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Amplifier Design Using a λ/4 High Impedance Bias Line with a Defected Ground Structure (DGS)

In this article, a new λ/4 bias line, combined with a dumbbell shaped defected ground structure (DGS), is proposed to suppress harmonics in power amplifiers. The proposed bias line maintains the required high impedance after the DGS is inserted, while the width and length of the λ/4 bias line are broader and shorter than those of conventional bias lines in power amplifiers. When the proposed bias line is used in power amplifiers, the third as well as the second harmonics are reduced because of the increased slow-wave effect of the proposed bias line over a wide harmonic frequency band. The proposed bias line is applied to a power amplifier for an IMT-2000 base station. It is shown that the reduction of the third

harmonic component and the improvements in the 1 dB power compression point, power-added efficiency and IMD_3 are 26.5 dB, 0.45 dB, 9.1 percent and 4.4 dB, respectively.

Recently, extensive research efforts on photonic band gap (PBG) structures where periodic patterns are etched on the ground plane of microstrip lines have been conducted for microwave circuit applications.[1–4] The applications of PBG for power amplifiers, filters and mixers have been reported. A defected ground structure (DGS), which is realized by etching a few dumbbell shaped patterns in the ground plane of microstrip lines, has been proposed.[5] Several applications to the design of directional couplers, filters and power amplifiers using DGS have been already reported.[6–8] It is expected that DGSs can be applied effectively in microwave circuits to utilize their advantages over conventional PBGs.

In general, small signal amplifiers at UHF use a chip inductor as an RF choke for bias. $\lambda/4$ transmission lines, terminated with chip capacitors or radial stubs, are also used as bias lines.[9] To minimize the interference between bias and signal transmission lines, the difference between their characteristic impedances should be as large as possible. Therefore, $\lambda/4$

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transmission lines with very high impedance are generally used.

In the case of high power amplifiers, however, because the transistors consume higher currents, the width of the bias line should be much wider than that for small signal amplifiers to avoid a voltage drop in the bias line and other potentially catastrophic situations. It should be noted that the broader the width of the bias line, the lower its characteristic impedance. Therefore, it is much more difficult to achieve the necessary isolation between the bias circuit and signal paths in high power amplifiers than in small signal amplifiers, and the possibility of oscillation is much greater. Additionally, when a capacitively terminated λ/4 bias line is connected to the signal path, the even harmonic frequency components of the fundamental are blocked, but the odd harmonic components are transmitted. This has been a serious problem as well. In addition, the proper harmonic terminations are necessary in order to increase the efficiency of a power amplifier.

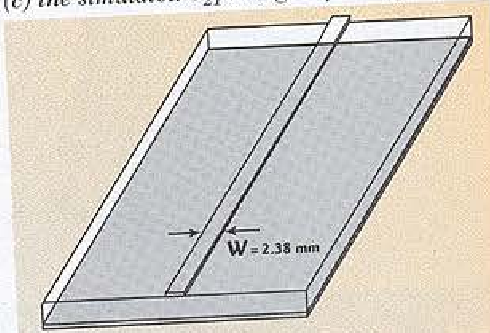
In this article, a new λ/4 bias line combined with a DGS is proposed. The proposed bias line maintains the required high characteristic impedance, while its width is much broader and its length shorter than those of the conventional λ/4 bias line. It will be shown that the third as well as the second harmonic components are effectively suppressed when the proposed bias line is used in a power amplifier.

DESIGN OF THE λ/4 HIGH IMPEDANCE BIAS LINE USING DGS

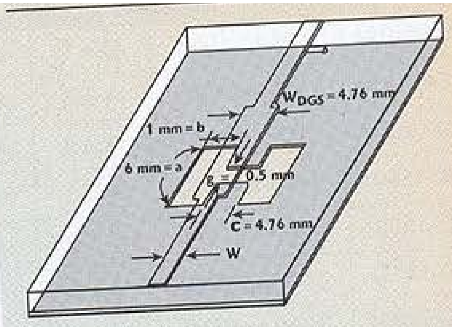
The etched DGS pattern under the microstrip line produces the equivalent of an inductance and an increased characteristic impedance. In the standard microstrip line, the line width becomes extremely narrow as the required line impedance increases more and more. However, in the microstrip line with DGS, because the additional inductance results in highly increased characteristic impedance, the line width is broader than that of the standard microstrip line for the same high characteristic impedance. The broadened width of the microstrip line can be considered as an increased equivalent capacitance, which plays a large role in increasing the phase constant and slow-wave effects. Therefore, it can be summarized that DGS leads to a reduced circuit size.

Figure 1 show the layout of a conventional microstrip line and a microstrip line with DGS. The transmission properties and group delay, predicted by electromagnetic simulation with Ansoft HFSS V6.0, are also shown. The substrate is Rogers' RT/duroid 5880 with a dielectric constant of 2.2, a thickness of 31 mils and metal thickness of 35 μm. The width of the DGS microstrip line is much broader than that of a conventional 50 Ω microstrip line. The measured results show that there is no transmission problem in the DGS microstrip

Fig. 1 Layouts and characteristics of (a) a standard microstrip line, (b) a DGS microstrip line and (c) the simulated S_{21} and group delay. ▼



(a) STANDARD MICROSTRIP LINE



(b) DGS MICROSTRIP LINE

(C) SIMULATED S_{21} AND GROUP DELAY

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line under 4 GHz, and the slow-wave effect is observed as the frequency increases.

According to the operating frequency, various slow-wave effects of a DGS microstrip line can be applicable to the capacitively terminated λ/4 bias line in power amplifiers. If the λ/4 DGS bias line offers a high impedance value, broader width and shorter length than a conventional bias line, and rejects the second and third harmonic signals, the power amplifier will be more stable and efficient.

Figure 2 shows the layout of the proposed capacitively terminated λ/4 DGS bias line connected to a 50 Ω signal transmission line. The characteristic impedance of the λ/4 DGS bias line is 120 Ω, and its width and length at the 2.14 GHz operating frequency of the power amplifier are 1.23 and 23.8 mm, respectively. It should be noted that the width and length of the conventional λ/4 bias line are 0.41 and 25.1 mm, respectively. Thus, the width is three times broader and the length is shorter.

Figure 3 shows the simulated and measured results of a conventional λ/4 bias microstrip line connected to a 50 Ω signal line. On the other hand, ***Figure 4*** shows the simulated and measured results of a λ/4 DGS bias line. The results show good agreement in the characteristics at the fundamental frequency band and the second harmonic band. But the char-

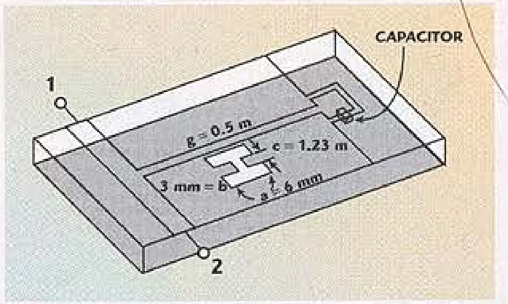


Fig. 2 Layout of a λ/4 DGS bias line connected to a 50 Ω microstrip line.

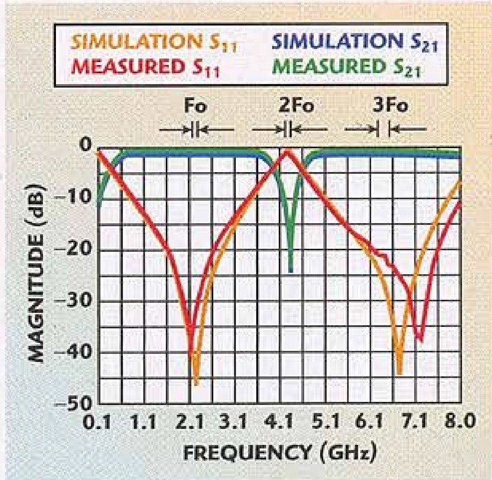
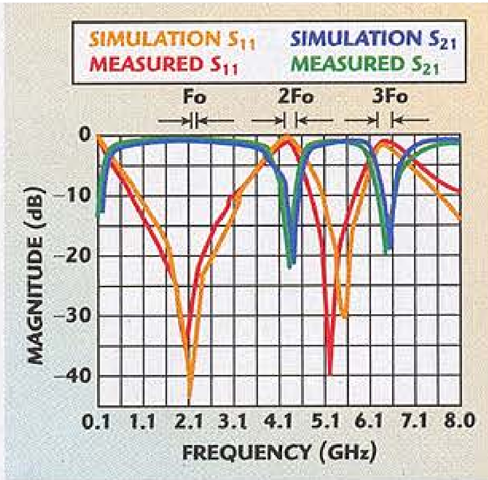


Fig. 3 Simulated input and measured characteristics of a λ/4 microstrip bias line connected to a signal transmission line.



▲ *Fig. 4 Simulated and measured characteristics of a λ/4 DGS bias line connected to a signal transmission line.*

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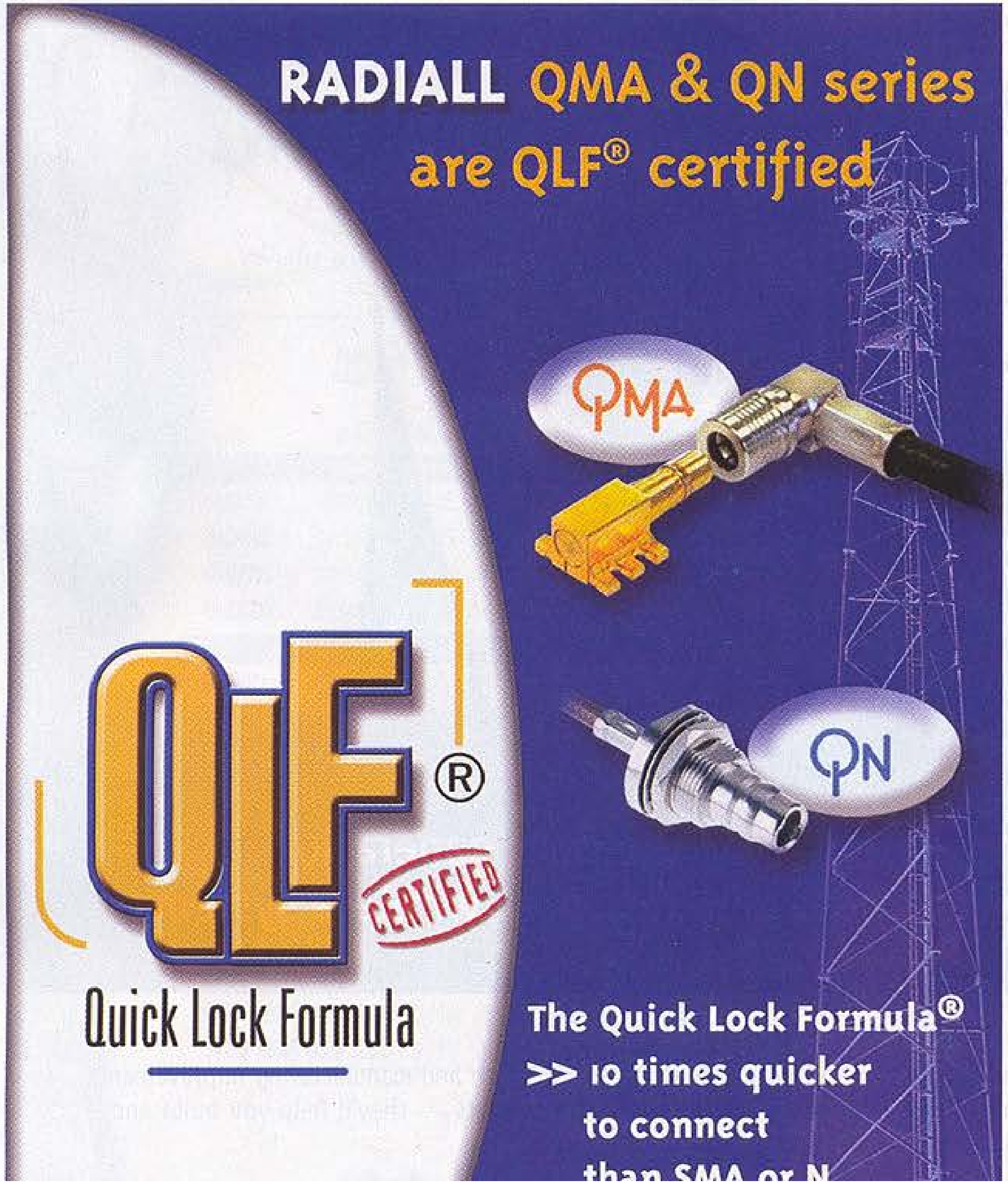
acteristics at the third harmonic band are quite different. It is obvious that the third harmonic component is blocked by the λ/4 DGS bias line, while it passes through when the con-

the IMT-2000 base station transmitter have been designed and fabricated to operate at 2.11 to 2.17 GHz using the FLL357ME power transistor. The recommended bias conditions for class

bias line. When the conventional λ/4 bias microstrip line is used, the measured gain, return loss and 1dB compression point (P1dB) of the conventional PA are 12.8±0.1 dB, −21 dB and ventional λ/4 bias line is used.

AMPLIFIER DESIGN AND MEASURED RESULTS

To show the validity of the proposed λ/4 DGS bias line, two kinds of power amplifiers that can be used for AB operation of this device are V_{ds} = 10 V and I_{ds} = 0.6 Idss given by its data sheet. Using a load-pull method, the input and the output matching conditions were obtained. The first power amplifier uses a conventional λ/4 bias line, and the other the proposed DGS



35.33 dBm, respectively. However, when the λ/4 DGS bias microstrip line is used, the measured gain, return loss and P1dB of the DGS PA are 13.35±0.07 dB, −21 dB and 35.78 dBm, respectively. ***Figure 5*** shows the measured results of the conventional and DGS PAs. The transmission and reflection characteristics of the DGS PA are very similar to those of the conventional PA.

Figure 6 shows the second and third harmonic suppressions compared to the fundamental signal of

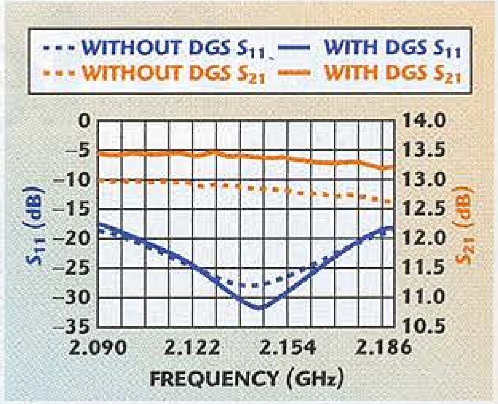
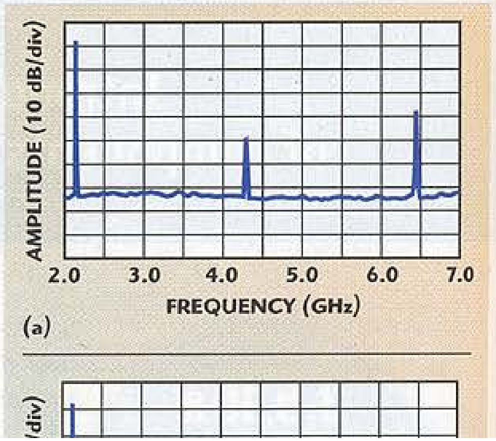
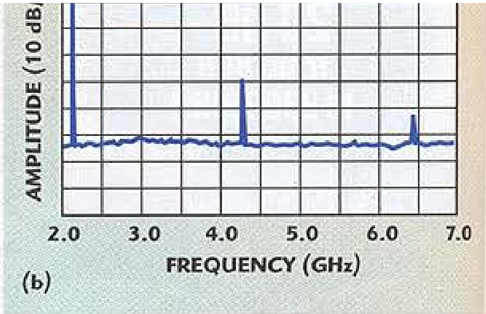


Fig. 5 Measured S-parameters of power amplifiers with conventional and DGS bias lines.





▲ *Fig. 6 Harmonics characteristics of the power amplifier with 35 dBm output with (a) conventional and (b) DGS bias lines.*

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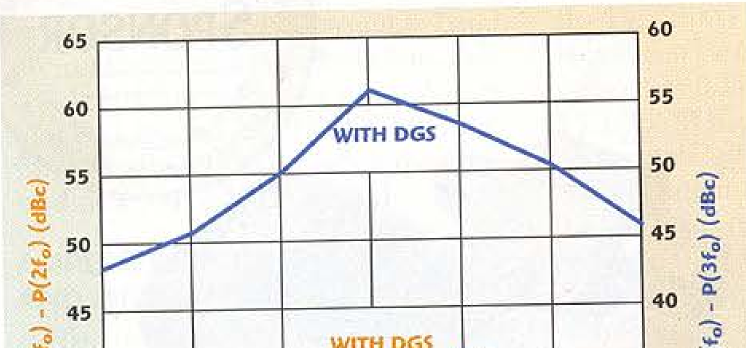


and third harmonics are 40.07 and 56.06 dBc below the fundamental. It is noticeable that the magnitudes of the third harmonic components of the DGS PA are quite smaller than those

Figure 7 shows the harmonic suppression of the two amplifiers for various carrier frequencies. The second harmonic suppressions are almost equal for the two amplifiers, but the third harmonic suppression of the DGS PA is more than 15 dB higher than for the conventional PA.

Figure 8 shows the measured output power characteristics of the two

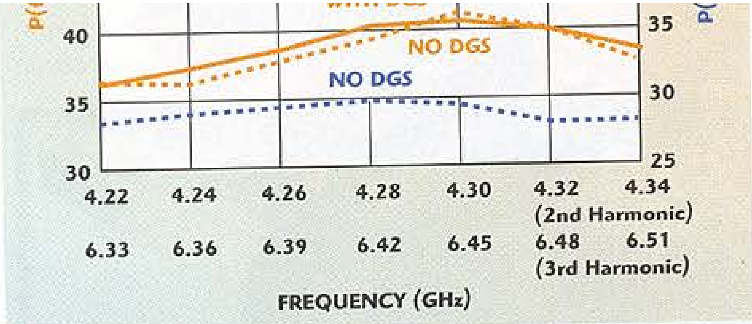


Fig. 7 *Harmonic suppression in the conventional and DGS power amplifiers.*

the conventional and DGS PAs. In the case of the conventional PA, the second and third harmonics are 39.21 and 29.55 dBc below the fundamental, respectively. However, in the case of the DGS PA, the measured second and third harmonics are ... of the conventional PA. This means that the DGS bias line terminates the third harmonic component properly. By comparing the conventional PA with the DGS PA, the gain of the DGS PA is 0.55 dB higher and the third harmonic signal level is reduced approximately 26.51 dB. Also, the P1dB is 0.45 dB higher than for the conventional PA. These improvements are caused by the suppression of harmonic signals.

amplifiers. For the same input power level, the gain of the DGS PA is 0.45 to 0.76 dB higher than that of the conventional PA. The P1dB of the DGS PA is 0.45 dB higher. The improvements in gain and output power result in the increase in power-added efficiency (PAE). The PAE of the DGS PA is 0.5 to 9.14 percent higher than that of the conventional PA. This is caused by less current consumption and the improved output power of the DGS PA. Because the improvement of PAE increases as the input power grows, the proposed DGS bias line is a good choice for power amplifiers with high efficiency.

Figure 9 shows the measured nonlinear characteristics in a two-tone test. The frequencies of the two

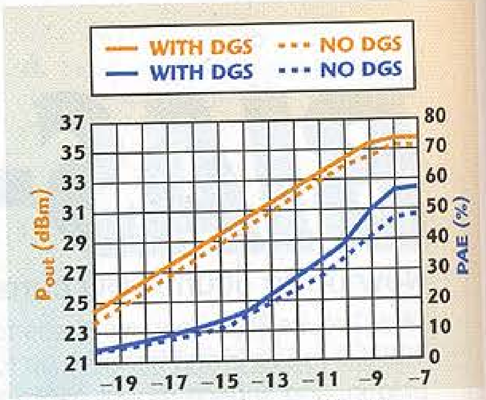
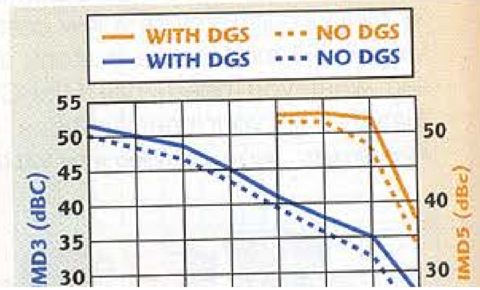
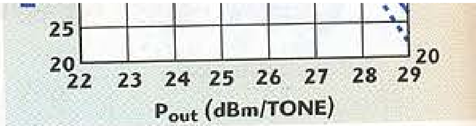


Fig. 8 *Measured P_{out} and PAE of the power amplifiers with and without DGS bias lines.*





▲ *Fig. 9 Measured intermodulation products for the power amplifiers with and without DGS bias lines.*

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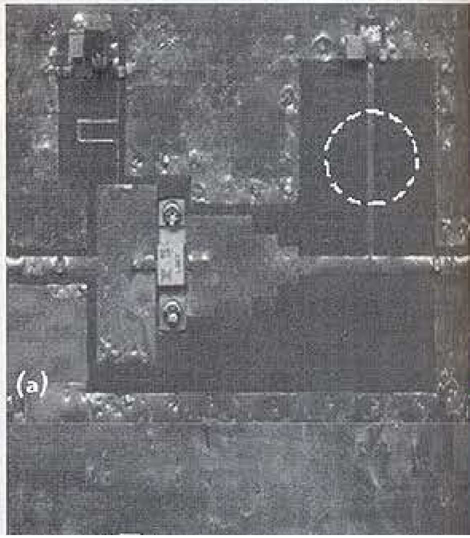
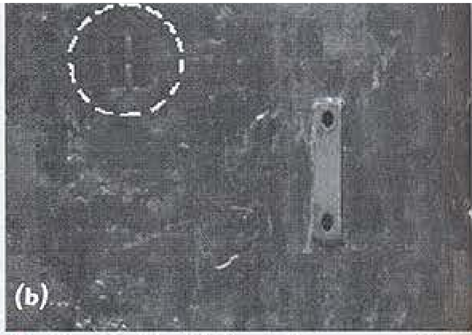
tones are 2137.5 and 2142.5 MHz. For the DGS PA, the improvements obtained for IMD3 and IMD5 are approximately 4.4 and 4.5 dB at P_o = 29 dBm/tone. ***Figure 10*** shows photographs of the fabricated amplifier using the proposed λ/4 DGS bias line.

CONCLUSION

A λ/4 DGS microstrip bias line has been proposed, which is realized by etching a dumbbell shaped pattern in the ground plane of the bias line. The DGS microstrip line offers broader width and shorter length than the conventional microstrip line having the same characteristic impedance. Additionally, it offers an increased slow-wave effect over a wide harmonic frequency band. When the DGS microstrip line is applied to a λ/4 bias line, the λ/4 DGS bias line provides the required high impedance. It also





▲ *Fig. 10 The fabricated power amplifier with a λ/4 DGS bias line; (a) top view and (b) bottom view*

offers a high rejection characteristic for the third as well as second harmonic components.

In this article, the proposed λ/4 DGS bias line has been used in a power amplifier that can be operated for an IMT-2000 base station transmitter. The transmission and reflection characteristics are similar to those of a power amplifier using the conventional λ/4 bias microstrip line. However, the measured third harmonic signal of the power amplifier using the DGS bias line was lower by more than 15 dB in the operating band. The obtained improvement in P1dB, PAE, IMD3 and IMD5 obtained were 0.45 dB, 9.1 percent, 4.4 dB and 4.5 dB, respectively. It is expected that the proposed DGS bias line can be well used in other microwave circuits because of its simple structure, potential role and excellent applicability. ■

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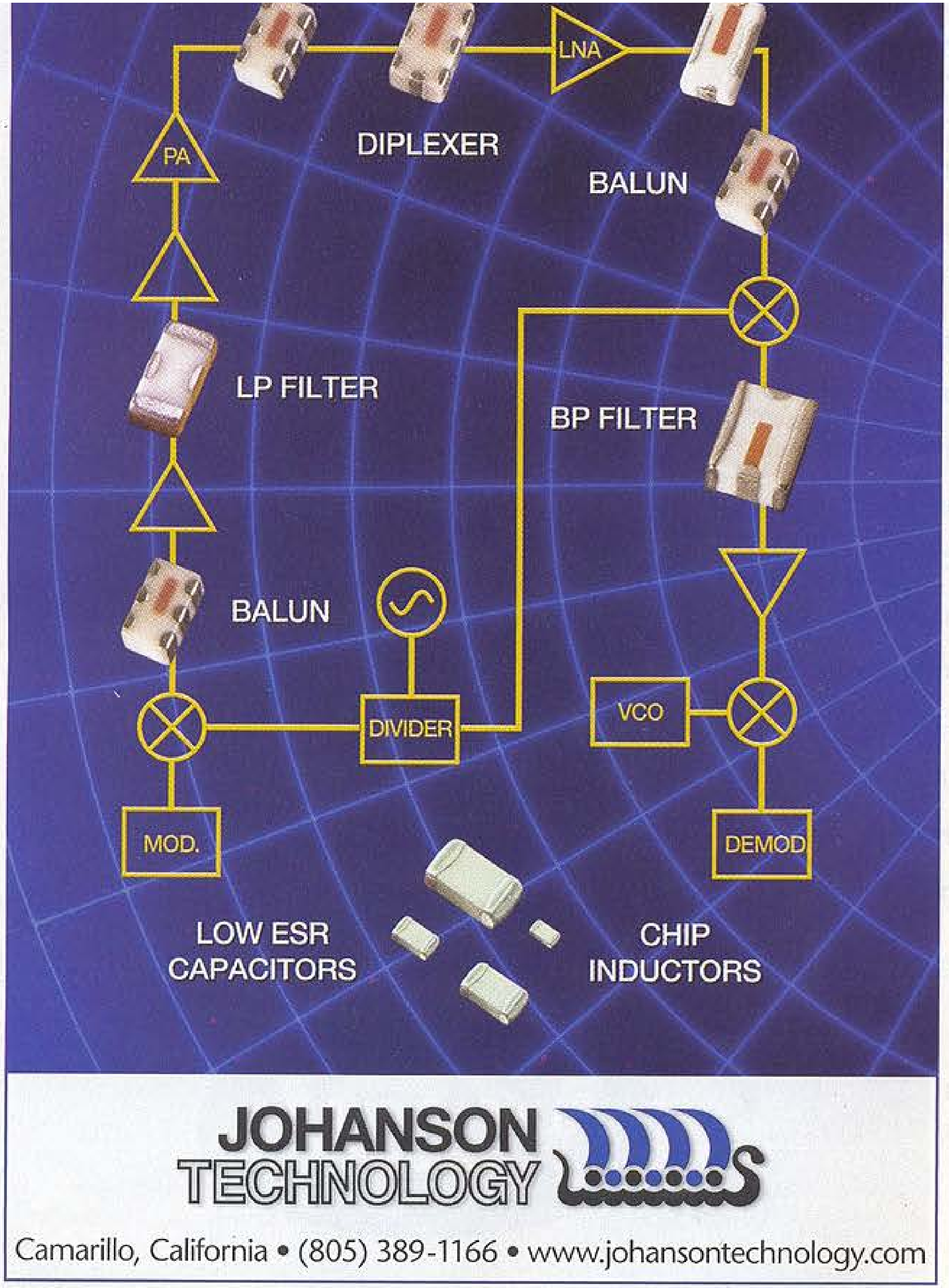

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