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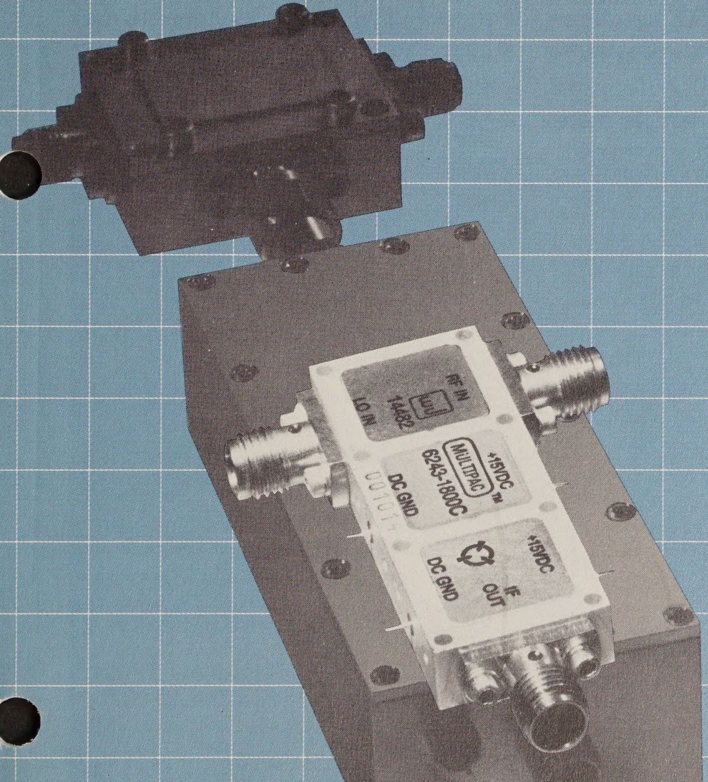
Integrated Mixer-Preamplifiers



WATKINS-JOHNSON COMPANY Tech-notes

System design engineers are finding it increasingly advantageous to use integrated mixer-preamplifiers rather than discrete mixers and amplifiers in microwave systems. Integrating the mixer and amplifier chain into one supercomponent allows for significant performance improvements, reductions in size, parts count and interconnects, as well as improving EMC (electromagnetic compatibility) performance and allowing the system designer to write only one specification drawing instead of many. Mixer-preamplifiers are available in many configurations and packaging schemes. The most common are those comprising a mixer as the first stage, with an IF amplifier following the mixer. Other combinations include: LO buffer amplifier/ mixer/IF amplifier, rf amplifier/ mixer/IF amplifier.

For the purposes of this article, mixer-preamplifiers are defined as comprising a mixer and IF amplifier chain integrated at the substrate level into a single package. Integrating devices at the substrate level into an MIC-compatible package offers all the above advantages, but sometimes at a higher price and longer delivery time than for discrete components integrated into a conventional aluminum enclosure. However, recent efforts have been made to reduce costs and delivery times for MIC-packaged supercomponents by standarizing packaging, documentation, and manufacturing processes [1].

Downconverters

Mixer-preamplifiers are generally used for downconverting applications, where the principle performance parameters are frequency range, noise figure, intermodulation suppression, VSWR, gain flatness and dc power consumption. The bandwidth performance of the mixer should not significantly exceed the actual frequency range required by the particular application in order to avoid unnecessary ripple in the gain response. This is discussed further in the section on gain ripple. Also, the conversion loss of the mixer and the noise figure of the IF amplifier must be minimized, while at the same time maximizing their ability to suppress unwanted intermodulation products. Minimizing noise figure and maximizing intermodulation suppression are conflicting goals that must be traded off to achieve the best overall performance. Parameters, such as VSWR and gain flatness can be optimized for integrated mixer-preamplifiers by alignment of the amplifier while it is operational with the mixer. In addition to rf alignment, the amplifier can be dc-aligned to optimize the trade-offs among dc power consumption, conversion gain and output power. The use of a tuned amplifier in place of a resistive feedback amplifier will also make more efficient use of dc power for either integrated or discrete mixer-preamplifier combinations.

Up-Converters

Mixer-preamplifiers may be used to convert a low-frequency input signal into a higher-frequency output signal. The IF input port of the mixer is driven by the low-frequency input signal, and the mixer R- or L-port is driven by the high-frequency carrier signal. The up-converted output signal is taken from the remaining L- or R-port. Usually, the low-frequency input signal is at the high level; i.e., the LO, in order to minimize the price of the required gain blocks. This allows for excellent carrier suppression, but can result in unacceptable suppression of the 1 X 3 intermodulation product, where the 1 and 3 are the coefficients of the high- and low-frequency input signals, respectively. The trade-off of having the low-frequency versus the high-frequency input signal be the LO has been explored in detail for the case where an image-reject mixer is used as a single-sideband up-converter [2].

Mixer With LO Buffer Amplifier

Whether up- or downconverting, a buffer amplifier for the LO input is often integrated with the mixer. Generally, this is desirable when high levels of LO power are required in conjunction with a high-level mixer to maximize intermodulation suppression. An example of this type of integrated mixer-amplifier is shown in Figure 1.

Technical Trade-Offs

Various performance parameters are especially important to consider when comparing integrated versus discrete mixer-preamplifiers. These include LO feed-through, VSWR, gain ripple, gain flatness, and noise figure.

LO Feed-Through

LO feed-through to the mixer R- and I-ports can pose a significant problem. Normal L-to-I isolation levels range from 20 dB to 45 dB; these, in conjunction with IF gain on the order of 20 to 50 dB, can allow LO feed-through to compress the IF amplifier chain. Also, at the mixer I-port, the LO feed-through can have the same or higher power than the desired IF output. This is especially prevalent in broadband mixer-preamplifiers with overlapping LO and IF bandwidths. Little can be done, in this case, to suppress the unwanted feed-through, unless a tracking filter is placed between the mixer and IF amplifier. When the LO frequency is within the IF bandwidth, conversion gain of the mixer-preamplifier

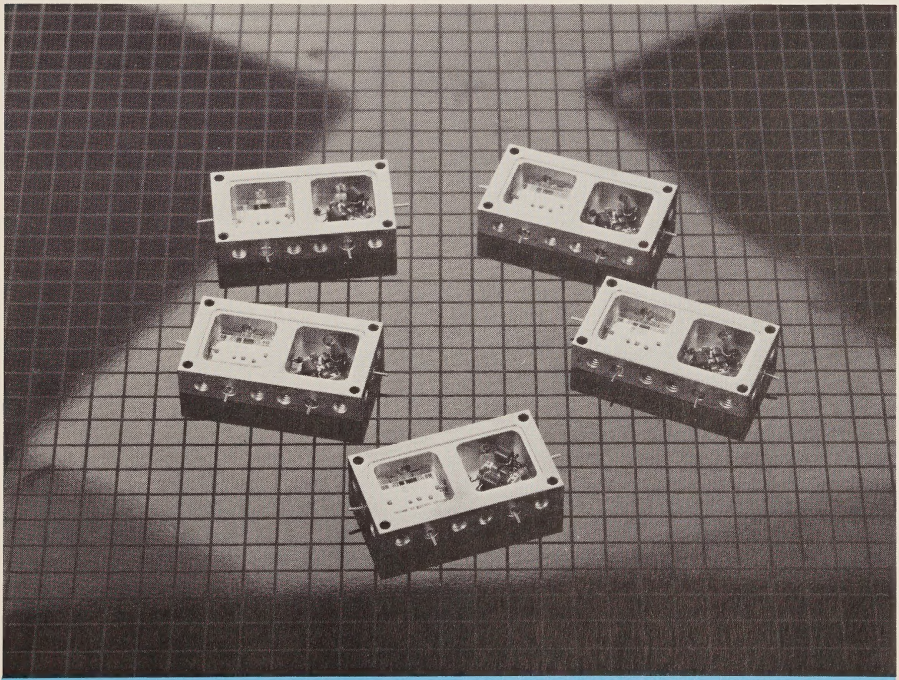


Figure 1. These WJ-6242-2001 MULTIPAC™ mixer-amplifiers consist of a WJ-PA48 GaAs FET (LO buffer) power amplifier and a WJ-M9H high-level rf mixer.

should be measured using a spectrum analyzer to correctly identify the actual power of the IF output signal.

VSWR

Voltage standing wave ratio (VSWR) is the measure of impedance mismatch that a device presents to an intrinsic impedance, normally 50 ohms. VSWR is defined at $(1+|\Gamma|)/(1-|\Gamma|)$, where $|\Gamma|$ is the magnitude of the reflection coefficient at the appropriate port. Mixer R- and L-port VSWRs are generally similar and can range from 2.0:1 to 3.5:1, while I-port VSWR is generally less than 2.0:1. Amplifier VSWR is generally less than 2.0:1 at both input and output ports.

Several options exist to improve mixer R- or L-port VSWR; the particular one used depends on the application. One method is to place an isolator in front of the appropriate mixer port. This method is limited by the bandwidth of the isolator, which is usually an octave or less. An isolator, placed at the mixer R-port, will slightly increase conversion loss and noise figure, but will greatly improve VSWR and can help improve intermodulation suppression. For frequencies below about 4 GHz, isolators can increase in size so as to offset the size reductions gained by integrating them with the mixer.

Another means of improving R-port VSWR is to place an amplifier in front of the mixer R-port. This method also improves noise figure, but can reduce the overall third-order intercept point because the contribution that the amplifier makes to the overall output intercept point will be reduced by the conversion loss of the mixer. Similarly, an LO driver amplifier can be integrated with the mixer to reduce L-port VSWR, and increase the LO drive to the mixer. This approach will also help decrease the power requirements for the rest of the LO amplifier chain.

Another method to improve L-port VSWR is to place an attenuator pad at the L-port. Attenuator pads are very broadband and, thus, do not limit the L-port bandwidth. The trade-off is that more LO drive power is required to compensate for the loss in the attenuator, which can be very costly in high-level or microwave-mixer applications. An attenuator pad is almost never used at the R-port because it increases noise figure by the amount of the attenuation.

Improving IF VSWR

The industry standard for in-band amplifier VSWR is 2.0:1, while mixer I-port VSWR can be as great as 3.0:1. This means, for example, that the mixer output impedance can be as low as 16.5 ohms, while the amplifier input impedance can be as great as 100 ohms. This mismatch between the mixer and amplifier can increase amplifier output VSWR. If the amplifier is treated as a two-port device, as shown in Figure 2, the output match of the

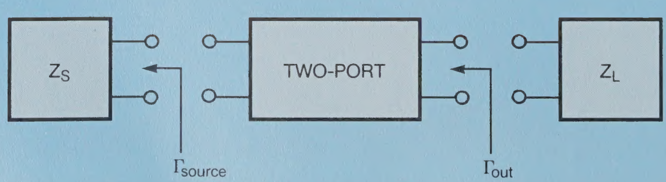


Figure 2. Block diagram defining Γ_{out} and Γ_{source}.

amplifier is related to its input match by equation (1) [3]:

$$\Gamma_{out} = S_{22} + ((S_{12} \times S_{21} \times \Gamma_{source})/(1 - (S_{11} \times \Gamma_{source}))) \qquad (1)$$

As shown in Figure 2, Γ_{out} is the reflection coefficient looking into the output of the amplifer and Γ_{source} is the reflection coefficient looking back at the source from the amplifier input. In the case of a mixer-preamplifier cascade, the source impedance would be the I-port impedance of the mixer. The S-parameters are the normal two-port S-parameters measured with a 50-ohm termination at the appropriate port. Thus, it can be seen that when Γ_{source} is anything but zero (a perfect 50-ohm source), Γ_{out} will degrade from its value of S_{22}. This is true for a mixer or any non 50-ohm source impedance placed at its input. Also, the amplifier should be selected to have low S_{11} and low S_{12}, in order to minimize degradation of Γ_{out}. S_{21} should be minimized, but its value is usually dictated by the particular application. With discrete components, the sealed amplifier cannot be tuned to compensate for this degradation. However, if the mixer and amplifier are integrated at the substrate level, the amplifier output VSWR can

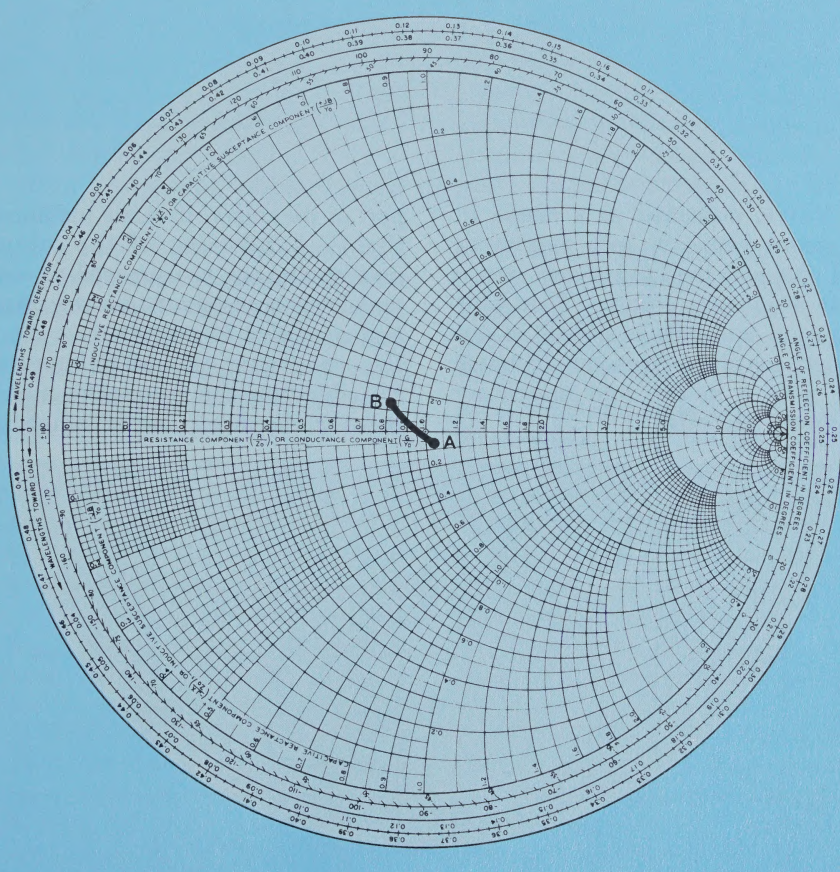


Figure 3. I-port VSWR of the WJ-M2T mixer with a constant IF frequency of 200 MHz and a swept LO frequency of from 100 MHz (A) to 2400 MHz (B).

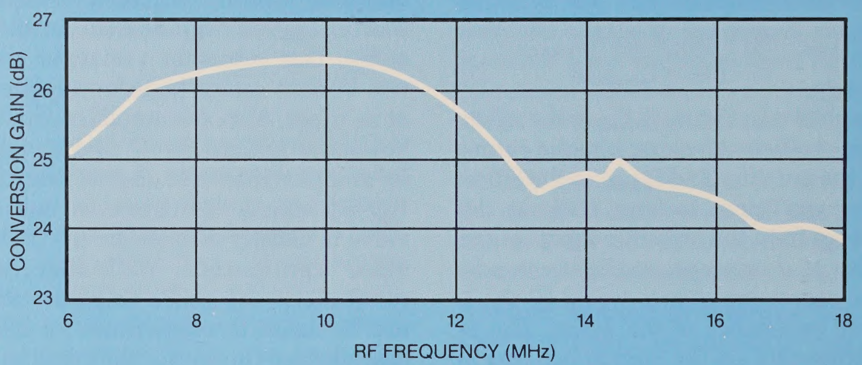


Figure 4. Conversion gain vs. rf frequency of a discrete WJ-M86 microwave mixer cascaded with WJ-EA53 and WJ-EA7 IF amplifiers. (RF: 6 to 18 GHz, IF: 200 MHz, LO @ +10 dBm)

be improved by aligning the amplifier while it and the mixer are operational.

One aspect of I-port mixer VSWR that is not generally considered is the effect that sweeping the LO frequency has on IF VSWR. Figure 3 illustrates that the IF VSWR measured at a single IF frequency varies in both magnitude and phase as the LO is swept over a wide frequency range. This phenomenon can make it difficult to cascade even a single-frequency IF amplifier with a mixer, and match for minimum noise figure.

Gain Flatness

Another parameter that can be optimized is gain flatness when either the rf or IF signals are swept. Gain flatness of the IF amplifier can be adjusted to compensate for gain roll-off in the I-port of the mixer. In some instances, the IF bandwidth of the mixer-preamplifier can be increased, as compared to the cascade of a discrete mixer and amplifier. Flatness across the rf frequency range can also be improved by adjusting the interstage match between the mixer and IF amplifier.

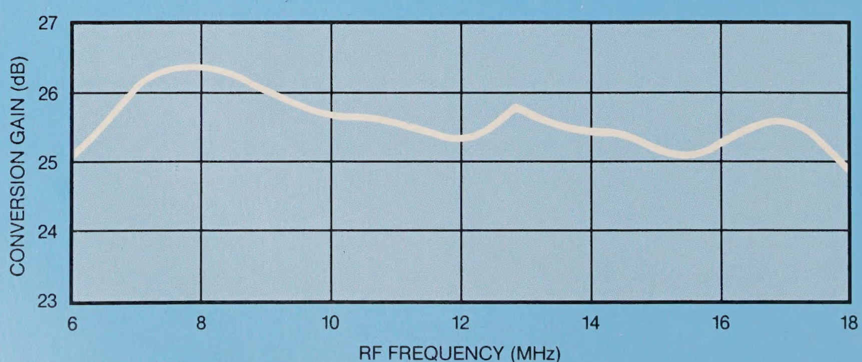


Figure 5. Conversion gain vs. rf frequency of a WJ-6242-1702 MULTIPAC™ mixer-preamplifier, composed of a WJ-M86, WJ-EA53 and WJ-EA7. (RF: 6 to 18 Ghz, IF: 200 MHz, LO @ +10 dBm)

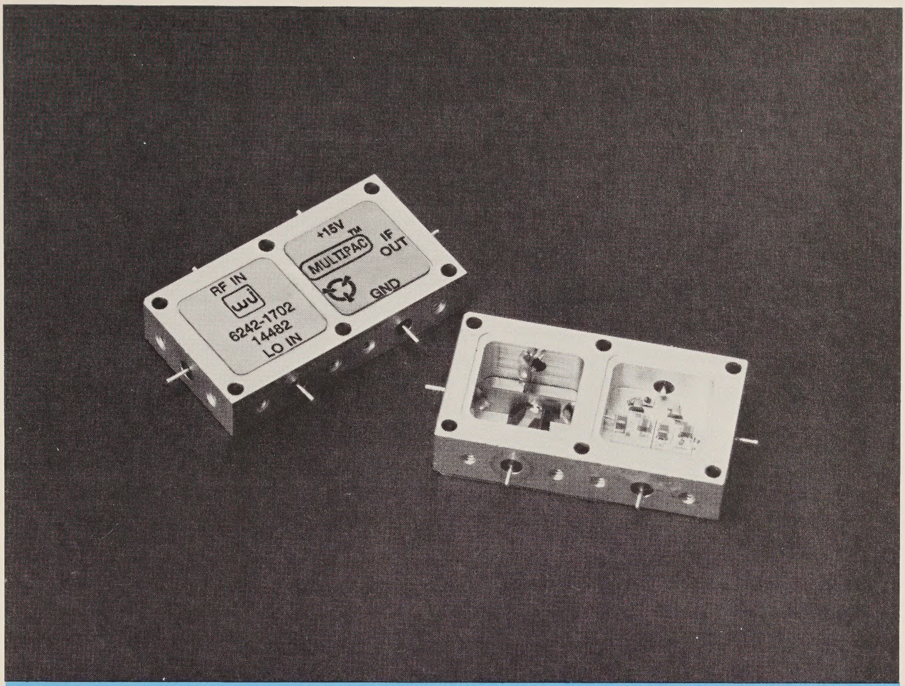


Figure 6. The WJ-6242-1702 MULTIPAC™ mixer-preamplifier.

Figures 4 and 5 show one example of how gain flatness compares for discrete and integrated mixer-preamplifiers, respectively. The conversion gain flatness shown in Figure 5 is for the integrated mixer-preamplifier shown in Figure 6.

Gain Ripple

Another problem caused by the mismatch between discrete mixers and amplifiers is ripple in the gain response. This phenomenon is most apparent when a length of cable is used to connect the two components. When a mixer is used as a downconverter, the desired IF frequency, Fi, equals Fr–Fl or Fl–Fr, and is sometimes referred to as the *difference product*. In upconverting applications, the desired IF frequency equals Fr+Fl, and is sometimes referred to as the *sum product*. The mixer will generate both the difference and sum products, and if the bandwidth of the mixer I-port is broad enough to allow both products to exit, ripple will often be present in the gain response. Ripple can also be caused by the rf signal leaking out of the I-port.

All of these signals become incident at the amplifier, after having traversed the cable interconnecting the mixer and amplifier. The sum product and rf feed-through signals are reflected back to the mixer due to the non 50-ohm input impedance that the amplifier usually exhibits at these frequencies. The fixed length of cable causes the phase angle of the reflected signals to vary proportionately with frequency so that the reflected signals will remix to increase conversion loss at some frequencies and decrease it at others, producing ripple in the overall gain response. When the rf and LO input signals are swept over a broad bandwidth so as to maintain a constant IF (difference) frequency, ripple and a

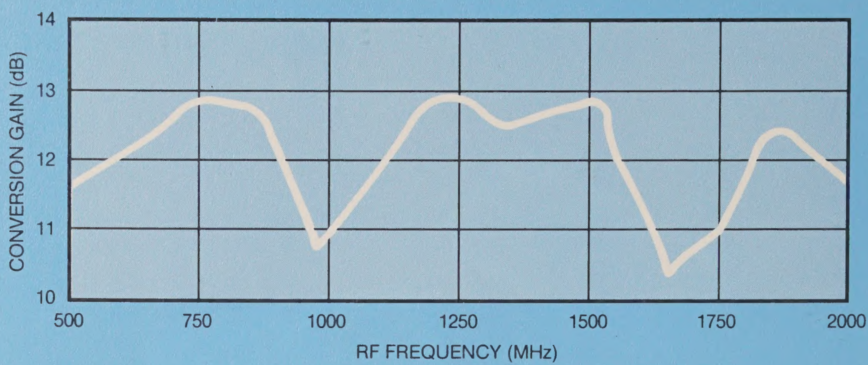


Figure 7. Conversion gain vs. rf frequency of a WJ-M2T mixer cascaded with a WJ-A75 amplifier. Approximately 0.75 in. of SMA connectors separate the two devices. (RF: 500 to 2000 MHz, IF: 200 MHz, LO @ +10 dBm)

constant offset in the conversion-loss response can result, depending on the load conditions that the IF amplifier presents at the sum, rf, and difference frequencies. The ripple in the conversion-loss response is caused by the reflected sum product and rf signals remixing. The constant offset in average conversion loss is caused by the remixing of the reflected difference product, which is kept at a constant frequency. Figure 7 illustrates that ripple is present in the conversion-gain response of a discrete rf mixer and amplifier when the two are mounted in housings, and connected by an SMA male-to-male connector with an interconnect length of approximately 0.75 inches. As the interstage connection is lengthened, the phase of the sum product and rf signals change more rapidly with respect to frequency and, hence, the periodicity of the ripple increases, as in Figure 8. By bringing the mixer and amplifier as close together as possible, as with the integrated mixer-preamplifier of Figure 9, the severity of the ripple can be minimized as shown

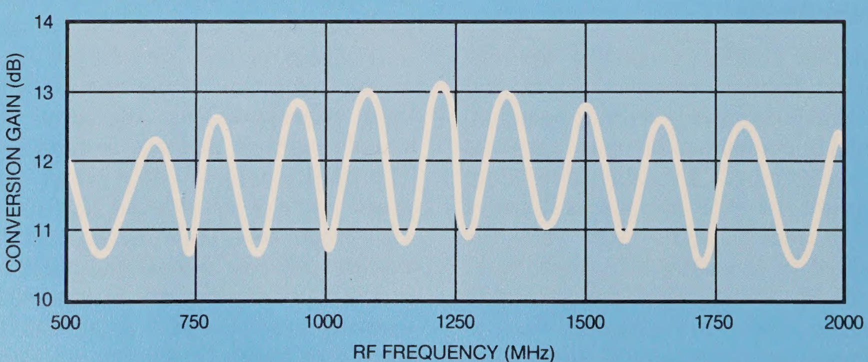


Figure 8. Conversion gain vs. rf frequency of a WJ-M2T mixer cascaded with a WJ-A75 amplifier. A 6-inch semirigid cable separates the two devices. (RF: 500 to 2000 MHz, IF: 200 MHz, LO @ +10 dBm)

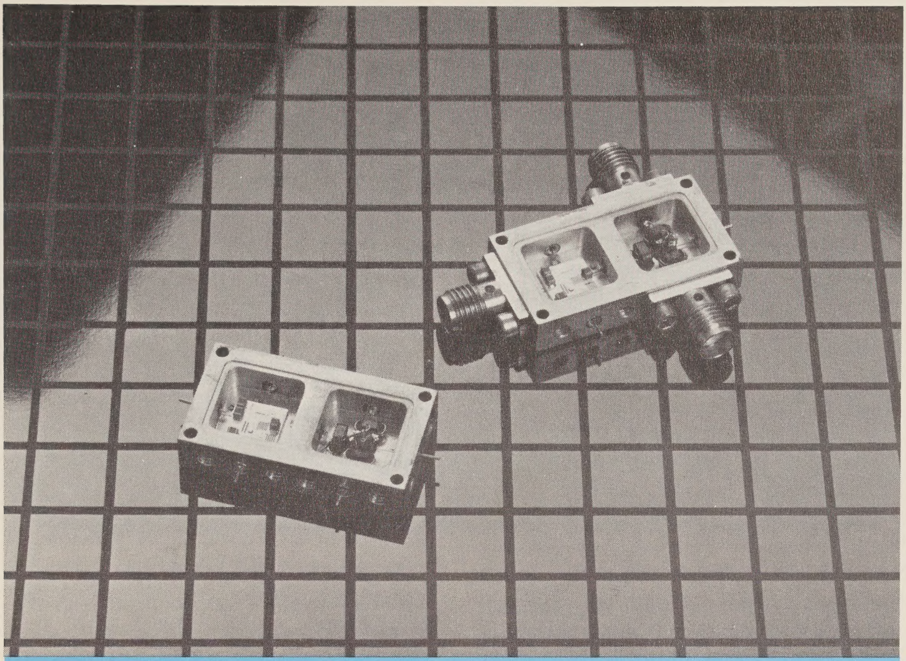


Figure 9. The WJ-6242-1005 MULTIPAC™ mixer-preamplifier. It consists of a WJ-M2T rf mixer and a WJ-A75 low-noise IF amplifier.

in Figure 11.

Ripple is reduced in integrated mixer-preamplifiers due to the close proximity of the mixer and amplifier. It can also be reduced by tuning the input matching circuit of the IF amplifier to minimize reflections of the sum product and rf signals. A comparison of gain ripple before and after this has been done is given in Figures 10 and 11. Ripple can also be reduced by placing a diplexer filter between the mixer and the amplifier to resistively terminate undesired signals leaking out of the mixer I-port. This approach is limited to applications where the rf and sum products are far enough apart in frequency from the difference product that a simple filter having minimal insertion loss can be used.

The most important contributors to conversion-gain ripple are the sum product (because it contains the same amount of power as the desired difference product) and the rf leakage signal. (This is true, as long as the mixer I-port bandwidth will let the sum product and rf leakage signals exit the mixer.) The reflected LO feedthrough signal has a negligible effect on ripple because it produces varying levels of dc when it remixes with the LO in the mixer.

Noise Figure

Two main options exist for minimizing the noise figure of a mixer-preamplifier. One option, if the IF bandwidth is narrow (approximately 10 percent or less), is the use of a tuned amplifier. Low-noise tuned amplifiers, newly available from Watkins-Johnson Company, can be aligned to have center frequencies ranging from 150 to 1200 MHz, with 1-dB bandwidths of approximately ten percent. They can also be integrated at the substrate level with a mixer, or cascaded to obtain more gain. A tuned amplifier offers

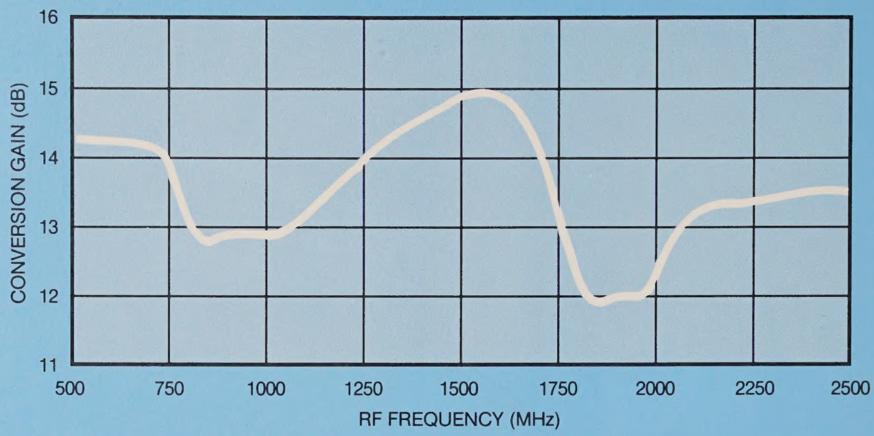


Figure 10. Conversion gain vs. rf frequency of a WJ-6242-1005 before alignment of the amplifier input matching circuitry. (RF: 500 to 2500 MHz, IF: 100 MHz, LO @ +13 dBm)

several advantages over wideband feedback amplifiers, one of which is reduced spurious responses appearing in the IF amplifier chain, since a tuned amplifier is essentially an amplifier and bandpass filter all-in-one. Other benefits over resistive feedback amplifiers include lower noise figure and lower dc power consumption, for comparable output power. Care must be taken to make certain that the tuned amplifier is unconditionally stable because mixer I-port VSWRs can vary widely. A performance comparison of a discrete microwave mixer cascaded with a discrete resistive feedback amplifier, versus the same mixer cascaded with a tuned amplifier is given in Table 1. Use of the tuned amplifier in place of the feedback amplifier allows for 1-dB lower noise figure and less than half the dc power dissipation, without sacrificing output power.

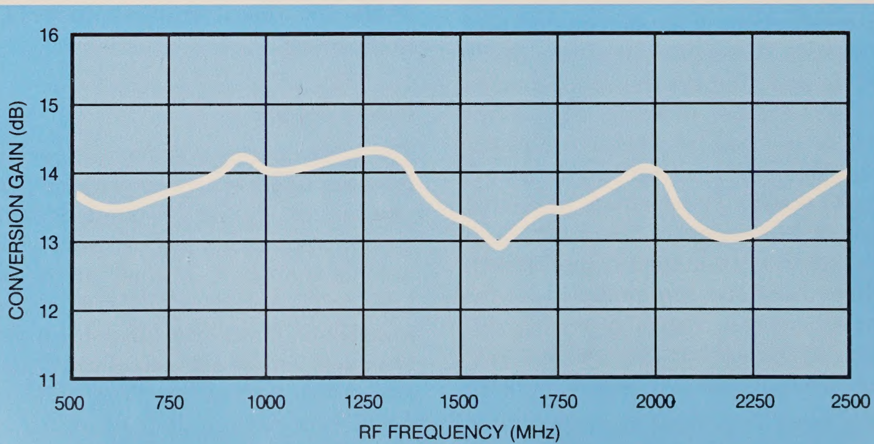


Figure 11. Conversion gain vs. rf frequency for a WJ-6242-1005 MULTIPAC™ mixer-preamplifier after alignment of the amplifier input matching circuitry. (RF: 500 to 2500 MHz, IF: 100 MHz, LO @ +13 dBm)

Characteristic	WJ-M86/ WJ-A75	WJ-M86/ WJ-TA025-000
DC Current (@ +15 volts)	23 mA	10 mA
Noise Figure	8.3 dB	7.3 dB
Power Output (1-dB compression)	8.5 dBm	8.5 dBm
Frequency		
RF	10.00 GHz	10.00 GHz
LO (@ +10 dBm)	10.25 GHz	10.25 GHz
IF	250 MHz	250 MHz

Table 1. Mixer-preamplifier comparison.

Another option to reduce the overall noise figure of a mixer-preamplifier is to tune the amplifier input matching structure so that the load presented by the mixer I-port impedance represents a minimum noise-figure match. This approach has been found to only work for narrow LO and IF bandwidths and only with certain amplifier models. One side-effect is that gain ripple can increase as the amplifier is tuned for a better noise match, because optimum noise match is different from the optimum match for gain.

Intercept Point And Noise Figure

Intercept point is the measure of single- or two-tone intermodulation suppression [4], and is normally referenced to the input power level for mixers, and to the output power level for amplifiers. For mixer-preamplifiers, it should be referenced to the output power level due to the conversion gain, but in practice it may be referenced to either the input or output power level, so care must be taken when specifying it. It can be seen from equation (2) that the cascaded third-order output two-tone intercept point is maximum when all the gain is placed after the mixer.

$$IP3_{total}\,(dB) = -10 \log \left(\frac{1}{g_2 \times ip3_1} + \frac{1}{ip3_2} \right) \qquad (2)$$

where: IP3 is output third-order two-tone intercept point.

$$ip = 10 \exp((IP_{(dB)})/10)$$
$$g = 10 \exp((G_{(dB)})/10)$$

This conflicts with the necessity of placing all the gain before the mixer to minimize noise figure. The well known formula for cascaded noise figure is given in equation (3).

$$F_{total}\,(dB) = 10 \log \left(f_1 + \frac{f_2 - 1}{g_1} \right) \qquad (3)$$

f_1 = numerical noise figure of device 1
g_1 = numerical gain of device 1
f_2 = numerical noise figure of device 2

where:

$$f = 10 \exp((F_{(dB)})/10)$$

The best means of achieving optimum intercept point and noise-figure performance is to place a medium-level, low-conversion-loss mixer in front of a low-noise, high-intercept point IF amplifier chain. In addition, placement of a low-noise, high-intercept point rf or microwave amplifier ahead of the mixer can further reduce noise figure. Care must be taken to minimize the bandwidth of this amplifier in order to minimize its noise contribution.

Risk Factors

Various elements of risk must be considered when deciding between integrated or discrete components. These usually pertain to electrical performance, delivery time and design flexibility. As shown in this article, electrical performance is almost always enhanced by integrating devices at the substrate level. For the case of the mixer-preamplifier, the amplifier can be aligned to optimize the overall performance of the device. Delivery time is often a concern, since integrated devices generally are customized and, thus, can take longer to produce than simply using discrete components available from stock. This is a valid concern, especially when prototypes are needed for a quick breadboard design. However, customized devices are often required for these applications anyway, so integrating the optimized devices at the substrate level into standard housings, such as the W-J MULTIPAC™, may not significantly increase delivery time over that for discrete components. In fact, delivery time may be reduced, along with price, when using integrated mixer-preamplifiers, because discrete components must still be integrated into a top-level housing.

Design flexibility is also a concern because the system designer can lose control over the topology of the blocks in his system. If too many devices are packaged together, he is more limited in his ability to make system improvements. The solution to this potential problem is to keep the integrated devices limited to the key blocks that are normally adjacent, such as mixer/IF amplifier or LO buffer/mixer/IF amplifier. This approach provides all the benefits of component integration without limiting future design changes. Usage of integrated components may also simplify the design of other new systems by using the very same generic mixer-preamplifiers in the new system instead of having to design and qualify a new component.

Size And Weight Reduction

An important consideration for many systems is size and weight, especially for airborne and satellite applications. Usage of integrated components, including mixer-preamplifiers, allows for significant reductions in size and weight. For example, a three-stage MULTIPAC™ component weighs approximately 25 grams, compared to the weight of a comparable aluminum-box device that can weigh on the order of 50 grams. In addition to having less than half the weight, the volume required by a three-stage MULTIPAC™ component can be on the order of one third or less than that of discrete devices in an aluminum enclosure.

Examples of integrated mixer-preamplifiers having reduced size and weight relative to discrete units include the miniature rf mixer-preamplifier shown in Figure 12 and the microwave mixer-preamplifiers shown in Figures 13 and 14.

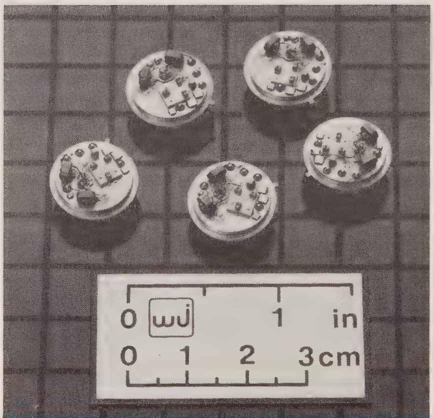


Figure 12. The WJ-6242-1110 TO-8B mixer-preamplifier covers the 0.2 to 2.0 GHz frequency range with at least 23 dB of conversion gain.

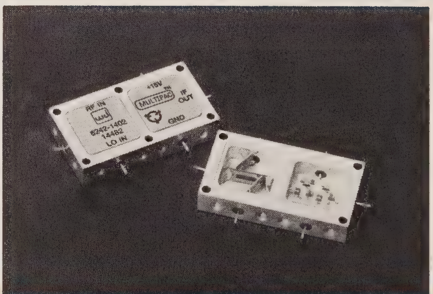


Figure 13. The WJ-6242-1402 MULTIPAC™ mixer-preamplifier covers the 2.0 to 6.0 GHz frequency range with at least 23 dB of conversion gain.

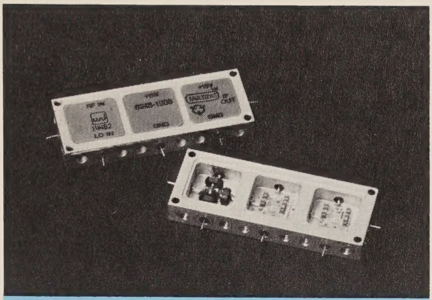


Figure 14. The WJ-6243-1206 MULTIPAC™ mixer-preamplifier covers the 0.05 to 3.0 GHz frequency range with at least 18 dB of conversion gain. The mixer is the Class IV M4T.

Summary

Integrated mixer-preamplifiers offer many advantages over discrete mixers and amplifiers, including improved electrical performance, reduced size and weight, reduced parts count, fewer interconnects, and the generation of only one specification drawing instead of many. The important improvements in electrical performance include reduced conversion gain ripple, optimized efficiency, lower VSWR and an optimized trade-off between noise figure and intercept point. The important aspects of risk, when comparing discrete versus integrated components, are electrical performance, delivery time and design flexibility. These elements of risk are minimized when standard mixers and amplifiers are integrated into standard MIC-compatible packages.

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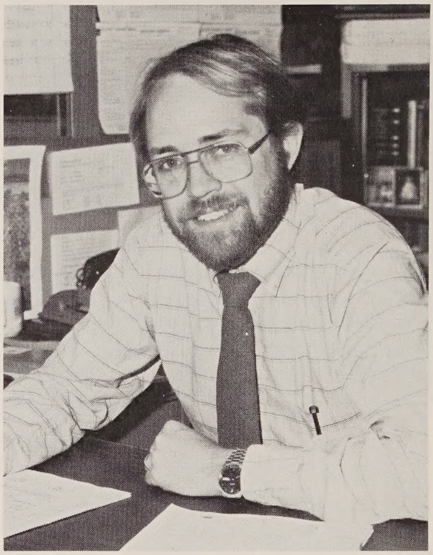

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Mr. Henderson is Head of the Special Products Section of the Cascadable Amplifier Department, Components Division. He is responsible for development engineering, production engineering, production test and program management for all component integration and cascaded amplifier products. He generated the initial business plan for the new component integration product lines, and is responsible for profit and loss, as well as meeting booked orders and shipment plans for both component integration and cascaded amplifiers. The component integration product lines include mixer-preamplifiers, AGC amplifiers (open-and close-loop), cascaded limiting amplifiers, active frequency doublers and IF amplifiers. Cascaded amplifier products comprise discrete amplifiers, attenuators and limiters cascaded together in aluminum enclosures.

Mr. Henderson has also served as Head of the Engineering Section of the Cascadable Amplifier Department, where he was in charge of development engineering, production engineering, and production test for the Cascadable Amplifier Department's product line of over 140 different signal processing components.

Mr. Henderson has also held the position of Head, Development Engineering Section, Mixer Department, where he was responsible for the design and development of over forty new frequency conversion and control products that range in frequency from 10 kHz to 40 GHz. These products include mixers, frequency doublers, microwave switches, transformers and hybrids.

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