VARIABLE POWER DIVIDERS IN SATELLITE SYSTEMS

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Abstract

Variable power dividers (VPD's) are used for electronically despinning an antenna on a rotating satellite, and for beam steering or shaping in a multiple-beam satellite antenna system. Designs of each type for the SMS and DSCS III satellites are described, comprising both diode and ferrite varieties.

I. Applications

Two principal uses of VPD's in satellite systems have evolved in recent years, associated with electronically despinning an antenna on a continuously rotating satellite, and with steering/shaping beams in a multiple-beam antenna system on a geostationary satellite. These applications present requirements distinct from switching, in that partial power division between two or more ports is required, in a continuously-controllable manner, generally while also maintaining constant phase.

The first application is represented by the Synchronous Meteorological Satellite (SMS), first launched in May 1974, and currently providing pictures of the earth's cloud cover on a continuous basis for weather predictions. This satellite rotates at about 100 r/min, and is equipped with an array antenna distributed around the satellite, whose beam is steered electronically in synchronism with the rotation, to maintain pointing toward the earth. Both receive (at 2 GHz) and transmit (at 1.7 GHz) functions are provided through a 4 x 4 array of radiating dipoles as pictured in Fig. 1. Variable power dividers (VPD's) are used to shift power gradually from one receding column of 4 elements to the fifth adjacent column. This provides continuous beam steering and avoids sudden jumps in phase or amplitude inherent in simple switching that could cause loss of phase lock in ground receivers.

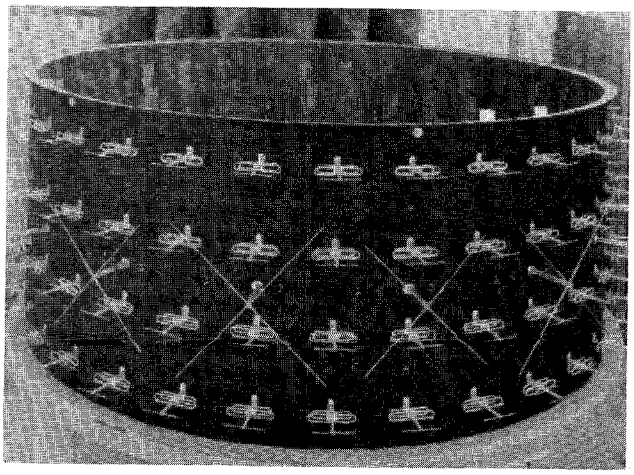

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Fig. 1 SMS Antenna

The second application is represented by the proposed use in the DSCS III satellite, which may incorporate a lens antenna with multiple feed horns. Each feed horn produces a beam in a different direction. An arbitrary composite antenna pattern can be produced by simultaneously exciting the appropriate feed horns, at appropriate amplitudes, from a common (transmitter) input. This excitation is achievable through an array of three-port variable power dividers, shown in Fig. 2, and designated a Beam Forming Network (BFN). The requirement for continuous control of power division is apparent from an application which would involve forming a single beam from such an array, whose position could be steered between the fixed locations of the individual beams by varying the relative power to three or more adjacent beams. Equally important could be the ability to produce nulls in desired directions within a broad coverage pattern, to discriminate against interfering signals.

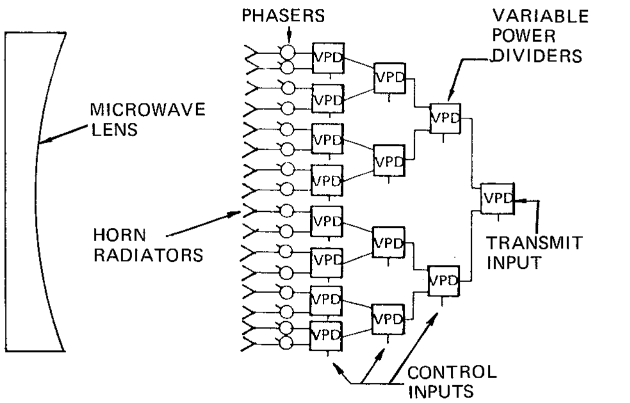


Fig. 2 DSCS III Transmit BFN

II. Types of Variable Power Dividers

Three principal types of VPD's have evolved - mechanical, ferrite, and diode - with many variations of each type. The mechanical version is the simplest and may consist principally of an H-plane movable vane in a waveguide Y-junction to divide the input power in a controllable manner between the two outputs. (See Fig. 3.) Input matching is maintained for all vane positions by gradually tapering the output waveguides; however, the outputs are inherently mismatched, varying from a 3:1 VSWR at the equal-power position to a short circuit in the off position.

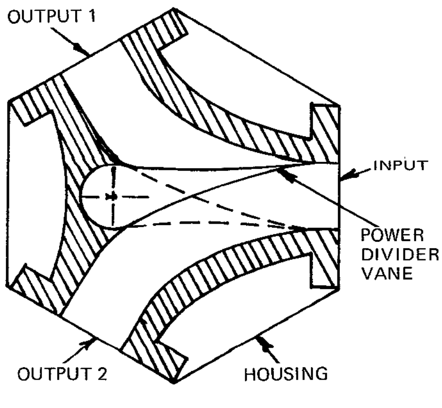
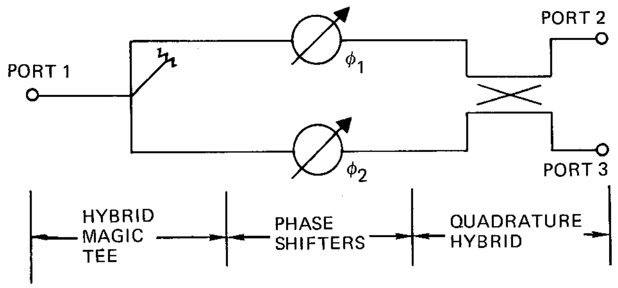


Fig. 3 Mechanical VPD

Most diode and ferrite VPD's utilize a circuit involving one or more 4-port hybrids to maintain a match condition at all ports for all VPD settings. One common circuit, shown in Fig. 4, involves a pair of hybrids interconnected by means of a pair of variable phase shifters, whose settings determine the power division ratio at the two output ports. Operation in the reverse direction (with two inputs, as on receive) allows the common output port to accept various proportions of energy from each of the inputs; the remainder of the input energy is delivered to the unused loaded fourth port of the output hybrid, to maintain matched inputs. An alternate use of hybrids occurs in the ferrite dual-mode or Faraday-rotator type of VPD, shown in Fig. 5, utilizing a hybrid junction to separate horizontal and vertical polarized signals from a square or circular waveguide input to two outputs. The ferrite element merely rotates the polarization plane of the input energy to achieve the desired power division ratio. These ferrite units may be constructed either as magnetically latched or continuously driven units, for continuous or pulsed control.



$$E_{02} = E_{IN}\, e^{-j\left(\frac{\phi_1 + \phi_2}{2} + \frac{\pi}{4}\right)} \cos\left(\frac{\phi_1 - \phi_2}{2} + \frac{\pi}{4}\right)$$

$$E_{03} = E_{IN}\, e^{-j\left(\frac{\phi_1 + \phi_2}{2} + \frac{\pi}{4}\right)} \sin\left(\frac{\phi_1 - \phi_2}{2} + \frac{\pi}{4}\right)$$

Fig. 4 Dual-Hybrid VPD Circuit

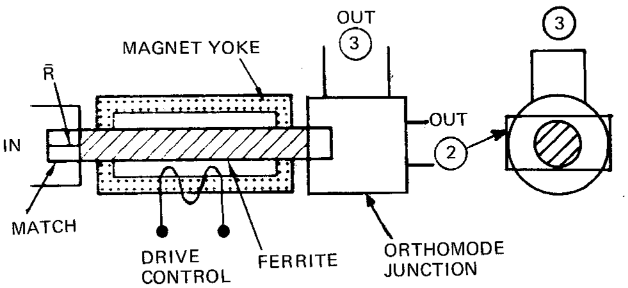


Fig. 5 Latching Faraday-Rotator VPD

III. Design Examples

a. SMS. The VPD developed for the SMS Program[1] consists of a pair of varactor-controlled variable phase shifters in the dual hybrid circuit of Fig. 4. The phase shifters are also reflection type hybrid devices, utilizing the variable capacitance of the varactors to effect a change in reflection phase terminating two ports of a quadrature hybrid. Typical measured electrical characteristics of this device are listed in Table 1, and an assembled unit is shown in Fig. 6. A typical response characteristic appears in Fig. 7. Although the unit was required to handle only 5 watts, it was necessary to use 16 varactors with breakdown voltages of 60 volts in each unit, operating between control bias voltages of -10 and -40 volts, to achieve adequate phase differential (90°) and sufficiently low intermodulation products. The latter is especially critical, since both receive and transmit energy are routed through the same set of VPD's and are separated at the common VPD port by means of a diplexer. This usage gave rise to another operational problem in that the VPD ports are essentially reactively terminated at frequencies far from the operating range (either by the diplexer, or by mismatched antenna elements). Thus, it was discovered that the VPD's were subject to parametric subharmonic oscillations when installed in the SMS antenna system. This problem was finally overcome by adding a "tuned load" at the VPD diplexer port - essentially a 50 ohm load shunted by half-wave stubs at both receive and transmit frequencies, but providing a proper match at the half-harmonic oscillation frequency. An alternate VPD design using balanced varactor pairs would avert a number of these problems, and probably decrease insertion loss as well, by avoiding harmonic conversion, which accounts for a sizable portion of the present total losses.

Table 1. Electrical Characteristics of SMS-VPD

Frequency Bands:	1687 and 2029 ±20 MHz
Diode Type:	Varian VAT-71, 6 pf varactor 60-volt breakdown, 150 GHz cutoff
Control Voltage:	-10 to -40 volts
Power Level:	5 watts cw
Typical Insertion Loss:	1.1 dB max.
Typical Isolation:	20 dB min.
Phase variation with setting:	±3°

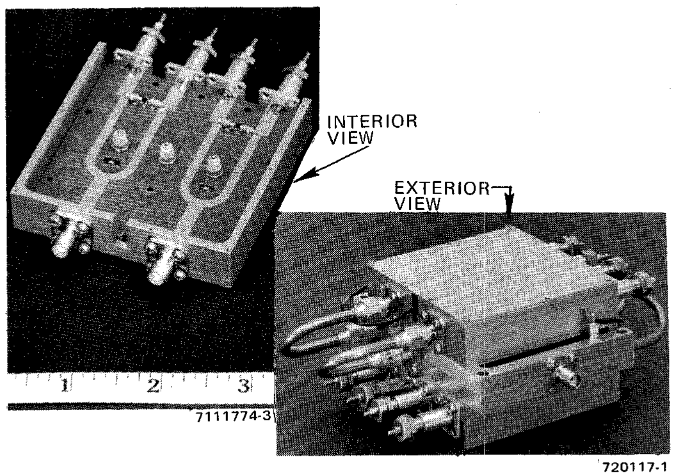


Fig. 6 SMS VPD

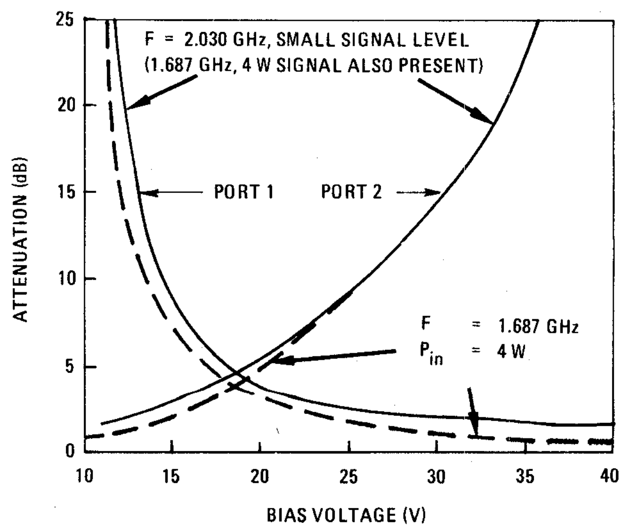


Fig. 7 VPD Power Division vs Bias Voltage

b. DSCS III. The beam-forming networks proposed for the DSCS III multibeam antenna system are composed principally of variable power dividers, using separate networks for receive and transmit, with potentially as many as 120 VPD's in each satellite. As a result, the selection process for the optimum VPD becomes rather critical. Some of the key selection criteria are listed in Table 2. WDL evaluated models of four different types of VPD's for this application, as pictured in Fig. 8. Nonferrite types were eliminated on the basis of power-handling capability, intermodulation product generation (IMP's), match and losses, which narrowed the choice to three ferrite candidates: a latched differential phase-shift type and two Faraday rotation types, both latched and continuously driven[2]. Comparative experimental data on the two different basic types are given in Table 3. The continuously driven dual-mode Faraday rotator was selected for the baseline design, based on the following comparative features:

1. Lowest loss device
2. Lowest weight device
3. Lowest level IMP's
4. Continuous control characteristics that avert possible loss of signal while resetting and allow active temperature compensation
5. Best reliability, based on relative driver complexity
6. More benign failure mechanism (loss of drive current forces unit to 3 dB state, avoiding loss of coverage)
7. Availability of telemetry monitoring parameter (control current)

A typical control curve for this device is shown in Fig. 9.

Table 2. DSCS III VPD Requirements

Frequency/bandwidth	500 MHz bands at 7 and 8 GHz
Power levels (on transmit)	50 to 100 watts, cw
Insertion loss	Minimum (under 0.3 dB)
Isolation to off-port	25 dB minimum
Setting Accuracy	±1 dB at -10 dB state
Temperature stability	Within tolerances over -10° to +40° C.
Reset characteristics	No sudden jumps in amplitude or phase (to avoid loss in communications signals)
Intermodulation products	Under -100 dBm, 5th order
Phase characteristics	Constant with setting to -20 dB state
Reliability	99% for 7 years, including 120 units; benign failure mechanism desirable
Weight	Minimum (under 8 oz. each)

The additional power required to operate 120 such units, relative to the latched versions, was estimated to be only 30 watts, since many of the units would normally be operated in the 3 dB zero-current state, and others in intermediate positions. The extremely low-level IMP's measured on this device were the result of a unique two-piece RF construction. The potential of mass-producing devices of this sort with the degree of high tolerances and tight quality control necessary for space applications presents a real challenge.

It also appears possible to utilize a diode-type VPD matrix for the receive BFN, with individual low-noise preamplifiers incorporated into each BFN input port to avoid S/N degradation due to losses in the solid-state VPD's (estimated to be in excess of 1.0 dB each). This would be a viable approach if preamplifiers and diode units can be developed with sufficient stability and reliability to meet space requirements. Furthermore, additional filtering would be needed at each port, as well as continuous control power for the diode VPD's and preamplifiers, so that relative size, weight, and power advantages are moderated.

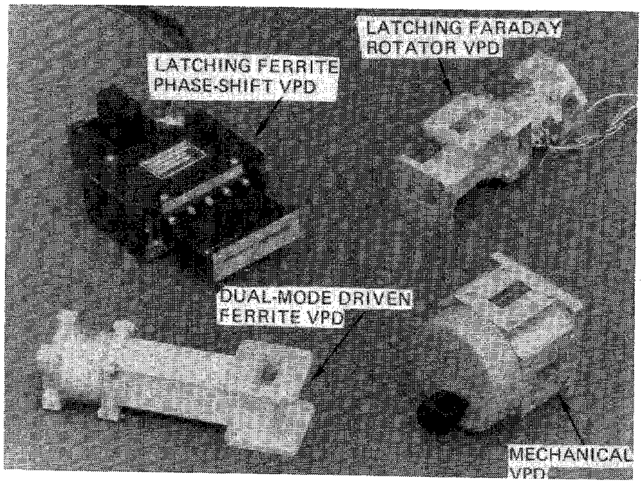


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Fig. 8 DSCS III VPD Candidates

Table 3. Measured DSCS III VPD Characteristics

Characteristic	Ferrite Phase-Shift	Faraday Rotation
Frequency Band (GHz)	7.25 - 7.75	7.25 - 7.75
Control Type	Pulsed Latching	Current Drive
Insertion Loss (max)	0.3 dB	0.25 dB
Isolation (min)	30 dB	25 dB
Phase Variation	±3 deg.	±3 deg.
Weight	12 oz.	8 oz.
Max. Drive Power	Pulsed	0.5 watts
Max. RF Power	100 watts	100 watts
Intermodulator Products (max. fifth order, with two 27-watt carriers)	-104 dBm	-123 dBm

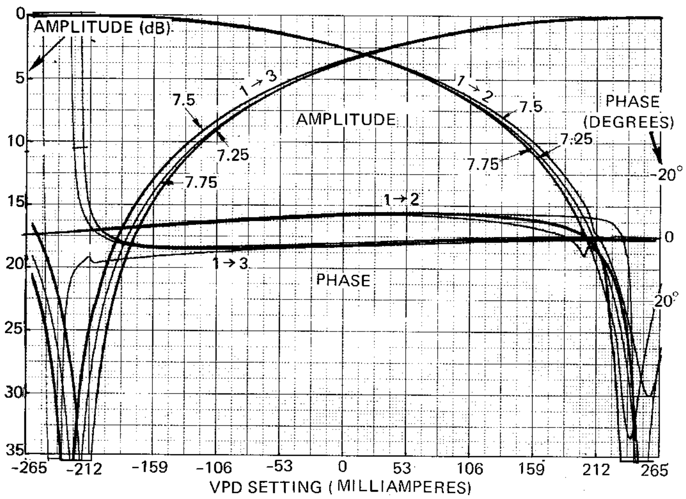

Fig. 9 Dual-Mode VPD Characteristics

References

1 U.S. Patent No. 3,769,610 awarded to A. Savarin and G.S. Rader, Philco-Ford Corp, Oct. 30, 1973; described in paper by inventors at National Telecommunications Conference, Houston, Texas, Dec. 1972.

2 The ferrite phase-shift types were developed by Electromagnetic Sciences, Inc, Atlanta, Georgia, while the Faraday-rotation types were developed by Microwave Applications Group, Chatsworth, Calif.