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A NEW 5 AND 10 MHz HIGH ISOLATION DISTRIBUTION AMPLIFIER

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Abstract

Increasing performance demands made by precision timing have made NIST's present 5 MHz distribution amplifier system obsolete. A new design providing improved phase stability with temperature, harmonic purity, and phase noise is presented. By building on previous designs, a modified cascode amplifier was created with performance increases of more than 10 fold in phase noise, temperature coefficient and isolation. An input-output isolation of 140 dB and channel to channel isolation of greater than 125 dB was achieved. Phase noise performance of -152 dBc/Hz at 1 Hz with a noise floor of -170 dBc/Hz was also achieved. Input and output matching provide average return losses greater 30 dB. Harmonics are all -45 dBc or better at an output of +13 dBm, and the temperature coefficient of output phase is less then 1 ps /°C.

Introduction

The improved performance of new frequency standards as well as the advent of the trapped ion clocks, places a greater demand on signal distribution and measurement systems. In order to reach fractional frequency stabilities on the order of 10^{-16} in 10^4 seconds, timing errors due to transmission and measurement must be less then 1 ps. At 5 MHz this corresponds to holding phase variations to under 30 microradians for about 3 hours. The old design, summarized in table 1, fails this criteria mainly in aspects of temperature coefficient and timing errors due to voltage standing wave ratio (VSWR). In order to approach the error budget of 1 ps a new set of design criteria was created and is shown in table 2.

Table 1, Summary of old design performance

isolation	125 dB
phase noise at 1 Hz	-142 dBc/Hz
phase noise floor	-165 dBc/Hz
temperature coefficient	12 - 15 ps/°C
input/output return loss	25 - 13 dB
harmonics	-20 dBc
power consumption	160 mW

Table 2, Performance goal of new design.

isolation	120 dB
phase noise at 1 Hz	-145 dBc/Hz
phase noise floor	-165 dBc/Hz
temperature coefficient	1 ps/°C
input/output return loss	35 dB
harmonics	-45 dBc
power consumption	<160 mW

The development and performance of an amplifier that meets these requirements will be described.

History

The amplifier presented here has a long evolution beginning in 1976 with the work of Gray and Glaze [1]. The amplifier shown in figure 1, consisting of two common base bipolar junction transistors (BJT) driven by a common-emitter stage, still shows impressive isolation and phase noise performance. This design is presently used in about 100, five channel units for NIST's atomic clock ensemble. Building on this design, De Marchi, et al. [2] produced a very high performance amplifier with a 350 MHz bandwidth and isolation as high as 150 dB. This was achieved using the circuit shown in figure 2. The amplifier used three alternating npn and pnp transistors with their bases tied directly to ground. This required a bipolar power supply and a separate bias

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current for each transistor. The signal was coupled out via a common emitter stage. By using only SMT technology, parasitics were greatly reduced and the very high bandwidth was realized. The high isolation is also attributed to having the bases tied directly to ground, effectively forming a shield between the collector and emitter, thus reducing capacative coupling.

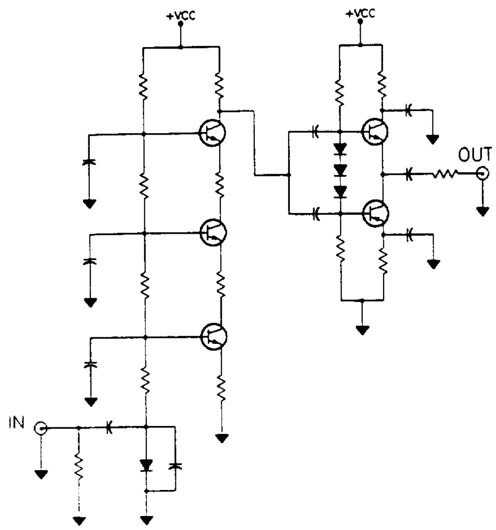

Figure 1. NIST's present isolation amplifier

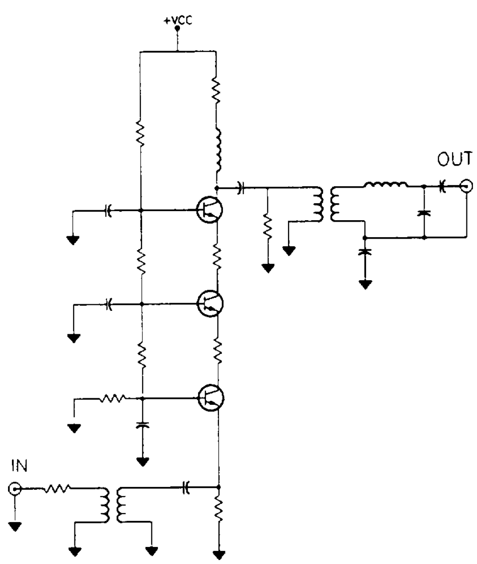

Figure 2. De Marchi's isolation amplifier.

Circuit Description

The power constraint placed on the amplifier by the existing rack system ruled out De Marchi's design, which consumed five watts per channel. The following circuit was created by combining aspects of both Gray and De Marchi designs.

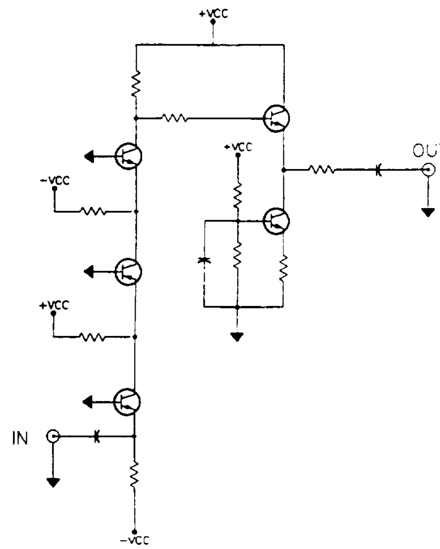

Figure 3. NIST's new isolation amplifier

De Marchi's approach of three common base stages was combined with Gray's single current and voltage bias network. This required tying the bases to ground via large capacitors to maintain isolation. This approach dropped the power requirement for a single channel from five to less than one watt. To improve the harmonic distortion and temperature coefficients, the output drivers of the previous designs were removed. In order to achieve current gain in this common-base configuration, it was required to couple in with transformers. This coupling also enabled very precise impedance matches. The output is also transformer coupled and DC isolated. Simple L-type networks were used for input and output matches. The configuration of the voltage bias network supplying the transistor bases forms a very effective active noise filter, which is responsible for the extremely low phase noise of the circuit. Nickel-plated steel shields were soldered around each channel to help improve the isolation. By moving back to the single bias current configuration, the amplifier's power consumption was greatly reduced, at a cost of reducing the operating bandwidth.

Performance

The amplifier was configured to accept 5 and 10 MHz at +13 dBm and to provide five +13 dBm outputs. The plot of gain vs. frequency (figure 4) shows a 1 dB bandwidth of 22 MHz.

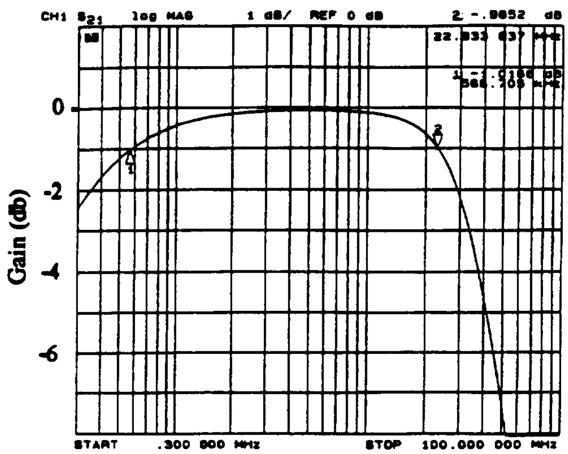

Figure 4. Gain vs. Frequency

Isolation was measured by injecting a +13 dBm signal at one port and measuring it at another. Reverse isolation was determined to be 144 dB, isolation between adjacent outputs is 125 dB, and isolation between non-adjacent outputs is 135 dB. We also attempted to measure isolation by opening and closing a port at a certain frequency while observing the other channels on a cross-correlation time measurement system. The effect could not be distinguished from the noise floor of the system.

Phase noise shown in figure 5, measured using a cross-correlation technique, shows a 1 Hz intercept of -152 dBc/Hz and a flicker floor of 170 dBc/Hz. The 1/f corner appears to be about 40 Hz. The droop at less than 2 Hz is due to the measurement being ac coupled. DC coupled spans of 20 Hz were not practical due to the high numbers of averages required for the cross-correlation and the possibility of overloading the analyzer.

By integration over the 1/f and f^0 noise components one can obtain an estimate of the short term fractional frequency stability of the amplifier (figure 6). This of course assumes a continued 1/f noise process inside of 1 Hz. This result could not be experimentally verified because NIST is presently unable to measure stabiltites of 10^{-16} at 5 Mhz and measurement times of 100 seconds.

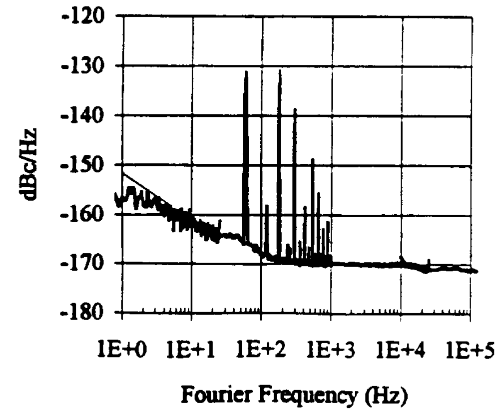

Figure 5. Phase noise of isolation amplifier

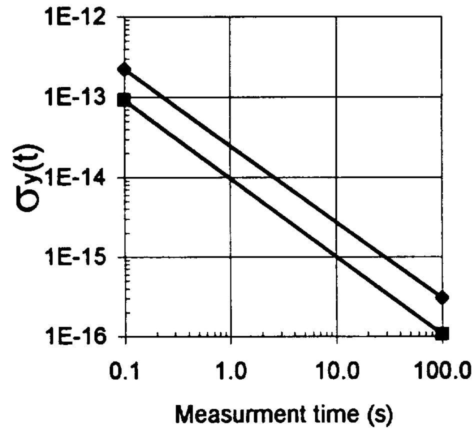

Figure 6. Estimated fractional frequency stability for a 1 Khz Bandwidth

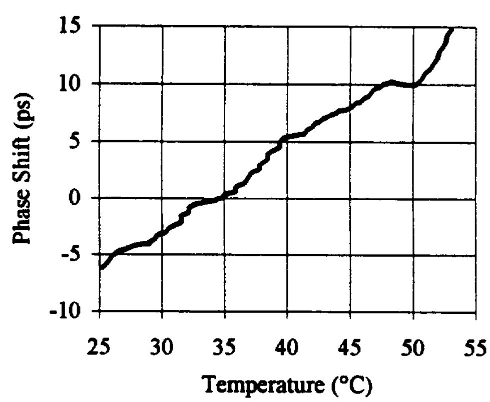

Figure 7. Phase-temperature coefficients

Phase stability vs. temperature was measured using the usual phase bridge technique[3]. In order to reduce noise the mixer output was integrated with a time constant of 10 seconds. Over a 25 °C range we observed a change in delay of only 750 fs/°C (figure 7). The range tested included 10 °C above and below the nominal temperature.

Special attention was paid to input and output impedance matches. Equation 1 shows the timing errors due to a transmission system [3].

$$\delta t = \frac{L}{\beta c} + \frac{1}{4 v_o} \frac{\rho_S \rho_L}{\eta} \sin\phi \qquad (1)$$

where δt is the timing error, L, β, c have to do with the transmission media, v_o is the frequency, ρ_S and ρ_L are the reflection coefficients of the source and load, η is the round trip attenuation and $\sin\phi$ is the angle of the twice reflected signal at the load. Table 3 shows the VSWR of the old isoamps and the worst case timing errors (η=1 and $\sin\phi$ =1) for two identical amplifiers connected in series. Table 4 shows the same for the new isolation amplifier.

Table 3 Timing errors of old amplifier due to VSWR

	input VSWR	output VSWR	error
5 MHz	1.52	1.19	900 ps
10 MHz	1.46	1.11	250 ps

Table 4 Timing errors of new amplifier due to VSWR

	input VSWR	output VSWR	error
5 MHz	1.002	1.04	2 ps
10 MHz	1.01	1.15	10 ps

The above tables show the extreme importance of impedance matching in precision timing applications. By carefully cutting all cable lengths to integer multiples of $\lambda/2$ one should be able to get the error due to VSWR down to 0.2 ps at 5 MHz.

With all transistor stages running in class A operation harmonic distortion was greatly reduced. A comparison between the old and new isoamps is shown in figures 8 and 9. These figures were both measured at +13 dBm output power. The new isoamp shows the second harmonic at -45 dBc and the third at -50 dBc. Running with an input of +15 dBm the amplifier runs with 0.25 dB compression and -35 dBc harmonic distortion.

Conclusion

With the performance improvements presented above, the new isolation amplifier can achieve the required 1 ps error budget. It is presently being installed at NIST to distribute signals from masers and other high stability sources.

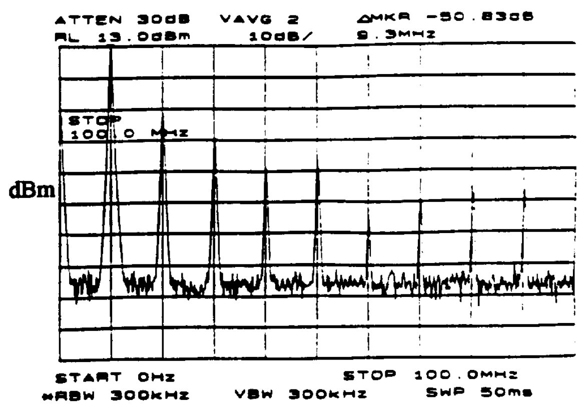

Figure 8. Harmonic distortion of old amplifier at an input level of +13 dBm

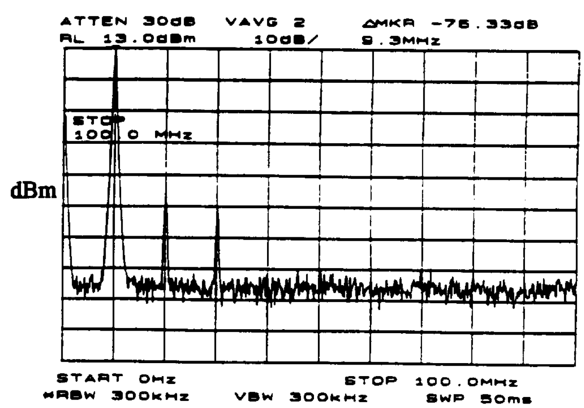

Figure 9. Harmonic distortion of new amplifier at an input level of +13 dBm

Acknowledgments

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References

[1] F. L. Walls, S. R. Stein, J. E. Gray, D. J. Glaze, "Design considerations in state-of-the-art signal processing and phase noise measurement systems", Proc. 30st Ann. Frequency Control Symp., 1976, pp. 269-274

[2] A. De Marchi, F. Mussion, M. Siccardi, "A High isolation low noise amplifier with near unity gain up to 100 MHz", Proc. 47st Ann. Frequency Control Symp., 1993, pp. 216-219

[3] L. M. Nelson, and F. L. Walls, "Environmental effects in mixers and frequency distribution systems", Proc. 46st Ann. Frequency Control Symp., 1992