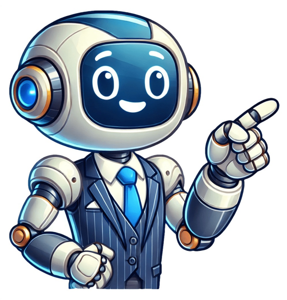

A Directional Coupler is a device that measures microwave power by sampling a small portion of the energy. It records incident power, reflected power, and VSWR values. The coupler consists of a primary waveguide and an auxiliary waveguide, forming a 4-port junction. The device couples unidirectional or bi-directional microwave power. Its properties include matched terminations at each port. When power flows from Port 1 to Port 2, some is coupled to Port 4 but not to Port 3. Conversely, when power travels from Port 2 to Port 1, some is coupled to Port 3 but not to Port 4. Ideally, Ports 1 and 3 are decoupled as are Ports 2 and 4. Practically, a small amount of back power is observed at Port 3. The device's performance is defined by its coupling factor, directivity, and isolation. The Coupling Factor measures the ratio of incident power to forward power in dB. Directivity measures the ratio of forward power to back power in dB. Isolation defines the directive properties, measuring the ratio of incident power to back power in dB. A Two-Hole Directional Coupler is a design that meets ideal directional coupler requirements by incorporating two small holes between the main and auxiliary waveguides. These holes are λg/4 apart, where λg is the guide wavelength. The device minimizes back power by allowing some power to escape through the holes while maintaining phase at one hole and canceling it at the other. Waveguide Joints require careful joining to prevent reflection effects and ensure proper microwave power transmission. Waveguide joints must avoid irregularities and not affect E and H field patterns, while types include bolted flange, flange joint, choke joint, etc. Radio tech devices use directional couplers for 10 dB 1.7–2.2 GHz and power dividers/combiners for 3 dB 2.0–4.2 GHz, coupling power in transmission lines to ports. Directional couplers only couple power flowing one direction, splitting it equally between two ports as hybrid couplers. In directional couplers, isolation refers to the ability of a port to reject signals from another port. It can be measured between the input and isolated ports or between the two output ports. Isolation is typically expressed in decibels (dB) and is calculated as the ratio of the power at the output port to the power at the input port. A higher isolation value indicates better rejection of unwanted signals. For example, the isolation between ports 1 and 4 might be 30 dB, while the isolation between ports 2 and 3 could be 25 dB. The isolation can be estimated from the coupling and return loss of the coupler. In ideal couplers, the isolated port is completely isolated, but in practice, some RF power will always be present. Directivity is another important parameter related to isolation. It measures the ability of a coupler to distinguish between the coupled and isolated ports. Directivity is also expressed in dB and should be as high as possible. Waveguide directional couplers typically have the best directivity. The directivity can be calculated from the addition of the isolation and coupling measurements. Note that if the positive definition of coupling is used, the formula for directivity changes. The S-matrix for an ideal symmetrical directional coupler shows perfect matching and isolation between ports. In general, the transmission coefficient (τ) and coupling coefficient (κ) are complex, frequency-dependent numbers. For a passive lossless directional coupler, the sum of the squared magnitudes of τ and κ must equal 1, ensuring that all power entering the input port leaves through one of the other two ports. Insertion loss is related to the transmission coefficient τ. Overall, isolation and directivity are critical parameters in directional couplers, and their values can significantly impact the performance of the device. L(dB) = -20 log |τ| C(dB) = 20 log |κ| The coupling factor κ is related to the power difference in dB between ports, while the scattering matrix coefficients relate to return loss and isolation. In a practical device, amplitude balance and phase difference are frequency-dependent, departing from ideal values of 0 dB and 0°, respectively. Directional couplers can be realized using transmission lines or planar technologies like stripline and microstrip, with implementations shown in figures 4 and 6. The main line carries the majority of power, while the coupled port has a smaller connector size, such as SMA. Accuracy of coupling factor depends on dimensional tolerances for spaced coupled lines, limiting tight coupling in some designs. Tightly coupled lines can be produced using air stripline technology. The λ/4 coupled-line design is suitable for coaxial and stripline implementations but not ideal for microstrip format due to its non-homogeneous nature. This leads to signal dispersion caused by different propagation velocities of even and odd modes. A shorter coupled line, as shown in figure 5, can be used for microstrip but has a rising coupling factor with frequency. An alternative design, depicted in figure 6, features a higher impedance coupled line, benefiting power monitoring applications by producing a higher RF voltage. The main line response is typically broader than the specified frequency range of the coupled line. The λ/4 coupled-line coupler exhibits periodic responses at nλ/4 frequencies, visible when an impulse on the main line is propagated through the coupler. The induced signals on the coupled line have opposite polarities and cancel each other, resulting in no response on the exit port. The delayed signal, however, contributes to a maximum response on the coupled port. For bandwidths exceeding an octave, multiple λ/4 coupling sections are used, treating the sections as filter components to achieve desired filter responses such as maximally flat or The design of coupled-line directional couplers and branch-line couplers is based on the ripple, which represents the maximum variation in output of the coupled port in its passband. A ripple value of plus or minus a certain dB from the nominal coupling factor can be used to describe this property. At all frequencies, coupled-line directional couplers have purely real τ {\displaystyle \tau \ } and purely imaginary κ {\displaystyle \kappa \ } , leading to simplification of the S-matrix and the result that the coupled port is always in quadrature phase (90°) with the output port. This phase difference can be utilized in some applications. The ideal case of lossless operation can be simplified using the equation τ 2 + κ I 2 = 1 {\displaystyle \tau ^{2}+{\kappa _{\mathrm {I} }}^{2}=1\ } . Microstrip directional couplers are often used on the output of local oscillators in spectrum analyzers. A branch-line coupler consists of two parallel transmission lines physically coupled together with two or more branch lines between them, which represent sections of a multi-section filter design. The branch lines are spaced λ/4 apart and control the impedance of each section, resulting in a main line impedance that is 2 {\displaystyle \scriptstyle {\sqrt {2}}} times the system impedance. The ratio of impedances of the branch lines increases with the number of sections in the coupler, limiting the design to three sections due to manufacturing limitations. Branch-line couplers are suitable for high-power applications and can be used as crossovers instead of air bridges, which cause unacceptable coupling between the lines being crossed. The ideal branch-line crossover has no coupling between the two paths through it. Part of the power reflected back from port 2 finds its way into port 3, making it theoretically impossible to simultaneously match all three ports of a passive, lossless three-port device with poor isolation being unavoidable. However, four-port devices can be designed to split power arriving at port 2 between port 1 and port 4, terminating the latter with a matching load, and none going to port 3. The term hybrid coupler originally referred to 3 dB coupled-line directional couplers, which are quadrature 3 dB couplers with outputs 90° out of phase. Today, any matched 4-port device with isolated arms and equal power division is called a hybrid or hybrid coupler, regardless of the phase relationships. The Wilkinson power divider consists of two parallel uncoupled λ/4 transmission lines that can be realized in planar format but has a more natural implementation in coaxial format. It solves the matching problem of the simple T-junction by having low VSWR at all ports and high isolation between output ports, with equal input and output impedances at each port designed to match the characteristic impedance of the microwave system. Coupled-line directional couplers are described above, where 3 dB coupling is called a hybrid coupler. The S-matrix for an ideal, symmetric hybrid coupler reduces to; S = 1 2 [0 − i − 1 0 − i 0 0 − 1 − 1 0 0 − i 0 − 1 − i 0]. The hybrid ring coupler, also called the rat-race coupler, is a four-port 3 dB directional coupler consisting of a 3λ/2 ring of transmission line with four lines at the intervals shown. Power input at port 1 splits and travels both ways round the ring, adding in phase at ports 2 and 3 while canceling out of phase at port 4, making this an example of a 0° hybrid. The design for a specific implementation can also be applied to coax or waveguide, allowing for versatility in its application. To achieve a coupling factor different from 3 dB, it's possible to alternate between low and high impedance λ/4 sections within the ring, but for a 3 dB coupler, the entire ring is made 2 {\displaystyle \scriptstyle {\sqrt {2}}} of the port impedances – for instance, in a 50 Ω design, this would equate to approximately 70 Ω. The S-matrix for this hybrid is represented as; S = 1 2 [0 − i − i 0 − i 0 0 i − i 0 0 − i 0 i − i 0] {\displaystyle \mathbf {S} ={\frac {1}{\sqrt {2}}}{\begin{bmatrix}0&-i&-i&0\\-i&0&0&i\\-i&0&0&-i\\0&i&-i&0\end{bmatrix}}} Notably, the hybrid ring exhibits asymmetry on its ports; selecting a different port as the input does not necessarily yield identical results. Specifically, using port 1 or port 3 as the input results in a 0° hybrid, whereas employing port 2 or port 4 as the input leads to a 180° hybrid. This characteristic enables another beneficial application of the hybrid ring: it can be utilized to generate sum (Σ) and difference (Δ) signals from two input signals. As shown in figure 12, with inputs applied to ports 2 and 3, the Σ signal appears at port 1 and the Δ signal appears at port 4. This design generates a 3 dB coupler quite frequently.[36] Another variant using parallel waveguides is the Schwinger reversed-phase coupler, where the long side of one guide is connected to the short wall of the other, with two slots cut between them, spaced λ/4 apart. The Schwinger type acts as a backward coupler, possessing a nearly flat directivity response but showing significant frequency dependency in coupling compared to the Bethe-hole coupler.[37] Unlike the Bethe-hole coupler which exhibits little variation in coupling factor,[37] the Moreno crossed-guide coupler features two stacked waveguides at right angles instead of parallel. Off-centre holes, usually cross-shaped, are drilled on the diagonal between the guides a distance 2 λ / 4 {\displaystyle \scriptstyle {\sqrt {2}}\lambda /4} apart in this design. The Moreno coupler is suited for tight coupling applications and finds a balance between the characteristics of Bethe-hole and Schwinger couplers.[38] It also experiences both coupling and directivity variations with frequency.[38] Waveguide implementations of hybrid rings are possible, as mentioned earlier.[39] Figure 15 shows the Magic tee configuration. Main article: Magic tee Coherent power division was first achieved using simple Tee junctions at microwave frequencies. Waveguide tees come in two forms – the E-plane and H-plane – with these configurations splitting power equally but resulting in different field configurations, leading to phased electric fields at output arms for both types.[40] The combination of these two tees is known as the hybrid tee or Magic tee, which is a four-port component that performs the vector sum (Σ) and difference (Δ) of coherent microwave signals.[40] Figure 16 depicts a standard 3 dB hybrid transformer. In this setup, power at port 1 splits equally between ports 2 and 3 but in antiphase to each other, making it a 180° hybrid. The centre-tap is usually terminated internally but can be brought out as port 4 for sum and difference hybrids; however, port 4 presents a different impedance and may require additional transformers for conversion if needed.[41] Main article: Hybrid coil Hybrid transformers are commonly used in telecommunications for converting between two to four wires. Telephone handsets incorporate such converters to change the 2-wire line into the four wires from the earpiece and mouthpiece.[42] Figure 17 illustrates a directional coupler using transformers, which is suitable for lower frequencies (less than 600 MHz). This setup involves RF transformers for compact broadband implementation and consists of two lines where one transformer reduces voltage while the other decreases current, thus matching impedance. The direction of an outgoing signal in a transmission system is determined by the relative sign of the induced voltage and current. The coupling coefficient between two ports can be calculated using the formula C3,1 = 20 log n, where n is the ratio of secondary to primary turns. A 3 dB coupling indicates equal splitting of the signal between ports. A simple resistive tee circuit can be used as a power divider in a system with characteristic impedance Z0. This circuit has two major drawbacks: it dissipates power and results in poor isolation due to a directivity of 0 dB. However, by replacing the output resistors with T pads, the isolation can be improved at the expense of insertion loss. A true hybrid divider/coupler with infinite isolation and directivity can be made from a resistive bridge circuit. This device consists essentially of two resistors (plus port 4 termination) and has a 6 dB insertion loss. It is ideal for balanced telecommunication lines but cannot be used with unbalanced circuits without the addition of transformers. Directional couplers are useful for monitoring frequency and power level on signals in a system, as they can provide high isolation and allow for combining multiple signals to feed a single line to a receiver. The signal loss at ports P3 and P2 will be minimized by the port in figure 20. If isolators are overlooked, the isolation measurement (port P2 to port P3) determines how much power from signal generator F2 is injected into signal generator F1 as the injection level increases. This can cause modulation of signal generator F1 or even phase locking due to the symmetry of the directional coupler. The same potential issues with signal generator F2 by F1 could arise from reverse injection. To increase the isolation (or directivity) effectively, isolators are utilized in figure 20. As a result, the injection loss is the sum of the isolation of the directional coupler and the reverse isolation of the isolator. Applications of this hybrid include monopulse comparators, mixers, power combiners, dividers, modulators, and phased array radar antenna systems. Both in-phase devices (like the Wilkinson divider) and quadrature (90°) hybrid couplers may be used for coherent power divider applications. For instance, an example of quadrature hybrids being utilized in a coherent power combiner application is presented in the following section. A cheaper version of the power divider is used domestically to divide cable TV or over-the-air TV signals to multiple TV sets and other devices. In most cases, multiport splitters with more than two output ports internally consist of a number of cascaded couplers. Domestic broadband internet service can be provided by cable TV companies (cable internet). The domestic user's internet cable modem is connected to one port of the splitter, as it is bi-directional, hybrid circuits can also be used to coherently combine power in addition to splitting it. In figure 21, an illustration is given of a signal split up to feed multiple low-power amplifiers and then recombined to feed a single antenna with high power. In figure 22, the phases of the inputs to each power combiner are arranged such that the two inputs are 90° out of phase with each other. This causes the powers to add at the output of the combiner and cancel at the isolated port, as shown in a representative example from figure 21. It's worth noting that there is an additional fixed 90° phase shift to both ports at each combiner/divider which is not shown in the diagrams for simplicity. Applying in-phase power to both input ports would not yield the desired outcome: the quadrature sum of the two inputs would appear at both output ports – that is, half the total power out of each. This approach makes it possible to use numerous less expensive and lower-power amplifiers instead of a single high-power TWT. Another way to combine power is to have each solid state amplifier (SSA) feed an antenna and let the power be combined in space or used to feed a lens attached to an antenna, as shown in figure 23. The phase properties of a 90° hybrid coupler can Hybrid couplers are useful in microwave circuits, such as balanced amplifiers, where they can effectively cancel out reflected energy from FET devices due to their identical characteristics. This results in a good input match and low VSWR (Voltage Standing Wave Ratio). When phase-matched lines are used with 180° hybrid couplers, nulls can be created between antennas, making it ideal for rejecting signals or creating specific patterns like monopulse radar. Phase-difference couplers also enable beam tilt and beam-forming networks, such as the Butler matrix, to create radio beams in any desired direction. The text discusses various applications of hybrid couplers, including their use in: * Antenna systems: creating nulls between antennas, rejecting signals, or creating specific patterns * Beam-forming networks: enabling beam tilt and creating radio beams in any direction * VHF FM radio stations: delaying phase to lower elements of an antenna array for beam tilt The text also mentions various authors and their works, which provide further information on the applications and characteristics of hybrid couplers. The article incorporates information from various academic and technical publications, including books, journal articles, and conference proceedings. The sources cover topics related to power dividers, directional couplers, and their applications in various fields such as telecommunications, radar, and microwave engineering. Some of the notable sources include: * Academic textbooks on electronics and telecommunications * Conference proceedings and research papers on antenna systems and signal processing * Industry publications and guides on RF design and measurement The references also cite government reports and publicly available information from organizations such as the Naval Air Warfare Center.

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