

# **CHAPTER - 7**

## **PIN DIODE CONTROL CIRCUITS FOR HF BAND INDUSTRIAL APPLICATIONS**

## NOTES

## PIN DIODE RF POWER CONTROL CIRCUITS FOR INDUSTRIAL APPLICATIONS

### INTRODUCTION

Two new series of thick I-region PIN diodes have been developed by Microsemi - WTN specifically for Industrial RF Power Applications. The UM2100 Series was developed for the 2 - 30 MHz Band (HF Band), and the UM2300 Series was developed for the 200 - 3000 KHz Band (MF Band). The unique characteristics [1] of these diodes will be discussed in terms of their performance in a number of selected industrial applications.

### HF BROADCAST BAND ANTENNA SWITCHES

Fundamental work on very thick I-region, long lifetime PIN Diodes was reported in the 1980's by the former RCA David Sarnoff Laboratories [2,3]. These PIN diodes were designed to be capable of replacing the mechanical drive, rotary transmit / receive switches then being used as multi-band antenna switches for exterior communications systems. The bands of interest were the 225 to 400 MHz band (a portion of the UHF band), the 2 to 30 MHz band (HF band), and the 10 to 300 KHz band (VLF band).

Subsequently, Microsemi - WTN has developed two series of thick, long lifetime PIN diodes [1] to provide devices for these and similar high power, lower frequency applications. The UM2100 Series (nominal lifetime of 25 micro-seconds) can switch high RF power (up to 2.5 KW) in HF Band and the newer UM2300 Series (nominal lifetime of 80 micro-seconds) can switch high power (up to 2 KW) through MF Band (200 KHz to 3000 KHz).

A seven-position single pole, useful for HF Band transmitter switching applications, is shown in Figure 7.1. The specifications for the seven-position switch are shown in Table 7.1.

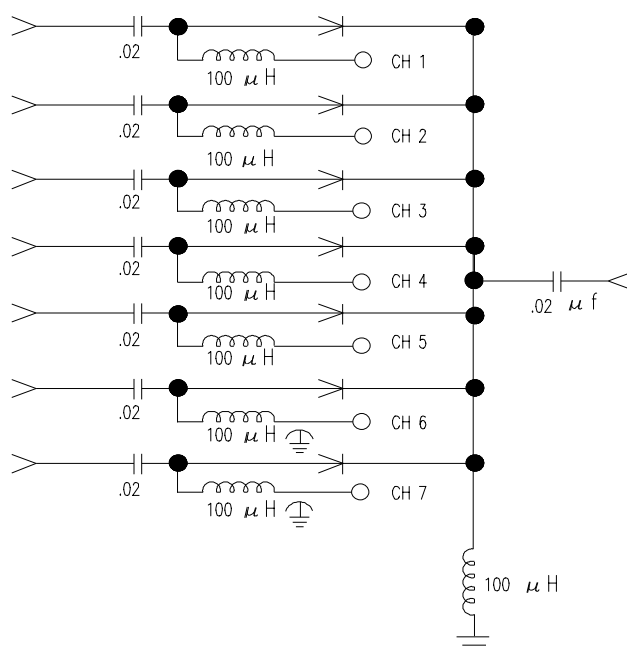


Figure 7.1 HF Band Switch Configuration

**Table 7.1 Specifications for 7 Position HF Band Switch**

Power Handling Capability	1000 W (Max)
RF Voltage	450.0 V Rms (Max)
RF Current	8.9 A Rms (Max)
Characteristic Impedance	50.0 Ohms
Number of Positions (Channels)	7
OFF State Isolation	25.0 dB (Min)
ON State Insertion Loss	0.5 dB (Max)
Forward Bias Current (ON State)	300.0 mA
Reverse Bias Voltage (OFF State)	-400.0 V
IM 3 Distortion Products	-60.0 dBc

An equivalent circuit for a switch branch, convenient for calculating the reverse biased switch performance parameters, is shown in Figure 7.2.

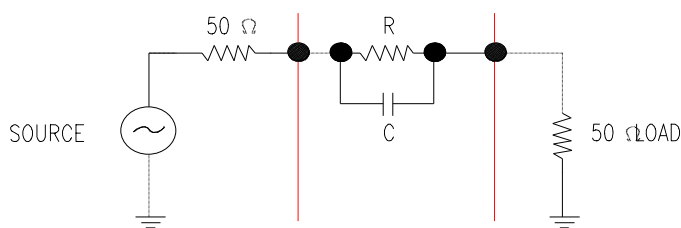


Figure 7.2 PIN Diode Equivalent Circuit

Figure 7.2 is similar to Figure 1 ( c ), Chapter 1, except that the series Inductance was omitted because its Reactance is negligible in HF Band. The equations for calculating the Insertion Loss ( $I_L$ ) and Isolation ( $I_{SO}$ ) of a Single Pole, Single Throw Switch are given in Chapter 2. In HF Band, the UM2110 PIN diode is recommended for this application. If the PIN diode is forward biased such that  $R_s < 1$  Ohm, then  $I_L$  is less than 0.1 dB. The Isolation depends on the PIN diode's Capacitance ( $C_t$ ) under reverse bias. At 2 MHz, the Isolation is greater than 50 dB, and at 30 MHz, the Isolation is about 30 dB.

We note that the ON state Insertion Loss is constant with frequency but the OFF state Isolation varies with frequency since it is a function of the OFF state Capacitive Reactance of the PIN diode. Referring to Figure 7.1, these Insertion Loss and Isolation calculations are valid from any of the seven input ports (individually) to the common output port. When two ports are in the OFF state, their input port to input port Isolation is increased by 6 dB ( above that of a single branch) because the OFF state Capacitance of the two PIN diodes in the dual branch is half that of a single PIN diode. Note that two input ports are not switched on simultaneously.

Appendix E contains a discussion of "Non-linear Effects in Semiconductor Devices" in which the inter-relationship between device non-linearity and rectification of an impressed signal is developed. The main

difference between a pn-junction diode and a PIN diode is that the pn-junction is a non-linear resistance that rectifies the input signal. The PIN diode, over a specific set of operating conditions, presents a linear resistance to the input signal, and thus, does not rectify the signal. These operating conditions are discussed in Chapter 1, sections titled: Large Signal PIN Diode Operation and Low Frequency PIN diode Operation.

It has been experimentally observed [1,2,3] that an incremental increase of signal power while the signal frequency is continually lowered, can cause an on-set of rectification in the PIN diode. This effect is observed when the dc induced stored charge in the I-region is no longer at least five times larger than the rf induced stored charge. The PIN diode rectifies the rf signal because it presents a non-linear impedance to the rf power source and load under these operating conditions.

Under normal operating conditions, PIN diode switches need a relatively small amount of dc bias current to control (switch) large values of rf current. This is the unique feature of a PIN diode. Several hundred milli-amps of d-c current can control several hundred Amperes of rf current.

PN-junction diodes (Varactors) can be used to switch high values of rf power, but the current demands on the switch's power supply are enormous. If a hundred Amps of rf current must be switched by a pn-junction diode, a hundred Amps of dc bias current must be available from the bias current supply. High dc current levels greatly complicate the implementation of rf / dc isolation circuits, especially at low frequencies.

## HF BAND TRANSMISSION LINE TUNER

Industrial manufacturing equipment, such as rf sputterers, use a length of RF transmission line to connect the high power (several KW) transmitter or power amplifier to the load, some distance away from the source. Invariably, the load presents an impedance mismatch to the connecting transmission line. The usual solution is to introduce a matching network between the source and the cable. This matching network consists of a number of Capacitors of varying values that can be switched in or out depending on the nature of the mismatch. A typical impedance matching network is shown in Figure 7.3. PIN diode switches are gradually replacing relay switches for this application.

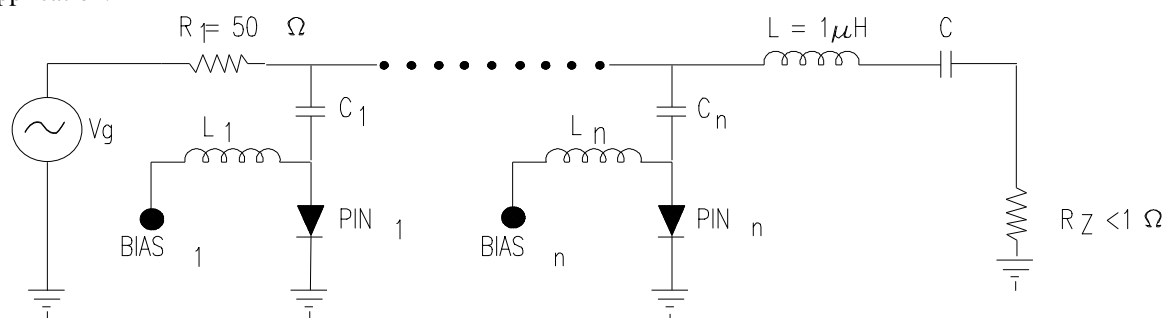


Figure 7.3 HF Band 50 Ohm Transmission Line Matching Network

Sputtering systems delivering 2 KW @ 2 KV line voltage are being produced for the semiconductor industry currently and 5 KW @ 5 KV systems are in the design phase. Microsemi - WTN manufacturers several series of High Voltage PIN diodes for these systems.

## HIGH POWER TRANSFER SWITCH FOR HF BAND TRANSMITTERS

A number of manufacturers of HF Band Power Amplifiers for the Amateur Radio market have introduced solid-state switching using PIN diodes[4]. In comparing the various switching devices available to switch the antenna, such as vacuum relays, reed switches, or solid state devices, the ARRL Handbook (reference [5] ) states “ Perhaps the most modern and elegant approach to switch the antenna between the transmitter and the receiver is the use of PIN diodes. There are no keying-speed constraints when PIN diodes are used, and if the proper devices are

selected, the spectral purity of the output signal will not be affected (by the PIN diode switch). The most important parameter in this regard is the (minority) carrier lifetime”.

Reference [5] is referring to the Transmit/Receive Switches as described in Chapter 2. Figure 2.11 shows a narrow band (5 to 10 %) Quarter Wavelength Antenna switch configuration and Figure 2.12 shows a broadband Antenna switch, both adequate for several hundred Watt applications. Figure 2.13 shows High Power Broad band T/R Switch that can control 1 Kilo-Watt transmitter power with excellent distortion characteristics (IM3 less than -80 dBc).

Another antenna switch configuration, shown in Figure 7.4, is the Double Pole - Double Throw (DPDT) Switch or the Transfer Switch, which is used to calibrate the transmitter-antenna interface.

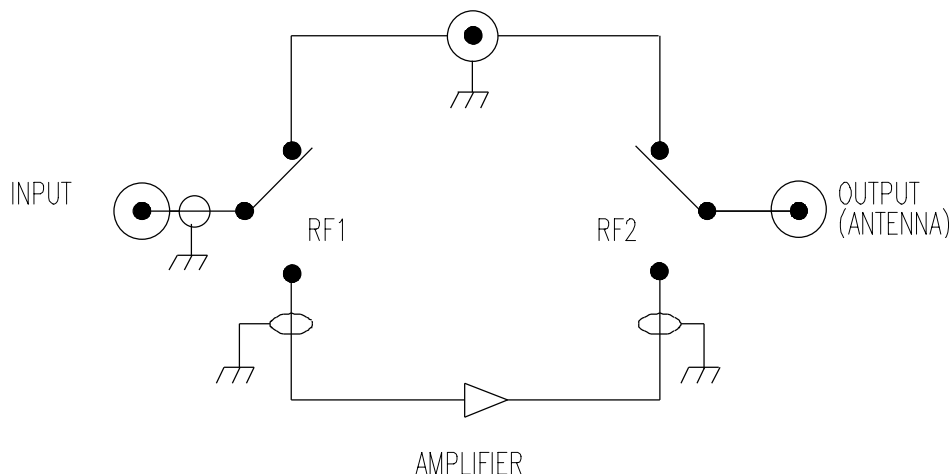


Figure 7.4. Equivalent Circuit of an Antenna Transfer Switch

The transfer switch allows either the “feed through” line or the Power Amplifier to be switched to the Antenna. The connector shown at the center of the “feed through” line may be terminated either in a short circuit (feed through state) or a 50 Ohm load, for transmitter calibration.

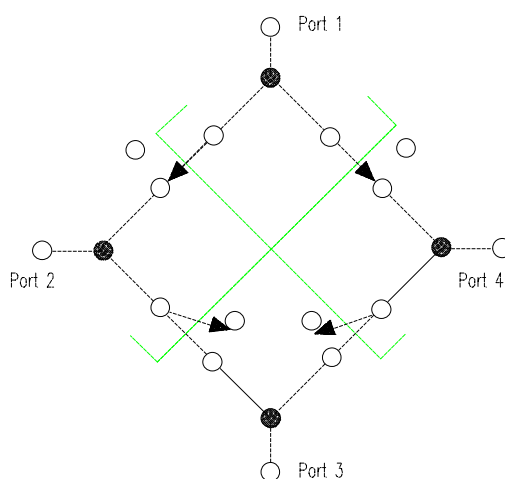


Figure 7.5. Double Pole-Double Throw Transfer Switch

In general, a Transfer Switch (Figure 7.5) is a four port device that has two valid operating states that are defined by the “truth table” (below). SPDT Switches can only connect a single input to either of two loads. SPDT Switches cannot perform the function of inserting sections of transmission line between the source and the load (antenna). Note that Figure 7.5 is not an exact representation of Figure 7.4, since the lower path in Figure 7.4 contains an amplifier and there is no independent Port 3 available.

TRUTH TABLE

Control Input State		RF1 - RF2	RF2 - RF3	RF3 - RF4	RF1 - RF4
1	2				
ON	OFF	ON	OFF	OFF	ON
OFF	ON	OFF	ON	ON	OFF

The Truth Table shows the bias control conditions that set either of the two valid operating states of the Transfer Switch. In control state 1, power flows from Port 2 to Port 4 via branches RF1 - RF2 and RF1 - RF4. In the case of Figure 7.4, this control state would provide the “feed through” line if Port 1 is terminated in a short circuit. Control state 2 “transfers” the inserted path to RF2 - RF3 and RF3 - RF4.

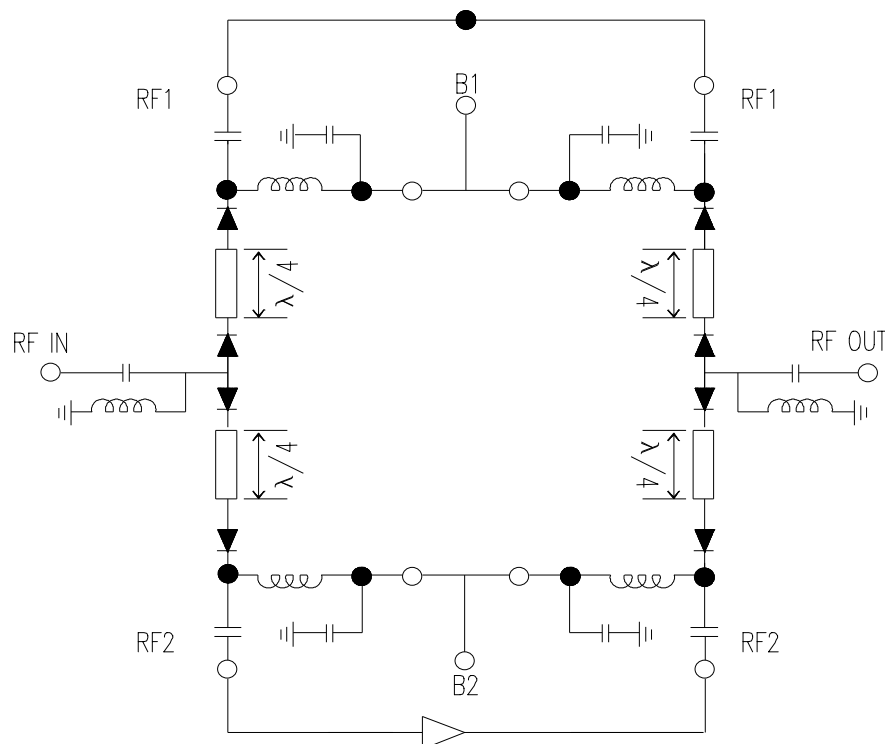


Figure 7.6 DPDT Switch Configured With Two SPDT Switches

The DPDT Transfer Switch in Figure 7.4 can be configured using two SPDT Switches interconnected as shown in Figure 7.6 such that the RF output #1 ports of both SPDTs are joined at a common connector terminal and the RF output #2 ports are connected to the amplifier. When bias control #1 is ON (and bias control #2 is OFF), the through line is inserted between the source in the antenna. When bias states are reversed, the amplifier appears between the source and the antenna. The biasing sequence is the same as that indicated in the “truth table” above.

The performance characteristics of this Transfer Switch depend on the choice of the SPDT design. Various SPDT Switch design tradeoffs were discussed in Chapter 2. The choices consist of Series Diode SPDT, Shunt Diode SPDT, and Compound (series and shunt connected diodes) SPDT switches. Each design has its own bandwidth and power handling abilities.

The 4 Port Transfer Switch is a bridge network and hence has extremely wide bandwidth capability. The Transfer Switch shown in Figure 7.7 combines the wide bandwidth characteristic with the high power handling capability of the compound switch. Several hundred Watts and 0.5 - 18 GHz bandwidth switching capability are achievable with this design.

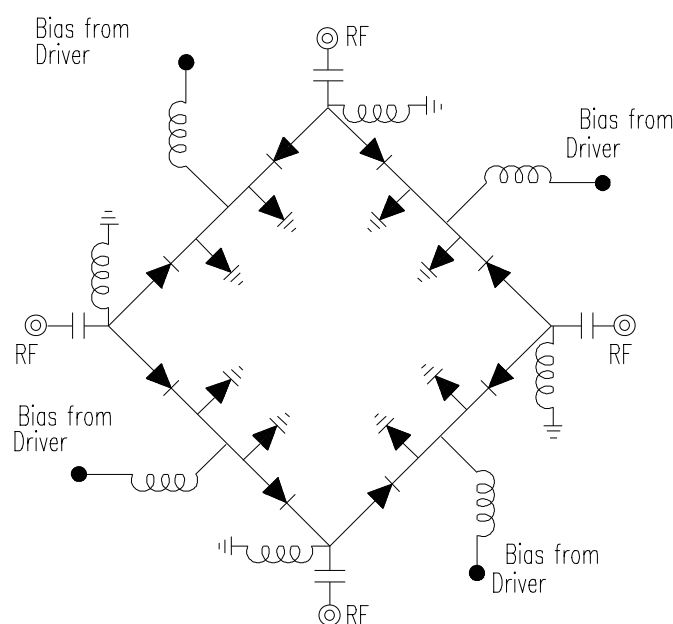


Figure 7.7. Broadband High Power Transfer Switch Configuration

## RECOMMENDED PIN DIODE TYPES

### DIODES

HUM2020, UM2100, UM2300, UM4000, UM4300

### MODULE

UMM5050 5 KW, 5 KV