V-5 LUMPED ELEMENTS IN MICRO-WAVE INTEGRATED CIRCUITS

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The cost of manufacturing an integrated circuit is inversely related to the number of circuits processed simultaneously on a single starting wafer. Most of the work on microwave integrated circuits reported to date has concentrated on applications using microstrip lines deposited on high-resistivity semiconducting and ceramic substrates. At X-band frequencies and above the overall size of the distributed microstrip circuits is relatively small, but at lower frequencies (L- and S-band) the circuits tend to become large enough so that it is difficult to process many on a single substrate. At L- and S-band, however, lumped elements may be used with a considerable size reduction. Circuits can be fabricated by low-frequency integrated circuit and device technology that are sufficiently small compared to a wavelength so that they behave as true lumped elements up to reasonably high frequencies. There are many applications in which the reduction in circuit Q for lumped elements due to the low volume for energy storage is outweighed by the advantages of size reduction.

From an integration point of view the size of the circuit elements must ultimately be comparable to the size of the active elements. Measurements of such small elements are difficult. We have obtained resonably accurate and reproducable results by mounting and bonding the elements on a short section of microstrip line, and then making slotted line VSWR and phase comparisons with open and short circuits over a range of frequencies.

Inductors and capacitors have been fabricated with Q's in excess of 50. Figure 1 is a plot of Q^2 vs. f for the 25 nanohenry copper coil shown in Fig. 2. The coil conductor is 2.5 mils wide and 0.5 mil thick with a 1.5 mil spacing between turns. The linear variation shown in Fig. 1 is expected for a true inductor. The self-resonant frequency of this coil is 4.7 GHz. Assuming bulk resistivity, the measured Q is approximately one-half of what would be expected if the current divided itself equally between the upper and lower surfaces of the coil. The variation of inductance and Q with coil parameters have been measured for other coils. SiO_2 is used to insulate the crossovers in integrated circuit applications of these inductors.

For electrical performance in microwave integrated circuits the most desirable capacitor is the thin-film type. Diffused and MOS capacitors have considerable parasitic reactance which lowers their usable frequency. Thin-film capacitors have been constructed using Si 0 at BTL deposited SiO_2 as a dielectric. A 15 $\mu\mu$f capacitor had an essentially constant measured Q of 50 from 0.5 to 2.0 GHz. 1.5 to 50 $\mu\mu$f capacitors have been built and measured. Higher Q capacitors have been reported; an order of magnitude improvement is expected when dielectrics with properties approaching those of the pure material can be deposited. In addition to SiO_2, other materials such as Ta_2O_5 and Al_2O_3 are being investigated.

Several lumped-element matching circuits were evaluated prior to their use in transistor power amplifiers. The results for a series L-C circuit are shown in Fig. 3. The straight-line response shows the absence of distributed effects; the circuit behaves like a lumped series L-C circuit across the band 0.5 to 2.5 GHz. The element values shown were determined from the circuit response and are close to the design values.

Transistor power amplifiers using these elements are under study. Figure 4 is a simple circuit to match an experimental transistor pellet to 50 ohm transmission lines at 2 GHz. The transistor chip was first tested in a microstrip test fixture. The required input and output impedances for the desired operation were determined from the measured impedances of the stub tuners that matched the test fixture. The impedances are calculated at the planes (experimentally determined) of the transistor pellet bonding points. Initial operating amplifiers have been breadboarded using thin-film lumped elements. Figure 5 is a photograph of the breadboarded version of the Fig. 4 circuit. The entire amplifier occupies an area 130 mils by 110 mils. This amplifier yielded 2.4 dB of gain at 1.86 GHz. Using stub tuners to compensate for a faulty input match the gain was increased to 4.4 dB. In other circuits with stub tuners to adjust for parasitic reactances introduced by the breadboarding gains as high as 3.8 dB have been achieved at 2 GHz with 0.5 watt output power and 25% collector efficiency. The loss of a simple circuit is $\cong 8.7\ Q_L/Q_o$ dB, where Q_L is the loaded and Q_o the unloaded Q of the circuit. For the circuit of Figs. 4 and 5 with $Q_L = 1.5$ and an estimated $Q_o = 40$ the loss of each matching section would be about 0.35 dB. About 5 dB of gain with over 0.5 watts output power at 2 GHz has been measured for this transistor when used in a coaxial circuit.

An integrated version of the 2 GHz lumped amplifier is under construction. Forty-five of these one-stage amplifiers are processed simultaneously on a 3/4" x 1" substrate. The transistors are mounted and bonded subsequently. Figure 6 is a reproduction of a part of one of the photoresist masks which illustrates the relative sizes of the different circuit elements. In contrast to microstrip amplifiers the transistor size is about equal to the other circuit elements. A 2 GHz microstrip amplifier using the same transistor and designed for minimum size is about ten times larger than the layout in Fig. 6.

These lumped amplifiers can be used as driver stages for a power amplifier in which the final stage is a distributed circuit. The "chip" containing cascaded lumped element stages would be mounted on the input line of the power amplifier. The thin-film lumped elements might also be used as chokes and bypass capacitors in the distributed stage.

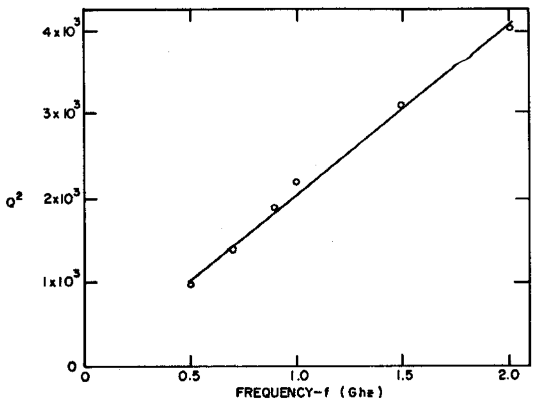

FIG. 1 - Measured Frequency Variation of Indicator Q

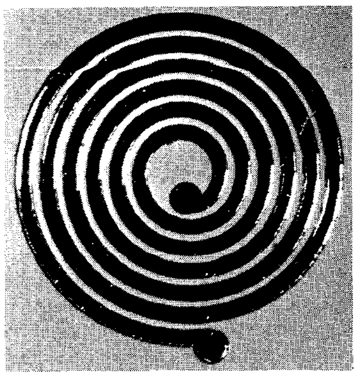

FIG. 2 - Photograph of 25 nh Indicator (0.060" diameter)

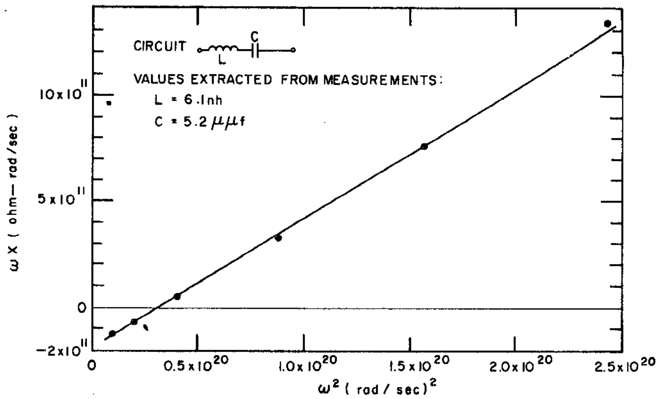

FIG. 3 - Measured Frequency Response of the Reactance of a Lumped L-C Circuit

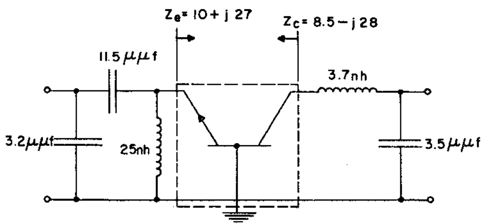

FIG. 4 - RF Circuit Diagram for Power Amplifier

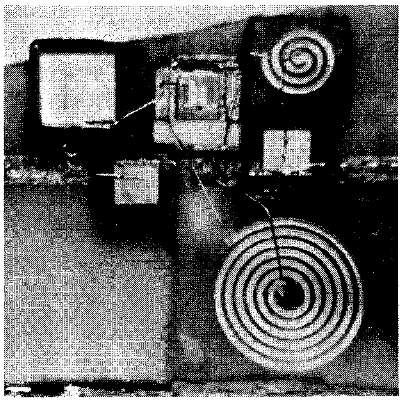

FIG. 5 - Breadboarded Version of Fig. 4 Power Amplifier

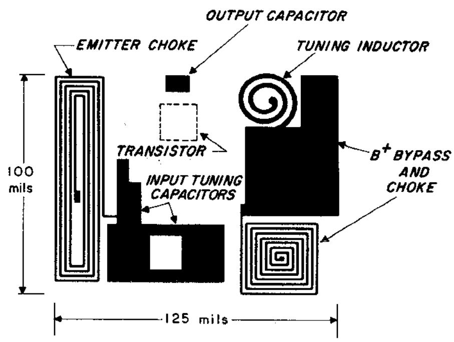

FIG. 6 - Layout of 2 GHz Integrated Lumped-Circuit Amplifier