A TDRSS COMPATIBLE TRANSMITTER WITH AGILE RF ROUTING

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ABSTRACT

An agile RF routing system has been developed which utilizes phasing techniques to direct signal power to any one of four orthogonally mounted antennae, or either set of two antennae mounted 180° apart on a launch vehicle. The system has been integrated into a telemetry transmitter and has shown superior performance to traditional methods of antennae switching. The unit is self-correcting to maintain maximum RF power at the desired antenna port(s) across a dynamic mission environment. Due to its low loss and high reliability, this method of antennae switching provides a robust RF link.

KEY WORDS

Antennae switching, RF routing, Phase shifting, TDRSS.

INTRODUCTION

At the heart of any telemetry system is the RF link used to carry the data from the launch vehicle to the monitoring receiver. As vehicle position varies during the mission, it is important to maintain antennae alignment between the transmitter and receiver in order to avoid signal dropout. Thus switching between multiple antennae becomes necessary.

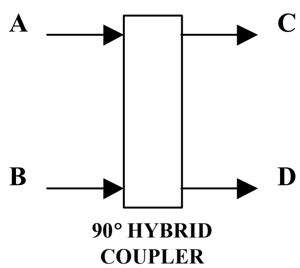
Typically, a launch vehicle is equipped with two antennae located 180° apart. Antennae switching is achieved by routing the RF signal to the appropriate path via a mechanical or semiconductor switch. Problems inherent in this implementation include physical size constraints, relatively large DC power consumption, limited power handling capability, signal degradation due to insertion loss, and questionable reliability in shock and vibration environments.

As an alternative to the existing methods of RF routing, Cincinnati Electronics has developed a method of electrically switching between four antennae, and incorporated the design into a Tracking and Data Relay Satellite System (TDRSS) compatible transmitter.

Unit testing has yielded superior system performance over the dynamic environments of a launch vehicle mission.

THEORY OF OPERATION

The agile RF routing system utilizes the fundamental concept of constructive and destructive interference between interacting signals of various relative phases[1]. The concept is illustrated in figure 1, which depicts how signals of the appropriate relative phase can be combined through a 90° hybrid coupler to yield the sum of the input signal powers at one output port and no signal power at the opposite output port, or equal signal power at the two output ports.



INPUT A	INPUT B	OUTPUT C	OUTPUT D
1W$\angle$0°	1W$\angle$0°	1W$\angle$-45°	1W$\angle$-45°
1W$\angle$0°	1W$\angle$90°	2W$\angle$0°	0W
1W$\angle$0°	1W$\angle$-90°	0W	2W$\angle$-90°
1W$\angle$0°	1W$\angle$180°	1W$\angle$45°	1W$\angle$225°

Figure 1- Combination of input signals of various relative phases to direct signal to desired output.

A phase shift circuit has been developed in order to create the appropriate relative phases of the input signals[2]. The circuit is shown in figure 2. The signal to be phase shifted is input to the standard input port of a hybrid coupler. A varactor diode and length of shorted transmission line are connected in shunt to the standard main and coupled ports. The phase shifted output signal is taken from the standard isolated port. In a ‘off’ state, the varactor diodes have a low voltage applied to them and appear as a short to ground. The signal therefore is reflected from these ports and appears at the isolated port with a finite phase shift. In a ‘on’ state, the applied voltage to the varactor diodes is increased, thereby changing their reactance. At some point, a reactance value is reached such that a parallel resonance is created with the distributed reactance of the shorted length of transmission line. The main and coupled ports then appear as a high impedance, and the signal is reflected to the isolated port. The signal is again output with approximately the same magnitude as the input signal, but there is a difference of 180° in phase when reflecting from an open versus reflecting from a short. The circuit creates a linear phase shift, such that at some applied voltage between the 0° state and the 180° state, a 90° phase shift is obtained. Due to the fact that the circuit generates a leading phase in a ‘on’ state, a ‘off’ state is set as either -90° or -180° relative phase, and a ‘on’ state is set as 0° relative phase.

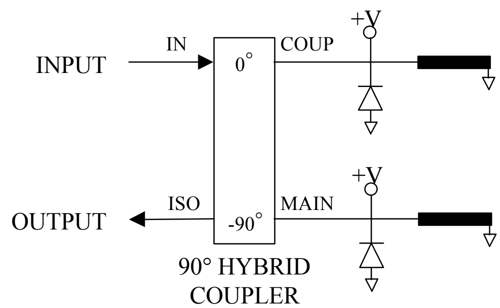


Figure 2- Phase shift circuit.

These phase shift and combination techniques have been integrated into a RF routing system which directs signal power to any one of four orthogonally mounted antennae, or either set of two antennae mounted 180° apart on the launch vehicle. A block diagram of the system is shown in figure 3. The input signal modulated with data is input to the phase shift board. The signal is split into two paths by a 90° hybrid coupler. The path from the main port (-90°) is delayed an additional 90° by a fixed length of transmission

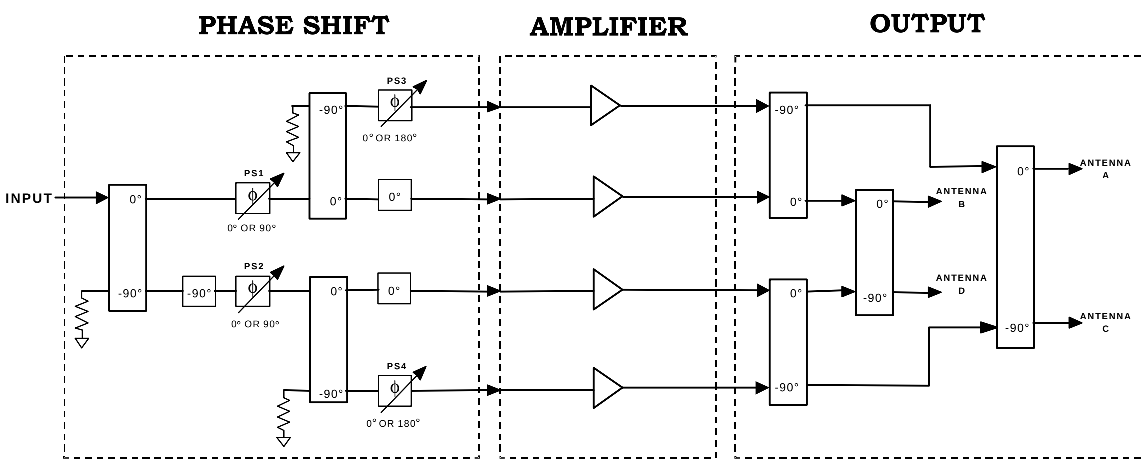


Figure 3- Block diagram of the agile RF routing system.

line. A phase shift circuit configured for a 0° or 90° phase shift is in each of the paths. These two paths are each split into two additional paths by 90° hybrid couplers. Each of the paths from the main ports have a phase shift circuit configured to yield a 0° or 180° phase shift. The paths from the coupled ports (0°) have an additional fixed length of transmission line to compensate for the finite phase shift in the main paths in a 0° state. The phase shift board outputs four signals which have been conditioned to have appropriate relative phases. The signals are then amplified and sent to the output board. The output board consists of four 90° hybrid couplers that recombine the four signals and direct power to the desired antenna port(s). Switching from one antenna port to another is accomplished by creating the appropriate relative phases of the signals on the phase shift board, such that when the signals are recombined on the output board, power is summed at the desired port(s) and nulled at the undesired ports. Figure 4 displays a table of the phase shift states necessary to direct power to the desired antenna port(s).

PHASE SHIFT STATE				ANTENNA OUTPUT POWER			
PS1	PS2	PS3	PS4	A	B	C	D
OFF	OFF	OFF	OFF	0	HALF	0	HALF
ON	OFF	OFF	OFF	0	FULL	0	0
OFF	ON	OFF	OFF	0	0	0	FULL
OFF	OFF	ON	ON	HALF	0	HALF	0
ON	OFF	ON	ON	FULL	0	0	0
OFF	ON	ON	ON	0	0	FULL	0

Figure 4- State table for selecting antenna output port(s).

SYSTEM PERFORMANCE

Cincinnati Electronics has integrated the agile RF routing system into a TDRSS compatible transmitter (CE model number T-711). The transmitter features binary phase shift keying modulation at symbol rates up to 5 mega-symbols per second, and operates in the frequency range of 2200-2300 MHz. The unit delivers a minimum of 30 watts of RF power to any one of four antennae, or 15 watts of RF power split between either set of two antennae. Antennae selection is remotely commandable. Power and temperature telemetry is also provided.

The system's feature that makes it more advantageous than previous methods of RF routing is its agility. Because the phase shifters are implemented in a linear fashion rather than binary, phase errors that degrade RF output power can be dynamically corrected. In space and launch vehicle applications, the temperature range that a transmitter will be exposed to is wide. As the temperature varies, so does the amount of phase shift introduced by the components in the unit. These phase errors result in signal power being misdirected to antennae other than the desired, or alternately, as a loss of power at the desired antenna. The agile RF routing method has the capability to continuously adjust for phase errors, thereby maintaining maximum delivered RF power to the desired antenna. RF routing systems that use simple switches display greater nominal insertion loss, and the insertion loss varies greatly across temperature. The agile RF routing system provides a lower loss alternative with minimal variation across temperature. Furthermore, the ability to switch between four antennae provides a robust RF link with little to no signal dropout.

The T-711 transmitter controls the RF routing through the use of a Field Programmable Gate Array (FPGA). A thermistor is mounted in the transmitter and is monitored by the FPGA to provide a temperature reference. The varactor diodes in the phase shift circuits are biased by the outputs of digital-to-analog converters (DAC). The transmitter is aligned through a computer interface. The unit is tested across the necessary temperature range, and with a click of the mouse the output voltages of the DACs can be adjusted to correct for phase errors. The DAC coefficient values are then stored in an EEPROM. During the mission flight, the FPGA monitors the temperature, retrieves the correct coefficient values from the look-up table in the EEPROM, and outputs these values to the DACs. Thus throughout the entire mission in a dynamic temperature environment, maximum RF power is delivered to complete the link.

The agile RF routing system offers many additional advantages over previous antennae switching methods. It is highly desirable to minimize the insertion loss of the routing circuitry, for any power lost after the final amplifiers cannot be regained. The 90° hybrid couplers used throughout the agile RF routing system have a maximum insertion loss of 0.2 dB. The phase shift circuits have a total insertion loss of approximately 0.7 dB. The phase shifting is done prior to final amplification, thus the associated losses become near negligible to the system. The result is a low loss method of antennae switching. Because the system is implemented mainly with transmission lines, its power handling capability is superior to semiconductor switches, and it is much more reliable than mechanical switches in shock and vibration environments. The only DC power the system requires is used to reverse bias the varactor diodes, which draw a near negligible leakage current. Therefore the system consumes far less DC power than other methods of antennae switching. The system can be implemented in a relatively small circuit board area as well. The switching time it takes to direct power from one antenna to another is limited by the slew rate of the DACs that control the phase shift circuits. A plot of the measured antenna switching time is shown in figure 5. The agile RF routing systems provides an extremely smooth, quick, and low loss method of switching between multiple antennae.

CONCLUSION

The agile RF routing system provides a method of antennae switching that is superior in performance to traditional switching methods. The system continually self adjusts to maintain maximum RF power at the desired antenna port(s), providing a strong and reliable RF link across dynamic mission environments. A TDRSS compatible telemetry transmitter has been developed utilizing this technology, and the method can be applied to any multiple antenna transmitter as well.

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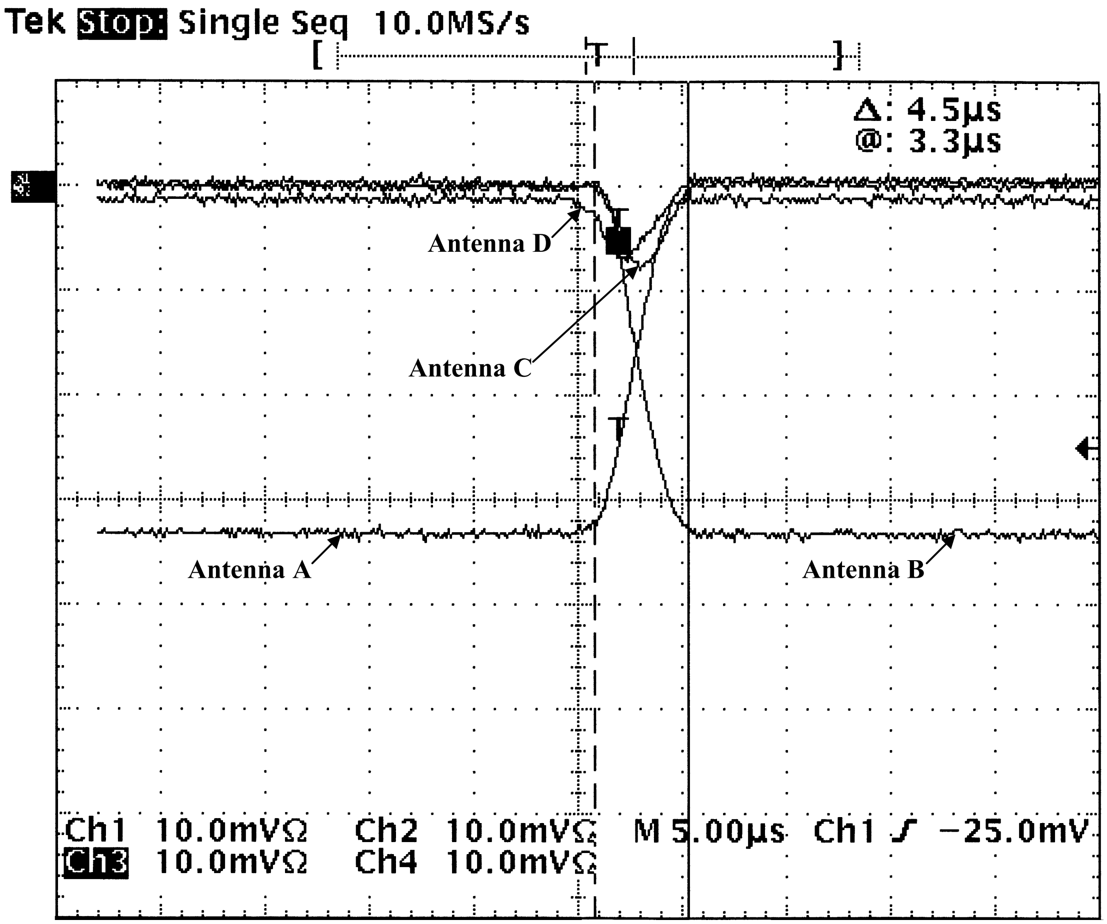

Figure 5- Oscilloscope plot of antenna switching time measured using crystal detectors to rectify the RF signals. Note that a negative deflection indicates increasing RF power detected.

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