Insights and best practice

AMPLIFIER KNOW-HOW

TECHNICAL NOTE 0104

MANAGING STABILITY AND SPURIOUS SIGNALS IN RF AND MICROWAVE AMPLIFIERS

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The challenge

Whatever the application, accurate results that can be consistently repeated is a reasonable expectation for any engineer using an RF or Microwave Amplifier.

But many things can conspire against such an outcome. Outside influences, including stability and spurious signals, are a significant risk that can, if not managed or considered, have a serious impact on the accuracy of results and even the safety of individuals.

The solution

AMETEK-CTS has been designing and manufacturing amplifiers for more than XX years. During that time we've learnt a thing or two about how best to manage external influences.

This technical note draws on this experience, and provides actionable insights that will help users identify and manage external factors that may negatively affect performance and results.

Use the guide to minimise the risks to ***accurate performance,*** *and the* ***safety of individuals***

INTRODUCTION

Use the guide to minimise the risks to ***accurate performance,*** *and the* ***safety of individuals***

Amplifiers need to be stable and not produce unwanted signals for safety and functional reasons. An uncontrolled oscillation could damage the amplifier itself, or if connected to a transmitting element at certain frequencies be a risk to other equipment or at worst personnel. Unwanted lower level signals could interfere with system operation, reducing sensitivity or giving false responses in applications like radar. In some applications amplifiers may have to cope with undefined source and load impedances, hence we have the requirement for unconditionally stable amplifiers – they must not oscillate whatever termination is put on their input or output. This is a particular issue for amplifiers used in applications such radiated immunity testing as the load is typically a very wideband antenna which can have mismatches of >10:1 VSWR (<1.8dB return loss) at any phase.

Instability can be visualised as discrete spurious (unwanted) signals in the frequency domain. These may only be visible when there is a (wanted) output signal, at other times they can appear as broader bandwidth, noise 'humps' or unexpected decreases in output power or gain – appearing like a 'bite' being taken out of the gain response in the frequency domain. They should not be confused with interfering signals such as power supply spurious interference, which are a separate but also important issue. The two problems have different solutions, hence it is necessary to distinguish between them. A simple way to do this is to observe the effect on the suspect frequency, of adjusting the tuning on the amplifier circuit. Interferers will usually change in amplitude but not frequency, whilst oscillations will typically do both.

Knowing the sources of interference in the system design, such as switching frequencies, greatly helps in tracking down the mechanisms, and hence the remedy, of any interfering signals. If it looks like Ohms Law isn't applying – search for oscillations!

Although in a system context minor oscillations may be tolerable, (low enough down or in a non-interfering part of the spectrum), they are indicative of a design that could be better controlled. They are produced within the amplifier active devices themselves, either as a result of positive signal feedback or the presentation of a negative resistance to the device at a particular frequency. In dealing with spurious signals the normal challenges presented by component loss actually work in our favour. High gain makes positive feedback more likely and rapid phase transitions increase the possibility of oscillation at some frequencies. Hence stability is often less of an issue in wide bandwidth designs where the phase and gain are naturally controlled as part of the design process. Paradoxically, narrowband designs still need to be scrutinised for the out-of-band response.

The Guidelines

The guidelines provide general insights and many steps that can be taken to get the best possible performance from your amplifier.

Contact us for a discussion if you require specific application assistance.

1	Use lossy matching networks between stages with a positive gain slope.
2	Use resistive decoupling in the bias lines, and lossy capacitors as well as the low loss ones to de-couple the RF.
3	Use negative feedback, series or shunt.
4	Avoid hi-Q circuits, where possible.
5	Incorporate good solid grounds, since resonators move rapidly through a range of impedances.
6	Include pad capacitances and other parasitics in models.
7	Reduce the number of inductive coils that could launch fields into the surrounding space and adjust the orientation of those that are used to reduce coupling.
8	Avoid running wires in the air or alongside walls; shield if possible and ensure that they are de-coupled at both ends.
9	Attenuate positive feedback – through supply lines, radiated couplings and box modes.
10	Check the amplifier housing for box modes. If the cavity size cannot be reduced sufficiently then pillars can break up the fields. It is important that these are grounded top and bottom; screw fixings through the lid are usually adequate.
11	Use steady-state analysis for most designs, but also consider what happens at such instances as switch-on.
12	Understand the accuracy of device models in nonlinear modes or during switch-on. Test beyond the drive power ranges as parametric oscillation in particular can be drive-level sensitive.

13	Assess stability using K or B1 factors and stability circles based on small signal data, although remember that some variables change with drive level Gm, Cgs, Cgd, etc. Small signal analysis is quicker to optimise and generally (but not always) indicates the areas of greatest concern. Ensure that the frequency step size is small enough to pick up resonant transitions.
14	E-M simulation of passive structures is generally more accurate but typically uses large frequency step sizes, due to greater processing time. In order to pick up oscillations small sizes are needed to show perturbations. Interpolation can be cautiously employed to reduce the step size, provided care is taken in determining the optimum trade-off between step size and simulations time.
15	Odd mode oscillation problems occur where parallel devices exist with low levels of isolation between them. These may not be detectable at the output ports directly. They are internal voltages and currents but can mix with even mode instabilities. If there are odd mode voltages and currents and if there is negative resistance at any of the internal nodes, then oscillations can build up. Odd mode analysis is incredibly complex and the mathematically minded should consult Weber [1], but in summary sensible precautions are: • Use symmetrical layouts. A stability problem is the same for a single cell as for the parallel ones. • Resistors between parallel gates and drains. • Analysis using Freitag method [2] and time domain simulations. • Even mode stability is calculated, and then odd mode stability is determined from the stabilised even mode Z matrix.
16	Marginal stability = marginal instability. Many factors will alter the conditions: • Temperature, • Component tolerances, aging, etc. Stability needs to be included among yield analysis parameters.
17	When dealing with power amplifiers we may not be aware that internally we have multiple devices connected in parallel – sometimes with a driver. Understand the construction of the devices you use.
18	Reduce out-of-band gain – and do it resistively.

[1]Using Radar Absorbent Material (RAM) is not necessarily a sign of design 'weakness' any more than adding additional via holes is. The size of some cavities/chambers makes them susceptible to moding, (the ability of signals to travel in modes other than the intended controlled manner). These need to be dealt with and RAM is a perfectly acceptable method. However, a design littered with RAM may suggest that some of the other precautions listed haven't been well implemented.

19	Consider the stability due to the following amplifier stages; e.g. class C – their impedance changes dramatically during the rising edge of a pulse. This will change the load presented to prior stages. If the earlier stages aren't unconditionally stable there could be trouble. This problem is exacerbated as the number of stages increases, hence ferrite circulators are often employed to 'break up' the line-up by increasing the isolation. However – remember that out-of-band circulators and isolators can present highly reflective loads.
20	Conditional stability – there is a trade-off in how hard you have to work to achieve unconditional stability, (over the full operating range and up to the maximum frequency of oscillation of the transistors), and the application space. An amplifier intended for use in a standard laboratory environment doesn't need to include stability checks at -40 and +100°C.
21	If you're not going to do the full stability analysis, then take a "belt & braces" approach to stability precautions. These can then be removed if they are found to be unnecessary during the prototyping and evaluation stages; it is usually easier to remove something later than try and incorporate an unplanned feature.
22	Finally, in dealing with oscillation issues, applying stability techniques randomly can lead to lost performance and additional unnecessary costs. It is important to understand the cause of the instability and therefore target the 'fix' to that issue. Similarly, don't treat the symptom, address the cause.

The topic is discussed further in [3] edited by John Walker and to which the author was a contributor.

[1] R. Weber, "Even mode versus odd mode stability," in Proceedings of the 40th Midwest Symposium on Circuits and Systems, 1997.
[2] R. Freitag, "A unified analysis of MMIC power amplifier stability," in Microwave Symposium Digest, 1992.
[3] J. Walker, The Handbook of RF and Microwave Power Amplifiers, Cambridge: Cambridge University Press, 2011.

ANY QUESTIONS?

If you have any questions on this, or any other related topic please send them to: amplifiers@ametek-cts.com