M e m o

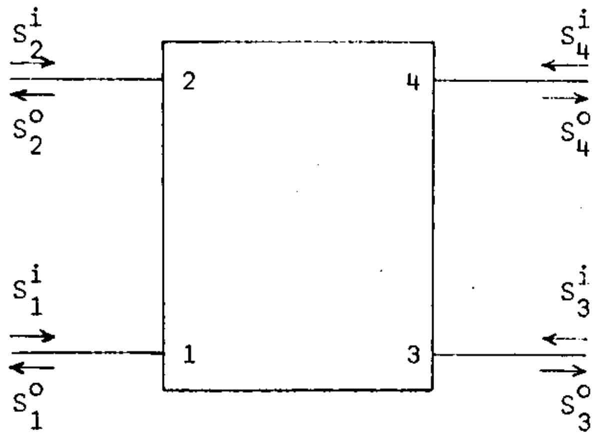
From: R.F. Woodman

To: SOUSY group members

Subject: On an alternative solution to the TR switch

An alternative solution is presented for the design of the transmit-receive switch making use of the high power 3-dB-directional couplers which would be used in the SOUSY antenna. The system presents some advantages and may be worth to evaluate its performance in parallel with the present approach. (The diodes could be replaced for evaluation of the scheme by their equivalent network to avoid delays due to delivery of the parts.)

Model for the 3-dB-directional coupler



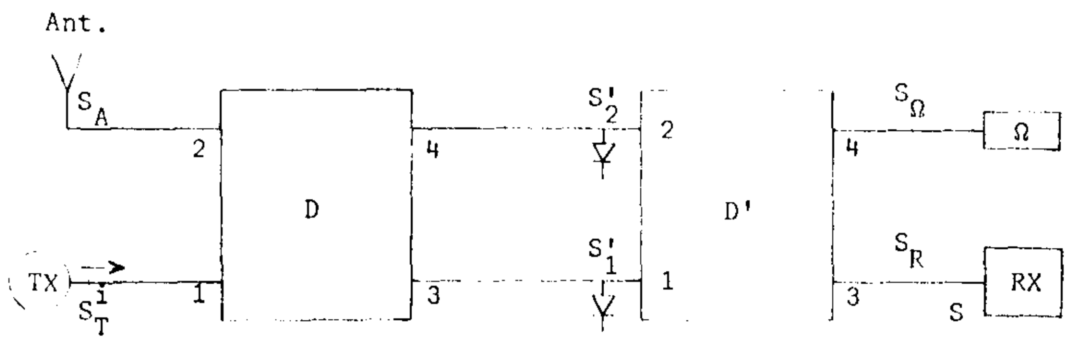
Let us call S_n^i, S_n^o the amplitude of the waves traveling in and out of the device in the transmission line connecting to port "n". The characteristics of the device are such that

$$\begin{aligned}
\sqrt{2}\, S_1^o &= S_3^i - j\, S_4^i \\
\sqrt{2}\, S_2^o &= -j\, S_3^i + S_4^i \\
\sqrt{2}\, S_3^o &= S_1^i - j\, S_2^i \\
\sqrt{2}\, S_4^o &= -j\, S_1^i + S_2^i
\end{aligned} \qquad (1)$$

The ratio of S_n^i to S_n^o is determined by the SWR of the load (if passive).

Proposed system

The system proposed is shown in the following figure.



It is assumed that the transmitter, receiver, dummy load (Ω) and the antenna present a match load to their transmission lines. During transmission the diodes are conducting, shorting the lines between the two dividers. They should be at equal distances from the respective ports. This distance is arbitrary.

Analysis - During transmission

The shorting diodes reflect all the power back into the transmitter divider so we have

$$S_3^i = S_3^o \qquad \text{and} \qquad S_4^i = S_4^o . \tag{2}$$

(There is actually an extra phase shift involved which does not affect the computations.)
The set of equations (1) takes the form

$$
\begin{aligned}
\sqrt{2}\, S_T^o &= S_3^o - j\, S_4^o \\
\sqrt{2}\, S_A^o &= -j\, S_3^o + S_4^o \\
\sqrt{2}\, S_3^o &= S_T^i \\
\sqrt{2}\, S_4^o &= -j\, S_T^i
\end{aligned}
\qquad (3)
$$

Here we have neglected S_A^i, i.e. the signal coming from the antenna.

We can write (3) as

$$
\begin{aligned}
S_T^o &= (S_T^i - S_T^i)/2 = 0 \\
S_A^o &= -j\,(S_T^i + S_T^i)/2 = -j\, S_T^i\,.
\end{aligned}
$$

Therefore: (a) There is no reflected power in the transmitter.

(b) All power goes into the antenna.

(c) No power goes into the receiver or the dummy if the diodes were ideal (since $S_1'^i = S_2'^i = 0$).

If the diodes are not perfect a small fraction of the power gets through. Let us assume then the diodes are such that

$$
\begin{aligned}
S_1'^i &= \alpha\, S_3^o = \frac{\alpha}{\sqrt{2}}\, S_T^i \\
S_2'^i &= \alpha\, S_4^o = -\frac{\alpha\, j}{\sqrt{2}}\, S_T^i
\end{aligned}
$$

in which case we have

$$
\begin{aligned}
S_R^o &= (S_1'^i - j\, S_2'^i)/\sqrt{2} = \frac{\alpha}{2}\,(S_T^i - S_T^i) = 0 \\
S_\Omega^o &= (-j\, S_1'^i + S_2'^i)/\sqrt{2} = -j\,\frac{\alpha}{2}\,(S_T^i + S_T^i) = -j\,\alpha\, S_T^i\,.
\end{aligned}
$$

Therefore: (a) Still no power gets to the receiver.

(b) All leaked power goes into the dummy.

Thus, there is a double isolation from receiver to transmitter, one part due to the diodes and the other due to the second power divider, i.e. if we assume 30 dB isolation due to the diode and 30 dB for the power divider, one would get a 60 dB isolation between TX and receiver.

Analysis - During reception

During reception the diodes are open and similar algebraic manipulations lead us to the following relations:

$$S_R^o = -j\, S_A^i$$

$$S_\Omega^o = 0 \, .$$

If the dummy load and the receiver are matched, there is no reflected power and $S_T^o = S_A^o = 0$. Usually the TX when off will not dissipate any power, that is it will present a load with infinite SWR, thus $S_T^i = S_T^o$; but since $S_T^o = 0$, then $S_T^i = 0$.
In conclusion we have that during reception:

(a) All received power by the antenna goes into the receiver.

(b) There are no reflections neither into the antenna nor into the transmitter.

(c) The antenna loading is not affected by the transmitter mismatch.

If we allow for some input from the transmitter, for instance shot-noise capacitively coupled to the output, we can show that

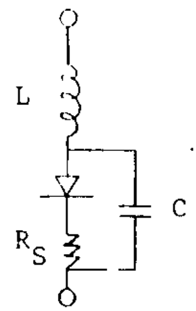
$$S_R^o = 0$$

$$S_\Omega^o = -j\, S_T^i \, .$$

That is, any noise or signals leaking through the transmitter input are dissipated in the dummy load and none goes into the receiver.

Effects of non-ideal behaviour of the diode

An equivalent circuit for a diode is as follows:



where the diode symbol represents an ideal diode. The inductance L is mainly determined by the size of the diode. In a typical PIN diode, capable of switching the power levels involved:

$L \approx 0.1$ nH

$R_S \approx 0.5\ \Omega$

$C = 3$ pF.

The effects of these residual impedances are as follows:

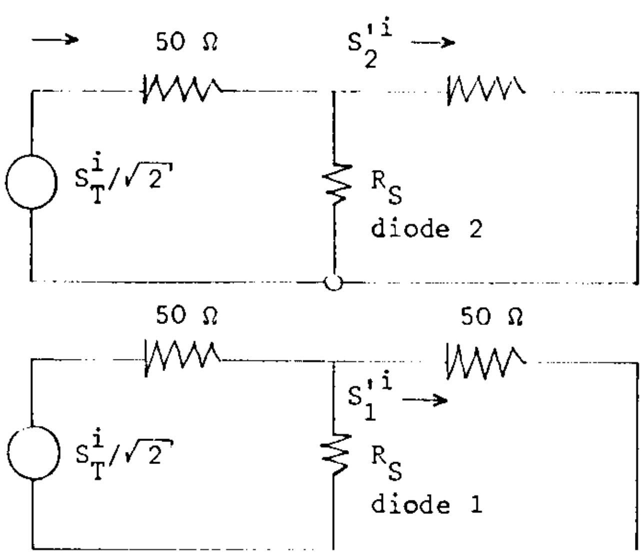
(A) When in the transmit mode, i.e. when the diode is conducting, the effect of the capacitance is negligable. The diode behaves mainly as a low resistance in series with a low inductance. Still for all practical purposes most of the power gets reflected as assumed but for a small fraction (of the order of 1/100 the transmitter power for a 0.5 Ω diode in a 50 Ω line) which gets dissipated in the diode. Again a small fraction of the dissipated power gets coupled to the transmission line on the receiver side through the voltage drop across the diode terminals which are common to both lines on either side. As we have seen before, this power does not go to the receiver, it gets dissipated in the dummy load (in the extend the coupler behaves as an ideal coupler).
It is clear from above, one should try to minimize L and R by keeping

the size of the device as short as possible and by using as high of a bias current as practical.

(B) When in the receiving mode, i.e. when the diode is open, the diode presents itself as a small capacitance, this produces power reflection from the diode. This capacitance can be tuned out by placing a capacitance of equal value $\frac{\lambda}{4}$ wave length away in the interconnecting transmission line. This implies that this transmission line should be at least $\frac{\lambda}{4}$ long. There is no other requirement for its length, so this condition defines the length of the interconnecting transmission line to $\sim \frac{\lambda}{4}$. This length will also allow transmission line techniques for the necessary decoupling of the DC circuitry.

Rough computations of the diode dissipated power

When one looks into any port of a matched 3-dB-directional coupler, one sees the characteristic impedance of the device. If we use a 50 Ω interconnecting transmission line and, for simplicity, assume that the diode acts as a simple resistance R_S then the equivalent circuit for the system in the transmission mode as seen from the diodes is as following:



which means that the power dissipated in each diode P_D is given by

$$P_D = \frac{R_S}{50\ \Omega} \frac{P_T}{2},$$

where P_T is the power output of the transmitter, and the power dissipated in the dummy load P_Ω:

$$P_\Omega = 2 \frac{R_S}{50\ \Omega} P_D = (\frac{R_S}{50\ \Omega})^2 P_T .$$

For a diode resistance of 0.5 Ω we get an isolation of 40 dB between the dummy and the transmitter. As we have seen before, none of this power would get into the receiver if the coupler would behave ideally. If we allow a -30 dB coupling due to imperfections, the total transmitter to receiver isolation would be of the order of 70 dB.
For 0.5 Ω diode resistance the total dissipated power for each diode will be $P_D = \frac{1}{200} P_T$. For a transmitter power of 600 kW and a duty cycle of 5 %

P_D = 3 kW peak

P_D = 150 Watt average.

It appears at the moment that a single PIN diode of UNITRODE, 4900 series would take 1.5 kW maximum peak
and 50 Watt maximum average.
If two of these devices are placed in parallel R_S = 0.25 Ω and the power dissipated in each device would be ~ 750 W peak and ~ 37 W average, which would be within the specifications.
Another possibility would be to reduce the power into the diodes by the use of higher transmission line impedance (only in the interconnecting lines) and the use of higher bias currents into the diodes to lower their residual resistance.
If one uses an interconnecting transmission line of higher impedance than 50 Ω, one should then make this line $\frac{\lambda}{2}$ to avoid mismatching in the receiving mode and place the diode in its centre.

2 February 1976