

‘Fuzz Button’ interconnects at microwave and mm-wave frequencies

David Carter *

The Connector can no Longer be Ignored.

The connector can no longer be ignored in the modern electronic world. The speed of systems today and in the future require every pcb via, termination, component and connector to perform at very high frequencies. Components such as connectors even with relatively short signal path lengths can no longer be modeled and treated as a ‘straight through’ connections that will have no effect at all on the signal passing through it.

The important parameters which effect the performance of a connector at high data rates and rf frequencies are: Crosstalk, Signal propagation delay, capacitance, inductance, signal bandwidth, skin effect and phase shift amongst others.

The characteristic impedance that is an important parameter of this type of connector is determined largely from the capacitance value and in some minor ways by the inductance value. This capacitance value, which is very low on a Fuzz Button connection, also affects directly the amount of crosstalk between adjacent pins. Capacitance and inductance also produce the phase shift between voltage and current and play an important role in the signal bandwidth.

The higher the capacitance and the lower the value of inductance gives a lower characteristic impedance and vice versa. Characteristic impedance increases as the conductor cross section decreases.

The History of the Fuzz Button

The fuzz button was first used by Tecknit as static dissipation pad for computer chassis in the mid eighties. Then in 1988 GE approached Tecknit with a radar application where the Fuzz Button was used as a signal coax connector for an OTH (over the horizon) radar system. The Fuzz Button was ideally suited to this application because it offered a very good low loss connection and it was able to cope with some very severe vibration without being damaged while maintaining a good connection. Another early application was for the ARM missile ring shape pcb to pcb connector. Then in 1991 work began on using the Fuzz Button in the IC test market with noticeable first orders coming from Texas Instruments for PGA type ICs, who are today one of Tecknit largest customers for Fuzz Buttons test sockets. In more recent times the Fuzz Button has solved many RF connector problems.

The Fuzz Button and its Uses

These resilient little contacts are made from a large quantity (approximately 300mm) of gold plated BeCu material compressed into a cylindrical shape by a purpose built machine.

* David Carter of Tecknit Europe Ltd, Swingbridge road, Grantham, Lincs. England. NG31 7XT.
Tel +44 (0)1476 590600 Fax +44(0) 1476 591600 dcarter@metroninc.com www.twp-europe.co.uk



Figure 1: showing magnified view of a Fuzz Button.

The low inductance value (typically $< 2\text{nH}$) and short signal path length (typically $< 3.5\text{mm}$) provides a virtual signal distortion free connection. Due to the high performance of the Fuzz Button its primary use at present is for test sockets for various chip packages, including BGA, PGA and LGA. The importance of testing integrating circuits during manufacture or development is becoming more and more important and as one recent electronics magazine quoted, “appealing as it may seem, eliminating testing is not an option; inadequate testing leads to product rework and recall costs that can force companies into bankruptcy”[1]. It is therefore necessary to have a high quality, reliable proven test socket.

At the heart of our test socket is the Fuzz Button. Due to this construction technique the skin effect becomes minimal even at high frequencies, enabling these sockets to perform very well at frequencies in excess of 10GHz when configured in a coaxial arrangement.

The spring characteristics of the Fuzz Button contacts are excellent because they are made from high tensile strength gold plated BeCu wire. Each Fuzz Button is designed to compress 15% with virtually no compression set within the socket. This means that $>500,000$ insertions are possible on a single test socket before the Fuzz Buttons have to be replaced. Replacement of the Fuzz Buttons is a simple procedure which can be done by the test engineer using the existing socket body. An individual Fuzz Button can also be removed to aid testing and fault finding on a particular device.

The required pressure per contact is around 2.0 ounces, which means that even the most delicate of packages can be tested without damaging the contacts, including the solder balls on a BGA device.

The Fuzz Button represents a significant reduction in total force exerted onto the ic under test and test fixture and pcb. This reduction in force becomes even more important when testing the new small Micro electronic packages (MEP) because the high test point density results in an even greater pressure per square inch. The small amount of pressure for a Fuzz Button is needed to ensure a good electrical contact but is high enough to penetrate oxides and contaminants that will accumulate on the hard hat tip and the integrated circuit under test. These Fuzz Button connections do not require constant cleaning and each fuzz contact can carry 5 Amps. Typical height to width ratios are 8 to 1 for a Fuzz Button connection.

Gold plated hard hats (miniature contact pins) are used to connect various IC packages such as LGA, PGA, BGA and gull wing to the Fuzz Buttons. Specially shaped hard hats are used to minimize the damage to the solder ball or pins of the IC.

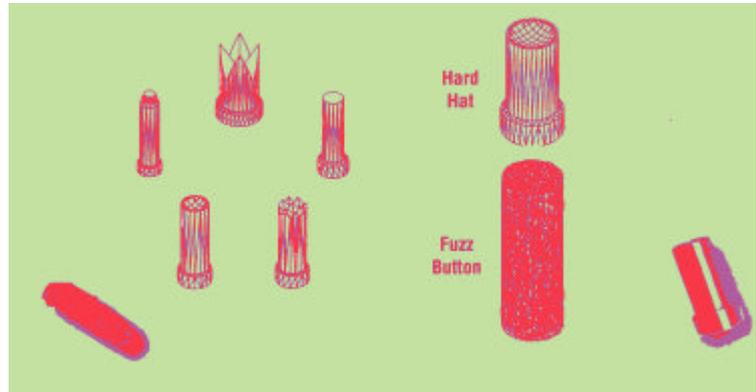
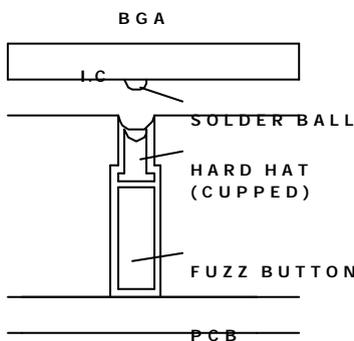


Figure 2: Types of hard hat. Including serrated, crown, and concave

The sockets are available with manual hand clamps or designed for use with automated test handlers. This enables the sockets to be used from R & D to test production areas, where ever the application, an overall improved test repeatability can be expected over conventional socket technology.

Signal Path Lengths and Skin Effect



The signal path length from the device to the test board is kept very low, typically less than 3.5mm.

Compared to 'pogo' pin technology this distance is very low.

The random orientation of the wires within the Fuzz Button helps negate to a large extent the skin effect of the connection. The skin effect directly affects the impedance of the connection. When a signal is passed through a conductor, the electrons tend to attract to the outside of the conductor and as the frequency increases the effect gets worse. This as the overall effect of increasing the impedance since there is now effectively less surface area to pass the signal. With the Fuzz Button this problem is dramatically reduced since now we have many small conductors instead of one large one.

Test Results from an Independent Test house. [2]

The purpose of the tests was to determine a lumped spice compatible element model from the results and to assess the Fuzz Button's electrical performance.

The Fuzz Button performance was tested in a complete test socket. The socket tested could have been any style such as a PGA, BGA or LGA. The socket was mounted onto a custom printed

circuit board. To simulate an integrated circuit that the test socket is to test, a second custom PCB (called a surrogate package) was used and inserted into the socket in the same manner as an integrated circuit would be. The surrogate package consists of an array of pins that include a set of open, shorted and grounded pins.

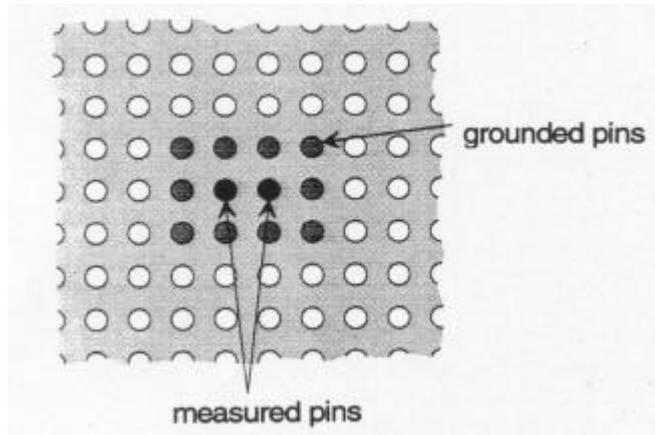
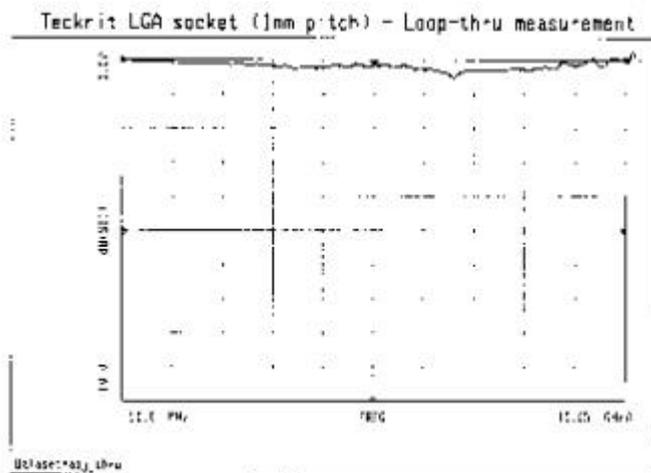


Figure 3 – test set up.

All of the measurements were recorded using coplanar probes. Coplanar probes are simply micro coaxial cables where there are two (2) contacts for each probe (a signal and ground). All measurements were taken on a HP8510C network analyzer.

Loop Through measurements.

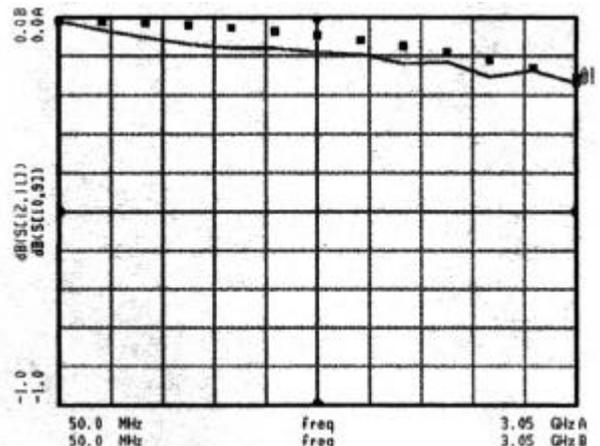
The bandwidth for a LGA socket was determined from a loop through measurement on two adjacent pins. The nearest row of pins to the ones under test was all grounded, see above figure 3. The 1dB bandwidth for each contact was greater than 10GHz (highest measurable frequency).



The figure left shows the actual results from the loop through measurements.

The figure right shows the transmission between the adjacent pins during the test to be less than 0.02dB upto 3GHz.

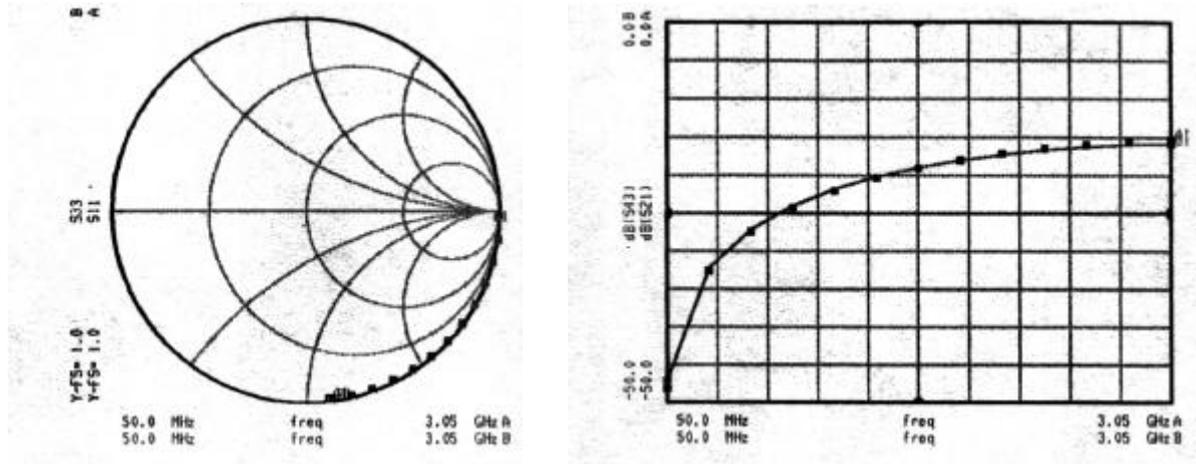
The square dots indicate the results of the spice model, to be shown later. The bandwidth for a socket is determined from the loop-through measurement. It



means that when two pins are connected together with a short transmission line, the voltage loss is less than 10% (1dB) below 10 GHz. You can convert from dB to voltage ratio by using the equation:

$$V = \text{alog}(\text{dB}/20) \text{ where the alog function is base 10.}$$

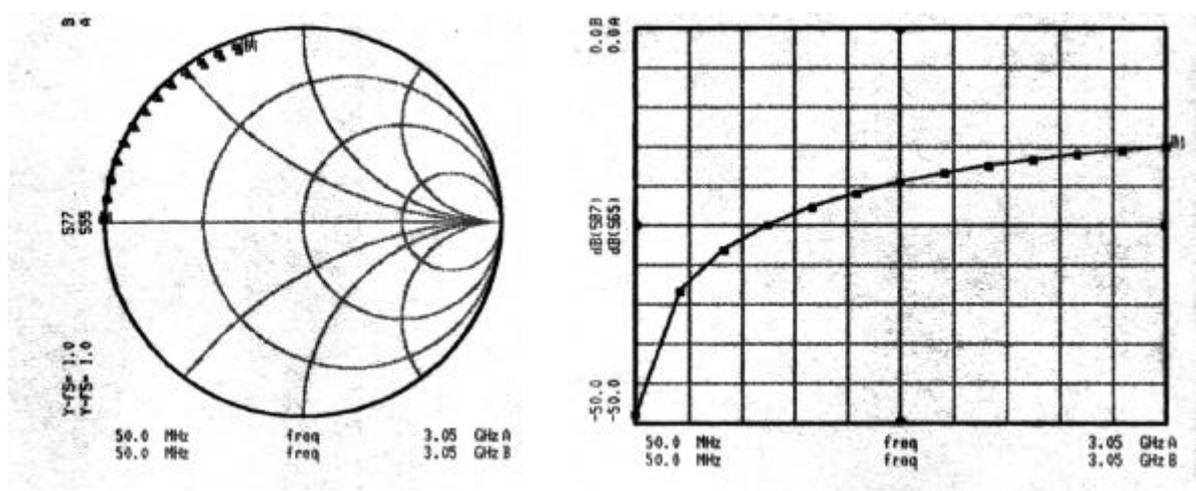
Open Measurement on Adjacent Pins.



This smith chart shows the reflection response of the two pins under test. It can be seen that in this condition the capacitance between the pins is the dominant factor since the smith chart indicates a $-jZ_0$.

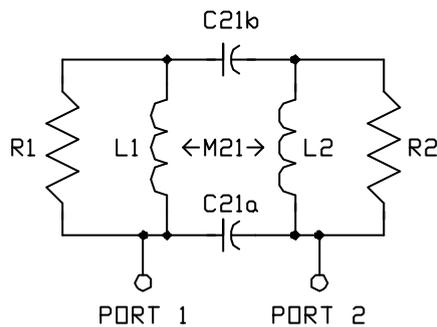
The capacitance is C21 on the model and is the mutual capacitance between the adjacent pins. The linear plot shows the cross talk between adjacent pins.

Shorted measurement on adjacent pins



This Smith chart is derived from measurements taken when the two test contacts are short circuited together in the surrogate package. The chart indicates a predominantly inductive reflection impedance. This inductance is coming from L1, L2 and M21 on the model and is the self inductance and mutual inductance between the pins. The linear graph shows the cross talk between the adjacent shorted pins.

Circuit Model Derived from these results



An equivalent circuit can be used to represent a model of the Fuzz Buttons in the actual test. The impedance of the Fuzz Button is a combination of resistance, capacitance and inductance. To determine the impedance of the Fuzz Button for a given frequency, the equivalent circuit diagram can be inputted into a SPICE simulation program. This model is valid from DC to 3.05GHz.

- L1,L2 Pin self inductance
- M21 mutual inductance between adjacent pins
- R1, R2 shunt resistance of inductors L1 & L2, used to model the high frequency response loss due to the skin effect and dielectric loss of the socket
- C21a mutual capacitance between adjacent pins (PCB side)
- C21b mutual capacitance between adjacent pins (surrogate package side)

Actual Values:

pins	L1 & L2 (nH)	M21 (nH)	R1 & R2 (Ohms)	C21a (pF)	C21b (pF)
Field adjacent	1.0	0.12	600	0.04	0.04
Field diagonal	1.0	0.01	600	0.01	0.01
Edge adjacent	1.1	0.18	700	0.05	0.05
Corner adjacent	1.1	0.25	800	0.06	0.06

References:

- [1] EDN Europe magazine, March 2000, [2] Giga Test labs – Cupertino, CA, USA

As presented at the IEE colloquium ‘Packaging and interconnects at microwave and mm-wave frequencies’ on June 26th 2000

Other useful reading books

- ‘Electromagnetics’ by John D. Kraus
- Engineering Electromagnetics by Umran S. Inan & Aziz S. Inan.

Appendix Smith Charts: (Basics)

In any transmission system, a source sends energy to a load, such as an antenna. When designing a transmission network, ideally the characteristic impedances of the source, the transmission line and the load are all identical. However, in the real world this is seldom true. When the transmission line impedance does not match that of the load, part of the transmitted waveform is reflected back towards the source. The reflected wave, which varies in phase and magnitude, adds to the incident (transmitted) wave and the sum is called Standing Wave.

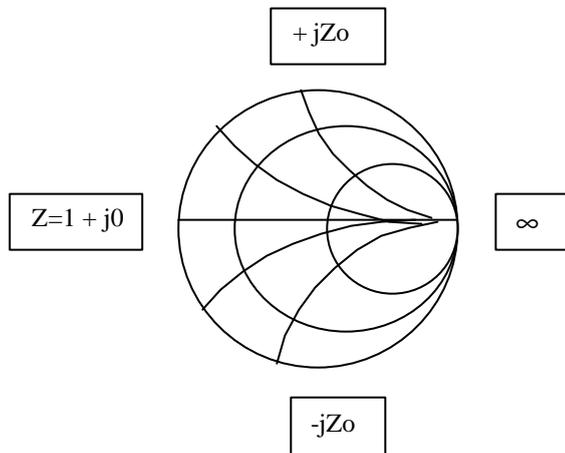
If the impedance match is perfect, the result is a SWR = 1 (maximum power is transfer to the load).

The Smith Chart has circles of constant resistance and arcs of constant reactance.

Where:

$$Z = r + jx$$

$$= \frac{1 + \gamma}{1 - \gamma}$$



By looking at a Smith Chart, the characteristics of the test socket can be viewed very quickly. If a line is plotted along the horizontal line ($Z = r + j0$), it can be said that the impedance of the socket matches the impedance of the load. If the line is plotted towards the top of the circle ($+ jZo$), the impedance is mostly inductive. Hence, if a line is plotted towards the bottom of the circle, the impedance is mostly capacitive.

Smith Charts (Gigatest):

This is a snapshot of the Fuzz Button under typical conditions. Depending on which graph / chart that is being reviewed, it is shown that the impedance of the Fuzz Button/Socket combination is closely matched to the impedance of the load. This is demonstrated by the trace along the horizontal axis ($Z= 1 + 0$).