WIRELINE® and WIREPAC® Design Guide

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SECTION 1 WIRELINE AND WIREPAC GEOMETRY AND COUPLING THEORY

Quadrature hybrids and couplers are widely used components in microwave and RF systems. They may be designed using a variety of lumped and distributed element approaches such as:

- Parallel coupled TEM mode transmission lines.
- Lumped element assemblies of transformers and capacitors.
- Capacitive loaded segments of tightly coupled wire pairs.
- Etched distributed coupled line devices.

WIRELINE and WIREPAC quadrature couplers and hybrids offer an alternative construction. (Figure 1, pg 4). This patented construction, developed by us, consists of a pair of wire center conductors surrounded by a continuous dielectric insulator and shielded by a drawn or extruded outer jacket. The resultant construction has the physical attributes of semirigid coaxial cable and the electrical performance of a precision TEM mode parallel coupled line coupler. Electrical performance includes frequency independent quadrature output phases, low VSWR, low insertions loss, high directivity and freedom from intermodulation products. The theoretical formulated coupling response versus frequency is closely followed by the WIRELINE and WIREPAC devices. These theoretical coupling curves are shown in Figure 2 for a quarter wavelength long coupler with 3 dB coupling. We also offer couplers with slightly tighter coupling for octave band applications and 10 dB coupling for other applications. The devices with coupling near 3 dB are commonly referred to as hybrids.

As Figure 2, pg 5 indicates the coupling reaches its tightest point when the electrical length is one quarter wavelength. The coupled signal strength approaches zero when the electrical length is zero or one half wave length. Coupling to the isolated port is weak at all frequencies. Figure 2 also illustrates a broad band, (octave) curve, a narrow band, (<30%) curve and a coupling window for dual band devices.

SECTION 2 HYBRID DESIGN INFORMATION

SECTION 2.1 Narrow Band Caseless Hybrid Information and Design Curves

Many communications and radar systems use narrow bandwidths (less than 30%). In these applications, low loss and coupling unbalance are critical parameters. To minimize coupling unbalance over narrow frequency bands, two approaches are available.

For bandwidths less than 10%, the coupler may be cut to an electrical length of 70 degrees or 110 degrees which is the length at which the coupling curves intersect for a hybrid with mid band coupling of 2.7 dB. Using this approach, the coupling unbalance will be less than 0.5 dB for bandwidths less than 10%.

For bandwidths up to 30%, the unbalance can be minimized by adjusting the physical dimensions of the center conductors and outer conductor to achieve looser coupling as indicated in curve 1 of Figure 2A. These special narrow band geometries are available for HC, JC, LC, FA and KC WIRELINE and WIREPAC products and are designated by a code 1. (See Figure 5, pg 8). The geometry changes for narrow band versus octave band materials are imperceptible to the naked eye; consequently, all bulk shipments of narrow band WIRELINE are marked with a color coded band surrounding one end of the WIRELINE outer jacket.

SECTION 2.2 Octave Band Caseless Hybrid Information and Design Curves

Curve 2 in Figure 2A illustrates the theoretical coupling curves for a 3 dB hybrid with minimum output unbalance over an octave bandwidth.

In Figure 2A the x axis represents the electrical length of the coupler. For a quarter wavelength octave hybrid, the electrical length at the band edges is 60 degrees for the lowest frequency and 120 degrees for the highest frequency. The red shaded area in Figure 2A highlights the octave band performance curves for two design geometries. The coupling unbalances are noted and illustrate that curve 2 provides the best performance over the full octave band. Octave band geometries are designated by a code 2 in the part number (See Figure 5, pg 8) and are available for HC, JC, KC, FA and LC configurations.

SECTION 2.3 Calculation Example

To determine the length of a 3 dB WIRELINE or WIREPAC hybrid, perform the following calculation:

Compute the quarter wavelength frequency (Fq),

1. Quarter Wavelength Frequency = F_q (MHz) = $\dfrac{F_{MIN} + F_{MAX}}{2}$

FMIN = lowest operating frequency
FMAX = highest operating frequency

Substitute Fq into length equation.

2. Coupler Length = L (inches) = $\dfrac{L_f}{F_q\ (MHz)}$

L_f = 1850 for HC, JC
L_f = 1970 for KC, LC, FA
L_f = 2100 for GC

Compute the fractional bandwidth to determine octave or narrow band geometries.

3. Fractional Bandwidth FBW = $\dfrac{F_{MAX} - F_{MIN}}{F_q}$

Example problem: What is the length of an HC or FA hybrid to cover he Fmin = 500 to Fmax = 1000 MHz band? What is the optimum geometry?

Substituting into equations 1 and 2 results in Fq = 750 MHz, L for HC = 2.47 in. and L for FA = 2.63 in.

Substituting into equation 3 indicates FBW = 2 which is the fractional bandwidth for an octave coupler; therefore, code 2, HC and FA devices should be selected for octave band performance. (See Figure 5, pg 8). If FBW were calculated to be less than 0.3, then Code 1, HC and FA devices should be selected for narrow band performance.

SECTION 3 COUPLER DESIGN INFORMATION

SECTION 3.1 Narrow Band Caseless Coupler Information and Design Curves

By examining the 3 dB hybrid coupling of Figure 2A outside the 60° to 120° region, it is easy to see how WIRELINE and WIREPAC can be used as a directional coupler. As you move away from the 60° to 120° region, the coupling to the output at arm C becomes less and less; about 7 dB at 30° and 12 dB at 20° and so on. Over the entire 0° to 90° range, the directivity is a minimum of 17 dB and the VSWR is less than 1.2 for all four ports. Therefore, when operating below the octave band region (i.e. the green shaded area), WIRELINE becomes a simple directional coupler with excellent characteristics. In Figure 2D, there is a chart of applicable equations which permit coupling values to be calculated. From these equations one can determine that a 4” length of WIRELINE can be an octave band hybrid at 463 MHz, or a 10 dB directional coupler at 100 MHz.

From the equations in Figure 2D, the coupling chart of Figure 3 was plotted making it possible to quickly determine dimensions and bandwidth. If necessary, the range of the chart can be extended by simply multiplying the numbers on the vertical axis by 10 and dividing the numbers on the horizontal axis by 10. It is important to note that when designing a directional coupler, the 0° to 60° Figure 2 green region is recommended for less frequency versus coupling variation. There are occasions, however, when it may be necessary to operate in the 120° to 180° Figure 2A blue region. In these instances, it is important to recognize that bandwidth and directivity will be significantly reduced and insertion loss will also be increased.

The dotted line marked “lower frequency octave hybrid” gives the dimension of an octave band hybrid whose lower frequency is known by simply finding the dimension where the lower frequency line intersects the dotted line. For example, a 100 to 200 MHz hybrid would be 12.3” long.

Information is frequently needed regarding maximum coupling variation over a specified bandwidth. Figure 3 is very convenient for determination of directional coupler bandwidths. For example, let us assume you want a 20 dB coupler at 50 MHz. According to the chart, the length would be about 2.37”. Where that vertical line intersects the 1 dB higher and lower lines, read the corresponding frequencies from the vertical axis. Reading from the chart gives a range of about 44 to 56 MHz. Conversely, it is a simple procedure if you know the frequency range of interest and you want to know the range of coupling. Again, starting with the 20 dB coupler at 50 MHz, you might want to know how much coupling varies from 40 to 60 MHz. This time look for the intersection of those two frequencies with 2.37” and find a coupling range of 3.5 dB.

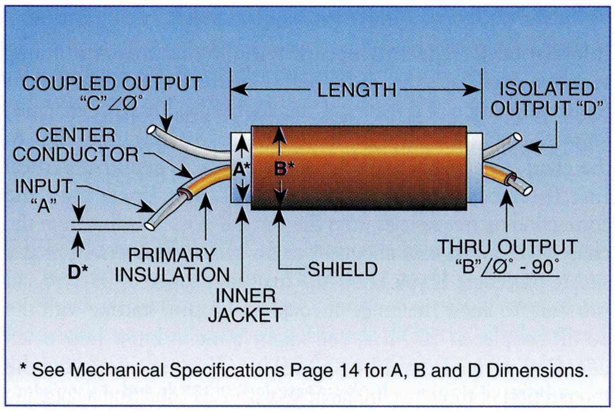
The coupling chart of Figure 3 is a very useful design tool. However, the equations in Figure 2D should be used to determine the exact coupling range and physical length. Solutions to these equations are available from Spectrum Microwave.

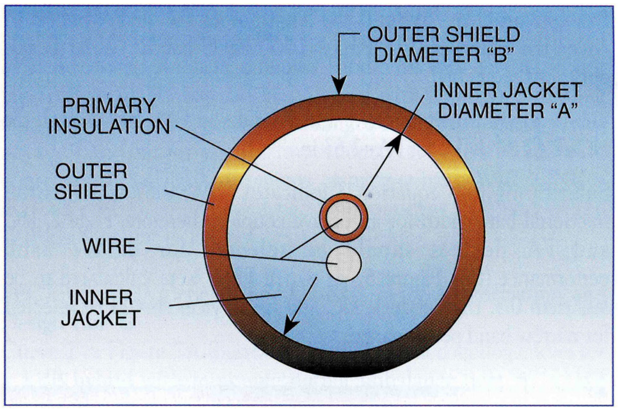
SECTION 3.2 Broad Band Caseless GC Series Coupler Information and Design Curves

For octave band performance, Figure 4 illustrates the theoretical coupling curves for a 10 dB coupler. This performance was accomplished by adjusting the physical dimensions of the 3 dB WIREPAC geometry for a nominal 10 dB coupling. The GC Series WIREPAC offers a nominal 10.25 dB and 9.75 dB coupling relative to input and output, respectively.

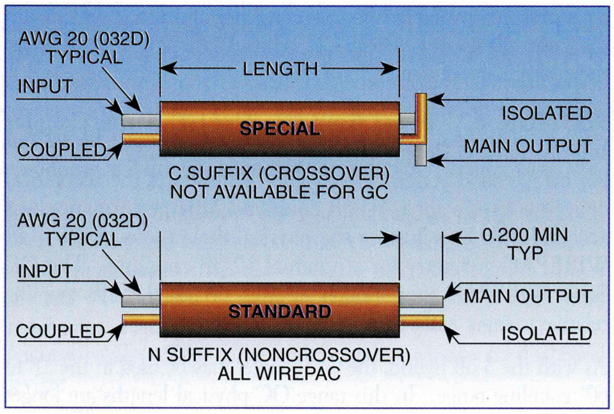
As with the 3 dB hybrid, the GC coupler may be used in the 0° to 60° coupling range. In this range, GC physical lengths are longer than the 3 dB hybrid lengths for the same coupling values. For example, a 3 dB hybrid cut to 0.016 wavelength long, will be a 20 dB coupler. Unfortunately, if the frequency is above 1 GHz, the length will be less than 0.12 inches long, which is difficult to handle. This difficulty can be reduced by selecting the WIREPAC GC Series with 9.5 dB coupling at one-quarter wavelength. Using GC product, the length will now be approximately 0.36 inches for a 20 dB coupling unit at 1 GHz. The longer lengths will permit higher frequency designs to be realized. When a coupler is cut to a length much less than one-quarter wavelength, the coupling will vary at a rate of 6 dB per octave. For broad band performance, this slope can be compensated for with a suitable lumped element network or several couplers can be combined to reduce the slope. (See Section 8.7, pg 13). Spectrum Microwave engineers can help you with these special applications.

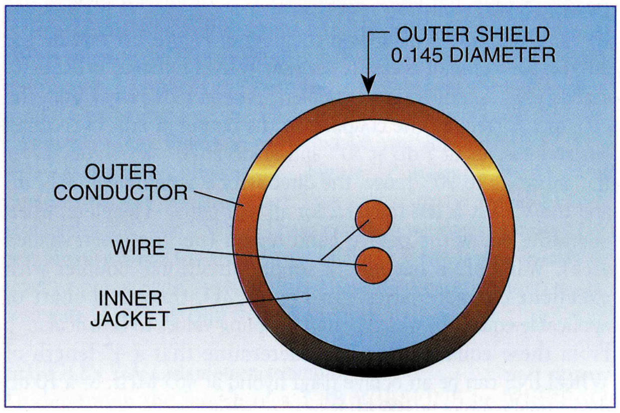
FIGURE 1
WIRELINE CONFIGURATIONS



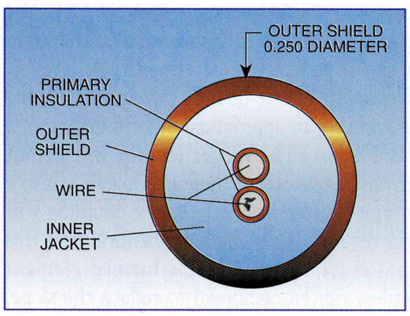


WIREPAC CONFIGURATIONS

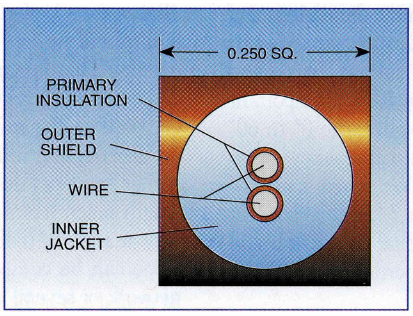




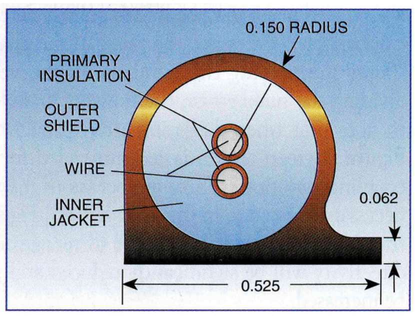
GC - 400W-CW



KC - 500W-CW



LC - 500W-CW



FA - 500W-CW

FIGURE 2A
Nominal Coupling Curves

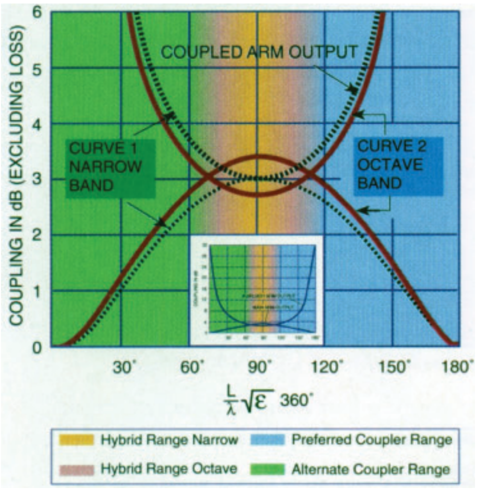


FIGURE 2C
Relative Power Output
Equations & Curves

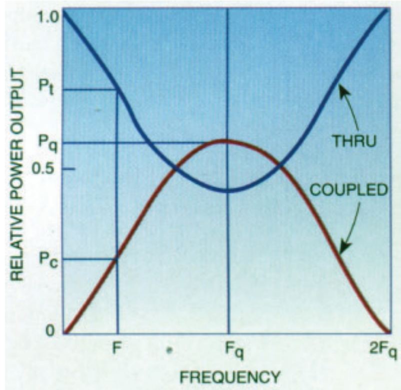


FIGURE 2D
Formula to Compute Relative
Power Output vs. Frequency

PARAMETER	SYMBOL	FORMULA (degrees)
Quarter Wavelength Frequency	F_q	$\frac{90F}{K_2}$
Relative Coupled Power to Input Power at F_q	P_q	$K_1\left(\frac{1}{P_c}-1\right)+1$
Operating Frequency	F	$\frac{K_2F_q}{90}$
Relative Coupled Power to Input Power at F	P_c	$\frac{K_1}{K_1-1+\frac{1}{P_q}}$
Relative Thru Power Output	P_T	$1-P_c$

Where:

$$dB = -10\log_{10}P,\ P_c = 10^{\frac{-dB}{10}},\ K_1 = \sin^2\left(90\frac{F}{F_q}\right),$$

$$K_2 = \sin^{-1}\sqrt{\left(\frac{P_c}{P_c-1}\right)\left(\frac{P_q-1}{P_q}\right)}.$$

FIGURE 2E
Sample Calculations

EXAMPLE: for 10 dB at F = 100 MHz using WIRELINE with 3 dB at F_q.

$P_c = 10^{\frac{-10}{10}} = 0.1$

$P_q = 10^{\frac{-3}{10}} = 0.5$

$K_2 = \sin^{-1}\sqrt{\left(\frac{0.1}{0.1-1}\right)\left(\frac{0.5-1}{0.5}\right)} = 19.47$

$F_q = \frac{90 \times 100}{19.47} = 463$ MHz and the WIRELINE length would be $\frac{1850}{463} = 4.0$ inches.

This same piece of WIRELINE would have a coupling at 105 MHz given by:

$K_1 = \sin^2\left(\frac{90 \times 105}{463}\right) = 0.1216$

$P_c = \frac{0.1216}{0.1216 - 1 + \frac{1}{0.05}} = 0.108$

$dB_c = -10\log_{10}(0.108) = 9.6$ dB and a thru output of:

$P_T = 1 - 0.108 = 0.892$

$dB_T = -10\log_{10}(892) = 0.50$ dB

FIGURE 3
Design Curves to Use Hybrid as Coupler

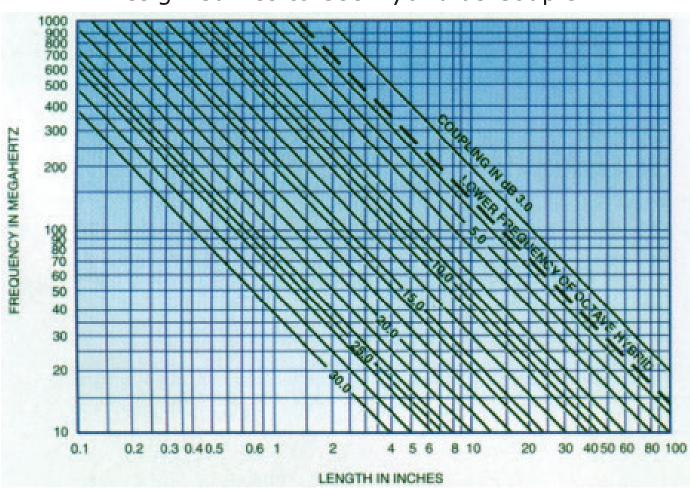
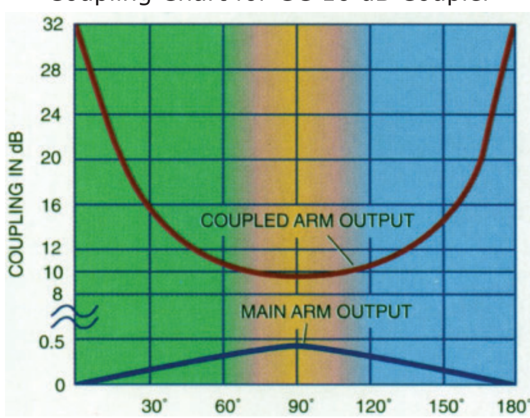


FIGURE 4
Coupling Chart for GC 10 dB Coupler



SECTION 4 WIRELINE / WIREPAC COUPLING TERMS DEFINED

The term hybrid is defined as a four port device that divides a signal fed into one of the four ports equally between two of the other three ports with very little signal reaching the fourth port. As Figure 1 indicates, a signal fed into Port A, the kapton encapsulated wire, will exit Port B, the main arm, and be coupled to Port C, the coupled arm. Port D receives no signal and is called the isolated port. The term quadrature indicates that the two equal output signals will have a relative phase difference of 90 degrees. Since the signal in the main arm travels 90 degrees farther than the coupled arm, the output signal at port C leads the signal at port B by 90 degrees.

Loose Versus Tight Coupling: Tight coupling means the coupled arm is receiving a significant portion of the input power. This condition occurs when the coupling value in dB is low. Conversely, a loosely coupled coupler will have higher coupling values. As Figure 2A indicates, octave band hybrids are more tightly coupled than narrow band optimized hybrids.

Isolation Versus Directivity: Power out at D may be discussed in terms of isolation or directivity. When specifying a hybrid operating within the octave band region (60° to 120°), it is preferred to specify the power at port D in terms of isolation which compares the power output at D to the power input at A.

4. $\text{Isolation (in dB)} = 10\ \text{Log}_{10} \dfrac{\text{Power in at A}}{\text{Power out at D}}$

The typical isolation of WIRELINE and WIREPAC is 20 dB minimum and 30 dB minimum, respectively.

When specifying a coupler or hybrid operating in the region below 60° or above 120°, it is preferred to specify the power at port D in terms of directivity.

5. $\text{Directivity (in dB)} = 10\ \text{Log}_{10} \dfrac{\text{Power in at C}}{\text{Power out at D}}$

The directivity of WIRELINE in the directional coupler range (below 90°), is 17 dB minimum. WIREPAC directivity is greater than 27 dB for all products except GC, which features 20 dB minimum.

VSWR: The Voltage Standing Wave Ratio (VSWR), for properly assembled WIRELINE and WIREPAC, remains below 1.1:1 (KC, LC, FA) and 1.2:1 (HC, JC, GC), for all four ports when properly assembled to 50 ohm lines.

Insertion loss: The WIRELINE coupler insertion loss is defined as input power minus the sum of all output powers, and is typically less than 0.3 or 0.4 dB over the frequency range. The insertion loss of WIREPAC is typically less than 0.2 dB over the operating frequency range.

SECTION 5 COMPONENT SELECTION

Sage offers four WIRELINE product series and four WIREPAC product series components. This array of products provides design flexibility when developing new components, assemblies and systems. To help select the proper component for the application, the following logical set of inquiries is presented.

Question 1: Does the application require 3 dB (equal output) hybrid performance or directional coupler (unequal output) performance?
For hybrid design information go to Section 2.
For coupler design information go to Section 3.

Question 2: Is the band of operation less than 30% fractional bandwidth, or between 30% and octave bandwidth?
For narrow band information go to Section 2.1 or 3.1.
For broad band information go to Section 2.2 or 3.2.

Question 3: What is the maximum average power incident on any port?
For average powers less than 200 watts at 300 MHz or 100 watts at 800 MHz or 50 watts at 2200 MHz or 20 watts at 8000 MHz, the WIRELINE product family should be reviewed first. For power ratings above the above-mentioned powers and frequencies, the WIREPAC product family should be considered. Please note that WIREPAC is often used at lower powers when more stringent electrical performance is required.

Question 4: Which products can satisfy the circuit mounting footprint?
WIRELINE has a unique capability of meeting the most demanding and unusual mounting footprints. The most popular mounting footprints are indicated in Figure 7, pg 8. If you have unusual circuit topology, need to jump over components, or need to have the input and output leads come out in very close proximity to one another, then the bendable property of WIRELINE is extremely valuable.

All WIRELINE products can be shaped, formed and bent with the limiting factor being the minimum radius of the bend. For the WIRELINE family, the minimum radius of bend is 1.5 times the diameter of the outer conductor (See Page 14). For more information on forming WIRELINE, refer to Page 10.

Question 5: Is the fractional operating bandwidth (FBW) less than 0.3?
To calculate fractional bandwidth (FBW) refer to Page 3. If FBW is less than 0.3 then code 1 and code 3 products should be considered. If FBW is greater than 0.3 then code 2 and code 3 products should be considered. The part selection key in Figure 5, pg 8 indicates which parts are available in code 1, 2 or 3 bandwidths. If coupling unbalance is critical to your system performance, then you should pick the geometry which minimizes the coupling unbalance. Coupling and bandwidth performance curves appear in Figure 2, pg 5.

Question 6: Are there any other electrical specs that are more important than power and coupling unbalance?
If insertion loss, VSWR, directivity or isolation are more critical to your design than size, then attention should be given to larger cross section devices such as the JC Series for WIRELINE and the KC Series for WIREPAC. The larger cross section devices have tighter tolerances, less insertion loss and better general electrical performance. Product performance specifications appear on Pages 14 and 15.

If coupling less than 10 dB is required, such as 20 dB or 30 dB designs, then your product selection should consider another set of criteria. The equations and design curves in Figure 2, pg 5 should be used to determine coupling variation and coupler length. Coupler design information is discussed on Page 3.

SECTION 6 COMPONENT PREPARATION

SECTION 6.1 Wireline Stripping

When WIRELINE is purchased in five foot lengths, it must be cut, trimmed, and shaped prior to installation. Figure 1 illustrates the various layers of material which must be removed prior to installation. Generally, the techniques used when working with semirigid coax, should also be used when preparing WIRELINE. These include:
Cut the overall center conductor length.
Cut the shield to length by scoring the metal jacket and snapping it off.
Temperature cycle the part per Figure 6 prior to trimming the Teflon inner jacket.
This procedure helps reduce (Teflon) insulation growth when the part is later subjected to temperature cycling caused by soldering or operating environments.

WIRELINE trimming differs significantly from semirigid cable trimming at the primary insulation removal step. The presence of two wires in the hybrid prevents the use of normal cable stripping tools. Two methods are used to strip the inner jacket and center conductor wires.

Thermal pliers (with suitable fume containment) are first used to remove the fluorocarbon inner jacket layers. A cutting pliers with a ground notch is then used to remove the kapton primary insulation layer. The thermal stripping may leave some Teflon strands. These are not detrimental to performance. They can be removed with a sharp knife to meet cosmetic requirements.

A laser also may be used to selectively remove the fluorocarbon inner jacket and kapton primary insulation layers. This method is recommended for higher frequency products and for volume production.

After the striping operation, the two wires must be identified and oriented. Since the wires in WIRELINE are twisted up to 3 twists per inch, the angular orientation of the wires is random.

However, only one wire has kapton and standard convention defines this wire to be the through wire or main line arm. During installation, the through wire and isolated wire may be moved into the desired orientation by an assembler. We do not orient WIRELINE wires prior to shipment.

WIREPAC parts are assembled from precut wires, jackets and shields and striping procedures are not relevant. Since WIREPAC wire is larger in diameter and more difficult to orient, the WIREPAC wires are pre-aligned in accordance with the Crossover, Code C, and Non-crossover, Code N, orientation illustrated in Figure 1, pg 4. All standard products are manufactured as Code N. If orientation is not specified, Code N will be supplied. GC WIREPAC is not available in Code C. To properly specify WIREPAC wire orientation refer to Figure 5, pg 8.

SECTION 6.2 Tolerance Considerations

In the specification tables on Page 14, you will notice that coupling values vary from 2.4 to 2.9 dB for BHCB1 and BJCB2 WIRELINE and from 2.75 to 3.25 dB for HC1 and JC1 WIRELINE. Due to the small dimensions of the wires and insulators (i.e. 0.0124” O.D. for HC center conductor wires), a variation in wire dimension less than (± 0.001”) can cause a significant change in line impedance which will cause this type of coupling variation.

It is also important to consider the effect on performance due to the tolerance on length. WIRELINE is a combination of two wires and hence, when cutting to length, it becomes increasingly difficult to maintain tight tolerances (inches per inch), particularly as the WIRELINE becomes shorter. For example, a 10” piece of WIRELINE can easily maintain a ± 0.031” tolerance on length, but tolerance problems become significant when cutting lengths are less than 1.0 inch. We presently control length tolerance to ± 0.020 and can offer precision length to ± 0.010 or ± 0.005, if applications demand.

FIGURE 5
WIRELINE and WIREPAC Parts Selection Key

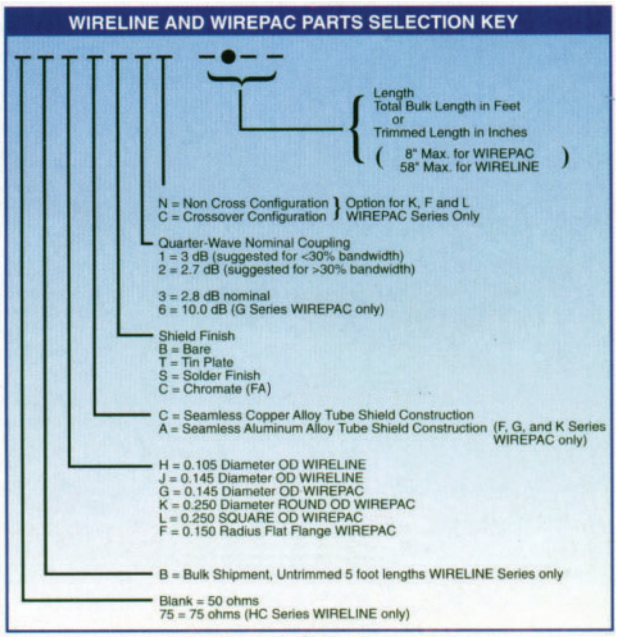


FIGURE 6
Suggested Temperature Cycling Procedure

START	TRANSITION TIME	DURATION
25˚C	15 MIN	-65˚C for 1 Hour
-65˚C	30 MIN	+140˚C for 1 Hour
+140˚C	15 MIN	+25˚C for 1 Hour
Repeat 3 times for total of 3 cycles prior to cutting WIRELINE to final length		

FIGURE 7
Popular Mounting Footprints

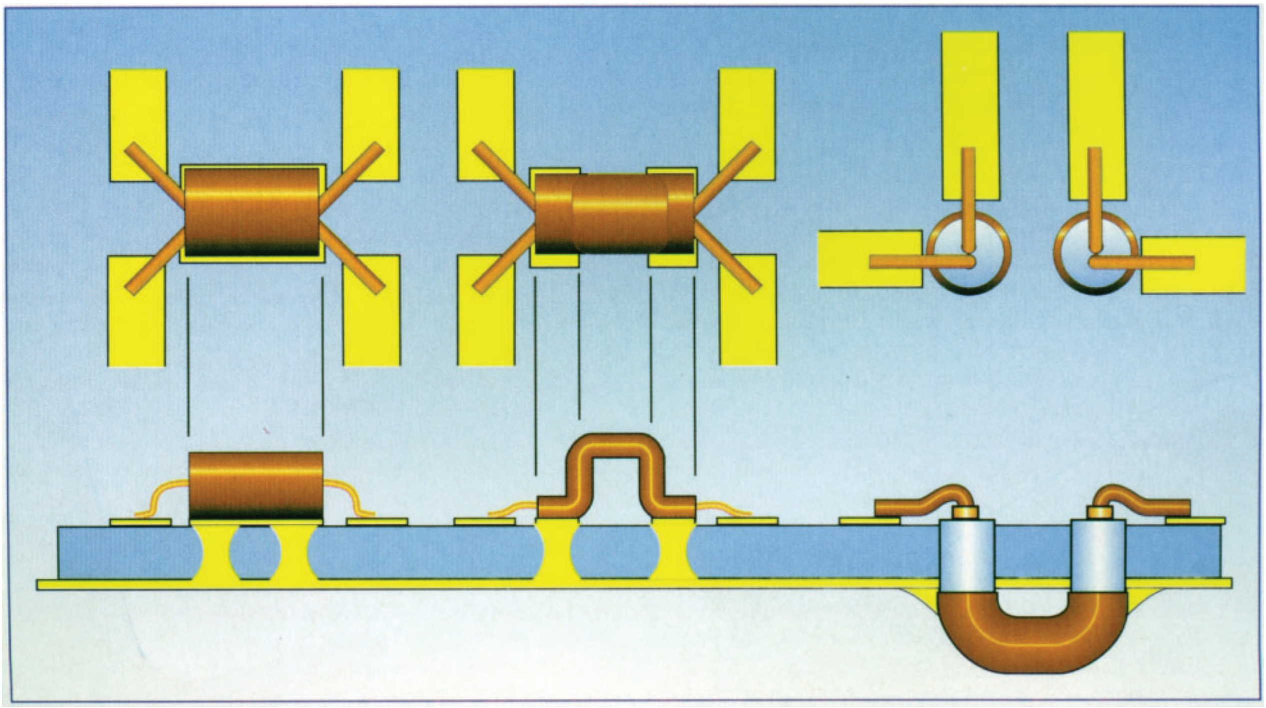
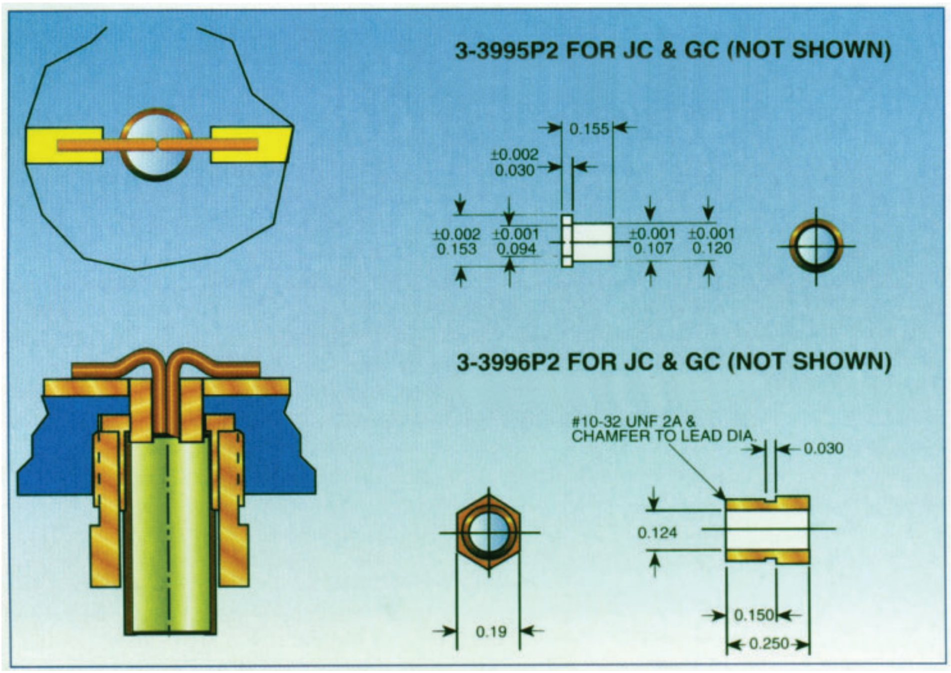
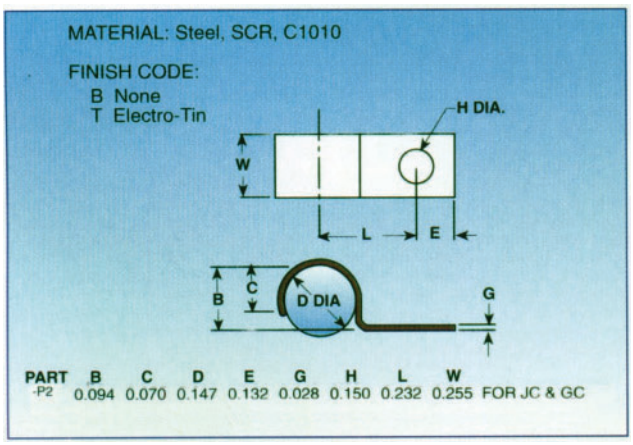


FIGURE 8
Grounding Clamps



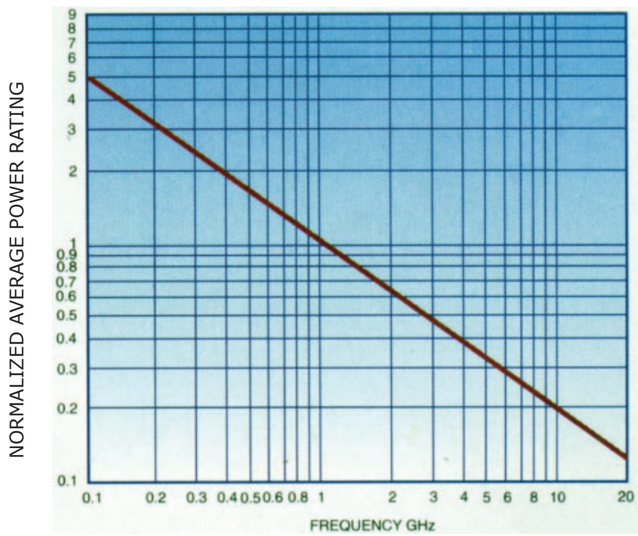
AXIAL CLAMP

FIGURE 8B
Grounding Clamps



RADIAL CLAMP 216-1019

FIGURE 9
Power Derating vs. Frequency Curve



When the power handling capability of a component is give a specific frequency, use this graph to determine the power handling capability at other frequencies.

SECTION 7.0 COMPONENT INSTALLATION

SECTION 7.1 Electrical Considerations

The primary electrical concern is the avoidance of, or compensation of, electrical discontinuities between the WIRELINE structure and the subsystem transmission lines to which it attaches. For narrow band systems, compensation of the discontinuity can be straight forward. For example, the lead inductance of the hybrid can be compensated by a capacitive pad on the circuit. For wide band systems, this compensation becomes less viable.

The length of all discontinuities in the physical structure must be made as short as possible. At high frequencies, this will normally require sinking the hybrid into the mating structure to bring the case of the WIRELINE to circuit ground level and the leads to, or near, the level of the mating transmission lines. Imbedding the component reduces lead lengths and has the additional advantage of minimizing the length of lead which is not conduction cooled. While short leads improve electrical performance, they may eliminate the ability to stress relieve the lead to circuit connection. When minimizing electrical discontinuities, care must also be given to mechanical demands on the component due to the operating environment.

The shield of the WIRELINE hybrid need only be electrically grounded at each end. Mechanical specifications will determine the attachment of the balance of the hybrid shield.

If the hybrid operates at high peak power at high altitude, conformal coating or grease encapsulation of the exposed center conductor leads may be required.

SECTION 7.2 WIRELINE and WIREPAC Hybrid and Coupler Bending

It is sometimes desirable to bend the WIRELINE to fit an available space or to optimally position the ends. Normal semirigid coax techniques should be used. For tight bends, a bending tool should be used. The bending tool should have radii on the inner form and on the outer follower. Bending without the radii will tend to flatten the WIRELINE. This will not ruin performance, but may shift the coupling values. After bending, thermal cycling (See Figure 6, pg 8) is recommended before final Teflon trimming and installation. In general, handle WIRELINE like semirigid coaxial cable. For very small radius bends, cracks may appear in the jacket. If this happens, the device should not be used. Jacket wrinkling, without cracks is of less concern, as it has little or no effect on performance. WIREPAC hybrids using copper alloy jackets are only available as straight units.

It is also possible to fit several shaped lengths into an assembly and just use segments of matched impedance uncoupled lines between the shaped segments of WIRELINE. To maintain 90 degrees phase difference between outputs, the total length of jumpers in the through and coupled wire paths must be equal. They need not be equal at any given split point.

SECTION 7.3 Component Installation For Low Power Applications

Soldering: The most common procedure for soldering a WIRELINE component is to attach the component to the board or carrier and solder the leads to the circuit traces using conventional soldering techniques (See Figure 7). This is a simple procedure, however, the heating, fluxing and cleaning operation will occasionally cause a condition called wicking which can increase the coupling by as much as 0.30 dB at the center of the band. To minimize the wicking effect, all solvents should be removed immediately after soldering is completed. Capping the ends with a relatively viscous conformal coating will also prevent further contamination. If your handling procedures do not result in wicking then the conformal coat is an optional step. The selection of solder, flux and cleaning agents should be compatible with the plating of your circuit and the plating or material composition of the center conductor and outer conductor shields of the WIRELINE products.

Grounding: To achieve the best performance out of the WIRELINE/WIREPAC products, proper care should be made to ground the outer conductor of the WIRELINE. The proper selection of grounding method insures optimum electrical performance and also mechanical integrity during shock and vibration. For low power applications, grounding only needs to occur at the ends of the WIRELINE component. This may be accomplished by conductive epoxy or soldering radial straps, mechanical radial clamps, or soldering sleeves / axial clamp configurations. (See Figure 7, pg 8).

Clamping: Figure 8, pg 9 indicates axial and radial clamps available for H Series, J Series, and G Series components. In many environments, these clamps are sufficient to provide adequate grounding. In more demanding cases, these products may be helpful in positioning or securing the product during an automatic soldering operation. If epoxy is used to effect a conductive interface, its resistivity should be adequate to insure good grounding or center conductor contact at the maximum frequency of operation.

Circuit Transition: In standard mounting configurations with the component above board (Figure 7, pg 8), the circuit layout should be established to prevent solder bridges and minimize center conductor lead inductance. For WIRELINE products, the center conductors may be oriented in crossover or non-crossover configurations at time of assembly. Be sure to identify main arm and auxiliary arm in your mechanical assembly drawings in accordance with Figure 1, pg 4. For WIREPAC products the center conductors are larger and can not be formed at assembly. Be sure to specify WIREPAC orientation Code N or Code C in accordance with Figure 1, pg 4 and Figure 5, pg 8.

SECTION 7.4 High Power Circuit Installation

Soldering: The major consideration in high power installation is heat dissipation. To improve heat dissipation, maximize power performance and improve reliability, some applications require silver plated conductors. If this silver plating is used, then a soft solder with 2 to 3% silver content is recommended to prevent the silver on the lead from leeching into the tin lead solder and producing a high resistance silver alloy. Under high power operation this silver alloy can result in localized heating and solder joint failure. In high power applications, the soldering operation is used for three purposes: Center conductor electrical contact, outer conductor grounding, and outer conductor to heat sink attachment for heat dissipation. Good soldering practices are essential to optimize high power performance.

Grounding and Heat Sinking: The grounding techniques for high power installation usually require that the outer shield be soldered to a heat sink for maximum heat dissipation. The heat sink may be the housing floor or a finned heat sink sleeve or solderable mounting flange. The governing element in selecting a heat sink is to keep the shield temperature below the value specified for a given power input, derated per Figure 9, pg 9. The dissipation can be calculated from the input power and net insertion loss. It should be noted that operations at higher than rating average power are possible, but there are reduced life consequences which can not be predicted without a controlled life test of the particular thermodynamic model.
To accommodate the high power heat sinking and grounding needs, we have developed several configurations of WIREPAC products for high power applications. KC products are round in configuration which lend themselves to custom heat sinking sleeves. The LC series is a square configuration and easily mounted to a case heat sink or a flat flange configuration. We introduced the FA Series WIREPAC which has an integral flange extruded into the sleeve of the outer conductor. These numerous mechanical variations provide the designer with a variety of design options. (See Figure 1)

Thermal Warning: During high power operation or during the process of soldering the outer conductor to the heat sink, the temperature rise of the Teflon will cause it to expand. It is desirable to allow for this expansion with a stress release bend in the leads to minimize the forces on the soldering joint. If lead stress relief can not be accomplished, then the Teflon expansion can be minimized by thermal cycling the component after trimming the outer shield and before trimming the Teflon insulation (See Figure 6, pg 8). It should be noted that after temperature cycling, the Teflon may extrude and produce a looser fit between the inner jacket insulation and the outer conductor shield. This condition will not effect reliability or electrical performance.

Transition: High power transitions should be designed to minimize center conductor lead length. Procedures for minimizing the center conductor lead length are discussed in Section 7.5. To maximize high power operation and peak power handling, the ends of the component should be encapsulated with a viscous conformal coating.

SECTION 7.5 High Frequency Component Installation

All WIRELINE hybrids have 50 ohms characteristic impedance from each of the four ends of the internal wires to the outer shield. For good performance, the discontinuities at the interface to external 50 ohm transmission lines must be small. The severity of the discontinuity produced by a given physical construction depends on the operating frequency. At 30 MHz, a 0.100 inch distance between the exit of the wires from the jacket and attachment to a fifty ohm system would not be noticeable. At 3000 MHz, the same distance represents nine electrical degrees. The wire impedance can easily be 150 ohms and nine degrees length will degrade performance dramatically.

Coaxial Interface: As noted above, the coaxial line must be fifty ohms and the length of high impedance line contributed by the lead to the coaxial line must be short (less than 1% of the physical length).
Custom 12 to 18 GHz mixers use JC WIRELINE hybrids about 0.2 inches long and Teflon OD of 0.125 inches. By using the extended leads from the hybrid as the coaxial line center conductors, the discontinuity is minimal. This transition has been operated successfully to 20 GHz.

Microstrip Interface: To minimize discontinuities, it may be necessary to machine a groove in the circuit board to drop the hybrid in. This permits short paths for the case ground and for the leads. If the hybrid is mounted on the ground side of the microstrip substrate, be sure the via holes to the circuit are 50 ohm lines.

Stripline Interface: A mounting technique which can be used for both stripline and microstrip to increase frequency of operation is to mount the component perpendicular to the ground plane of the printed circuit board or substrate and bring the hybrid through a hole in the substrate as illustrated in Figure 7, pg 8. The axial clamp in Figure 8, pg 9 may be used to accomplish this technique.

Maximum Frequency: Provided the interface to the attached 50 ohm circuit is good, WIRELINE and WIREPAC can be centered at frequencies where the component length is 1.0 to 1.5 times the Teflon diameter.

Scaling empirical data to the small diameter WIRELINE products provides the following guidelines to the maximum usable frequencies.

Part Series	Teflon OD Inches	Min Length Inches	Max Freq., GHz Center	Max Freq., GHz Band Edge
KC, FA	0.23	0.30	6.0	8.0
JC, GC	0.12	0.15	12.0	18.0

Obviously, cutting and handling the very small parts suggested by this table is not easy. However, innovative mounting techniques can extend the frequencies of operation toward the maximum frequencies referenced above.

SECTION 8 CIRCUIT APPLICATIONS

For those of you familiar with the traditional versions of these components, many applications come to mind. WIRELINE / WIREPAC can fulfill most requirements. In many instances, WIRELINE's simplicity, ease of fabrication and assembly make it an attractive alternative to other design methods.

SECTION 8.1 Fundamental Circuit Considerations

Before describing some specific applications of WIRELINE, it is useful to review the operation of a quadrature hybrid. Figure 10 shows the signal relationships of 2 cascaded quadrature hybrids. The relative ports are the same as those shown in Figure 1, pg 4.

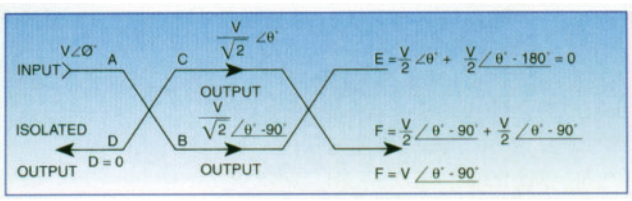


FIGURE 10
Cascaded Hybrids

From Figure 10, it is easy to determine that over the octave band, if short circuits are placed equidistant at outputs C and B, all of the signal power will be reflected back to Port D, with little signal power reaching A. Also, if C and B are left open circuited equidistant from the hybrid structure, all of the signal power will be reflected back to arm D, with little signal power reaching A. Although in each case all of the input power reaches arm D, the signals will be 180° out of phase for the two cases. This signal relationship forms the basis for numerous phase shifter designs.

If two hybrids are connected in series, as shown in Figure 10, a simple phase and magnitude comparison reveals that over the entire octave band all the power incident at port A will reach port F, with very little power reaching ports E or D. If the phase length in one of the paths between the hybrids is varied, the output power will be shifted to port E. This signal relationship can be used to design a variable attenuator.

The fundamental performance of a hybrid described above and shown in Figure 10 is basic to many of the applications of WIRELINE. In addition to the cascading of hybrids, two or more WIRELINE hybrids can be connected in parallel to provide 25 ohm, 17 ohm, 12 ohm, etc. hybrids to satisfy low impedance matching criteria.

SECTION 8.2 DC Block/DC Return

In some microwave applications, it is desirable to have a low-loss, well-matched DC block or DC return. WIRELINE, used as a 3 dB hybrid, provides a practical solution to this problem. Figure 11 shows a schematic for both applications. As a DC block, the opposite ends of the two wires are left open circuited. Because of the 90° hybrid characteristics, all of the power will be carried from the input wire to the output wire

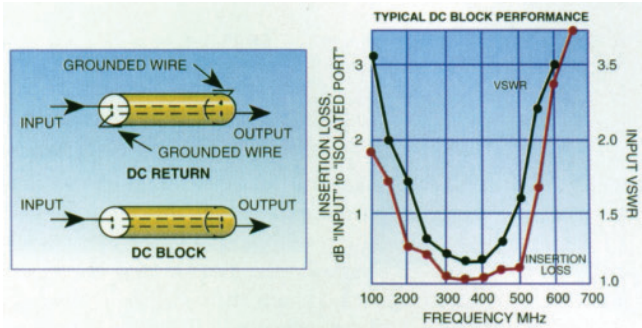


FIGURE 11
DC Block/DC Return

over the full octave. Typical data is shown in Figure 11. In similar fashion, by short circuiting the opposite ends of the two wires, the WIRELINE hybrid provides a low loss, well matched DC return.

SECTION 8.3 Diplexers

Simple Diplexer: If the two frequencies to be diplexed differ by a factor of 10 to 1 or more, a simple method of separating them is to use two WIRELINE hybrids, centered at the higher frequency, connected as shown in Figure 10.
A typical application might be to separate 1 GHz from a 30 MHz IF signal. Referring to Figure 10, the two hybrids must be designed with a center frequency of 1 GHz. If both signals are fed into port A, the 1 GHz signal would cross over to port F as described earlier. On the other hand, the 30 MHz signal would reach port E, since the 1 GHz hybrid becomes a very loose directional coupler at 30 MHz. The unit can also be used in reverse to combine two widely separated frequencies from separate outputs into a single port.
This type of diplexer has been used successfully in mixer applications, where the signal and local oscillator frequencies are in the microwave region and IF frequency is in the 10-60 MHz range.

Channel Dropping Diplexer: A more complicated diplexer can be achieved by placing two matched filters in the lines between the two hybrids of Figure 10. This is shown in Figure 12.

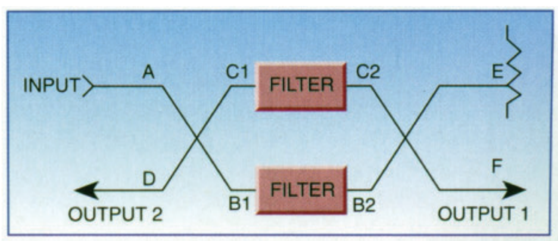


FIGURE 12
Channel Dropping Diplexer

The two filters can be either high pass, low pass, stop band or pass band. The only important consideration is that the band of interest be within the range of the two hybrids. For example, assume two hybrids operate at 500 to 1000 MHz and two pass band filters for 700 to 800 MHz are inserted between them. For a 500 to 1000 MHz signal fed into A, it would always see a low VSWR if the three other ports D, E and F are matched. However, only the frequency in the pass band from 700 to 800 MHz would reach port F. The signals over the rest of the 500 to 1000 MHz band would reach port D.

SECTION 8.4 Power Dividers / Combiners

One of the most common applications of WIRELINE is as a power divider or combiner over its octave band region. It should be kept in mind that the phase at the output ports will be 90 degrees apart. However, it is fairly easy to make a two-way, four-way, eight-way, etc. power divider or combiner by simple cascading. An electrical schematic of a four-way power divider with typical data is shown in Figure 13.

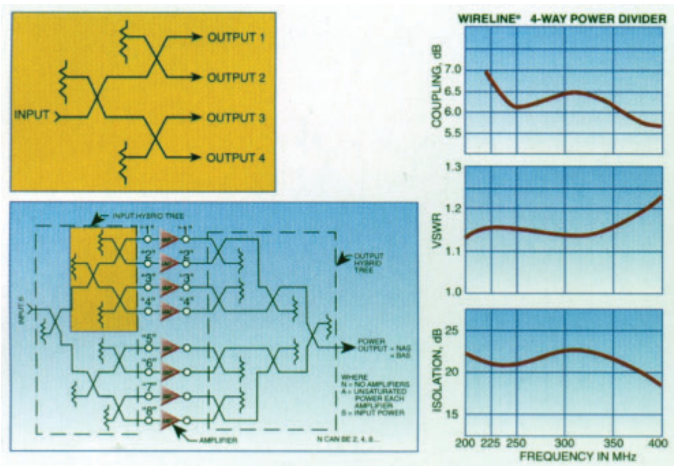


FIGURE 13
4-Way Power Divider and Amplifier Coupling Network

Figure 13 also illustrates using hybrids to feed and combine parallel amplifier stages. Interstage coupling networks of hybrids have been used successfully to 8 GHz for WIREPAC and 18 GHz for WIRELINE. These networks have the advantage of providing low input and output VSWR between amplifiers if the load is matched.

SECTION 8.5 Mixers

Single Diode Mixer: The simple circuit in Figure 14 uses the WIRELINE as a directional coupler. The value of coupling is determined by the local oscillator power available.

Single Balanced Mixer: Quadrature hybrids are commonly used in balanced mixers as indicated in Figure 14. The advantage of this application is that the hybrid provides suppression of local oscillator AM noise. Another mixer application for WIRELINE hybrids is to combine the quadrature IF signals in an image rejection mixer.

SECTION 8.6 Power Monitor

There are some applications where a power monitor may be required. WIRELINE solves this problem inexpensively and efficiently in many situations. The technique is to use WIRELINE as a directional coupler in the line being monitored.

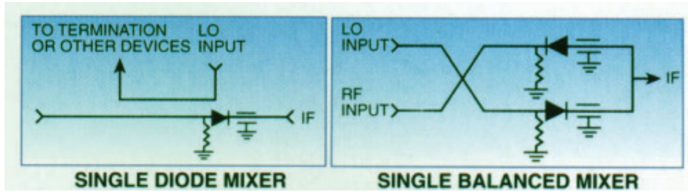


FIGURE 14
Mixer Circuits

If weak coupling of 20 dB or less is needed, the hybrid will be operating with a coupling slope of 6 dB per octave. This can be compensated for by connecting the power monitor video detector with a shunt capacitor or series inductor. The value of capacitance / inductance is dependent on the video load impedance and operating frequency. This is shown in Figure 15.

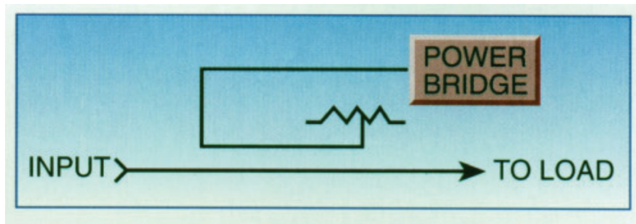


FIGURE 15
Power Monitor

SECTION 8.7 Wide Band Coupler

Wide band couplers can be designed by connecting several unequal WIRELINE segments in series with the correct electrical lengths. Figure 16 indicates the block diagram for a 3 section 10.7 dB coupler which covers the 100 MHz to 500 MHz with less than 0.6 dB through path insertion loss and excellent coupling flatness as shown.

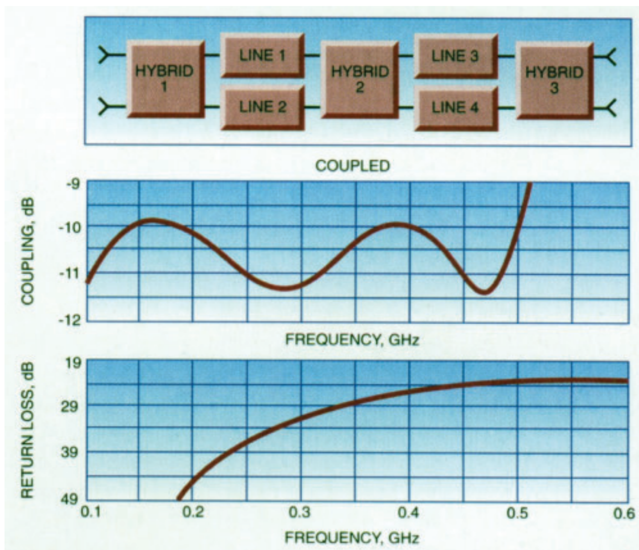


FIGURE 16
Wideband Coupler 100 MHz-500MHz

SECTION 9 WIRELINE PRODUCTS AND SPECIFICATIONS

BULK WIRELINE ELECTRICAL SPECIFICATIONS (test frequency 300 MHz)

PART NUMBER	BHC*1	BJC*1	BHC*2	BJC*2
BANDWIDTH OPTIMIZATION	NARROW	NARROW	OCTAVE	OCTAVE
MINIMUM COUPLING (dB)	2.75	2.75	2.40	2.40
NOMINAL COUPLING (dB)	3.00	3.00	2.65	2.65
MAXIMUM COUPLING (dB)	3.25	3.25	2.90	2.90
MAX. UNBALANCE (dB)	0.5	0.5	1.3	1.3
MAX. INSERTION LOSS (dB)	0.3	0.3	0.3	0.3
MIN. ISOLATION (dB)	20	20	20	20
VSWR	1.2:1	1.2:1	1.2:1	1.2:1
AVERAGE POWER WATTS	100	200	100	200
PEAK POWER WATTS	2000	2000	2000	2000
MAX. PHASE QUADRATURE ERROR	± 1 DEG	± 1 DEG	± 1 DEG	± 1 DEG
MIN. DIELECTRIC BREAKDOWN (VOLTS RMS)	500 MIN.	500 MIN.	500 MIN.	500 MIN.
OUTER SHIELD DIAMETER	0.105	0.145	0.105	0.145

*** = Shield finish code per Figure 5, Page 8.**

SECTION 9.1 Electrical Specifications

WIRELINE products are available in two diameters (0.105 in. and 0.145 in.) and one characteristic impedance (50 ohms). The products are sold in several configurations:

Bulk (by the foot) for engineering development, pre-production prototype fabrication and short run manufacturing.

Finished (precut and assembled) for operation over the popular, standard narrow and octave frequency bands.

Custom (shaped and/or cut and trimmed to non standard lengths) for special engineering or manufacturing applications.

All electrical specifications for all WIRELINE are independent of physical length and summarized in the Bulk WIRELINE Specification table. These specifications are determined by measurements at 300 MHz in a matched 50 ohm system. All specifications are independent of frequency with the exception of power. At jacket temperatures above 55°C the power should be de-rated linearly to 50% at 105°C and to 0 at 155°C.

Section 9.2 Mechanical, Material and Plating Specifications

Although WIRELINE appears to be similar to coaxial cable, the processes, materials and plating must be more tightly controlled to yield superior electrical and mechanical performance. The mechanical specification table should be used in conjunction with the assembly and mounting techniques discussed in Sections 6 and 7 to establish proper mechanical interfaces and design integrity.

BULK WIRELINE MECHANICAL SPECIFICATIONS

PART NUMBER		BJC*1 BJC*2	BJC*1 BJC*2
AVERAGE POWER	WATTS	100	200
WEIGH GRAMS/INCH		0.55	1.14
BENDABLE		YES	YES
MIN. C/L BEND RADIUS	INCHES	0.15	0.30
MAX. STD. LENGTH	INCHES	60	60
"A" INNER JACKET DIAMETER (Fig. 1, pg 4)	INCHES	0.086	0.125
"B" OUTER SHIELD DIAMETER (Fig. 1 pg 4)	INCHES	0.105	0.145
"D" WIRE DIAMETER (Fig. 1, pg 4)	INCHES	0.0124	0.0201
WIRE MATERIAL	NOTE 1	SILVER PLATED COPPER	
PRIMARY INSULATION	NOTE 2	KAPTON	
INNER JACKET MATERIAL	NOTE 3	PTFE	
OUTER SHIELD MATERIAL	NOTE 4	COPPER ALLOY	
OUTER SHIELD PLATING	NOTE 5		
QUARTER WAVELENGTH FACTOR (INCHES)		1850/FREQ IN MHz	

Note 1: copper wire per QQ-W-343, silver plated per ASTM-B-298
Note 2: Polyimide film per MIL-P-46112 with FEP binder per ASTM-3368
Note 3: Polytetrafluoroethylene (PTFE) per ASTM-D-1457, Tetrel™ (duPont)
Note 4: C Series (Seamless Copper Alloy Tube): copper CDA ALLOY 122
Note 5: B: Bare/Unplated
T: Tin Plate per MIL-T-10727
S: Solder Plate per MIL-P-81728

Section 9.3 Product Guide Information

We maintain a large inventory of bulk material which can typically be delivered within one week. Finished parts can be processed and delivered within 3-4 weeks. Please call the factory for exact lead times.

SECTION 10 WIREPAC PRODUCTS AND SPECIFICATIONS

SECTION 10.1 Electrical Specifications

WIREPAC products are available in four geometries (0.250 in. Dia., 0.145 in. Dia., 0.250 in. Square and .150 in. Radius with flange). All WIREPAC products are designed for 50 ohm systems and are sold in precut straight lengths determined by operating frequency. The KA Series allows for the forming of WIREPAC for tight fit applications.

The electrical specifications for WIREPAC are summarized in the WIREPAC Electrical Specification table. These specifications are determined by measurements at 300 MHz in a matched 50 ohm system. All specifications are independent of frequency with the exception of power. At jacket temperatures above 55°C the power should be de-rated linearly to 50% at 105°C and to 0 at 155°C.

WIREPAC ELECTRICAL SPECIFICATIONS (test frequency 300 MHz)

PART NUMBER	FA*1, KC*1, LC*1	FA*2, KC*2, LC*2	GCB6
BANDWIDTH OPTIMIZATION	NAR-ROW	OCTAVE	OCTAVE
MINIMUM COUPLING (dB)	2.75	2.45	10.00
NOMINAL COUPLING (dB)	3.00	2.70	10.25
MAXIMUM COUPLING (dB)	3.25	2.95	10.50
MAX. UNBALANCE (dB)	0.3	1.1	NA
MAX. NET INSERTION LOSS (dB)	0.2	0.2	0.1
MIN. ISOLATION (dB)	30	30	30
MIN. DIRECTIVITY (dB)	27	27	20
VSWR	1.1:1	1.1:1	1.2:1
AVERAGE POWER WATTS	500	500	400
PEAK POWER WATTS	2500	2500	2000
MAX. PHASE QUADRATURE ERROR	±1 DEG.	±1 DEG.	±1 DEG.
MIN. DIELECTRIC BREAKDOWN (VOLTS RMS) CASE SIZE (SEE FIG 1, PG 4)	1000 MIN	1000 MIN	1000 MIN

*** = Shield finish code per Figure 5, Page 8.**

Section 10.2 Mechanical, Material and Plating Specifications

The WIREPAC processes, materials and plating are carefully controlled to yield superior electrical and mechanical performance. WIREPAC is more frequently used in high power applications which require heat sinking. Mounting techniques and mechanical specifications must be considered very carefully to insure good heat transfer and mechanical integrity. The assembly and mounting techniques in Sections 6 and 7 discuss clamping procedures which can be adapted to the most demanding environment. The FA flanged WIREPAC is designed to accommodate #4 screws which provide a rugged fastening method to secure the WIREPAC to the housing or heat sink.

WIREPAC MECHANICAL SPECIFICATIONS

PART NUMBER		FA*1, FA*2	KC*1, KC*3	LC*1, LC*2	GCB6
AVERAGE POWER	WATTS	500	500	500	400
WEIGHT GRAMS/ INCH		4.3	3.0	3.0	1.2
BENDABLE		NO	NO	NO	NO
MIN. C/L BEND RADIUS	INCHES	NA	NA	NA	NA
MAX. STD. LENGTH	INCHES	8	8	8	8
MAX. OPER. FREQ.	MHz	8,000	8,000	8,000	8,000
"A" INNER JACKET (Fig 1, pg 4)					
"B" OUTER SHIELD (Fig 1, pg 4)		SEE FIGURE 1, PAGE 4			
"D" CENTER CONDUCTOR DIA. (Fig 1, pg 4)		0.032	0.032	0.032	0.032
WIRE MATERIAL		BARE COPPER	BARE COPPER	BARE COPPER	BARE COPPER
PRIMARY INSULA-TION	NOTE 2	KAPTON	KAPTON	KAPTON	KAPTON
INNER JACKET MATERIAL		PTFE SYLGUARD	PTFE SYLGUARD	PTFE SYLGUARD	PTFE SYLGUARD
OUTER SHIELD MATERIAL		6061-T6 ALUMINUM	BRASS	BRASS	BRASS
OUTER SHIELD PLATING	NOTE 5	C	B, T OR S	B, T OR S	B, T OR S
QUARTER WAVELENGTH FACTOR (INCHES)		1970/ FREQ. IN MHz	1970/ FREQ. IN MHz	1970/ FREQ. IN MHz	2100/ FREQ. IN MHz

*** = Shield finish code per Figure 5, Page 8.**

Note 2: Polyimide film per MIL-P-43112 with FEP binder per ASTM-3368

Note 5: B = Bare/unplated
T = Tin plate per MIL-T-10727
S = Solder plate per MIL-P-81728
C = Chromate Conversion Coating Yellow per MIL-C-5541

Section 10.3 Product Guide Information

Sage maintains a large inventory of bulk WIREPAC component parts. Due to the number of geometries offered, pre-cut and assembled parts are not kept in stock. To define a WIREPAC product, use the product selection key in Figure 5, pg 8.

SECTION 11 ENVIRONMENTAL INFORMATION

SECTION 11.1 Temperature Ratings

All products are rated for full power performance at 55°C jacket temperature. This rating should be de-rated linearly to zero power at 155°C jacket temperature. The curve in Figure 9 provides additional de-rating information. It should be noted that these are operating power conditions. The material will withstand vapor phase soldering without damage. When the preparation and installation methods outlined in Sections 6 and 7 are utilized, all WIRELINE and WIREPAC products meet the operating temperature ranges specified in MIL-E-5400 for military aircraft and MIL-STD-2036 for shipboard equipment.

SECTION 11.2 HUMIDITY

Since the outer jacket is either seamless copper alloy or aluminum, it is watertight. For humidity considerations the ends must be protected just as with semirigid coaxial cable. To meet severe humidity requirements, these ends should be conformally coated, encapsulated or sealed. If they are unprotected, moisture may wick into the unit and change the electrical performance slightly. We have qualified products to humidity specification MIL-SPEC-202 Method 103, 106.

SECTION 11.3 Shock And Vibration

For shock and vibration considerations, WIRELINE and WIREPAC products should be handled similar to coaxial tube cable. The main consideration is to adequately support the outer conductor to prevent it from reaching damaging resonance during vibrations. With proper use of mechanical clamps or outer conductor soldering, the shock and vibration level are almost without limit. An additional advantage to the WIRELINE/WIREPAC construction is that the Teflon insulation tends to dampen the effects of vibration. For unusual or unsupported mounting techniques, we recommend the installation be subjected to the appropriate environmental test.

SECTION 11.4 Programs And Operating Environments

WIRELINE and WIREPAC have been subjected to many demanding operating environments and are presently qualified on the following programs and applications:

• 777 • GOES • INTELSAT V •
• TIROS • MANPACK GPS •
• P TO P MICROWAVE BASE STATIONS •
• COMMERCIAL SECURITY SYSTEMS •
• INMARSAT • TCAS • XTE •
• POWER AMPLIFIERS •

SECTION 12 ORDERING INFORMATION

There are three ways to order caseless hybrid products. Bulk, finished and custom length or custom shaped special orders.

SECTION 12.1 Bulk Ordering Procedure

WIRELINE products may be ordered in bulk for customer fabricated hybrids and couplers. WIREPAC products are not available in bulk. To specify bulk WIRELINE the B code is used in the ordering key. Bulk WIRELINE is convenient for development programs or for projects which require several iterations before optimum performance is achieved. When ordering bulk WIRELINE, it should be noted that the cutting and trimming is a delicate operation and proper experience and tools are necessary to avoid scoring or damaging the center conductor wires. HC and JC products may be prepared with the tools described in Section 6 under component preparation. For ordering bulk WIRELINE, use the ordering key and create your own model number. Bulk WIRELINE is typically supplied in five foot lengths for ease in packing and shipping.

SECTION 12.2 Ordering Finished WIRELINE Units

To order parts that will be cut and trimmed by us, simply select the series geometry you prefer and compute the desired length in inches using the design equations on Page 2 of this Design Guide. Once your length and geometry are determined, use the product selection key in Figure 5 to define your finished product, including shield finish and narrow or octave band nominal coupling. If special stripping or lead lengths are required then custom products with configuration control specifications should be ordered.

SECTION 12.3 Ordering Custom Products

A unique part number is assigned to each custom product. The custom product is controlled through a control document which references the customer specified mechanical configuration and either standard or customer specified electrical specifications. This part number is under Sage configuration control.