin 10 is the common RF port.

Here capacitors C4, C3 and C5 are used for coupling that means this capacitors drop the DC voltage only pass the AC voltage. C1, C2 and R1, R2 are used for voltage divider. This IC is operates 1.65v to 2.75v, so, using voltage divider we can drop the voltage to operate the IC as properly.

Also R2, R4 used in the port for control signal. This is also used for voltage divider. R-Comm. is the common port of the RF signal.

Now come to the internal circuit of the IC. In this IC two common RF port RFCA and RFCB are present. 4 output port like RF1A, RF2A, RF1B and RF2B. In this IC two SPDT switch are present but we consider only one SPDT which output is RF1B and RF2B. One RF common port is RFCB and one control signal port is INB. First of all IC operated signal is present in pin 2. When control signal come in the control port in pin 12 then INB selects the input/output ports. When TX mode then port1 is input and port2 is output, when RX mode then port2 is input and port1 is output. According to the control signal and INB port we will select the TX and RX mode and also which port is input and which port is output. When control signal is high then from fig output port is RF2B, input port is RF1B. So in TX mode switch through RF1B is connects to pass the signal to RF2B port. Here input port is port1 and output port is port 2. During RX mode it happens just opposite.

2. DDC (Dual Directional Coupler)

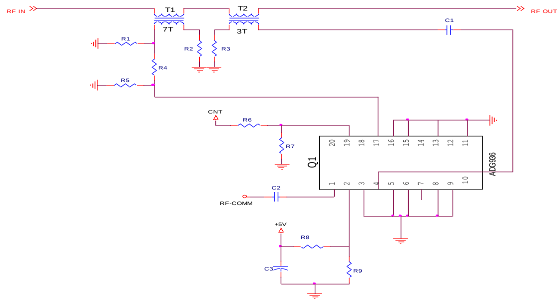

Fig.8. Schematic of DDC

DDC (Dual Directional Coupler), which is also high for this TR module. It is used for calibration purpose. It is used both transmit and receive path. When RF signal come it checks the level and inform to the digital anntenuator also inform to the phase shifter. It also informs to the phase shifter to maintain the same phase for all antennas for transmit as well as receive mode.

This circuit is little more same as SPDT-1 because here also used the ADG936 IC. Here extra two transformers which are T1 and T2 used. Pin 1 is for RF-Comm. which is common port of RF signal. Here also pin 2 is used for IC operating port. That means IC operating voltage should be maintain using this port, here 2 resistors and 1 capacitor is used for voltage divider. Pin 3, 5, 6, 8, 9, 11, 13, 15 and 16 are ground pin. Pin 4 and pin 17 are used for selecting the input output port. Pin 19 is input control port for RF signal; here R6 and R7 are used for voltage divider. In TX mode input port is pin 17 and output port is pin 4. In RX mode input port is pin 4 and output port is pin 17.

In this IC two SPDT switch is present, but we use only one switch. Input is INA and output is RF1A and RF2A, and common port for RF signal is RFCA. It is a dual directional coupler, used for calibration purpose. It coupled both the TX and RX mode. Here two transformers one is for RF in and another is for RF out. Here two transformers are used for couple the signal. When RF signal is come it pass through T1 transformers, here R1, R4, R5 are used for voltage divider shown in fig. IC doesn't tolerate high voltage that's why voltage divider is used to drop the voltage level which is passed through the T1 and come to the IC. According to control signal the input port INA gets excited. Then if the voltage level is high then output port is RF2A and input port is RF1A. If the voltage level is low then output port is RF1A and input port is RF2A. Also T2 transformer is used for RF out path, here C1 capacitor used for coupling.

3. SPDT-2 (Single Pole Double Through-2)

This is same as SPDT-1,difference is that it is always low condition. In transmit path it when it low then it pass the signal to the forward path. It's on time is always 18 µsec.That means this switch act as a toggle switch.

This circuit is also same as SPDT-1 except that one resistor is used in port1 and 3 resistors are used in port2. All the functions is same as SPDT-1.

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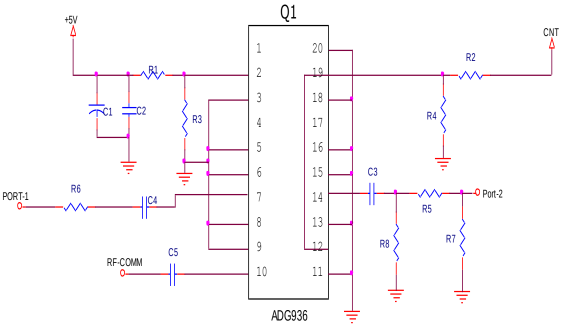

Fig.9. Schematic of SPDT-2

In this circuit R6 resistor is used before the C4 capacitors used in this IC to protect from high voltage in TX mode. Also R5, R7 and R8 resistors are used for voltage divider to protect from high voltage in RX mode.

Here also used one SPDT switch as shown in the fig. In this circuit pin2 is for IC operating port. Using this 5v port this IC will be operated. Pin19 and pin12 are used for control signal port. Using this control port we will be select the input output port in both TX and RX mode. SPDT-1 and SPDT-2 both functions are same but the difference is SPDT-1 signal is always high in both TX and RX mode but SPDT-2 signal is high in TX mode and for few time it should be low in RX mode. Usually SPDT switch is always high. When SPDT-2 is worked in TX mode and pass through the signal to power amplifier section then it is high signal. In RX mode SPDT-2 is low signal for just few microseconds to pass the signal. That means when signal level is low then SPDT-2 is connected with RX path. This because if the low voltage level duration time is more, then when TX path signal come and pass to the received path, it will burn the LNA. That's why just for few microseconds it will connected to RX path, otherwise it is high. Its switching speed is high. From internal schematic of ADG936 we see that depending upon control signal when INB is high then input port is RF1B and output port is RF2B and worked in a TX path. But when INB is low then upper side switch is closed and lower side switch is opened, then input port is RF2B and output port is RF1B and worked in a RX path. In TR module TX path gain is 56 dbm and RX path gain is 27 db. So, in RX path if high gain comes then it will damage the IC, that's why voltage divider circuit is connected with port2.

4. BLK-1 & BLK-2 (Blanking switch)

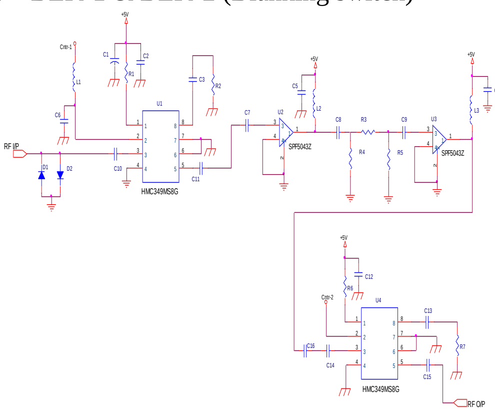

Fig.10. Schematic of BLK-1 & BLK-2

BLK-2: This blanking switch is used for isolation purpose.This is used before LNA in receive path. In transmit path when signal pass through from SPDT 2 and go to the transmit path. Then if any current pass to receive path then current burn the LNA, so, forward path isolation is to be required.

BLK-1: This is same as the BLK 2; this is also used for isolation purpose. It works in receive path. In receive path when signal comes then if high signal come then it will damage the LNA, so, here need to isolate the LNA from the damage.

Using pin1 we can active or turn on IC properly. Pin2 is used for control purpose. This is the input control signal pin. Using this control pin we can control the signal state path. Pin3 for RF signal input port. Here one limiter used because of RX echo signal which is comes from sky if signal level is high then it will damage the IC. That's why using limiter we can drop down the voltage level. Pin4 is the enable pin, it is always low state, and otherwise if it is set to high then all switches are goes to off state. Pin5 for RF signal output pin. This signal is input of the LNA. Here C3, C10 and C11 capacitors are used for blocking the spike. Pin6 and pin7 is ground pin. Pin8 is also RFout signal pin but it is used to bypass the signal. When RX echo signal comes in RF input then control signal in pin2 selects the RF output path. The major part of this circuit is HMC349MS8G, which is a high isolation non-reflective DC to 4 GHz GaAs MESFET SPDT switch in a low cost 8 lead MSOP8G surface mount package with an exposed ground paddle. The switch is ideal for cellular/PCS/3G base stations applications yielding 50 to 60 db isolation low 0.8 db insertion loss and +52 dbm input IP3. An enable input (EN) set to logic high will put the switch in an "all off" state [5].

If signal is low and bias condition is 0 to 0.8 Vdc then RFC-RF1 connection is off and RFC-RF2 connection is on. When signal is high and bias condition is +2 to +5 Vdc then RFC-RF2 connection is off and RFC-RF1 connection is on to pass the signal to LNA. In this switch control signals off time duration is just few microseconds and it is just more than other switch, because this switch is used for high isolation between RF signals to LNA. Now when signal comes then using limiter dropdown the high power level and then this signal pass through the LNA via BLK1. This BLK-1 is connect with LNA just for few microseconds then after it goes to previous position and disconnects the connection between BLK-1 to LNA.

This BLK-1 and BLK-2 switch is nothing but a guard band in both side of LNA. It is used for high isolation from TX and RX signal. This BLK protect the LNA from damage. LNA is so sensitive, is small extra signal comes then it will damage. In RX path it is a main device. So, in BLK switch we use one IC that is HMC349MS8G. This IC is used for high isolation i.e. 50-60 db and low 0.8 db insertion loss and its power handling capability is excellent. This switch is used only RX mode. So, RX echo signal come from sky through antenna then the signal pass through the BLK-1 switch because BLK-1 switch is isolate the high signal from LNA. If signal is high then it

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will directly burn the RX path. So, protect from damage the LNA will be isolate from high signal. Here also one limiter is used to down the power level of RF echo signal. In this circuit BLK-2 switch is also used, which is used after LNA, because if any signal will comes from TX path then it will damage the LNA. That's why another one BLK-2 is used at the output of the LNA to protect from TX path signal. In this circuit we used for LNA two IC i.e. SPF5043Z, which is nothing but a LNA. Because of weak echo signal and need to generate 27 db gains in RX path, so we used 2 LNA in this circuit to maintain the exact power level.

Switching strategy is worked by control signal. After that the echo signal goes to the LNA1. Before LNA two capacitors C7 and C11 is used for blocking purpose. The LNA IC is SPF5043Z, which is used for ultra low noise amplifier. It has 4 pins, pin1 is RF out, pin2 and pin 4 is ground connection, pin3 is RFin. The SPF-5043Z is a high performance pHEMT MMIC LNA designed for operation from 50MHz to 4000MHz [6]. It has near about 10-11 db gain, but in RX path gain is 27 db. So, during RX mode we use 2 ICs (SPF5043Z) instead of 1 IC for proper gain. However signal is come from pin5 of BLK-1 to pin3 of LNA, and then its amplified. Then signal again goes to next LNA. Reaching the next LNA pin here used again one voltage divider to maintain the power level. Signal will be amplified and pass to the BLK-2 switch. BLK-2 switch functions also same as BLK-1. It passes the signal to the SPDT-2. This BLK-2 is used here because SPDT-2 switch is worked on both TX and RX mode, so, in TX mode if any kind of signal will pass to the RX path then it will damage the LNA. So, that's why to protect the LNA from high voltage two BLK switch is used before and after LNA in both TX and RX mode. This BLK switch needs for isolation purpose and its work is just passing the signal and it is connect with LNA for few microseconds.

5. DPDT (Double Pole Double Through)

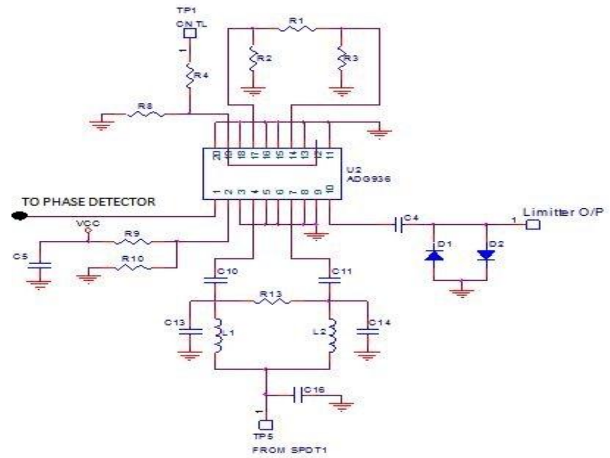

Fig.11. Schematic of DPDT

DPDT (Double Pole Double Through) which is used for calibration purpose. It is always stays low condition. When need to be calibration then it takes high. Otherwise it will be always low.

Here also used ADG936 IC. In this IC two SPDT switch is present. Its working principle near about same as SPDT but the difference is here both SPDT switches are used simultaneously. Here also one limiter is used. Pin2 is used for operate the IC. Pin19 and pin12 are used for input control signal. In this circuit pin4 and pin7 are connected using power divider and it is also connect with SPDT-1. Pin14 and pin17 are connected with power divider. However this DPDT only worked on low signal. It is also worked in RX mode. During RX mode when RX echo signal come then pass through the limiter. Limiter here used for drop down the high power level. Then it passes to the DPDT. DPDT control signal selects the output path. From SPDT-1, one signal also comes to DPDT using 1:2 power dividers. This DPDT checks the signal and pass the signal to the phase detector. This phase detector signal is passing to the control card. Then control card call the digital attenuator and phase shifter to check the RX path power level and phase. From the internal fig of ADG936 we see that the input control signal INA and INB, here both are used. RFCA is used for the phase detector and RFCB is used for received the echo signal. RF1A and RF1B are connect using power divider and RF2A and RF2B are connect by own. When low voltage signal come then RF1A and RF1B switch is closed and RF2A and RF2B switch is opened. So, here RF2A & RF2B switch are used as an input port and RF1A & RF1B switch are used as an output port. However capacitors are used for a blocking purpose, which means it is act as bypass capacitors.

6. GATE BIAS

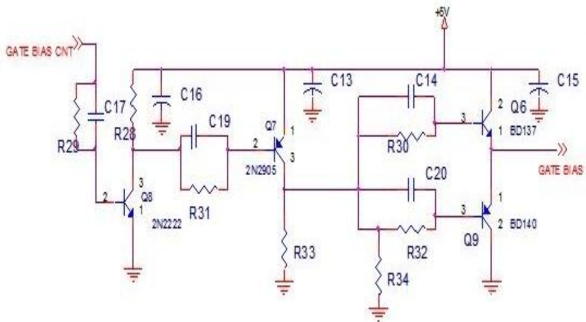

Fig.12: Schematic of GATE BIAS

It is used for handle the forward path device. It is always high pulse. It handles the Driver, Pre-Driver and Power amplifier. It indicate the level of transmit voltage, receive voltage and when it cross the limit its break the connection.

During TX mode Gate bias circuit act as a switch. It is very important switch in this TR module. It connects with Pre-driver, Driver and Power amplifier. It is like a gate of these three devices. When this gate bias is on then these three devices will work properly. Here in this circuit 4 different transistors are used for switching. It always stays in low state when TX mode then it goes to high state for performing these devices. These three devices working time depends on gate bias and this gate bias on time is few microseconds.

When RF control signal is low then the signal pass through the NPN transistor (Q8) via capacitor C17 and resistor R29. But due to low signal transistor is not turn-

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on, it goes to cut-off region. Here in cut-off region emitter-base and collector-base both are in reverse bias condition. Here also one 5V signal present which operate the internal circuit of this switch. Here before each transistor one parallel connection is connecting to protect the transistor. This parallel RC connection used for drop down the input voltage level of the transistor. So, 5v signal turn-on the PNP transistor (Q7) and this transistor base voltage is low. So, this PNP transistor goes to active region. Output signal come from Q7 transistor collector region and it divides into two ways. One goes to NPN transistor (Q6) and other goes to PNP transistor (Q9). But this signal does not turn on the Q6 transistor; it directly turn-on the Q9 transistor and this transistor act like a switch and signal goes ground. So, from Q6 transistor does not generate any kind of gate bias voltage. So, in low voltage condition the gate bias is not work.

When RF control signal is high then high voltage signal turn-on the Q8 transistor. Q8 transistor goes to active region and here base-emitter is forward biased and base-collector is reversed biased. So, 5v operating signal directly goes to ground. Then 5v signal does not turn-on the Q7 transistor. Then output of Q7 transistor is low. This low voltage signal turn-off the Q9 transistor and turn-on the Q6 transistor. So, gate bias signal generate from Q6 transistor. It produces the bias voltage. So, in high voltage this gate bias will operate properly.

7. T/R SWITCH

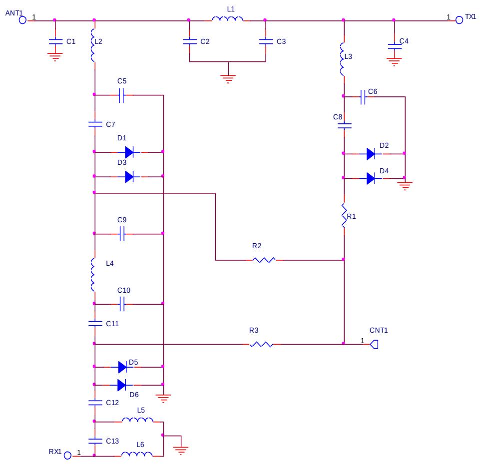

Fig.13: Schematic of T/R switch

It is used for fast switching. Its switching time is few nano seconds. In this TR module we used it for transmit the signal and receive the signal very quickly. If this switch is not used then when receiving the signal information will be lost.

T/R switch is the most important switch in this TR module. It works both transmit and receive path. It is used for fast switching. Its switching time is just few nanoseconds. Eventually T/R switches stay in RX mode. That means T/R switch normally stay in low state condition. During TX mode it is high just for few microseconds, after that it will again goes to low state condition. One question may arise why we use T/R switch instead of SPDT? Where T/R switch used for on-off switch and also SPDT switch is used for this. The answer is SPDT switch is used before amplifier and this SPDT switch have low power handling capability. In this SPDT switch have one IC i.e. ADG936. However it operates using single 1.65v to 2.75v power supply. So, if we use this switch after power amplifier then this IC could not tolerate the power, it will be damage. Because in TR module TX path power is 400w and it is so high power. That's why we use T/R switch in the RX path of the TR module. But T/R switch also used in the TX mode. One thing more that for TX and RX signal need very fast switching, so, we choose T/R switch. For fast switching in the T/R switch we use PIN diodes. PIN diodes used for best switching purpose and it tolerate the high power and give high accuracy.

When control signal is low then PIN diodes are all reverse bias and act as an open circuit, then all capacitors are act as a short circuit. RF echo signal directly come from antenna to the RX path via T/R switch. In antenna port C1 capacitors is used for DC bias. L2 inductor is a RFC which allow the RF signal to pass to the RX path and blocks the DC. Then in RX mode diode D1, D3, D5 and D6 all are open circuit and C5 and C7 capacitors are short circuit. L4, C9 and C10 together act as a LC circuit i.e. λ/4 transmission line. It is used for isolate the high power from RX path. So, in this case C6 and C8 also short circuit and D2 and D4 are open circuit. Then TX port is not working. Transmit signal not pass through the RX path, λ/4 transmission line isolate it. A typical T/R switch generally has two switch elements. One is a pass element that connects the TX path while the other is a shunt element that is located along the RX path. For receive, open the TX and RX switch elements to flow to the receiver. For high frequency ranges stub length get increasingly important. However, the RX shunt element needs to be isolated from the TX path or the shunt element will supply short out the TX path. This is accomplished by inserting a λ/4 transmission line between the RX shunt element and the common switch point. The λ/4 element transforms the short at the RX element to an open at the common switch point. However, at VHF frequency the line lengths become ungainly at best. However, a λ/4 transformer can also be approximated using a LC network. L1, C2 and C3 are together made a LC circuit combination which is nothing but a λ/4 transmission line.

When control signal is high for transmitting the signal to the antenna. Then just for few microseconds T/R switch goes to RX mode to TX mode. Then RX path is off and TX path is on. In this circuit then PIN diode of TX path D2 and D4 are forward biased and act as a short circuit and capacitors are also open circuit. Also in the RX side diode D1, D3, D5 and D6 all are forward biased and act as a short circuit and ground the high power signal. In this time no high power will be flow through the RX path. In this moment RX path is open and TX path is closed. Transmit signal directly goes to the antenna via T/R switch through L1 inductor. No power will pass to the RX path λ/4 transmission line prevents RX path from High power.

Of course, the 1/4λ transformer aspect of solid-state switches is the Achilles heel of this method of T/R switching. It forces the T/R switch into a narrow band of operation. Generally, this isn't a serious issue since T/R systems at VHF and above are typically not broad-band. However, the LC 1/4λ transformer is generally preferable in systems that will or might cover an entire band since transmission line transformers are very narrow band and their performance will suffer for even modest excursions from the design frequency.

V. CONCLUSION

In this paper description of different switches of TR module of VHF active phased array radar is discussed. Circuit diagram of control switches in this radar is implemented and also verified in the laboratory. The operating frequency is used in this particular radar is 206.5 MHz. Further work is required to design and control TR module of VHF wind profiler radar.

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