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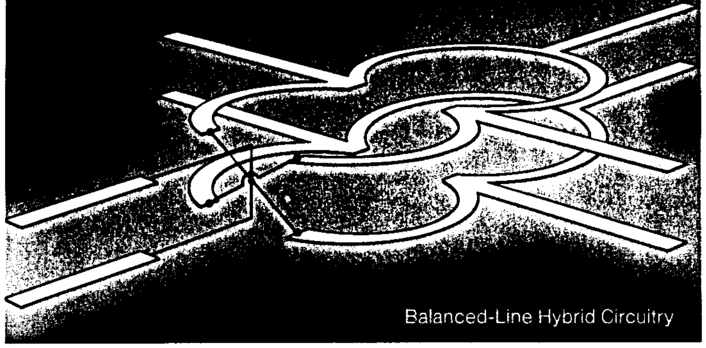
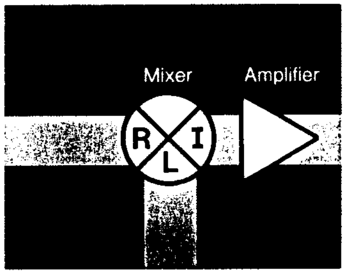
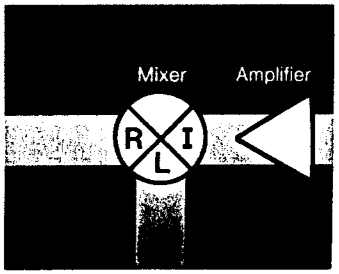
The Coplanar Mixer



Balanced-Line Hybrid Circuitry

Progress in Microwave Frequency Converters





The microwave community has used frequency converters for many years to either up or down convert relatively narrow portions (MHz) of the frequency spectrum. Although the input and output frequencies of the converting device differed in magnitude by as much as 100 to 1, the bandwidth of the converted signal still remained relatively limited.

Today, microwave frequency converters are available with extremely wide bandwidths, now making it possible to transform gigahertz (GHz) of bandwidth using a new coplanar mixer device. Also, the coplanar mixer structure allows it to be integrated into current microwave integrated circuit (MIC) assemblies, or appear as an individual component interconnected by semi-rigid coax. Since frequency converting devices transform segments of a band or channel, they are often referred to as "channelizers", the subject of this issue of Tech-notes.

This issue presents three examples that demonstrate the coplanar mixer's flexibility in both commercial and military channelizer applications, and then discusses the hybrid circuit technology that permits the realization of the W-J "flatpack" coplanar double balanced mixer.

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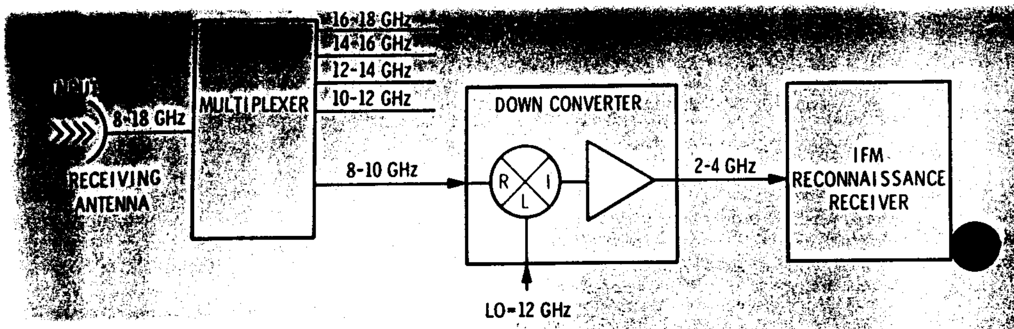


Fig. 1
Channelizer used to down convert the 8–18 GHz frequency region to 2–4 GHz in order to input into a lower band instantaneous frequency monitor (IFM) reconnaisance receiver.

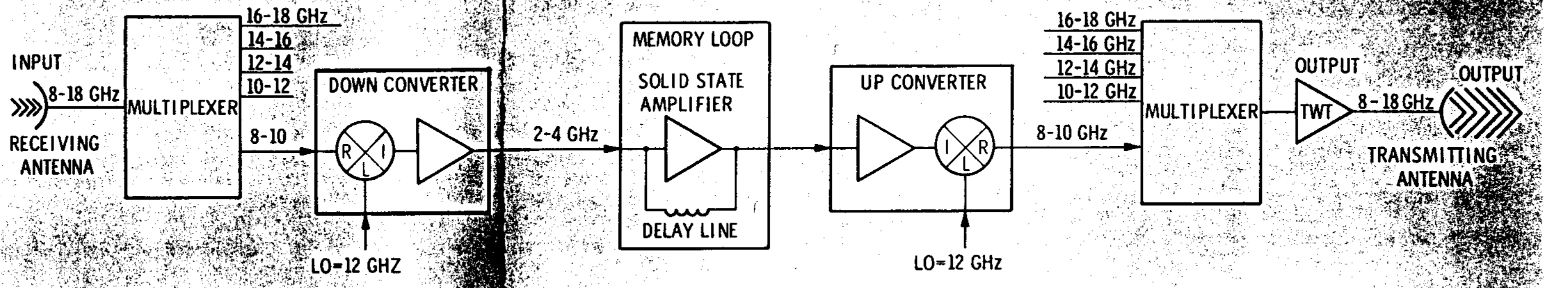
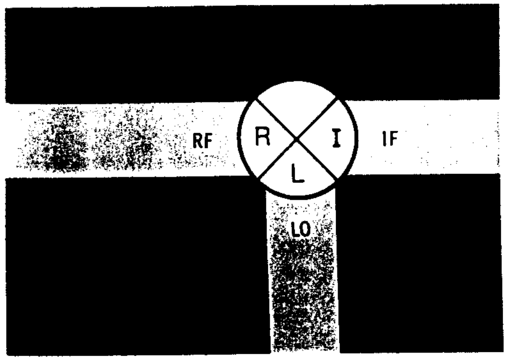


Fig. 2.
A simplified repeater jammer system using channelizers and a memory loop device. The channelizer down converts the 8–18 GHz input to S-band (2–4 GHz) where a solid state S-band amplifier and delay line processes and "stores" the frequency transmitted from a threat radar. After processing in S-band, a second channelizer up converts the false range signal to the original frequency range. Final power required for transmission is supplied by an output TWT amplifier.



Three-Port Mixer

The channelizer examples used in this issue concentrate on the frequency conversion property of the three-port mixer. The mixer, however, also can be used as an amplitude modulator, pulse modulator, bi-phase modulator or phase detector where accurate amplitude and phase translation occurs. The function of the mixer ports depends on application, and in the channelizer applications to follow the R-, I-, and L-ports perform both input and output functions.

Inputs to the L-port are normally sources of energy that cause the mixer diodes to behave as a time varying impedance, and in the ideal mixer as a time varying resistance. The R-port is used for a high frequency input, or a high frequency output signal. The I-port is normally used for a low frequency input, or a low frequency output signal. Local oscillator (LO) power at the L-port is used during frequency conversion by the mixer. As a result, LO power contributes to the IF frequency component at the I-port, or RF frequency at the R-port when the R-port is the output, but does not affect the output power level. The IF, or RF output power depends upon the level of the incoming signal and conversion loss of the mixer circuitry.

Three Microwave Channelizer Applications

A specific application of the communications industry has been to convert the 7.9 - 8.4 GHz communications band into the 3.7 - 4.2 GHz band. Each of these microwave bands has a 500 MHz bandwidth. By using a microwave mixer, a bandwidth centered in the 8 GHz region can be readily converted into the more established 3.7 - 4.2 GHz band. Further processing of the microwave signal can then occur using lower cost equipment originally designed for the 4 GHz band. Several other bands that also can be converted into the 4 GHz band include: the 11.8 - 12.2 GHz band, and bands in the neighborhood of 14 GHz and 18 GHz. All of these can be converted into the 3.7 - 4.2 GHz band for much lower cost processing while still retaining the full instantaneous bandwidth required for high volume traffic.

Within the military spectrum is the need for inexpensive reconnaisance receivers that can adequately cover the microwave band. In particular, is the development of the instantaneous frequency monitor (IFM) systems at the 2 - 4 GHz range. The use of IFM receivers at 8 - 18 GHz, however, has been somewhat limited by cost. By using the channelizer in a circuit as shown in Figure 1, the frequency segments or channels of the 8 - 18 GHz band can be down converted and then processed using either a single time shared or multiple 2 - 4 GHz IFM receiver. This has several advantages as far as redundancy, in that only a single type of a relatively inexpensive IFM receiver is required, and yet highly reliable solid state mixers and amplifiers can be used in front of the IFM receiver rather than the more expensive higher frequency components.

Another military application is in the ECM field, where a tremendous concern exists for adequate coverage at the higher frequencies. In particular, deceptive jamming loop systems (see March 1974 issue of Tech-notes) have created the need for channelizers that can be interfaced with existing loop systems. The repeater jamming system, Fig. 2, shows a channelizer used to down convert part of the X-band (8 - 12.5 GHz) into the S-band range. Here an S-band solid state amplifier and delay line can be used with the advantages of lower

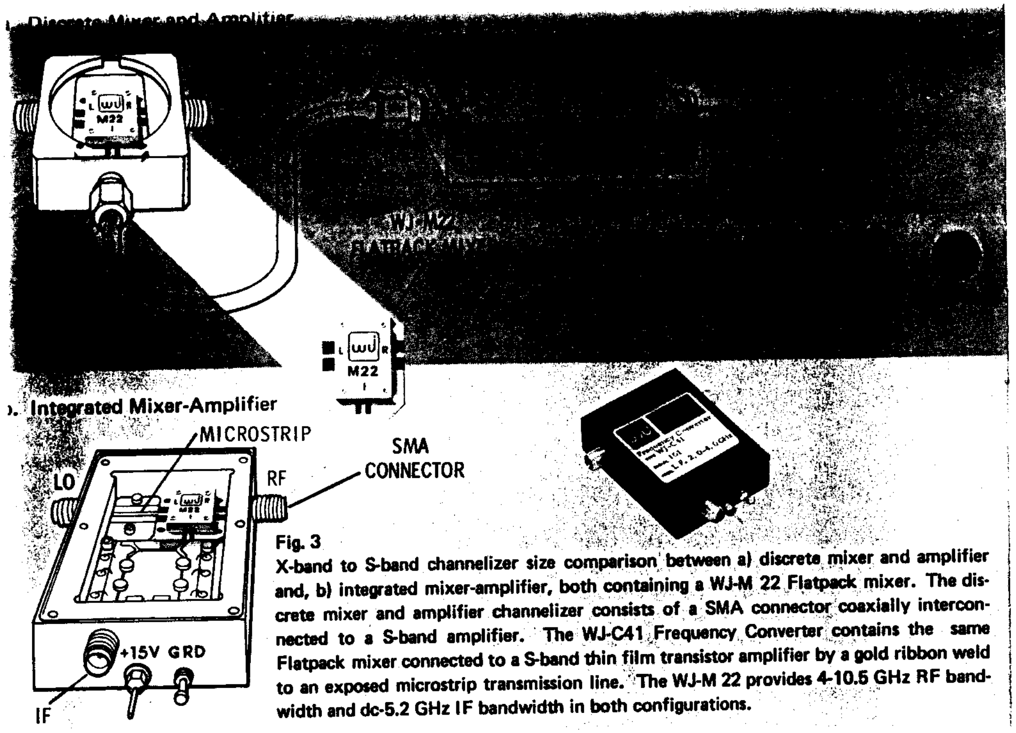


Fig. 3
X-band to S-band channelizer size comparison between a) discrete mixer and amplifier and, b) integrated mixer-amplifier, both containing a WJ-M 22 Flatpack mixer. The discrete mixer and amplifier channelizer consists of a SMA connector coaxially interconnected to a S-band amplifier. The WJ-C41 Frequency Converter contains the same Flatpack mixer connected to a S-band thin film transistor amplifier by a gold ribbon weld to an exposed microstrip transmission line. The WJ-M 22 provides 4-10.5 GHz RF bandwidth and dc-5.2 GHz IF bandwidth in both configurations.

cost, smaller size, and less weight than an 8 to 18 GHz TWT. In addition, the dispersive characteristics of the S-band delay line are superior to delay lines available for 8 to 18 GHz. Following the processing at S-band frequencies, the signal is again converted to the original frequency range and an Output TWT supplies the required output power.

Integrated Mixer-Amplifier Channelizer

These applications, requiring large instantaneous bandwidth and high dynamic range, generally evolve through the use of a separate mixer and amplifier coaxially interconnected as shown in Figure 3a. With the advance of the Watkins-Johnson Company coplanar "Flatpack" mixer, the coaxial transmission line between mixer and amplifier is eliminated, resulting in a smaller channelizer circuit block, Fig. 3b.

Here most of the passive circuit consists of a microstrip or lumped elements on a ceramic substrate; diodes, transistors and other components bonded into the circuit. This smaller frequency converter is constructed as a connectorless module with a 50 ohm microstrip input and output transmission line. The mixer and amplifier are mounted on metal carriers which serve as ground planes, and which also provide mechanical support. Since both mixer and amplifier are on the same microstrip surface, electrical interconnection between mixer and amplifier is by a gold ribbon. The subminiature screw type connector on the RF-port is soldered directly to the microstrip of the mixer. Actual size of the WJ-C41 Frequency Converter shown is 1.5 x 1.8 x 0.6 inches.

Flatpack Performance as a X-Band to S-Band Channelizer

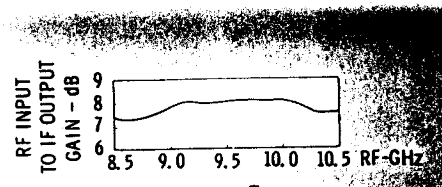
The channelizer applications illustrate the high IF frequency (>2 GHz) capability of the 2 - 4 GHz frequency converter shown in Fig. 3b. In order to further evaluate its application in converting portions of X-band to S-band, a look at some specific electrical characteristics of the integrated coplanar mixer-thin film amplifier is required.

- AMPLIFIER GAIN AND MIXER CONVERSION LOSS

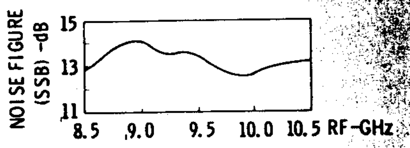
Since the converter translates a 2 GHz portion of X-band to S-band, any gain variation will degrade the flatness of the overall system gain. The curve of Figure 4a shows a flatness of 1 dB (±0.5 dB) using the WJ-C41 during conversion over the 8.5 to 10.5 GHz RF frequency range. Converter gain results from a typical amplifier gain of 14 dB and mixer conversion loss of 6 dB across this frequency range. Mixer conversion loss ratio of IF power to RF power is flat to ±.2 dB and is specified with single sideband (SSB) conversion.

- NOISE FIGURE AND R- TO I-PORT GAIN

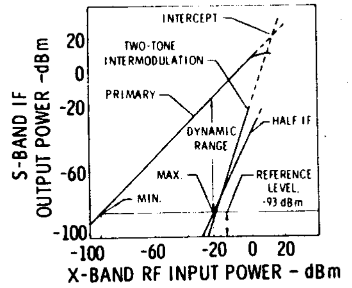
The limits of these parameters depend on the particular system application. The noise figure ratio of signal-to-noise at the input to signal-to-noise at the output determines the "noisiness" of the processing system. A noise figure of 14.2 dB maximum, Fig. 4b, is considered low with a 2 GHz IF instantaneous bandwidth and IF output Intercept Point of +20 dBm (Figure 4c). Mixers with Schottky-barrier diodes have noise figures approximately the same as the SSB conversion loss. For this frequency converter, a noise figure of 15 dB maximum and R- to I-port gain of 7 dB minimum could apply to a wide range of system applications.



a. Gain versus Frequency



b. Noise Figure versus Frequency



c. Dynamic Range

Fig. 4. X-band to S-band performance characteristics of the WJ-C41 Frequency Converter using the coplanar [illegible]

- SPURIOUS FREE DYNAMIC RANGE

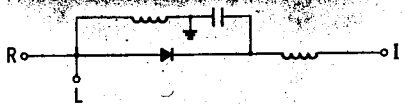
Dynamic range is a measure of output amplitude over which the frequency converter operates without degradation in performance, and is dictated by mixer noise figure and spurious frequency distortion. The IF frequency band application determines which spurious products will limit the system dynamic range. The Primary Response output, Fig. 4c, increases linearly with RF input until the IF output level becomes strong enough to generate "false signals" within the 2 GHz bandwidth. The "two-tone" intermodulation response is an example of spurious frequency distortion produced by two high level RF inputs. Also shown is a Half IF spurious response caused by a RF frequency that combines with the LO frequency to produce not only the Primary Response but an output level which is many dB lower. The dynamic range is also dependent on the noise figure which is shown by the horizontal reference level. This is a noise figure of a 1 MHz effective bandwidth, plus 7 dB. This reference level determines the minimum reliable Primary Response output. A 68 dB dynamic range was achieved between maximum and minimum RF inputs using the WJ-M22 Flatpack mixer.

- MIXER LO AT R-PORT ISOLATION

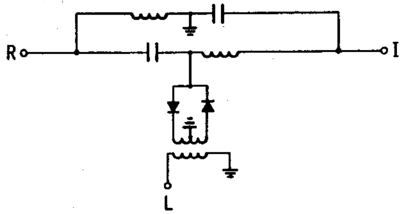
Isolation is a measure of the amount of "leakage" between ports. The LO at R-port isolation is the amount of attenuated power when measured at the R-port, and is the ratio of LO at the R-port (in dBm) to LO at the L-port (in dBm). Similar relations hold for LO at the I-port isolation. A minimum of 10 dB is required in this example to avoid degradation of LO power available at the mixer diodes due to the loading effect on the R-port. Typically, the W-J M15-M18 mixers have 20 dB of LO at R-port isolation.

- R- AND I-PORT VSWR

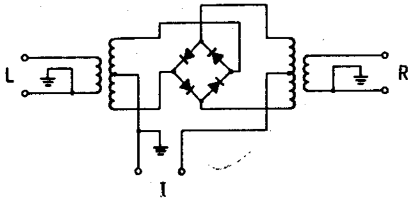
A 2.5:1 Voltage Standing Wave Ratio (VSWR) is a realistic requirement on the RF and LO ports and is easily obtained with the coplanar mixer. The VSWR of a typical Flatpack mixer is 1.5:1 and thereby establishes a well controlled source impedance which minimizes the interface requirements on the I-port.



a. Single-Ended



b. Single-Balanced



c. Double-Balanced

Fig. 5. Equivalent circuits of a single-ended, single-balanced and double-balanced low frequency (<2 GHz) microwave mixer.

Single-Ended, Single-Balanced and Double-Balanced Mixers

Mixer diodes behave like on-off switches, switching at a rate determined by the microwave LO frequency. For the simple, single diode mixer (single-ended), Fig. 5a, the diode interrupts the input and produces an output frequency spectrum that contains harmonics, and combinations of the input and LO frequency. This spurious frequency generation limits the information transmission and retrieval efficiency.

Operating two single-ended mixers in parallel and 180° out-of-phase, results in approximately 50 percent suppression of the spurious frequency generation. In this single-balanced configuration, Fig. 5b, the L-port input now produces an output spectrum which contains suppressed even harmonics of the LO frequency.

By placing two single-balanced mixers in parallel and connected 180° out-of-phase, Fig. 5c, the spurious frequency content of the single-ended mixer is reduced by 75 percent. In this double-balanced mixer the local oscillator and four diodes alternately reverse the input to output connection on each half cycle of the L-port input.

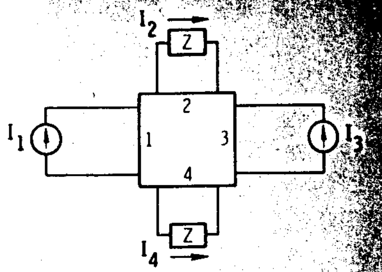
Double-Balanced Mixer from Four-Port Hybrid Junction

Development towards obtaining a high level double-balanced mixer requires that the microwave equivalent replace the wire wound transformer used in the double-balanced mixer of Figure 5c. By integrating well matched Schottky-barrier diodes with capacitance less than 0.15 pF into microstrip format, the frequency range is extended from 2 GHz to 18 GHz.

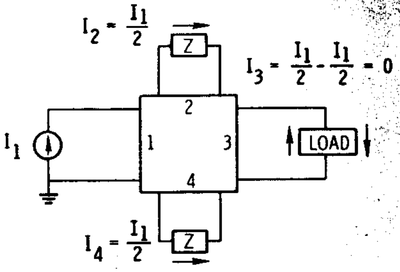
The mixer transformer incorporates many of the properties of the four-port hybrid junction shown in Figure 6a. Characteristics of this four-terminal pair structure include: octave bandwidth operation as opposed to narrow bandwidth, equal power division between two impedance matched ports, and power isolation from one port. It provides a replacement to the wire wound transformer by exhibiting the property of both in-phase and out-of-phase power division.

- IN-PHASE POWER DIVISION, FIG. 6B

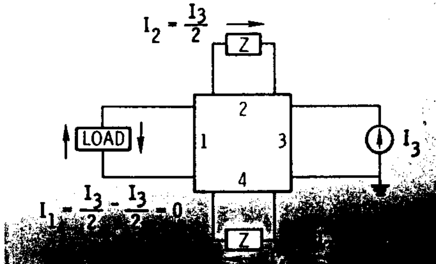
Equal in-phase power division occurs at Ports 2 and 4 for an input applied at Port 1 if the loads at ports 2 and 4 are equal. No power is supplied to a load at port 3. As a result port 3 is isolated from an input at port 1.



a. Four-Port Hybrid Junction (Four-Terminal Pair Network)



b. In-Phase Power Division and Isolation

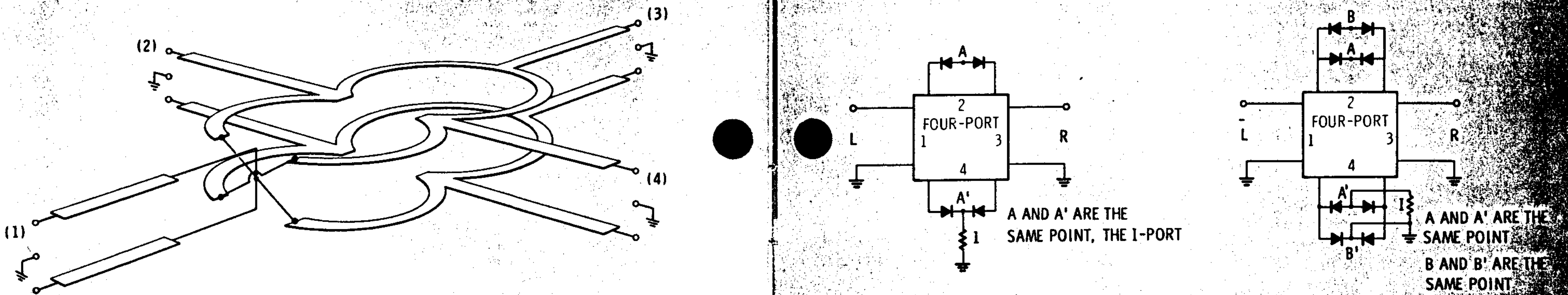


c. Out-of-Phase Power Division and Isolation

Fig. 6. Four-Port Hybrid Junction building blocks to high frequency (>2 GHz) double-balanced mixers.

- OUT-OF-PHASE POWER DIVISION, FIG. 6C

Equal and 180 degree out-of-phase power is supplied to ports 2 and 4 for an input applied to port 3 if the loads at ports 2 and 4 are equal. Port 1 is isolated from an input at port 3.



a. W-J Coplanar Balanced-Line Hybrid Circuit

b. Double-Balanced Mixer from Four-Port, Diodes and Transmission Line

c. Eight Diode Double-Balanced Mixer with Balanced I-Port

Fig. 7. Electrical circuits of the W-J Flatpack double-balanced mixers

Flatpack from Coplanar Balanced-Line Hybrid Circuitry

A unique coplanar balanced-line hybrid structure, Fig. 7a, developed at the Watkins-Johnson Company allows the hybrid circuitry to occupy only two dimensions. This parallel structure permits diode connections to be made on both sides of the surface for smaller size, without compromising electrical performance. Mechanical integration of the Flatpack mixer and thin film amplifier in the Frequency Converter of Figure 3b is a direct result of this coplanar circuitry.

Materialization of the flatpack mixer consists of electrically connecting Schottky-barrier diodes via transmission lines to the basic four-port hybrid junction, Fig. 7b. The L- and R-ports of the mixer are determined by the isolation properties of the four-port hybrid junction. Selecting the mutually isolated ports 1 and 3, as the L- and R-ports, ensures L- to R-port isolation in the frequency band of operation. Since isolation of ports 1 and 3 depends upon equal loading of ports 2 and 4, these two ports are loaded down in a symmetric diode configuration. The I-port is created by forming a junction with Schottky-barrier diodes connected to ports 2 and 4. The I-port will have a dc response since the diodes separate the I-port from the hybrid circuitry.

The WJ-M22 mixer used in these frequency converting examples consists of an eight-diode balanced I-port configuration, Fig. 7c. This double-balanced mixer has a balanced output port at points A and B. A balun (balanced to unbalanced transformer) is placed between points AB and the I-port. Therefore, the I-port bandwidth is that of the balun and is not affected by the hybrid frequency sensitivity. The L- and R-port bandwidth and frequency sensitivity is that of the basic four-port hybrid junction.

A balun constructed with bifilar wound on a ferrite core exhibits a bandwidth from 100 kHz to 6 GHz. By using this balun approach in the WJ-M22 mixer, the specified I-port bandwidth extends from 5 MHz to 4 GHz. Because the I-port is dc coupled, a dc bias can be applied, or a dc voltage can be detected at the I-port. The 1 dB gain flatness achieved by the WJ-C41 Frequency Converter, Fig. 4a, is made possible by the 0.2 dB conversion loss flatness characteristic of this eight-diode balanced I-port double-balanced mixer.

Conclusion

The high level double-balanced mixer used here shows a wide bandwidth with minimum conversion loss variation across the 2 - 4 GHz frequency range, near 50 ohm IF output impedance, and a spurious-free dynamic range. Its channelizer applications illustrate the advantages of wide broadband operation, equivalent performance to discrete mixer configurations, smaller size and capability of being integrated with existing microstrip technology. All of these improvements are important to today's advanced microwave systems.

Author

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Ferenc (Frank) A. Marki received his B. S. at the University of California. He became a member of the W-J technical staff in 1972, and is currently responsible for the R & D of double-balanced MIC mixers of the Solid State Division. He has designed and developed the WJ-M12, M12A and M19 mixers that cover C-, X- and Ku-band, the WJ-M15 to M18, and the M21 to M24 Flatpack mixers that cover 2.5 - 18.5 GHz in octave bands. Mr. Marki is a member of the IEEE.

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4. Marki, F. A., "Broadband Microwave Mixers Incorporate Balanced-Line Hybrid," originated at the Watkins-Johnson Company, July 1974.
5. Neuf, D., D. Brown and B. Jaracz: "Multi-Octave Double-Balanced Mixer," Microwave Journal, pp 13-14, January 1973.

Clarification of the March 1974 issue of Tech-notes, Part Two.

On page 10 it is stated that a well-designed low power TWT amplifier is capable of reliable operation of 50,000 hours. This applies only to high reliability amplifiers used in orbiting satellites and other space applications in which special screening of power supply parts and processing of the tube eliminate premature wear-outs. Typical lower-cost production catalog items do not have high reliability (selected and screened) power supply parts or extended TWT burn-in and processing. Therefore, both cathode wear out and power supply failures occur in much less time, of the order of 10,000 hours. Warranty for these types of amplifiers is usually one year.

The 60,000 hour MTBF is a statistical prediction based on a room temperature life test of 27 X-Band PPM tubes. All units operated successfully in excess of a required 2,000 hours in a terminated life test.

It was also stated that life times of 70,000 hours can be achieved when dispenser cathodes are operated at 1000°C at 2 amps per cm^2. It was not stated that these types of cathodes are in the developmental stage. Typical production units employ dispenser cathodes operating in the temperature range of 1050°C to 1100°C. This higher operating temperature limits the tube life to approximately 10,000 hours.