HIGH PERFORMANCE TRANSMITTER COMBINERS AND RECEIVER MULTICOUPLERS TO ENCHANCE CHANNEL CAPACITY AND COVERAGE

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In the growing wireless industry, service providers are constantly looking for methods to improve signal clarity and coverage. Two noticeable solutions that are implemented nowadays are licensing of new operators and cell splitting on existing networks. This in turn demands installation of new towers to provide coverage in dense residential and urban location, which becomes expensive proposition and has to overcome community resistance. Moreover, co-location of new carriers presents serious problems in interference and intermodulation products.

Design engineers are constantly looking for techniques that will aid in increasing capacity and coverage of the existing base station structure. Expansion racks are now being designed that would add to existing base station more number of channels by adding more radio transmitters and receivers when the demand arises. Reliability of other devices viz., transmitter combiners and receiver multicouplers that goes on these expansion racks are expected to be significantly higher than the ones that go on the primary because of environment not being optimum. Moreover, there is a demand for these devices to be highly flexible in terms of its configuration layout so as to satisfy any custom requirement in terms of electrical and or mechanical characteristics. Other factors like ease of transportation and net weight of the expansion racks are now becoming stringent for cost optimization purposes.

Keeping the above design constraints in mind, Renaissance Electronics Corporation (REC) located in Harvard, MA has developed two state-of-the-art AMPS devices that are highly reliable and extremely flexible to adapt any custom configuration requirement:

- **AMPS Band Dual 4-way Transmitter Combiner** is designed for urban microcell applications and combines 8 radio signals into 2 outputs. It consists of dual 4-way, low loss Wilkinson combiners with dual junction isolators on all input ports for isolation of 70 dB minimum between ports. The combiner’s case temperature maintains at less than 38°C (97°F), with all channels simultaneously activated with 70 watts of continuous input power thereby significantly enhancing the reliability of the device. Versatility of this design is displayed in the number of ways it can be configured for different combination of number of inputs and outputs. Details on this product are presented in SECTION I.
- **AMPS Band 3 x 6 Receiver Multicoupler** that splits three antenna signals into 18 channels with a selectable gain of either 2dB or 4dB. Front end LNA on each antenna port provides low noise figure of less than 2.5 dB along with high P1dB of 15 dBm and high 3rd ordewr intercept of 40 dBm. Each LNA feeds into a power divider that distribute equal amplitude signals to each of 6 separate receivers. The design incorporates a redundant power supply for continuos operation and has wiring alarm for Motorola’s GEN-4 rack system. Height of this device is only 1RU, which helps in conserving space on the rack. Other details on this product are presented in SECTION II.

SECTION I Transmitter Combiners

Transmitter combiners play a key role in present wireless communication systems as they combine signals from various radios and feed the combined signal to one single antenna. It also provides necessary isolation between transmitters, which decreases any modulation interference. There are three types of transmitter combiners that are widely used, based on end applications: (1) Remote/Auto-tuned cavity, (2) cavity-ferrite, and (3) hybrid-ferrite. The advantages and disadvantages of the three designs are compared in Table 1.

TABLE 1
Comparison of a typical 800 MHz Auto-tuned, cavity-ferrite and hybrid-ferrite type combiner

Parameter	**4 channel Remote/Auto-Tuned cavity**	**4 channel Cavity-ferrite**	**Dual 4 channel Hybrid-ferrite**
Channel capacity (Channel separation)	200 kHz min	500 kHz min	25 kHz min.
Cost	$15,000	$8,000 (?)	$2,000
Height (1RU = 1.75")	4RU	9RU	2RU
Weight	59 lbs	61 lbs	22 lbs
Insertion loss	3.6 dB	3.5 dB	7.0 dB
Tx – Tx isolation	70 dB	90 dB	70 dB
Rx – Rx isolation	60 dB	70 dB	60 dB
Maximum tuning time	< 2 seconds	Return to factory	0 seconds
VSWR	1:25 : 1	1.25 : 1	1.20 : 1
3rd order intermod	100 dBc	100 dBc	110 dBc

Remote/Auto-tuned cavity combiners are very attractive because of their low insertion loss. They consist of tuned cavities, each microprocessor controlled for automatic frequency tuning, and isolators to provide isolation between the transmitters. The circuit senses the forward and reverse power of each channel and tunes the cavities, via an actuator, allowing the transmit frequency through while rejecting the unwanted. However, there are certain major trade-offs to this design approach: (1) the minimum channel separation is about 200 kHz, that limits capacity severely, (2) cost per unit is high and is typically around $15,000 depending on the options, (3) height is about 7" on a standard EIA 19" rack severely limiting options especially on expansion racks, and (4) there is a tuning time of about 2 seconds and this may not be desirable in certain voice/data links.

Cavity filters are just like Remote/Auto-tuned cavity combiners except that they lack the microprocessor control circuit. Thus, many cavities are required to cover the desired bandwidth and so the height for a standard EIA 19" rack configuration is as high as 16". Their weight is comparable to that of the Remote/Auto tuned and its difficult to carry them around from site to site. Also, the channel separation in such combiners is typically about 500 kHz to achieve good channel-to-channel isolation. Unlike Remote/Auto-tuned combiners, the cavity ferrite combiners usually have to be returned to the factory for expansion and re-optimization to insure proper long-term performance. Moreover, due to constant change in antenna and cable's VSWR due to ambient conditions (wind, rain, ice and exposure), such combiners require constant maintenance and often result in failure of connectors, cavities and isolators.

Hybrid-ferrite type combiners are preferred in systems that require channel spacing on the order of 30 kHz. These combiners display inherent channel combining at a minimum separation of 25 kHz. This property can be exploited to boost the channel capacity at base stations that serve heavy traffic regions. In comparison to the cavity combiners, hybrid combiners have the potential to enhance capacity by 10 times more. Table 2 shows the various standards and their minimum channel spacing. They have also two big advantages; being compact occupying a minimum of 2RU (3.5") on a standard EIA 19" rack, and being the most cost effective technology at the present time. Such combiners are also very light compared to cavity ferrite or auto-tuned combiners making them suitable for expansion racks that need to be transported from site to site for capacity reasons. The one single most important drawback that hybrids have is the high insertion loss of 3dB per branch. However, there is no substitute for a hybrid ferrite combiner for increasing capacity and coverage in a densely populated location with the least amount of capital expense. Moreover, they are inherently broadband, and, unlike Auto-tuned/cavity ferrite combiners, require no tuning for frequencies within specified bandwidth. Hybrid ferrite combiners thus fit all prerequisites for expansion racks used in base stations that need to boost their capacity at a reasonable price.

REC has developed an AMPS band hybrid transmitter combiner, model number 9A2NAA that has dual 4-way combiner on a standard EIA 19" footprint and is only 2RU high (Figure 1). It is targeted for usage in the expansion racks where space limitation is severe and reliability an important issue. The combiner can combine eight base radios into two outputs. Both the input and the output ports are on the same side of the combiner. This combiner is designed for use in urban microcell applications wherein antenna placement on adjacent sides of a structure can provide maximum coverage to that area. The insertion loss per 4-way is 7.0 dB maximum and is stable over –30 to +70°C. When all eight channels are connected to 70-watt transmitters, the total power dissipation thorough this combiner is 420 watts. After extensive thermal calculations, an integrated heat sink arrangement comprising of metal fins along with forced air cooling provided by four fans was developed to keep the entire temperature of the combiner at a minimum. The source of heat generation in these combiners is the Wilkinson balancing resistors and therefore areas around these resistors were carefully mapped when designing the chassis (metal base) to maximize heat dissipation. Special attention was given to the connector configuration to minimize heating effects around that region. The final case temperature of the combiner running at full capacity was less than 38°C or 97°F, which by far is, lowest reported in its class of hybrid combiners. This low operating temperature ensures optimum performance even in cases of air-conditioning failures at base stations improving reliability of the device. Dual junction isolators placed directly at each input port provides the required transmit-transmit and transmit-receive isolation of 70 and 55 dB respectively. The loads (terminations) on each junction of the isolator are rated for 100 watts and are in good thermal contact with the chassis of the combiner. This assures that in case the antenna port sees a short or open, the expensive transmitter is protected from reflection overload. This combiner was field tested for weeks and constantly monitored for any malfunctioning which it passed without any failure.

TABLE 2
Channel spacing for various standards

Type	Standard	Mobile Frequency range Rx (MHz)	Tx (MHz)	Channel spacing
Analog cellular Telephones	AMPS/NAMPS	869 – 894	824 – 849	AMPS : 30 kHz NAMPS : 10 kHz
	ETACS	916 - 949	871 – 904	25 kHz
	NTACS	860 - 870	915 – 925	12.5 kHz
	NMT-900	935 – 960	890 – 915	12.5 kHz
Digital Cellular Telephones	TDMA IS-54/IS-136	869 - 894	824 – 849	30 kHz
		1930 - 1990	1850 – 1910	
	CDMA IS-95	869 - 894	824 – 849	1250 kHz
	CDMA 2000Asia	2110 - 2170	1920 – 1980	
	GSM	869 - 894	824 – 849	200 kHz
		925 – 960	880 – 915	
		1805 – 1880	1710 – 1785	
		1930 - 1990	1850 – 1910	
	DCS	1805 - 1880	1710 – 1785	200 kHz
	PDC	810 - 826	940 – 956	25 kHz
		1429 - 1453	1477 – 1501	
Wireless data	WAN	869 – 894	824 – 849	30 kHz
	Bluetooth	2402-2480 (North America & Europe)		1 MHz
		2447-2473 (Spain)		
		2448-2482 (France)		
		2473-2495 (Japan)		
	IEEE 802.1b	2401-2462 (North America)		FHSS: 1 MHz DSSS: 25 MHz
		2412-2472 (Europe)		
		2483 (Japan)		
	IEEE 802.1a	5150-5250 (USA lower band)		OFDM: 20 MHz
		5250-5350 (USA middle band)		
		5725-5825 (USA upper band)		
	IEEE 802.15.4	2402-2480 (N. America)		4 MHz
		2412-2472 (Europe)		
		2483 (Japan)		

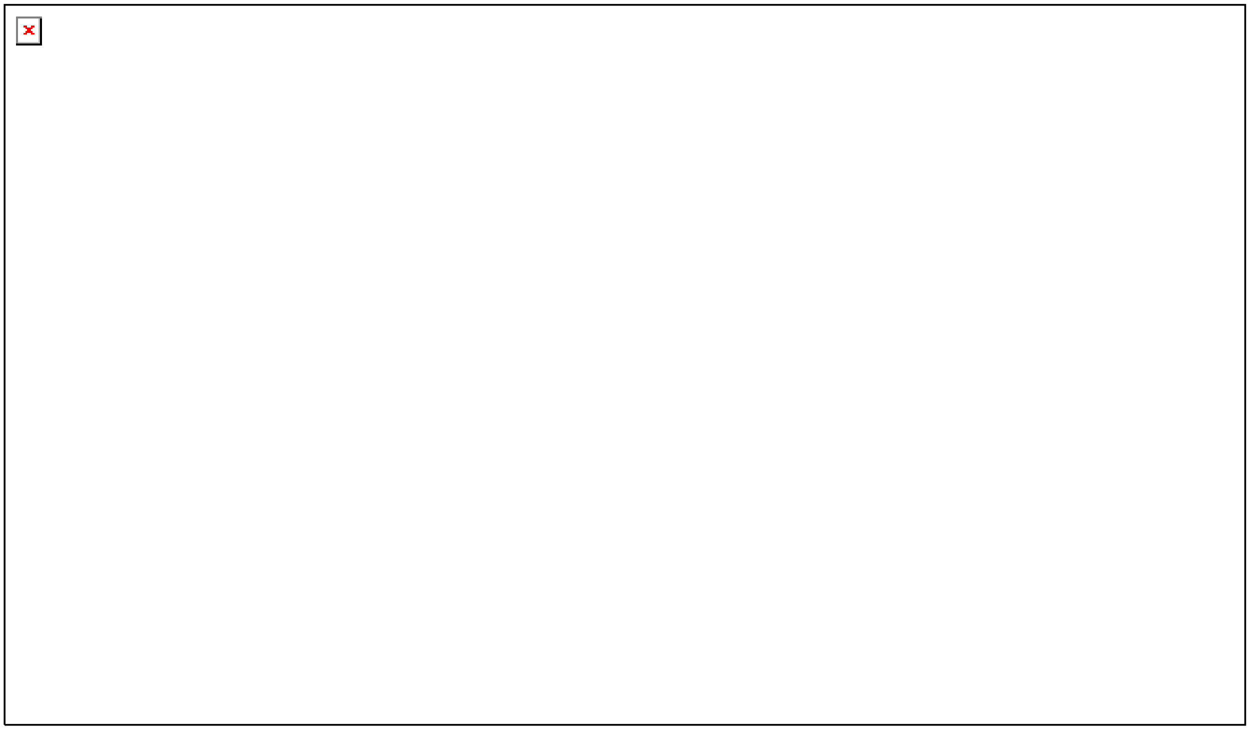

Figure 1. REC’s new AMPS band dual 4-way combiner 9A2NAA with integrated heat sink.

The S-parameter data on this combiner are shown in Figures 2 through 5. Due to its broadband design, the insertion loss is flat and close to 7.0 dB over entire bandwidth of 800 to 1000 MHz with less than ±0.1dB amplitude balance as shown in Figure 2. Unlike cavity-ferrite and Auto-tuned cavity combiners, the insertion loss does not change dramatically as the channels are spaced close to one another. There are three main contributing factors to the insertion loss: (1) theoretical 4-way Wilkinson loss of 6 dB, (2) insertion loss of the dual junction isolators which in this case is about 0.5 dB, and (3) loss of PCB and RF cables which amounts to 0.4 dB. Figure 3 and 4 show isolation of 55 dB minimum between antenna and transmitter and 70 dB minimum between transmitters ensuring good interference and intermodulation suppression over the operating bandwidth of 850 – 870 MHz. Figure 5 shows typical return loss of input (transmitter) port being more than 20 dB to ensure maximum power transmission. All S-parameters were stable over temperature range of –30 and 70°C.

Intermodulation data measured using standard two-tone measuring procedure with 70 watts incident on two of the transmitter ports is shown in Figure 6. The signal was measured after a 30 dB coupler and corrected for cable losses. The 3rd order intermodulation signal was measured to be less than –100 dBc. This low intermodulation assures the system noise to be low and does not interfere with the receive channels. Since the mixing of the tones does not occur till the first balancing resistor of the Wilkinson combiner, the non-linearity of the ferrite isolator does not come into play and affect intermodulation of the combiner. The balancing resistors were screened for non-linearities and power handling and then chosen for this design.

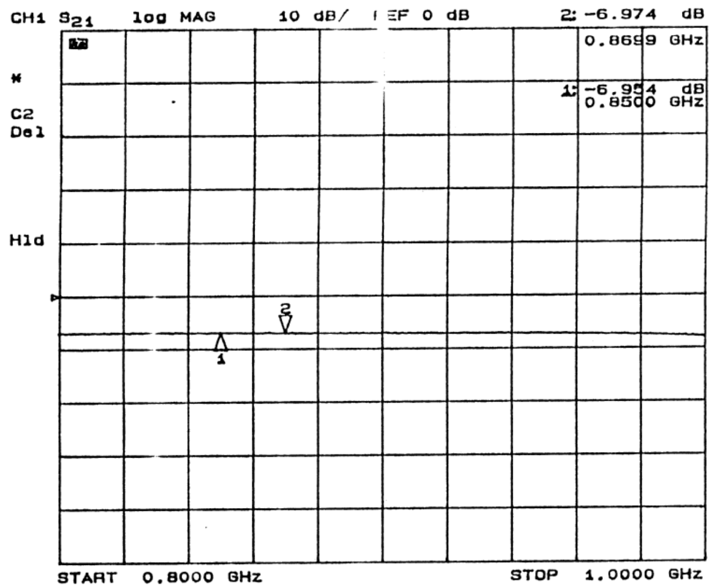

Figure 2. Insertion loss characteristic from Transmitter to Antenna port of 9A2NAA

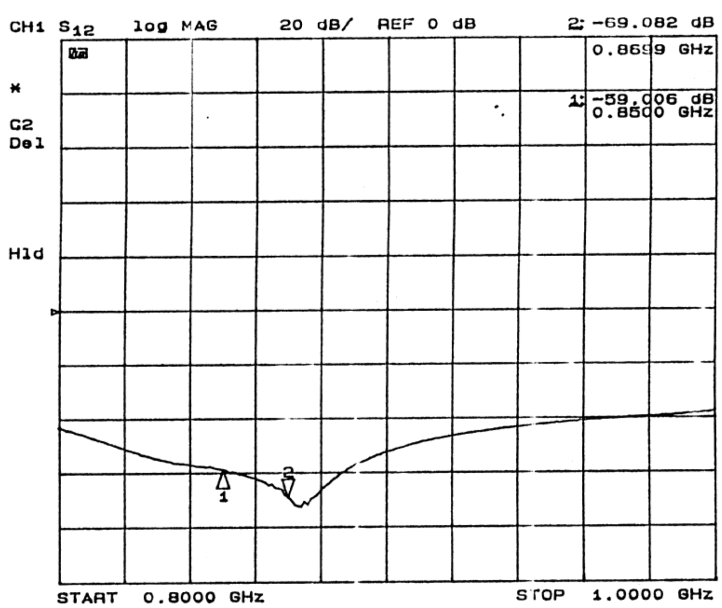

Figure 3. Isolation between Transmitter and Antenna of 9A2NAA

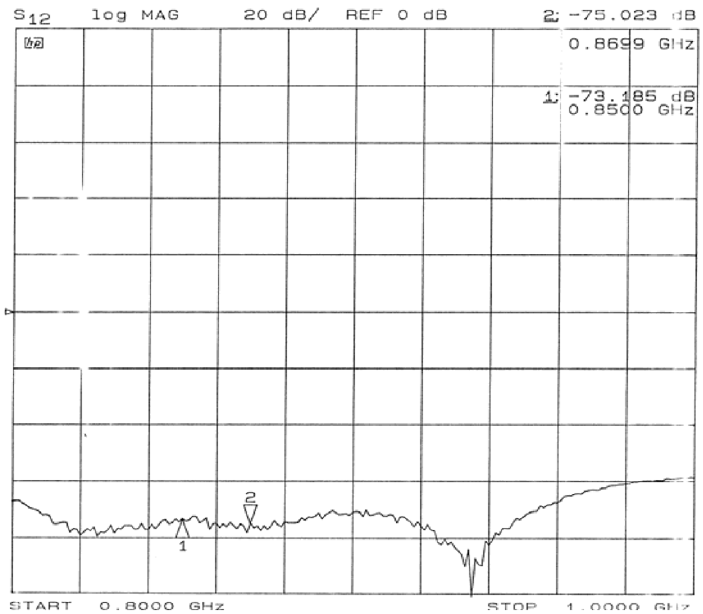

Figure 4. Transmitter-transmitter isolation response of 9A2NAA

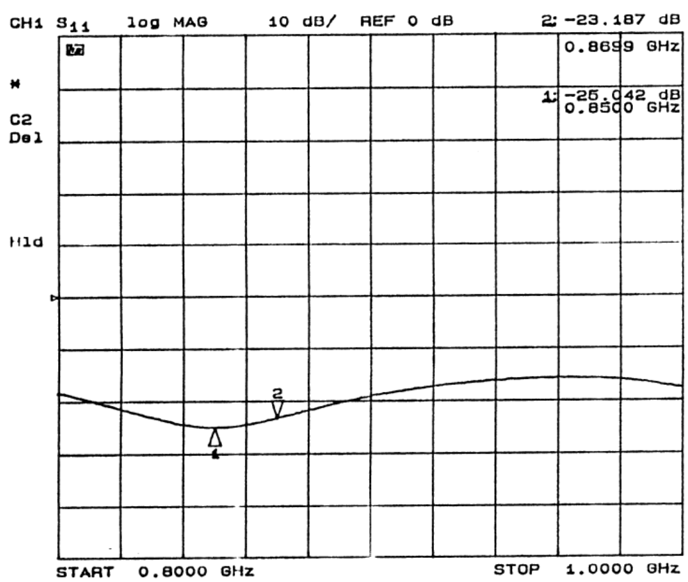

Figure 5. Transmitter port Return loss response of 9A2NAA

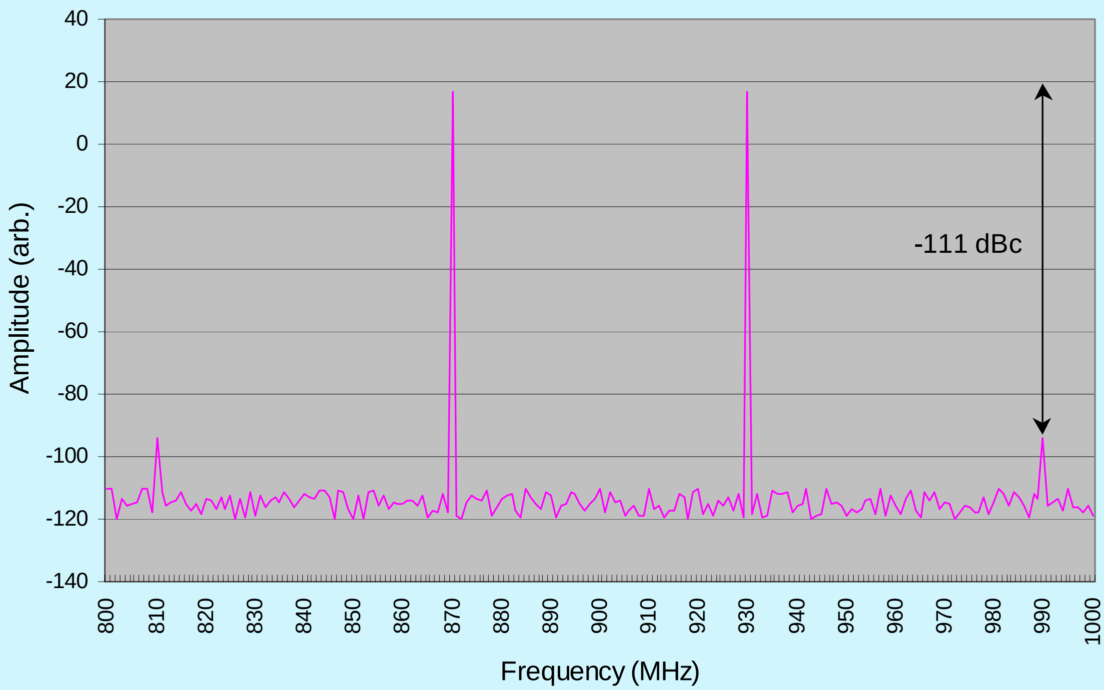

Figure 6. Intermod performance of 9A2NAA

The chassis of the combiner is designed to be versatile and accept four major market demands in combiner configurations: (1) two 4ways, (2) three 3-ways, (3) three 2-ways, and (4) four 2-ways. These combinations maintain the same electrical (but the theoretical Wilkinson loss) and mechanical performance and also the thermal performance is unchanged.

The new REC transmitter combiner 9A2NAA is targeted for base station expansion purposes that use AMPS, GSM, and CDMA standards and are looking to expand capacity and coverage in a timely and cost-effective manner.

SECTION II Receiver Multicouplers

The main function of a receiver multicoupler is to connect several receivers to a single antenna while maintaining signal integrity. There are essentially two types of receiver multicouplers: (1) Passive, and (2) Active. Active multicouplers have built-in LNAs to overcome signal loss due to divider circuit and pre-selector filters. Passive multicouplers do not have such amplifiers and therefore the through loss is substantially higher when compared to active multicouplers. This increases the total noise figure of the system and makes them unusable in certain base station applications. The choice of active vs. passive design is based on signal strength seen by the antenna port. For stronger signals like in case of HF broadcast stations, passive multicouplers are preferred so that their inherent loss provides required attenuation to prevent receivers on the output ports from going into saturation. Active multicouplers are more popular for UHF and VHF base station applications where the signals are weak and amplification is required to boost signal strength before they are introduced to the receive circuits.

In case of active multicouplers, front-end dynamic specs of P1dB and IP3 dictate input signal's power level range. Depending on site location and orientation, receive signals seen at the end of the antenna cable in a base station could vary significantly. The amplifier section of the multicoupler therefore should provide required overall gain while maintaining low noise figure and high 3^{rd} order intercept. Next major important parameter in a receiver multicoupler is the port-to-port isolation. Most receive circuits emit signals back to the antenna and in some cases, the reverse signal strength can be large enough to interfere with nearby receivers. Hence, isolation between ports needs to be high and be at least 20 dB.

To increase reliability of the receiver multicouplers, active components like the LNA and the power supplies are now being designed to lower failure rates. With the availability of high dynamic range LNAs with MTTF of more than 10 years, design of high reliability amplifier section becomes feasible. The power supply section usually uses a modular dc-to-dc converter that has wide input range for installation ease. These converters are now available with MTBF of 1 million hours. By using such reliable components, an active receiver multicoupler can be designed with enhanced reliability.

Based on these current markets requirements, REC has engineered an AMPS band active receiver multicoupler (model number 14A2NC) that is targeted for present and future base station expansion rack applications (Figure 7). It has three banks of 6-way Wilkinson type power dividers with front end LNAs. The GaAs MMIC based LNA is designed to overcome the splitting loss and further amplifies the input signal by either 2dB or 4dB. As signal strength varies from site to site, the option of having two different gain levels gives operator flexibility to adjust input power level for the receivers on site without any tuning. The output P1dB for the amplifier section is 15 dBm and IP3 is 40 dBm thereby making it usable for both weak and strong signal (maximum input signal of –40 dBm) applications while maintaining good linearity. The noise figure in the entire operational band of 806 to 824 MHz is less than 2.5 dB.

Isolation between ports is 22 dB minimum that aids in suppressing any receiver-receiver interference. This was achieved by optimizing the Wilkinson power divider circuit and choosing low capacitance balancing resistors. The power divider circuit was also optimized for amplitude balance and low return loss.

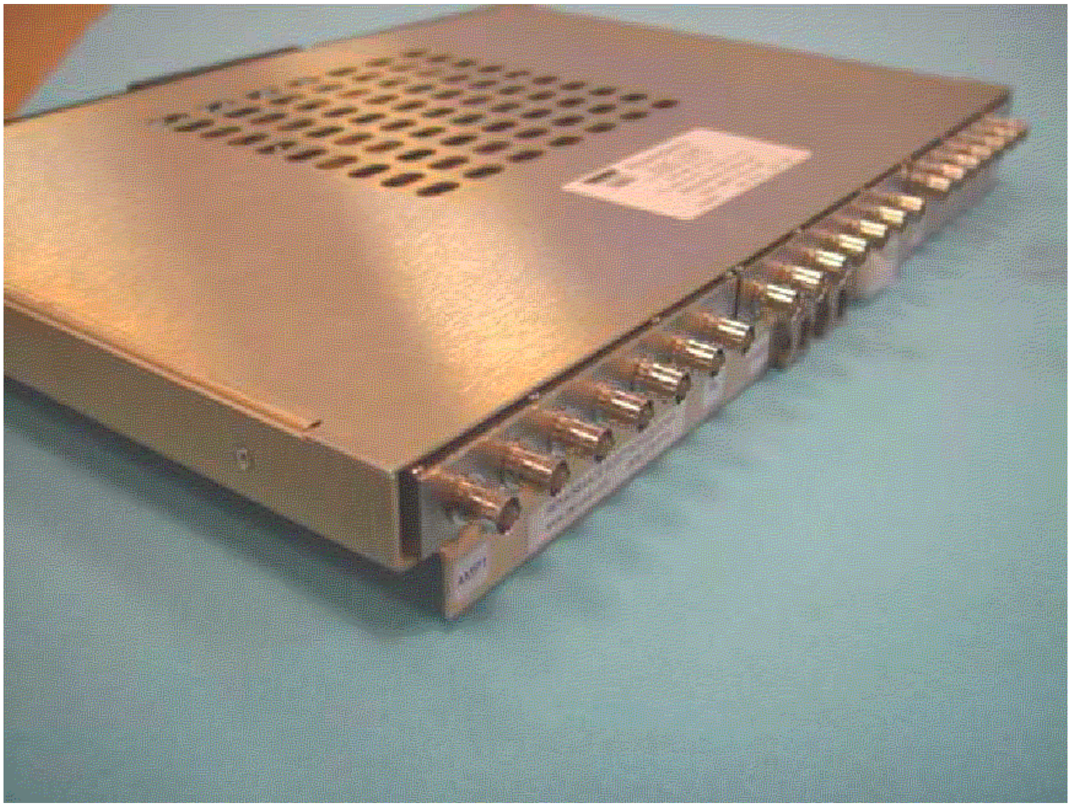

Figure 7. REC's new AMPS band 3x 6 Receiver multicoupler

The power supply section has a redundant backup circuit that is connected in parallel to the primary and gets activated immediately after the later breaks down. Both the primary and backup circuits are designed with a high reliable dc-to-dc converter with MTBF of 1 million hours. These converters have wide input range and therefore the multicoupler can be operated using any voltage between 20 and 75 volts. The front end of the multicoupler has various LEDs that indicate the functioning of the two power supplies and the three amplifiers. There also is wiring provision for Motorola's GEN4 alarm configuration in the form of two RJ45 connectors that are connected to the amplifier and power supply's relay sections.

All connectors are BNC type for ease of configuring and re-configuring when used in expansion racks of any cellular base station. The total height of the unit is only 1RU on a standard EIA 19" rack configuration and is weighs only 8.6 lbs.